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ENABLING COMMUNITIES IN THE ARAL SEA BASIN TO COMBAT LAND AND WATER RESOURCE DEGRADATION THROUGH THE CREATION OF BRIGHT SPOTS

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FINAL REPORT

Project Implementation Team

IARC Center	Project Staff
IWMI	Dr. Andrew Noble, Project Leader
	Dr. Asad Sarwar Qureshi
	Project Manager (April 1, 2007 to June 30, 2008)
	Dr. Iskandar Abdullaev
	Project Manager (August 1, 2005 to March 31, 2007)
	Dr. Akmal Karimov, Project Technical Coordinator
	Dr. Mehmood Ul-Hassan (Socio-economist)
	Mr. Alexander Platonov, GIS specialist
	Mrs. Ikbal Yusupova, Project Assistant/Translator
ICARDA	Dr. Manzoor Qadir (Marginal Water Management Specialist)
	Dr. Theib Oweis (Irrigation Management Scientist)
	Dr. M. Suleimenov (Agronomist)
	Dr. Aden Aw-Hassan (Socio-economist)
	Mr. Tulkin Yuldashev (Irrigation Scientist)
	Mr. Ikrom Khudoibergenov (Soil Scientist)
	Mr. Alisher Mirzabaev (Socio-economist)
ICBA	Dr. Shoaib Ismail(Plant specialist)
	Dr. Kristina Toderich (Plant Specialist)

National Teams

National teams	Project Staff
Uzbekistan	Dr. German Bezborodov, National Coordinator
	Dr. Toshbekov Uktam- soil scientist
	Dr. Kuliev Tajidin- agronomist
	Dr. Dusmatov Alisher-biologist
	Dr. Shurova Lyudmila- Irrigation specialist
	Dr. Koshekov Rashid -Irrigation specialist
	Dr. Mirhoshimov Rakhmankul- Irrigation Specialist
	Dr. Kushiev Habibjon– biologist
	Dr. Sadulla Avezbaev – Socio-economist
Kazakhstan	Dr. Sagit Ibatulin, National Coordinator
	Dr. Sergey Mogay, Soil Scientist
	Dr.Vishpolski F- Soil Scientist
	Dr. Mukhamedjanov V.N –Socio-economist
	Dr.Paramonov- A- Agronomist
	Dr.Kalashnikov A- Hydrotechnician
	Dr.Zhdanov G- Ameliorator
	Dr.Bekbaev R- Soil scientist
	Dr.Bekjanova- Chemist
Turkmenistan	Mr. Serdar Roziyev, National Coordinator
	Mr. Kadyrbek Redjepbaev, Soils scientist
	Mr. Durdybek Nurmedov, Agronomist

Project Partners

International Partner Organizations

International Water Management Institute **(IWMI-Lead Organization)**
International Center for Agricultural Research in the Dry Areas (**ICARDA**)
International Center for Biosaline Agriculture (**ICBA**)

National Partner Organizations

Scientific Research Institute of Water Economy
Ministry of Agriculture, **Kazakhstan**

Department of Land Resources
Ministry of Agriculture, **Turkmenistan**

Cotton Research Institute
Ministry of Agriculture and Water Resources, **Uzbekistan**

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Executive summary

The viability of irrigated agriculture in Kazakhstan, Turkmenistan and Uzbekistan is threatened by secondary soil salinization. This resource degradational issue is the consequence of a range of factors, including inadequate provision of surface and subsurface drainage, poor water management practices resulting in rising groundwater tables, insufficient surface water supplies and the use of poorl quality water for irrigation. The consequences of inappropriate irrigation and drainage management are endemic rural poverty, household food insecurity, and environmental degradation all of which threaten regional economic development. The overarching goal of the project is the management and rehabilitation of salt affected irrigated lands with the objective of enhancing the agronomic productivity of agricultural systems that have a positive impact on rural livelihoods through enhanced income generation. The specific activities of the project fall within three distinct but related components that include: 1) Identification, evaluate and promotion of local innovative practices and strategies that farmers have adopted to cope with prevailing biophysical and economic constraints. These have been termed "Bright" spots; 2) the selection of salt tolerant plant species and the assessment and development of innovative practices in managing or rehabilitating salt affected lands that includes the use of marginal irrigation waters; 3) the outcomes from the previous two components contribute to the third component that focuses on the dissemination of outcomes through a process of knowledge sharing, and capacity building amongst farmers and national partners.

Despite limitations in access to resources, farmers have shown significant resilience in developing coping strategies that directly influence their farming operations. Many farmers living in degraded environments have developed tools, methods and management skills to maintain soil productivity and obtain adequate yields of agricultural crops. These limited numbers of farmers have been termed 'Bright' spots. Sharing the experiences of these farmers with their peers can help in improving on-farm productivity and increase incomes. These 'Bright' spots effectively represent tested approaches to enhancing the productivity of farming systems under local conditions and hence have direct applicability. Further there are crop and forage species that are well adapted to the prevailing edaphic conditions innovative management practices that would significantly improved the productivity of agricultural production systems in Central Asia that need to be evaluated.

The International Water Management Institute (IWMI) together with International Center for Agricultural Research in Dry Areas (ICARDA) and International Center for Biosaline Agriculture (ICBA) and national partners (NARS) from Uzbekistan, Kazakhstan and Turkmenistan undertook a project with the objective of addressing endemic rural poverty amongst farmers in the target countries. The project was funded by the Asian Development Bank (ADB) over a three year period. Field activities were carried out in all three target countries with the collaboration of local NARS and associated international organizations. This report contains the major findings and outcomes of the project. A compendium to this report contains a comprehensive discussion of all studies and activities undertaken within the context of this project.

1. Identification, promotion and adoption of innovative practices

1.1 Identification of 'Bright' spots

A key activity in the systematic identification of bright spots was to develop a methodology that effectively discriminated between better performing farmers from the norm. In Uzbekistan, the selection process focused on the identification of farmers/communities that, despite having similar biophysical constraints and operating under the same socio-economic and policy environment, were performing above average. The classification of individual bright spots was based on identifying extremes of land degradation where farming is still being undertaken. They therefore represent the most robust and extreme forms of bright spots.

In Turkmenistan, the focus was on individual farmers that had been identified as superior farmers (termed *Mulkdars*) and control objects that represented the average farmer productivity in the region. Selected data on yields of wheat and cotton were collected for the years 2003 to 2005 along with

basic information on the production practices of farmers. This information, although limited, did provide insights into the performance of individual farmers. In Kazakhstan, identification of individual farmers who were deemed to be bright spots were achieved through analyses of secondary data obtained from local authorities. In this case the dominant criteria for bright spot farm identification were productivity and profitability of the farm.

The results from this study demonstrate that there are clear differences in the performance of farmers who appear to face the same biophysical constraints. The dismantling of collective farms in Uzbekistan and to a less degree in Turkmenistan, has in part resulted in the enhanced performance of the agricultural sector, this being based on a comparison of the yields of wheat and cotton prior to and post-privatization. It is widely recognized that land reforms around the world have a political dimension and are a key driver in enhancing productivity and land stewardship. There are distinct similarities between the Uzbekistan and Turkmenistan as both have approached land ownership in a cautious and phased approach, while retaining a planned agricultural sector based on wheat and cotton. Contrasting Uzbekistan and Turkmenistan, Kazakhstan has fully privatized land under cotton production and created opportunities for farmers to choose the crops to grow and trade them on an open market. It revised the land purchasing and leasing policy, which are having a profound effect not only on agricultural production but also the livelihoods of farmers in the Southern Kazakhstan.

These bright spots clearly demonstrate that farmers have developed coping strategies that significantly enhance their production systems. These strategies range from adhering to basis agronomic principles and practices in the production crops through to being able to access resources (inputs and finance). These are simple basic attributes that can be adopted by farmers with little external drivers and hence could become the catalyst for significant improvements in the productivity of current farming enterprises in the region. The key to effecting these changes is in the dissemination of this innate farmer knowledge from bright spots to the larger farming community. Farmer learning alliances may be an important tool in this process based on their success in this project.

1.2 National Roundtable meetings--expanding the project results to policy makers

Out-scaling of results generated within the context of this project was achieved through policy dialogues organized in the three target countries in the final year of the project. The focus of these meetings was on policy instruments that would allow up-scaling and adoption of project methods and strategies for incorporating promising outcomes from the diverse array of research activities into a policy framework. It would be presumptuous to expect that policy makers would undertake the necessary reforms and changes within the life of the project; however, a process of engagement and dialogue was initiated and appreciated by all parties that will in the long term result in change and improvements in rural development.

1.3 Dissemination of bright spots to other farmers

Since the existence of formal extension services as a conduit of research results and technologies that could assist farmers in enhancing the performance of their production systems are still at a fledgling stage in each of the target countries, innovative approaches were adopted that included the formation of knowledge alliances. In this respect, bright spot farmers were linked to neighboring control farmers and an alliance was established to facilitate the transfer of information between the two groups

The process of dissemination of practices used by bright spot farmers was achieved through discussion group exercises and the distribution of leaflets outlining the successful practices of bright spot farmers. In Uzbekistan, two potential bright spot farmers were linked with the potential bright spot farmers making a total of 30 farms in the project. In Kazakhstan 22 farmers were included in this knowledge alliance. The number of satellite farms has risen to 42 in 2007 as many farmers were willing to participate in the initiative and improve their farm performances. In Turkmenistan, 8 farmers producing wheat and 5 farmers producing cotton were linked with 13 potential bright spot farmers making a total of 26 farms in the project. Whilst it is still very premature and definitive

conclusions cannot be drawn, there is evidence to suggest that the formation of these alliances have contributed to increasing productivity.

2. Plant production on salt-affected soils

The work under this component was divided into several activities which were undertaken in the three target countries in close association with the local NARS. The studies were supervised jointly by IWMI, ICARDA and ICBA experts located in Tashkent and other parts of the world. For each study, a team of local and international experts was formulated for the implementation of the field activity. Most of the field work was carried out on farmer fields in collaboration with the local NARS and farmers. Data collection and analysis for all these studies were undertaken by the individuals of local scientific and research organizations involved in this project.

2.1 Evaluation and selection of plant species for salt-affected and waterlogged soils

The main focus of this component was to introduce and evaluate native wild halophytes and conventional and non-conventional cereals, oil, medicinal and fodder crops for their ability to grow and produce economic yields under saline environments. Special attention was paid to the development and adoption of innovative management options in order to increase productivity and income generation on salt affected and marginal lands. A large number of plant species have been recommended for local cultivation considering the climatic and land and water quality conditions. Pilot studies indicate the cost effectiveness of up-scaling of plant, trees, shrubs, fodder and grain crops in Central Asian region. However, there is a need for strong state support for the adoption of these drought and salt tolerant crops to transform salt-affected lands into more productive lands. Clearly diversification of current cropping systems should be encouraged and markets developed accordingly. Implicit in achieving these goals and out-scaling is changes in current restrictive policies.

2.2 Management of salt-affected soils

Evaluating the rate and time of phosphogypsum application on high-magnesium soils for improved crop productivity

The study was conducted in southern Kazakhstan during 2005-07. Cotton is the main crop grown in the region covering about 95% of the cropped area in summer. The results show beneficial effects of phosphogypsum (PG) application in terms of improvement in soil chemical properties, irrigation efficiency and crop yields. Based on the cumulative effects, application of gypsum before the snowfall to magnesium dominant soils improved soil properties to a greater extent compared with the application in spring after the snowmelt. The marginal rate of return from the application of 3.3 t ha^{-1} was double that of applications of 8.0 t ha^{-1}, suggesting that the lower rate is optimal. The application of phosphogypsum offers a practical approach to addressing a soil chemical constraint that will enhance productivity and income generation. Several mechanisms to encourage the widespread adoption of approach to soil rehabilitation have been proposed and are being considered by authorities in Kazakhstan.

Management of rice-wheat cropping system for saline soils through different tillage options in Uzbekistan

Studies carried out in the Kzyl Uzyak farm of Chimbay district of Karakalpakistan have demonstrated that zero tillage resulted in a better crop response when compared to traditional practices. Under zero tillage, rice yields were higher by 2-19% in comparison with traditional sowing method. Water productivity of the rice crop under zero tillage was higher by 48-90% over the control (rice-fallow system), while for winter wheat it was 77-100% higher over control (winter wheat-fallow system). Land leveling enhanced rice yields by 2-20% and water productivity by 29-81% over control (rice-fallow system). In the case of winter wheat, increases in water productivity were 17-100% over the control (winter wheat-fallow system). The results suggest that wheat-rice treatments enhanced water productivity by 17-100% in comparison with traditional wheat-fallow production systems and therefore offers an opportunity for farmers to enhance income generation through a double-cropping program.

Use of tree plantations as a biological ameliorant for the degraded lands in Uzbekistan

The principal objective of this activity was to determine the effectiveness of trees in regulating elevated groundwater levels associated with inappropriate irrigation practices. As previous experience have shown, bio-drainage reduces the need for disposal of saline water, restricts environmental impacts and brings benefits to farmers by producing wood for construction and fuel. This study was undertaken in Syr- Darya district. The results indicate that tree plantations were effective in lowering the groundwater table, which reduces salt accumulation by 18-42% at the end of cotton season. Furthermore, tree plantations have a direct benefit to farmers through the production of wood for construction and fuel. There is clearly a need for further research in this area to assess the strategic establishment of plantations within the landscape in order to achieve the greatest benefits in groundwater management.

Evaluating the fertilizer use as a management option to mitigate the effects of saline water irrigation

This study was undertaken to evaluate the effect of different rates of nitrogen fertilizers and combinations of water quality on chemical changes in the soil, growth of cotton, and economics of the applied treatments. The study was conducted in Makhamad private farm of the Dostyk Water Users Association in Makhtaaral district in Southern Kazakhstan. The results indicate that the application of saline water in conjunction with canal water in the ratio of 4:1 with 140 kg ha^{-1} of nitrogen is the most appropriate combination of inputs for the study area that maintain productivity levels of cotton. These finding are particularly important in areas where freshwater resources are limited or will be limited in the foreseeable future. Farmers can maintain productivity levels under conditions where high-quality freshwater is limited by using saline water along with the application of appropriate levels of nitrogen.

Evaluating the effect of waters of different qualities and mulching of furrows on crop productivity and soil evaporation

This field study was carried out in Akaltyn farm located in Syrdarya district of Uzbekistan in partnership with the Uzbek Cotton Growing Research Institute (UCGRI) to evaluate the effects of hay mulching and combinations of water quality on crop production and soil evaporation. The results indicate that mulching produces 2-12% higher cotton yields than without mulching. Mulching also reduced the soil salinity by 6-13% at the end of cropping seasons. The study suggests that water from open drains can be utilized for irrigation where there is a deficit of high quality waters. In addition, water pumped from vertical wells can be applied for irrigation in conjunction with the open drain water during the second half of the cotton growing season, when plants are more tolerant to ambient levels of salinity. This offers opportunities in reducing possible negative effects on the yield of cotton associated with mid-season shortages of fresh water which is common to downstream irrigators.

Productivity enhancement of fodder-based cropping systems through the use of saline water

Studies undertaken at Akdepe farm in Dashauz Province of Turkmenistan have demonstrated that applying canal water is critical during the first irrigation of the season, when the young plants are most sensitive to salt-affected conditions. In spite of high salinity levels in the soil, *Zea mays* L. showed relatively promising results in comparison to *Sorghum bicolor* (L.) Moench *and Sorghum sernuum* Host. In the first year of cultivation of fodder crops, heavy soil leaching (2000-2400 m^3 ha^{-1}) should be applied at the site in order to flush harmful salts from the root zone and create favorable conditions for crops growth and development. Only after this farming practice can the cyclic use of drainage and irrigation water be implemented.

Use of SWAP model to determine optimal irrigation water requirements and water table depth for Sardarya basin of Uzbekistan

The Soil-Water-Atmosphere-Plant (SWAP) relationship model was used to estimate suitable groundwater table depth and irrigation requirements to optimize cotton production. The results indicate that maximum yields of cotton can be obtained at a groundwater table depth of 200 cm. Maintaining an average groundwater table deeper than 200 cm would be excessive as the costs would

be higher and there would be no additional benefits in crop productivity. However, at this groundwater table depth irrigation quantities will have to be increased to 250 mm to keep the root zone free of excessive salts. Consequently, drainage systems capable of maintaining groundwater table depths at 200 cm would be adequate for sustainability of irrigated agriculture.

The potential impact of Licorice for remediation of saline soils

In this study, we investigated the economic potential for addressing of rehabilitating abandoned saline lands through the planting of a native, salinity-tolerant crop, licorice. Cultivation of licorice for the remediation of salinity-affected areas was studied by the Gulistan State University at Navbahor collective farm of Syrdarya province. The analysis shows that cultivation of grain (wheat) and commercial (cotton) crops after soil remediation with licorice, leads to increased yields and profitability of these crops. At the same time, certain possible constraints of licorice cultivation, such as initial investment costs and negative cash flow during the first 4 years, underdeveloped access to international markets, difficulty of eradicating licorice roots from the field once planted should be given due consideration. The analysis showed that switching to cotton-wheat rotation after the fifth year of licorice cultivation was the optimal option in the current policy, economic and social environment. A farmer learning alliance was established under the project and a total of 100 ha of licorice was established on abandoned land. This approach to out-scaling innovations may be an appropriate mechanism that could be promoted by the governments in the target countries.

Spatial and temporal assessment of soil salinity using RS techniques in the Syrdarya basin

A methodology for the identification of saline lands using remote sensing and GIS techniques was developed. Results indicate that the processing of multi-annual remote sensing images can assist to a reasonable extent in estimating temporal changes in the area affected by salinity. This method is particularly important when an objective assessment is required of the extent of the problem over larger areas. The approach is cost effective when compared to traditional land survey practices and less time consuming. Despite its effectiveness, there are limitations with respect to the identification of differences in low vegetation that may not be attributed to salinity but to other factors such as water stress.

Cost-benefit analysis of different technologies

The cost-benefit analyses of different innovative technologies tested under this project were performed to assess the economic viability of useful options to improve the livelihoods of farming community in all three target countries. The analyses were based on structured surveys and informal and formal interviews. The cost benefit analyses revealed that most of the technologies developed and/or disseminated under this project offer considerable advantages for farmers in the region. The economic assessment shows that the use of phosphogypsum for the remediation of high magnesium soils and plantation of licorice for lowering groundwater table to reclaim waterlogged soils are of particular importance.

Component 3: Capacity building, dissemination and knowledge sharing

Over the course the project a concerted team effort was made to build scientific capacity of the local NARS and staff involved in the project through training courses, workshops and other knowledge sharing activities. Training courses were presented that covered a range of subjects, including special courses on participatory rural appraisal (PRA); effective communication skills and interviewing techniques; outcome mapping, evaluating technologies addressing salt-prone land and water resources; advances in bio-saline agriculture with reference to Central Asia; procedures and tools for salinity related data processing and statistical analysis. To enhance capacities of local institutions one PhD student and 2 MSc degree students carried out their research within the context of the project. In addition, a number of workshops on different aspects of the project was organized for the benefit of local and international scientists.

Knowledge sharing and dissemination activities were undertaken using two approaches: (1) producing booklets and information sheets for distribution among farmer communities; (2)

establishing and promoting Learning Alliances for two main technologies developed under this project. A number of brochures, leaflets, technical bulletins were developed to share generated knowledge with farm communities. In addition, regular roundtable meetings with farmers and policy makers were conducted to discuss project results. Project scientific results were published in well respected international journals and were presented in national, regional and international conferences and seminars. The project also developed a toolbox which contains all the necessary information on technologies developed under this project. This is a user friendly tool which can effectively be used by farmers and land and water resources managers. The project has also developed a website that can be found under the Featured Projects on the IWMI website (http://www.iwmi.cgiar.org/). The website contains articles that have been derived from the project and other relevant information.

INTRODUCTION

Land degradation, in particular soil salinization, is one of the major factors threatening the sustainability of irrigated agriculture in the newly independent states of the Central Asia. According to recent estimates, approximately 60% of the total 7.5 million ha of irrigated lands of the region are salt affected which has reduced potential yields of cotton and wheat crops by as much as 50%. This has resulted in lower farm incomes and increase in poverty. To satisfy leaching requirements of these lands and maintain root zone salinity within acceptable limits, about 10 km^3 of fresh water is needed annually. In addition, due to increased population and increased use of water by other urban and industrial sectors, per capita water availability has declined to 2000 m^3 and there are predictions that it will be further reduced. As a result, use of marginal quality water for irrigation has increased over the last decade which is compounding existing problems of soil salinization.

Another major factor contributing to increased soil salinity is the poor quality of return flow from irrigated lands to water bodies that has a profound affect on the water quality of major river systems. About 40% of the total water applied through irrigation is returned to rivers with a consequent deterioration in water quality. Salinity issues in Karakalpakistan, Khorezm province of Uzbekistan, Dashauz province of Turkmenistan and Kzylorda province of Kazakhstan is predominantly related to poor quality of water flowing from the up streams. Consequently the use of marginal quality water for irrigation in the middle and lower stream reaches of river systems without proper outflow of salts is a major challenge.

The presence of shallow groundwater tables further contributes to the salinization of irrigated lands. Approximately 2.0 million ha of irrigated land in the region has groundwater tables within 2.0 m of the soil surface. This has led to widespread waterlogging and secondary salinization. Salinity issues in Fergana valley and Syrdarya province of Uzbekistan, Chardjou province of Turkmenistan and in southern Kazakhstan are mainly associated to shallow saline groundwater tables. Despite poor resources, farmers continue their efforts to reclaim these soils through a range of strategies. The common strategy used by most farmers is to flush salts from the root zone in the winter season. Moreover, the existence of shallow groundwater tables due to neglected maintenance of surface and subsurface drainage systems is exacerbating the situation making this leaching practice even more impractical.

Many farmers living in this degraded environment have developed tools, methods and management skills to maintain soil productivity and obtain adequate yields of agricultural crops. These limited numbers of farmers have been termed 'Bright' spots and clearly demonstrate the innate ability of farmers to adapt to biophysical and policy inhibiting factors in their production systems. Sharing this knowledge between farmers can assist in improving on-farm productivity and increase incomes. These 'Bright' spots effectively represent tested approaches to enhancing the productivity of farming systems under local conditions and hence would have direct applicability.

With these objectives in mind, International Water Management Institute (IWMI) together with International Center for Agricultural Research in Dry Areas (ICARDA) and International Center for Biosaline Agriculture (ICBA) and national partners from Uzbekistan (Central Asia Research Institute of Irrigation, SANIIRI), Kazakhstan (Institute of Water Economy) and Turkmenistan (Ministry of Agriculture) undertook a project with the objective of addressing endemic rural poverty amongst farmers in Kazakhstan, Turkmenistan and Uzbekistan through improving food security at the household level and ensuring environmental sustainability. This was achieved through the introduction of appropriate water management and soil conservation practices that significantly increase agricultural productivity. The project was funded by the Asian Development Bank (ADB) over a three year period.

The specific objectives of the project were:

1. Identify and promote the expansion of community based innovations termed 'Bright' spots that prevent further land and water degradation and enhance the livelihoods of agrarian communities in the target countries.
2. Evaluate plant species and management systems that have the potential to increased productivity and income generation on saline soils through farmer participatory trials in the three target countries.
3. Enhance the capacity of national research and extension services to develop and promote innovative strategies that address land water resource degradation.

To achieve the above-mentioned objectives, specific activities were divided into three distinct components:

- Identification, evaluation and promotion of local innovative practices and strategies that farmers have adopted to cope with prevailing biophysical and economic constraints. These have been termed 'Bright' spots;
- Selection of salt tolerant plant species and evaluation and development of innovative strategies in managing or rehabilitating salt affected lands that includes the use of marginal quality irrigation water;
- Dissemination of generated knowledge through a process of knowledge sharing and capacity building amongst farmers and national partners.

Field activities were carried out in all three targeted countries with the collaboration of local NARS and associated international organizations. The project covers diagnostic analysis, technical, socio-economic and knowledge dissemination aspects of the land rehabilitation. The project used a pragmatic approach to identify and promote approaches used by superior farmers, through development of learning alliances between farming communities. The outcomes of the project have clearly shown that on-farm improvements in management can play a significant role in enhancing profitability and sustainability. The results achieved under this project provide necessary information that can be used to extend these successes to other farmers and countries of the region. In this report, salient features and outcomes of all individual studies undertaken under this project are presented in a synthesized form. It is hoped that this information will be equally helpful for the scientific community and policy makers who are vested with the responsibility of driving the agricultural agenda for the region.

COMPONENT I

IDENTIFICATION, PROMOTION AND ADOPTION OF INNOVATIVE PRACTICES THAT PREVENT FURTHER LAND AND WATER DEGRADATION IN THE ARAL SEA BASIN.

1.1 IDENTIFICATION AND ANALYZING SELECTED BRIGHT SPOTS IN KAZAKHSTAN, UZBEKISTAN AND TURKMENISTAN[1].

INTRODUCTION

Privatization and liberalization of agriculture in the countries of the Former Soviet Union (FSU) have been rapid with significant economic impacts in some cases since independence in the 1990's. Although many countries have experienced initial declines in agricultural productivity, there are clear signs that the situation has improved over the last decade (Rozelle and Swinnen, 2004). It is however of note that former Soviet republics have performed relatively poorly when compared to countries of the Central and Eastern Europe (CEE). Rural populations have been affected the most and have experienced sharp declines in their standard of living and an increase in poverty. It has been suggested that the main factors in the success of this reform process are the pace and sequence of reforms, while others argue that not only reforms but also well-defined rights and the appropriate institutional environment for exchange of goods and services were vital for the success of reforms in transitional countries (Rozelle and Swinnen, 2004; Sachs, 2005; Stiglitz, 2006). Certainly, rapid dismantling of state and collective farms and privatizing their land and assets to individual farmers and members of these collectives without the establishment of new institutions to support newly created private farming structures, have resulted in the dramatic decreases in productivity of land and associated negative impacts on the livelihoods of rural communities (Spoor, 2007). Yet, some argue that the deterioration in agricultural production might have been predicted even if no such reforms had taken place due to underlying unsustainable collective and state farm systems in the countries of the former socialist bloc (Dudwick *et al.*, 2005).

Regardless of whether enabling conditions were created or not as a consequence of reform, agricultural producers are attempting to adjust to changed circumstance that will have a positive impact on their livelihoods as is evidenced in examples of farmers that have enhanced their production systems and income through their own efforts (Ul-Hassan *et al.*, 2005). However, these are not only limited to political, social and economic conditions, but further exacerbated by escalating environmental degradation. This situation is widespread in countries of the FSU, Central Asia in particularly, where institutional gaps in agricultural production support systems such as irrigation and drainage and extension services have been created due to the dismantling of collective farms and the inability of governments to finance and support these services. This situation is best exemplified in cotton growing areas of Central Asia where poor drainage systems, over irrigation, mono-cropping and other factors have led to a rise in ground water tables and secondary salinization greatly affecting the productivity of rural producers in the region (O'Hara, 1997).

The concept of agricultural sustainability revolves around food production that makes the best use of natures goods and services while endeavoring to minimizing damage to these assets (Pretty *et al.*, 2006). agricultural sustainability emphasizes the potential benefits that arise from making the best use of crop and livestock genotypes and technologies and practices that enhance productivity without compromising the environment. Evidence from literature suggests that rural producers and communities do employ different strategies not only to improve their livelihoods under very little or no support from external sources but also use environmentally sustainable production practices (Sherr and Hazell, 1994; Ul-Hassan *et al.*, 2005; Pretty *et al.*, 2006; Noble *et al.*, 2008).

[1] This component was led by IWMI. NARS partners include Dr. V. Mukhamedjanov, Mss. N. Gritscenko, Dr. M.Musekenov (Kazakhstan), Mr. R. Hekimov (Turkmenistan), Prof. S. Avezbaev, Dr. Mukumov (Uzbekistan).

Whilst the Central Asian region faces significant challenges in preventing, mitigating and reversing trends in land and water resource degradation, there is a critical need to enhance the livelihoods of rural communities before or in tandem with addressing these resource issues. Recent studies indicate that sustainable rural livelihoods have become a significant challenge for households even in the most productive areas of Central Asia such as Fergana Valley (Nizamedinkhojaeva *et al.*, 2006). While a more general picture of land and water degraded areas in the region would indicate that rural communities are trapped in a vicious cycle of deteriorating land and water quality, poor yields, declining incomes and purchasing power, increasing poverty, poor investments in land and water resource rehabilitation (Bucknell *et al*, 2003), there is evidence that many communities do have considerable capacity to adapt to environmental degradation (Scherr, 2000; Ul-Hassan *et al.*, 2005). Such communities might pursue a variety of coping mechanisms to deal with environmental degradation and stress, and some communities might adopt strategies which, *both* improve natural resources *and* reduce household poverty by protecting and preserving the asset base, diversifying and improving on-farm production systems, or taking out credit to invest in future production or resource protection (Scherr, 2000; Ul-Hassan et al., 2005).

The termed 'induced innovation' has been used to describe the ability of individuals and communities in overcoming both biophysical and social constraints in addressing livelihood issues (Leach and Mearns, 1996; Mortimore and Adams, 1999; Tiffen, 2002; Tiffen *et al.*, 1994; Tiffen and Mortimore, 2002; Wiggins, 1995). It would appear that there are a range of factors - or drivers - that are not mutually exclusive, influencing the development of this 'innovation' that include how well societies adapt to rapid population growth, globalization, market development, technological change, climate change, political change and agro-ecological conditions (Kuyvenhoven and Ruben 2002; Lopez 1998; Mortimore and Harris 2005 Niemeijer and Mazzucato 2002; Pender *et al.* 2001).

A key element in the argument for induced innovation is the development of markets or possibly, in the case of some of the newly independent Central Asian states, market liberalization, movement towards decentralized economies and land reform. Significant agricultural reform has occurred within the region, mainly targeted at 'privatizing' the large collective farms that were established during the Soviet era. These reforms include the establishment of smaller private and cooperative farms in order to improve the efficiency and equity of existing production systems. Land reforms generally trigger actions in key areas for pro-poor agricultural growth, by improving the incentives for land operators to invest in improved technologies, and by increasing equity and hence elasticity in poverty reduction with respect to growth (Dorward, *et. al.* 2004).

There is evidence (cf. Scherr, 2000) that the 'downward spiral' in livelihoods and resource degradation is both avoidable and reversible in many circumstances, if public policies are supportive, as these can positively influence micro-scale factors that determine how farmers adapt to environmental pressures. Due to the transition from central planning to a market economy, Central Asian farmers have seen a myriad of policy changes since independence. The simultaneous changes in many policies had severely affected their understanding of the operating environment, as well as the opportunities that arise associated with these changes (Ul-Hassan, *et al.*, 2005). These drastic changes also affected their access to key assets and resources. Thus, in addition to a dwindling and deteriorating resource base, Central Asian farmers have had to contend with, in most instances, unsupportive policies, weak or underdeveloped markets and monopolized service providers. In the context of emerging markets and evolving public policies, more pro-active policies and functional markets, supported by research and analysis, are needed to balance environmental and anti-poverty objectives simultaneously. Public policies could enhance access to, and the productivity of, poor people's natural resource assets and engage them as partners in public resource management. Such policies, which are yet at their formative stage in Central Asia, are only slowly emerging. Similar arguments have been forwarded by Kusters *et al* (2006), who assert that development interventions do not automatically reconcile conservation and development objectives. Rather, relevant agencies should formulate realistic objectives, and also consider the potential negative effects of their development interventions and policies. The downward trends in Central Asian environmental security, productivity and incomes in some of the newly independent States can thus be partly attributed to inhibitory policies and market barriers (Murray, 2007).

Bright spots in Central Asia clearly indicate the potential of individuals and communities in overcoming inhibitory policies, market barriers, and other impediments without significant external assistance (Ul-Hassan, *et al*., 2005). The opportunity arises in studying the attributes of these bright spots that pertain to their success and investigate the potential to expand them through knowledge transfer, influencing changes in policy and institutional structures. As an extension to the previous limited study undertaken in 2004 by Ul-Hassan *et al.* (2005) in Uzbekistan of cooperative farming systems, the activities in this component was to expand our investigation of bright spots in each of the three target countries in order to identify factors that contributed to the improved performance and, based on this evaluation, assess possible options for expansion and out-scaling of 'Bright' spots to larger areas.

METHODS AND MATERIALS

In this section we define the term bright spots describe the approaches that were taken to identify their existence in each of the target countries. A comprehensive discussion on the methodology used in the Uzbekistan study is undertaken as it forms the basis on a logical approach to the identification of farmers who are performing above the norm.

The term bright spots refers to individuals, communities or households who have adopted practices and coping strategies to reverse resource degradation in a sustainable manner whilst maintaining or enhancing food security and income generation. An important attribute of these bright spots is their reduced risk and vulnerability to the conditions framed by the external environment, such as governmental policies.

<u>Bright Spot Identification</u>

Uzbekistan: A multistage purposive sampling technique (Patton, 1990) was used to select the bright spots and control objects that consisted of 5 stages in Uzbekistan, involving a logical progression in the selection process that is both quantitative and qualitative. The selection process focuses on the identification of farmers/communities that, despite having similar biophysical constraints and operating under the same socio-economic and policy environment, are performing above average. The classification of individual bright spots was based on identifying extremes of land degradation where farming is still being undertaken. They therefore represent the most robust forms of bright spots. This was achieved through the following steps.

Stage 1 – Identification of Provinces with the highest incidence of irrigated salinity: Using national statistics, salinization data in irrigated areas from the Ministries of Agriculture and Water Resources for each of the Provinces were reviewed. As a result, Syrdarya Province was identified as having the highest level and extent of salinized agricultural land currently in production.

Stage 2 – Identification of the Administrative Districts within the selected Province, with the highest level of irrigated salinity: The focus of this stage was to identify the specific Administrative District in the selected Province (i.e. Syrdarya) where bright spots should be identified. Two criteria were used to identify the target district. Using national salinity statistics and an associated classification of land into salinity classes, the extent of saline soil within a district was determined (Table 1.1.1). In an assessment of the administrative districts of Syrdarya Province, Mirzaabad District had the highest percentage of irrigated land that fell within the moderate and severely saline (57.6%) categories. Contrasting this, the Sayhunabad District had a mere 13.1% of its irrigated area that fells within this range (Table 1.1.1).

Stage 3 – Assessment of soil quality at the administrative district level: Bonitet values were used in the assessment of soil quality. The Bonitet value is an effective qualitative and quantitative measure of the productive capacity of soils that is robust and is not prone to subjectivity (Ul-Hassan *et al*., 2005). It has a scientific basis and is a composite index that incorporates a number of biophysical factors. During the Soviet era, production fields were assessed on a five-year basis to determine their Bonitet values in order to set production levels for cotton and wheat to meet the 'plan' for a farming unit. The average Bonitet values as determined over two periods (1991 and 1999) for each of the Administrative Districts of Sydarya Province are presented in Table 1.1.2. By comparing the changes

in Bonitet values over the two periods, a qualitative assessment can be made of positive or negative change to the resource base.

Table 1.1.1. Classification of irrigated area into salinity categories in each of the nine Administrative Districts of Syrdarya Province**.** Values in table represent the % of irrigated area affected by different degrees of salinity and STD represents the standard deviation from the mean.

No.	District	Leached and low saline (2-4 dS m^{-1})	Moderate saline (4-8 dS m^{-1})	Severely saline (8-16 dS m^{-1})	Miscellaneous Non-classified land.
1	Akaltin	60.3	15.5	7.8	16.4
2	Bayaut	61.5	17.8	5.6	15.1
3	Sayhunabad	48.7	43	4.1	4.2
4	Gulistan	62.4	30.9	4.4	2.3
5	**Mirzaabad**	**36.9**	**45.9**	**11.7**	**5.5**
6	Sharaf Rashidov	66.0	5.6	21.3	7.1
7	Mekhnatabad	51.3	26.4	13.0	9.3
8	Syrdarya	60.2	17.1	5.7	17.0
9	Havast	55.7	25.2	9.2	9.9
	Mean (STD)	55.9(±8.5)	25.3 (±12.4)	9.2(±5.2)	9.2(±5.4)

Results showed that Mirzaabad has the lowest Bonitet value in 1999 (42) having undergone a decline of four points since 1991 (Table 1.1.2). It is interesting to note that out of the province's nine administrative districts, only two (Mekhnatabad and Havast) showed a positive increase in Bonitet values between the aforementioned period, suggesting that, in the majority of cases, there has been a steady decline in the productive capacity of land resources. As Mirzaabad had the highest overall percentage and total of moderate and severely salinized irrigated land, coupled with the fact that there has been a decline in its Bonitet value between 1991 and 1999, this Administrative District was selected to go forward into Stage 4.

Table 1.1.2. Mean Bonitet values for Administrative Districts of Syrdarya Province over two time periods, 1991 and 1999**.** STD is the standard deviation from the mean.

No.	Districts	Average Bonitet Grade 1991	Average Bonitet Grade 1999	Difference (±)
1	Akaltin	60	53	- 7
2	Bayaut	58	51	- 7
3	Sayhunabad	55	51	- 4
4	Gulistan	54	50	- 4
5	**Mirzaabad**	**46**	**42**	- 4
6	Sharaf Rashidov	49	45	- 4
7	Mekhnatabad	35	40	5
8	Syrdadrya	66	52	- 14
9	Havast	44	45	1
	Mean (STD)	52(±9)	49(±5)	- 4

Stage 4 – Identification of communities with the lowest land quality (i.e. Bonitet) values within the targeted administrative district: Communities in this case refer to villages that were formerly *kolkhoz* and *sovkhoz* territories under the Former Soviet Union (FSU), which after the post-independence land reforms were re-structured into individual farming units. From a statistical perspective, most of the agricultural land and water information are disaggregated down to the community level or farm associations. Based on soil quality assessments of the irrigated soils of Mirzaabad District using farmer associations, communities were selected wherein the search for possible bright spots would be undertaken. Within the old irrigation zone of Mirzaabad district, the lowest Bonitet grade was observed for the Dekhkanabad Farms Association (42) based on data collected in 1997 (Table 1.1.3). It is of note that this farming association has undergone a dramatic decline in Bonitet value from 51 as determined in 1991 (Table 1.1.3). In the new irrigation zone, the lowest Bonitet grade was observed in the A. Kulbekov Farms Association (38) (Table 1.1.3). These two farmer's associations were selected as target areas for the identification of bright spots and control objects for further study as they both fall within the same irrigation command area.

Stage 5 – The final step in the selection process is the identification of individual farmers from each of the target farmer associations: There are there are a total of 69 individual farmers in the Dekhkanabad Farmers Association. Similarly, the A. Kulbekov Association comprised 74 farming units. Based on the following three criteria, farmers were selected to go forward into a comprehensive assessment:

- crop (cotton-wheat) yield per Bonitet grade
- meeting the state quotas on a continuous basis
- positive reputation of the farm among local authorities and neighboring farmers.

Five bright spots farms from each of the farm associations and an equivalent number of control objects were selected. Individual visits to each of the identified farms were undertaken and data on production levels and income generation were collected.

Table 1.1.3. Soil quality assessment of farmer associations in the Mirzaabad District of Syrdarya Province (ha).

Name of Farms Association	**Below average**		**Average**		**Good**		**Total (ha)**	**Average bonitet grade 1997**	**Average bonitet grade 1991**
	III class	**IV class**	**V class**	**VI class**	**VII class**	**VIII class**			
	Bonitet Grade								
	21-30	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**			
Ok-Oltin		129	820	840		256	2045	51	67
T. Akhmedov		267	1110			576	1953	51	51
Mirzachul		2575	804				3379	38	40
Tashkent		113	3161		259		3533	45	43
Dekhkanabad		**952**	**1100**	**195**	**55**		**2302**	**42**	**51**
G. Akhmedov		2407		877	182		3466	41	47
Beruni	1810	531		175			2516	38	42
Ulugbek		1351	210				1561	39	40
Dustlik		212	1161	334			1701	44	45
A. Kulbekov	**498**	**1005**		**44**	**91**		**1638**	**38**	**-**
K/H tehnikum		97					97	38	-
Total for District	2308	9639	8366	2465	587	832	24197	42	46

Turkmenistan. Dashoguz Province is located in the north of Turkmenistan and was the focus of this study. It has a mean annual precipitation of 77 mm and is the most severally affected province by irrigation induced salinity. Agricultural production in Dashoguz Province is based on irrigated wheat and cotton. The water source that feeds its irrigation systems is the Amu-Darya River. Data collection in Turkmenistan followed a different approach. Here, the focus was on individual farmers that had been identified as superior farmers (termed *Mulkdars*) and control objects that represented the average farmer productivity in the region. Selected data on yields of wheat and cotton were collected for the years 2003 to 2005 along with basic information on the production practices of farmers. This information, although limited, did provide insights into the performance of individual farmers.

Kazakhstan. The study area was identified through a multistage purposive sampling procedure as described previously for Uzbekistan using the following four step: 1) identification of the cotton growing provinces with the highest reported levels of salinization of irrigated land; 2) identification of administrative district within the selected province with the highest salinity; 3) assessment of soil quality in the identified district; and the 4) identification of farming communities growing cotton with the lowest land quality.

Table 1.1.4. Threshold indicators for the identification of bright spots in Southern Kazakhstan

Indicators	Threshold value
Profitability	≥USD 300.0 ha^{-1}
Productivity	Cotton yields not less than 3.0 t ha^{-1}; Wheat yield not less than 4.0 t ha^{-1}
Asset returns	>1
Value of assets per 1 hectare	USD 400-700 ha^{-1}
Coefficient of technical capacity per farmer and per hectare	56 horse power farmer^{-1} and 6.2 horse power ha^{-1}
Efficiency of irrigation water use	USD 2.56 m^{-3} to USD 2.88 m^{-3}
Coefficient of land use	≤ 1

Identification of individual farmers who were deemed to be bright spots were achieved through analyses of secondary data obtained from local authorities. In this case the dominant criteria for bright spot farm identification were productivity and profitability of the farm. In order to qualtify as a bright spots farms were required to fulfill threshold indicators given in Table 1.4. On the basis of these indicators 11 farms were identified as bright spots and 11 as the control farms.

Statistical analysis. Descriptive statistics and relationship analysis were the main analytical tools used to describe differences between the two groups. In this respect, differences in means and medians of variables between bright spots and control objects were compared using an unpaired t-test for means and the Mann-Whitney test as a non-parametric counterpart for comparing medians. The non-parametric Mann-Whitney test was the preferred test for significance since the data were from a small population and they did not conform to a normal distribution (Mullee, 2002). It is of note that an unpaired parametric t-test with a 95% confidence interval was used for comparisons, however, parametric tests assume a Gaussian distribution, which is difficult to verify for small samples (Motulsky, 1995).

The relationship and effects between variables were tested and approximated by a linear regression model and other suitable statistical models depending on the type of dependent and independent variables. The statistical program, Statistix 7 (Analytical Software, 2000) was used to test relationships and approximate the effects.

RESULTS

General Characteristics:

Uzbekistan: The Hungry Steppes (‘*Mirzachul*’), has the highest degree of salinity and land degradation in the country. Syrdarya Province falls within this region and, as discussed above, formed the focus for the identification of bright spots (Figure 1.1.1). The province has 279,100 ha of irrigated land, 89.9% of which is affected by varying degrees of salinity. The Province comprises nine administrative districts, the majority of which are under the state quota system[2] for the production of agricultural commodities. Since the government plans to transfer all of the current agricultural producing areas to individual farms by 2008, the selected farms are currently held by individual farmers who have been farming under the changed policy for more than 3-5 years and can thus be described as ‘quasi-private’ since they are still required to operate under the quota system.

‘Private farms’ in Uzbekistan are something of an anomaly, given that the state retains ownership of the land. Here, the management of the farming enterprise is privatized to an individual or a family. This ‘manager’ has to submit a business plan to the state, accept to produce the state-determined target level of outputs (only for cotton and wheat producing farms) of state-planned crops, agree to buy the inputs from state input suppliers, and agree to sell the target levels of outputs to state

[2] The state quota or ‘state order system’ in Uzbekistan is a continuation of Soviet system of allocating production targets for major crops for agricultural enterprises, as well as providing agricultural inputs, based on the average ‘Bonitet’ index of land. State companies are responsible for the provision of inputs and procurement of outputs at pre-determined prices.

procurement organizations. The manager is free to decide on the levels of input use (water, labour, fertilizer, seed, machinery, pesticides and herbicides, etc.) and time of cultivation. All business has to be transacted through a state financial institution and transparent records have to be maintained. The farm is liable for inspection by state agencies responsible for agriculture, labour, taxation, and environment at any time. The 'private' farmers in Uzbekistan are best described as individual (as opposed to cooperative) agricultural producers rather then private farmers.

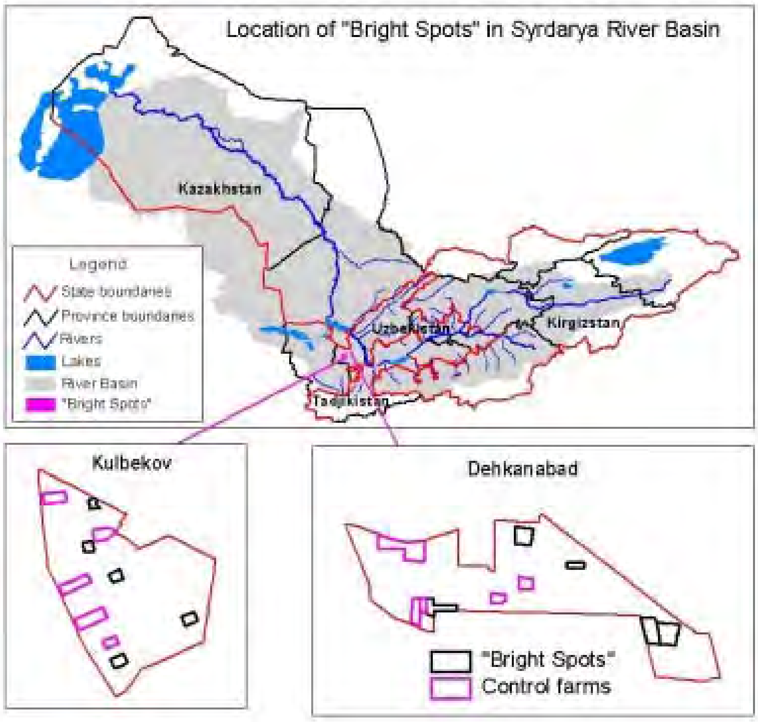

Figure 1.1.1. Map showing the location of bright spots and control object farms in the two farming associations in Syrdarya Province Republic of Uzbekistan.

Turkmenistan: Dashoguz Province has the highest degree of land degradation associated with salinity in the country. In discussing the bright spots in Turkmenistan, it is important to place current farming systems. Since 1990, there has been a significant shift from collective farming structures to more individualized agriculture within the context of so-called 'peasants associations' ('*daikhan berleshik*') where the collective and state farms have parceled out large fields to individual leaseholders (Lerman and Brooks, 2001; Lerman and Stanchin, 2004). The role of the associations is, firstly, as the 'guardians' or 'administrators' of state-owned agricultural land that is distributed to leaseholders for cultivation. Secondly, the associations are charged with maintaining rural infrastructure in the villages and they receive a certain payment from the leaseholders for this service. Thirdly, they are the conduit for transmitting state orders to the leaseholders and enforcing compliance (Lerman and Stanchin, 2004). As in the past, production targets for wheat and cotton are assigned to peasant associations; the association manager divides the overall quantities among leaseholders so that the full target is met or exceeded. These two commodities are sold exclusively through the state marketing organization (Lerman and Stanchin, 2004). Commodities that are not subject to state order, such as vegetables, milk or eggs, are generally produced under different institutional arrangements on family household plots (not on the leasehold) and are sold in nearby markets or through private traders (Lerman and Stanchin, 2004). The average size of these household plots is 0.2 ha.

The focus of the study is on leasehold farms that have an average size of four hectares where cotton and wheat are grown under state order. The bright spots are drawn from an elite group of farmers called *mulkdars* (*mulk* meaning ownership). The identification of *mulkdars* was initiated in 1996 by the President of Turkmenistan to reward farmers who consistently outperformed the plan yield levels for this land over a period of three to four years. The identification of *mulkdars* is the responsibility of the *hyakimliki* (district governor) who verifies their performance. Farmers who fall into this group are

reward with land 'ownership' rights and, in some cases, a small tractor from the President. Currently, there are approximately 500 *mukldars*. Control objects were selected from the same farmer associations and represented the poorest performing farmers.

Kazakhstan: Through the above methodology the Turkestan district was identified as the study area. The district covers an area of 7,400 km^2, which is 6.3 % of the area of South Kazakhstan Province. The population in 2004 was approximately 178,700, 50.7 % of which reside in rural areas. The district produces 6.7 % of the total agricultural output of the province. Cotton is the main and most important industrial crop of the Southern region. It makes up 34% of the total agricultural output of the Turkestan district. The area under cotton has been increasing in recent years, occupying almost half of total sown area in 2004, this presumably being due to buoyant international prices.

The district is located in the Aris-Turkestan irrigation zone (ATIZ) covering a wide territory of more than 17,000 km^2. The development of the zone began in 1961. The length of Aris-Turkestan canal is 140 km with a head flow of 45 m^3 sec^{-1}. It irrigates more than 70,000 ha of land where cotton is the main crop. More than 700 km of open and 770 km of closed collector drainage network have been constructed in the irrigation zone. However, due to over irrigation and the lack of maintenance and rehabilitation of drainage infrastructure in the region, there has been a rise in groundwater tables with associated salinity. This situation coupled with low relative humidity and high evapotranspiration rate from soil surface, are the main cause of salinization rapidly spreading in the region. This in turn is leading to significant decreases in productivity of irrigated farming.

The community was identified as *Stari Ikan* village in the Turkestan district (Figure 1.1.2). Irrigated land in this village is considered to be highly saline with low Bonitet values that range from 35-45. Soil analysis of the study area indicated that there are elevated levels of $MgSO_4$, Na_2SO_4, NaCl suggesting the presence of saline/sodic conditions similar to those described by Vyshpolsky *et al.*, 2008 and Karimov *et al.*, 2008.

The study area is located within the arid zone with a strong continental climate. The highest recorded precipitation rates are observed in the winter-spring period. Elevated wind velocities in the spring result in significant wind erosion and the loss of top soil. The spring is short, wet at the beginning and drying towards the beginning of summer. About 90 mm of precipitation falls in spring, which is 35-40 % of the mean annual rate. Relative humidity in March is 70 %, and in May 40 %. The summers are characteristically dry and hot with day time temperatures commonly reaching 40ºC with a relative humidity of less than 15%. A combination of high temperatures and humidity intensifies evaporation from the soil surface and leads to the accumulation of salts in surface layers.

Figure 1.1.2. Map showing the location of bright spots and control object farms in the two farming associations in the Turkestan region of southern Kazakhstan.

Productivity and biophysical characteristics:

In the discussion that follows, the outcomes of analysis are discussed within the context of each of the countries.

Uzbekistan

Within the context of a planned agricultural commodity market, a key attribute of the 'state order' system is the maintenance of detailed productivity records. Yields of cotton and wheat from individual farming units are meticulously recorded and maintained in order to make sure that planned quotas are met. Wheat and cotton production changes over time can therefore be discerned, particularly during the period prior to and after 'privatization'. Cotton and wheat yields were compared between production under the *Shirkat*[3] system prior to privatization with current productivity levels (Figure 1.1.3 and 1.1.4). During the *Shirkat* era, there was little difference between the two groups with respect to cotton production; the bright spot group had, however, higher wheat production (Figure 1.3). Post-privatization, yields for both commodities increased significantly ($P<0.05$) in the case of the bright spot group whilst yields tended to decline in the control objects (Figure 1.1.3 and 1.1.4).

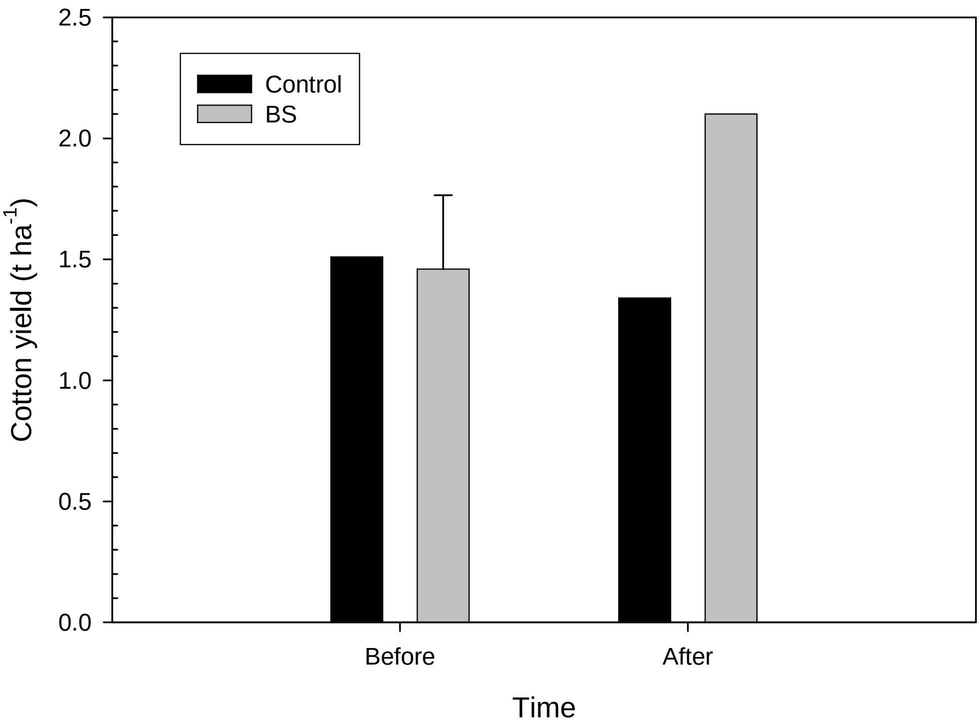

Figure 1.1.3. Changes in cotton yield over two consecutive periods, pre- (Before) and post- (After) privatization for the 'Control' object and Bright spot (BS) farming systems in the administrative District of Mirzaabad, Uzbekistan. n=10; vertical bar represents the least significant difference ($P<0.05$) between population means.

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[3] Shirkat (Uzbek): A cooperative agricultural production unit in Uzbekistan, where the farm chairman is appointed by the local government. Any citizen of Uzbekistan can apply for the membership of the shirkat who is allotted a piece of land based on the number of family workers. The farmer is provided with a residence in the area of shirkat, and receives a fixed monthly salary, plus a share in profits or losses of the farm, both in-kind and in cash. The shirkat as a whole is responsible for meeting the production targets dictated by the State, and is entitled to receive subsidized inputs and part of production costs as an advance. The shirkat has to deliver at least its target output to the State purchasing system. Shirkats failing to meet their production targets are under financial obligation to the State to pay for the value of production target not met. This debt is transferred to individual members in proportion to their land allocation.

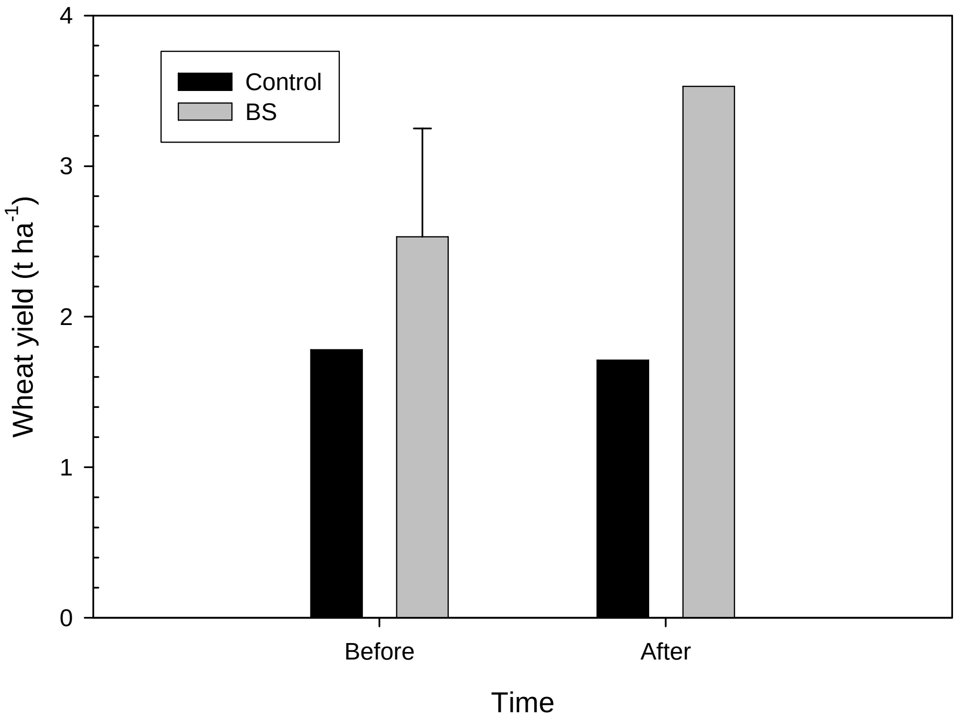

Figure 1.1.4. Changes in wheat yield over two consecutive periods, pre- (Before) and post- (After) privatization for the 'Control' object and Bright spot (BS) farming systems in the administrative District of Mirzaabad, Uzbekistan. n=9; vertical bar represents the least significant difference ($P<0.05$) between population means.

The performance of individual farmers and variations between farmers and groups is succinctly described by plotting changes in the relative yield of the two commodities against pre-privatization yields (Figure 1.1.5a and 1.1.5b). Values >1 represent an increase in yields post-privatization with <1 denoting a decrease in productivity. All of the control objects realized relative yield declines post-privatization whilst, except for one case for each commodity, relative changes in yield for bright spots were >1 (Figure 1.1.5a and 1.1.5b). The relationships between relative change in yield versus pre-privatization yield for the bright spot group resulted in significant ($p>0.05$) coefficients of determination (R^2) suggesting a diminishing relative yield change the higher the initial pre-privatization yield. No such relationship was found for the control objects (Figure 1.1.5a and 1.1.5b).

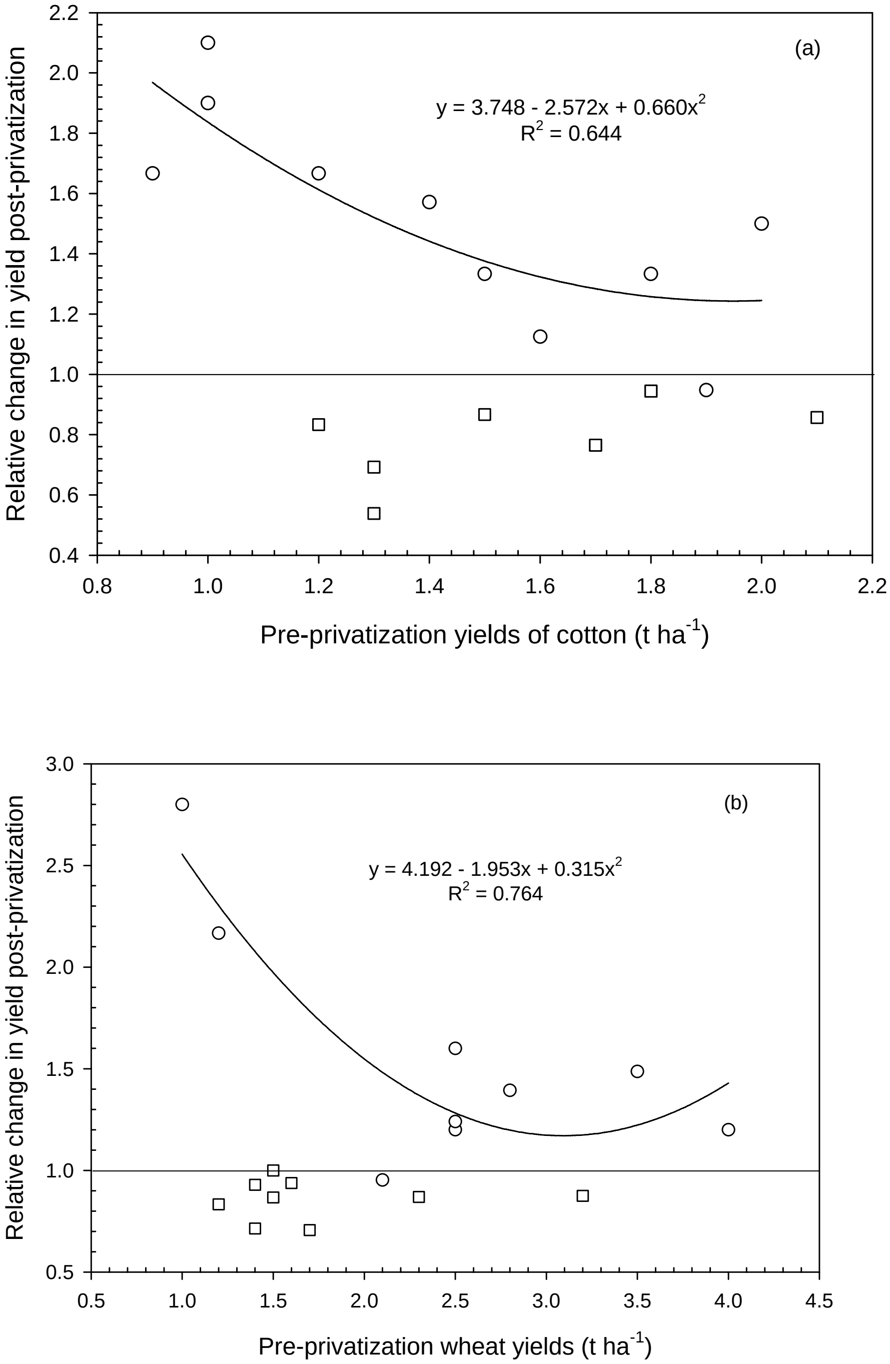

Figure 1.1.5. Relative change in yields of cotton (a) and wheat (b) post-privatization for the Control (□) object and 'Bright' spot (○) farmers with respect to pre-privatization yields.

In order to assess whether actual yields of cotton and wheat were significantly different between groups, an unpaired t-test and median test was performed on the data sets from the two groups. The statistics confirm the significantly higher yields achieved in both commodities on the bright spot farms compared to the control objects (Table 1.1.5). As the production of these two commodities is controlled under a quota system, production levels for each farmer are set and it is expected that the farmer will sell the requisite amount to the state at the end of the season. This level of production is termed the 'plan'. As discussed previously, the 'plan' level of production is based on the production capacity of soils and is generated using the average Bonitet value for the farm. Since the Bonitet values for the bright spot and control objects were similar, there should be no major difference in the 'plan' yields for both the groups. A comparison of the 'plan' yields for cotton and wheat between the two groups of farmers indicates that the means and medians did not differ significantly from each other (data not presented). Thus, the expected 'plan' production levels of the two groups were

similar. A comparison between the 'planned' and 'actual' yields achieved by the two groups, indicate that, in the case of bright spots, actual yields were significantly ($p>0.05$) higher than 'planned' yields for both commodities, which was not the case in the control objects (Table 1.1.5). This is important from an economic perspective as it predicates the viability of these farming enterprises. Farmers who are able to exceed planned quota levels are able to utilize the surplus to their own benefit. Failure to meet plan target levels can, however, have severe financial implications and the possible revocation of land entitlements.

Table 1.1.5. Descriptive statistics and level of significances for relationships between 'plan' and actual yields of cotton and wheat yields for the two groups in Mirzaabad District, Uzbekistan. SD = standard deviation from the mean.

Farmer group	Plan	Actual	Significances
Mean ± SD	**Cotton Yield (t ha^{-1})**		
Control object	1.49 ± 0.27	1.31 ± 0.36	0.228
Bright spot	1.72 ± 0.19	2.07 ± 0.40	0.024
Median (min; max)			
Control object	1.45 (1.10; 1.90)	1.30 (0.70; 1.80)	0.131
Bright spot	1.80 (1.40; 2.00)	2.00 (1.50; 3.00)	0.036
	Wheat Yield (t ha^{-1})		
Mean ± SD			
Control object	1.73 ± 0.52	1.48 ± 0.54	0.319
Bright spot	2.07± 0.79	3.48 ± 1.06	0.006
Median (min; max)			
Control object	1.60 (1.30; 2.80)	1.30 (1.00; 2.80)	0.131
Bright spot	1.80 (1.00; 3.00)	3.10 (2.00; 5.20)	0.045

Whilst it is clearly evident that the performance of the bright spot group of farmers is superior to the control objects, the question arises as to how these two groups relate with respect to the performance of the entire population of farmers from which these groups were derived? To address this question, data on cotton yields from the 120 farmers that make up the two Farmers' Associations were assessed. The difference between mean actual and 'planned' yields per hectare for cotton was plotted against the 'planned' yield for all farmers (Figure 1.1.6). A total of 35% of farmers fell short of meeting the 'planned' target yield level, 19% met the 'planned' yield requirements and 46% of the farmers exceeded the planned target yields. This would suggest that less than 50% of farmers exceed their quota commitments and hence benefit from the sale of production surpluses to markets that are not controlled by the state. As discussed previously, if it is assumed that prior to the privatization phase the majority of farms were just meeting 'planned' production levels, it can be argued that with privatization a considerably more (46%) have increased production levels and are potentially benefiting economically from their efforts.

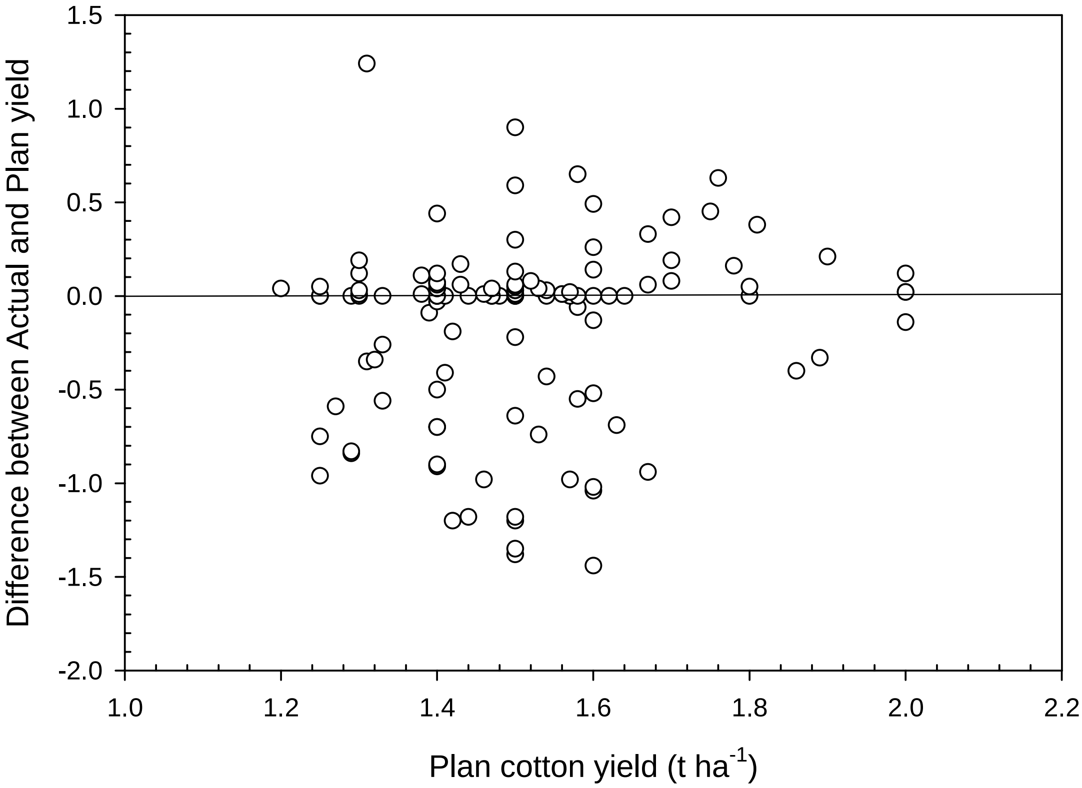

Figure 1.1.6. Relation between the difference of actual and 'plan' cotton yields versus the 'plan' yields for 120 farmers in the two farming associations in the administrative District of Mirzaabad, Uzbekistan from which Bright spot and Control objects were identified**.** Data are from the 2005 growing season.

From the previous discussion, clear differences in the productivity levels of the two groups of farmers are evident. Intuitively, one could assume that the disparities in yield might in part be associated with differences in biophysical attributes between the two groups. Selected biophysical attributes, including the areas of irrigated cotton and wheat; Bonitet value; soil phosphorus and potassium; soil organic matter; and depth to ground water table were analyzed to determine whether there were significant differences between the bright spot and control farmer groups (Table 1.1.6). It is of note that the mean areas cultivated to each crop and labor per irrigated area were not significantly different between the two groups, suggesting that the size of irrigated area and number of laborers were similar (Table 1.1.6). The Bonitet values for each of the groups are virtually the same suggesting from a biophysical perspective, the productivity potentials of each of the groups were virtually identical (Table 1.1.6). Furthermore, there were no significant differences between the bright spot and control object farms in soil organic matter contents, soil phosphorus and potassium, indicating that soil biophysical attributes were the same between the two groups and therefore may not have contributed to differences in their performances.

Whilst the Bonitet value is an index for the farming unit as a whole in establishing target yields of cotton and wheat, it can be viewed as reflecting an aggregated value for the farm. It may not reflect the individual biophysical attributes or productivity potential of individual fields or farming units. This limitation is supported by data on the percentage of production fields on each of the individual farming units that is affected by low, moderate and high salinity (Table 1.1.7). Since the two groups had similar Bonitet values (Table 1.1.6) there were differences in the number of farms affected by different salinity levels (Table 1.1.7). For example, five bright spot farms had land classified as highly saline, contrasting that of the eight in the control objects (Table 1.1.7). More importantly, the mean groundwater height was significantly higher in the control objects (0.95±0.27 m) when compared to the bright spots (1.62±0.37 m) (Table 1.1.6).

Table 1.1.6. Descriptive statistics and level of significances for selected biophysical attributes of the bright spot and control object farms in the Mirzaabad District, Uzbekistan**.** SD = standard deviation from the mean.

Attribute	Bright spot farmers	Control object farmers	Significances
Mean ± SD			
Area under cotton (ha)	16.0 ± 14.1	13.8 ± 10.47	0.696
Area under wheat (ha)	12.5 ± 6.7	12.0 ± 3.9	0.848
Area per labor unit (ha/unit)	4.6 ± 3.6	6.5 ± 2.7	0.214
Bonitet value	42.5 ± 4.6	41.2 ± 3.1	0.473
Soil organic matter (%)	0.651 ± 0.134	0.651 ± 0.108	0.940
Soil phosphorus (mg kg^{-1})	11.69 ± 5.51	15.21 ± 6.89	0.223
Soil potassium (mg kg^{-1})	346.8 ± 74.6	363.5 ± 89.2	0.654
Depth to water table (m)	1.62 ± 0.37	0.95 ± 0.27	0.000

These two factors would invariably contribute to the lower production potential of the control objects as evidenced in the yield data of cotton and wheat. The fact that there are differences in the percentage of land affected by salinity and groundwater height between bright spots and control objects that are not reflected in the Bonitet values indicates a possible limitation in utilizing this index to assess the production of wheat and cotton in the data sets at the farm level. A regression of Bonitet values against yields of cotton and wheat indicated that there is no significant relationship (data not presented). One could infer from this that intrinsic soil properties as assessed in this index do not contribute to the overall performance of the two crops due possibly to the aggregated nature of this index.

A regression of cotton and wheat yields against the height of groundwater from the soil surface resulted in a highly ($P<0.001$) significant linear relationship, and reasonably high correlation coefficients suggesting that groundwater depth is a major determinant in crop performance that accounts for a significant proportion of the observed variability between the two groups of farmers (Figure 1.1.7). In addition, high water tables are often associated with salinity and are a contributing factor to the overall problem. Hence it is suggested that water table height could be viewed as a surrogate for salinity or soil quality.

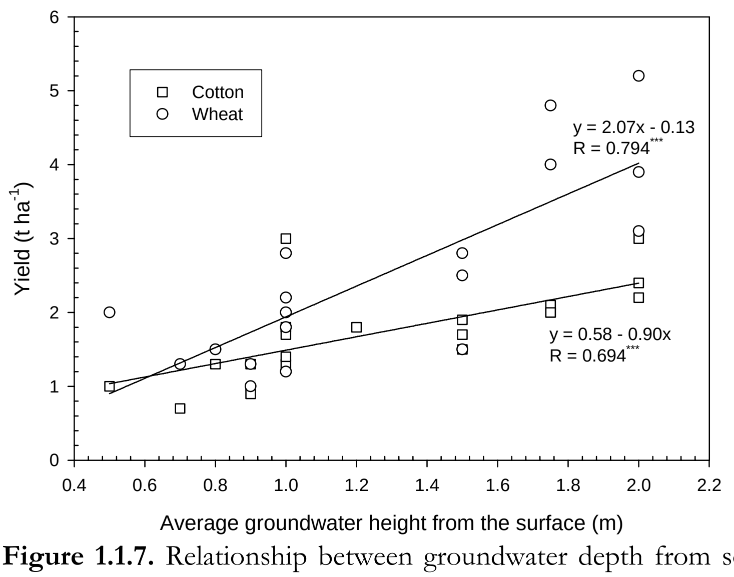

Figure 1.1.7. Relationship between groundwater depth from soil surface and yields of cotton and wheat for bright spots and control objects for farming systems in the administrative District of Mirzaabad, Uzbekistan.

Table 1.1.7. Percent of production fields classified as having low, moderate and high salinity levels and the groundwater height below the soil surface for bright spots and control objects in the Mirzaabad District, Uzbekistan.

Farmer	Low salinity (2 – 4 dS m^{-1})	Moderate salinity (4 – 8 dS m^{-1})	High salinity (8 – 16 dS m^{-1})	Groundwater height (m)
		I. Bright Spots		
Alpomish	70	30	-	1.75
Sultonkhon avlodi	12	-	13	1.00
Norin	-	57	43	2.00
Raim ota	87	6	-	1.75
Zomin	-	52	48	2.00
Bodomsoy	18	-	-	1.00
Nuroniy	20	80	-	1.75
Istiklol	-	-	13	1.50
Umar ota	-	50	-	2.00
Vijdon toji	15	10	5	1.50
Count	6	7	5	-
Mean (±SD)*	37.0 (±32.7)	40.7 (±26.7)	24.4 (±19.6)	1.62 (±0.37)
		II. Control Objects		
Bahor	20	50	30	0.70
Ibn Sino	-	26	4	0.80
Abdushokhid	-	25	25	0.90
Bobo Koh	20	20	-	1.50
Ropkon	-	50	36	1.20
Pirkhol	20	-	16	0.90
Laylakota	-	31	26	1.00
Holmat aka	12	-	-	1.00
Zomin toshduduk	-	28	28	1.00
Sadir Rakkos	10	54	36	0.50
Count	5	8	8	-
Mean (±SD)*	16.4 (±4.9)	35.5 (±13.5)	25.1 (±10.6)	0.95 (±0.27)

*SD = Standard Deviation.

Limited economic data on the performance of the farming units was collected, within which there were statistically significant differences between the two groups with respect to the annual salaries of labor units, production costs and profits for each of the commodities (Table 1.1.8). It is of note that there was a considerable range in these values between and within each of the groups indicating the variable nature of these attributes and the conditions each of these farmers are operating under. The annual salaries of labor were significantly higher for bright spot workers when compared to the control objects, given the better economic performance of the former. The production costs for both cotton and wheat were higher in the bright spots cases. (Table 1.1.8). It is of note that in the case of the control objects, negative returns in the production of wheat and cotton were observed (Table 1.1.8).

Table 1.1.8. Descriptive statistics and level of significances for selected economic attributes of the 'Bright' spot and control object farms in the Mirzaabad District, Uzbekistan. SD = standard deviation from the mean. Soum is the local currency; 1000 Soum is equivalent to USD1.

Commodity	Bright spot farmers	Control object farmers	Significances
Mean ± SD			
Annual income labor (thousand Soum/laborer)	414 ± 163	233 ± 139	0.016
Net production costs for wheat (thousand Soum ha^{-1})	213±148	102±21	0.042
Net profit wheat (thousand Soum ha^{-1})	237±542	8±33	0.223
Net production costs for cotton (thousand Soum ha^{-1})	371± 121	270±90	0.050
Net profit cotton (thousand Soum ha^{-1})	187±75	28±31	0.000
Individuals investment in the farming enterprise at privatization (thousand Soum ha^{-1})	1185±540	349±188	0.002
Median (min; max)			
Annual income labor (thousand Soum /laborer)	425 (100; 640)	160 (110; 500)	0.028
Net production costs for wheat (thousand Soum ha^{-1})	195 (46; 533)	100 (73; 136)	0.080
Net profit wheat (thousand Soum ha^{-1})	53 (0; 1680)	18 (-61; 46)	0.005
Net production costs for cotton (thousand Soum ha^{-1})	341 (250; 666)	250 (137; 416)	0.072
Net profit cotton (thousand Soum ha^{-1})	194 (75; 296)	35 (-22; 83)	0.000
Individuals investment in the farming enterprise at privatization (thousand Soum ha^{-1})	1000 (500; 2000)	350 (100; 600)	0.000

Further socio-economic indicators were collected that reflect the contrasting performance and financial capacity of these two groups (Table 1.1.9). The higher number of private motor cars and refrigerators within the bright spot group of farmers would reflect greater 'affluence' associated with increased disposable incomes. Furthermore, the higher number of farms having transport and tractor units within the bright spot group would reduce dependence on the centralized services commonly utilized for field operations. In addition, the bright spot farms had higher total numbers of cattle, sheep and chickens than the control objects (Table 1.1.9).

One question put to farmers was the amount of individual investment that went into the establishment of the farming enterprise post privatization. An analysis of the extent of individual investment revealed that bright spot farmers invested significantly higher (mean: 1000, range: 500 – 2000,000 soums) funds into the farm when compared to the control objects (mean: 350, range: 100 – 600 '000 soums) (Table 1.1.8). Hence bright spot farmers were able to mobilize greater funds to invest in the enterprise upon privatization than the control objects.

Table 1.1.9. Selected socio-economic indicators of 'Bright' spots and control objects from the Mirzaabad District, Uzbekistan.

Farmer	Number of families that own cars	Number of families with refrigerators	Number of transport units on farm	Number of tractors on farm	Cattle on farm	Sheep on farm	Chickens on farm
			Bright spot farms				
Alpomish	3	11	-	-	8	-	-
Sultonkhon avlodi	1	3	-	-	1	-	28
Norin	2	10	1	1	5	2	30
Raim ota	4	4	2	3	8	-	10
Zomin	1	6	3	4	1	8	10
Bodomsoy	-	-	-	-	-	-	10
Nuroniy	-	-	-	-	6	-	10
Istiklol	-	1	1	1	3	2	10
Umar ota	1	3	1	1	10	20	35
Vijdon toji	1	1	-	-	-	-	-
Count	8	8	5	5	8	4	8
Total	13	39	7	10	42	32	143
			Control farms				
Bahor	-	-	1	1	-	-	10
Ibn Sino	1	1	-	-	2	-	12
Abdushokhid	-	-	-	-	2	-	6
Bobo Koh	-	-	-	-	-	-	6
Ropkon	-	1	-	-	10	8	100
Pirkhol	-	2	-	-	2	-	6
Laylakota	2	2	-	-	1	-	8
Holmat aka	-	1	-	1	1	2	10
Zomin toshduduk	-	-	-	-	1	-	10
Sadir Rakkos	1	3	-	-	4	-	15
Count	3	6	1	2	8	2	10
Total	4	10	1	2	23	10	183

A clear biophysical constraint, namely elevated water tables, appears to have had a significant impact on the yield of cotton and to a lesser degree wheat, suggesting the importance of managing the water table. This is best achieved through the maintenance of surface and sub-surface drainage systems and networks that require significant investments. Implicit in this is the notion of greater access to resources, both financial and physical, and a degree of flexibility in undertaking farmer operations. A stepwise regression of independent variables on net profit from cotton production was undertaken to determine the importance of both biophysical and economic variables. The independent variables included water table height, the production cost of cotton, initial investment in the farm, number of tractors per farm and annual salary of labor were used as input into the regression. The only two variables were found to significantly (over 88% of variance accounted for) influence net profitability of cotton production was water table height and the production cost of cotton and were described by the following equation:

Net profit cotton ('000 Soum/ha) = 0.319±0.61PCost + 74.99±26.15WHeight – 125.47; $R^2 = 0.888$

where Pcost is the production cost of cotton in '000 Soum/ha and WHeight is the water table height in m from the surface.

Turkmenistan

In Turkmenistan, the focus of the study was confined to individual farmer's belonging to *Mulkdars*, whilst control objects were effectively neighboring farmers. Wheat is the dominant crop represented in the sample surveyed, with eight farms being assessed. In contrast, only five bright spots and control farms were sampled that grew cotton. The average size of wheat bright spot and control farms were 2.8±0.1 and 4.1±1.1 ha with a mean Bonitet value of 53 over both groups. The size of cotton farms assessed in the survey was the same for both groups at 2.1 ha and the mean Bonitet value for the Bright spot and control farms were 45 and 41 respectively.

The yields for three consecutive years for both crops are presented in Table 1.10. Bright spots consistently outperformed control objects over all years, with the yield differential in some years between groups being an order of magnitude higher. Over the three years that harvests were monitored, the mean yield of wheat for the bright spots and control objects were 5.22±0.51 and 0.57±0.07 t ha^{-1} respectively, clearly showing the superior performance of the former group. Similarly, overall mean yields of cotton for bright spots and control objects over the three-year period were 4.31±0.36 and 0.89±0.17 t ha^{-1}. In a 2006 survey of 94 farmers in the area (from which the current sample of farmers was drawn), mean wheat and cotton yields were 1.6 and 1.2 t ha^{-1} respectively.

Table 1.1.10. Descriptive statistics and level of significances for wheat and cotton at bright spot and control object farms in the Dashoguz Province, Turkmenistan**.** SD = standard deviation from the mean.

Attribute	Bright spot farmers	Control object farmers	Significances
Mean ± SD	(t ha^{-1})		
Wheat production 2003 (n=8)	5.22 ± 2.90	0.71 ± 0.48	0.000
Wheat production 2004 (n=8)	5.77 ± 2.87	0.59 ± 0.29	0.000
Wheat production 2005 (n=8)	4.66 ± 1.62	0.46 ± 0.13	0.000
Cotton production 2003 (n=5)	3.98 ± 1.58	0.54 ± 0.59	0.011
Cotton production 2004 (n=5)	4.40 ± 1.51	0.92 ± 0.62	0.012
Cotton production 2005 (n=5)	4.64 ± 1.02	1.42 ± 0.40	0.011

In the survey of these farms, data was collected on farming practices that were used in the production of each commodity (Table 1.1.11). These data included land preparation practices; application of manures and inorganic nutrients; irrigation and leaching regimes; and weeding practices. It is clearly evident that there were differences between each of the groups, particularly in the amount of manure applied to each of the crops, rate of phosphorus application and the depth of cultivation (Table 1.1.11). In a stepwise regression analysis of mean wheat yield against these agronomic attributes, the amount of manure applied was the only attribute retained in the regression equation that explained 62% of the variance. Similarly, a stepwise analysis for cotton of the same attributes resulted in ploughing depth being the only attribute retained that explained 81% of the variance.

Kazakhstan

Prior to land reform and the privatization no significant differences were observed between the two groups of farmers with respect to land size (Table 1.1.12). However, upon privatization there was on average a 10 and 5 fold increase in land size holding in the bright spot and control object respectively (Table 1.1.12). These differences in land size after privatization were highly significant. Further, the yield of cotton between the two groups prior to privatization were not significantly different averaging 1.77 and 1.54 t ha^{-1} in the case of bright spot and control objects respectively (Table 1.1.12). However, after privatization cotton yields increased dramatically in within and between both groups with average yields of 3.06 and 2.50 t ha^{-1} being achieved in the bright spot and control object groups (Table 1.1.12). Hence, these results suggest that although productivity levels of these

farms were similar prior to reforms, the move to the establishment of private farms has brought significant positive changes in their farm productivity and performance. Moreover, the bright spot farmers have managed to outperform the control objects.

Table 1.1.11. Farming practices and inputs used in the production of wheat and cotton crops by bright spot and control farmers in Dashoguz Province, Turkmenistan. Standard deviations of the mean are presented

Attribute	Bright spot farmers	Control object farmers
	Wheat	
Land leveling, number of passes	1.8 ± 0.3	1.3 ± 0.5
Ploughing depth (cm)	34.3 ± 1.1	31.8 ± 2.2
Weeding operation (number)	2	1.25 ± 0.4
Leaching volume (m3 ha-1)	1525 ± 46	1512 ± 35
Total irrigation applied (m3 ha-1)	1325 ± 70	1187 ± 188
Manure (t ha-1)	5.2 ± 0.5	1.2 ± 1.3
Phosphorus (kg ha-1)	356 ± 105	181 ± 84
Nitrogen (kg ha-1)	281 ± 99	256 ± 46
	Cotton	
Land leveling, number of passes	2	1.6 ± 0.5
Ploughing depth (cm)	37 ± 2	31 ± 1
Number of weeding operation	4	3.2 ± 0.4
Leaching volume (m3 ha-1)	1560 ± 54	1480 ± 130
Manure (t ha-1)	9.2 ± 1.0	1.4 ± 1.3
Phosphorus (kg ha-1)	200	80 ± 109
Nitrogen (kg ha-1)	300	230 ± 44

Table 1.1.12. Changes in land size and yield before and after privatization for farmers in the Turkestan area of Kazakhstan of bright spot (BS) and control farmers.

Attribute	Bright spot farmers	Control object farmers	Significance
Land size before (ha)	7.49 ± 5.12	10.56 ± 8.24	0.309
Median (min; max)	4.02 (3.35; 18.40)	8.71 (2.68; 32.67)	
Land size after (ha)	82.74 ± 16.36	55.88 ± 11.34	0.000
Median (min; max)	82.04 (60.00;112.07)	55.6 (40.69; 76.71)	
Cotton yield before (t ha^{-1})	1.77 ± 0.31	1.54 ± 0.67	0.304
Median (min; max)	1.8 (1.4; 2.4)	1,4 (0.8; 2.8)	
Cotton yield after ((t ha^{-1})	3.06 ± 0.13	2.50 ± 0.30	0.000
Median (min; max)	3 (3.0; 3.4)	2.4 (2.2; 3.0)	
	Before privatization	*After privatization*	
Cotton yield for BS (t ha^{-1})	1.77± 0.31	3.06 ± 0.13	0.000
Cotton yield Control (t ha^{-1})	1.54 ± 0.67	2.50 ± 0.30	0.001

From 2000 farmers in *Stari Ikan* were able to expand their production capacity though the buying or leasing of land. It is interesting to note that the bright spot farmers have been able to lease on average over 75 ha of land during this period which is contrasted approximately 45 ha in the case of control objects. According to both types of farmers expansion of the land size has given them the opportunity to increase their productivity, exploit machinery and seek better agronomic techniques to sustain and improve their productivity. Moreover, farmers were able to increase their animal numbers through the profits generated. Many farmers have expressed that their livelihoods have improved with these changes. The difference and variation in performance of bright spot and control objects are succinctly described through plotting the 'before' yields to relative yield change in

yields 'after' privatization . All farms have shown significant increases in cotton yields however the increases of bright spot farms were higher than the control objects.

Since productivity of land is a function of biophysical attributes which are best described using the Bonitet index and selected soil parameters, analyses of this attributes along with area per labor unit was undertaken (Table 1.1.13). The area per labor unit was significantly ($p>0.05$) higher under the bright spot group when compared to the control object (Table 1.1.13). Intuitively one could come to the conclusion that the lower the value the greater the degree of attention to in field operations and hence higher yields. However, this would not appear to be the case as the there an average of 3.26 ha per labor unit in the bright spots compared to 2.37 ha per labor unit in the control object (Table 1.1.13). This may indicate that due to the poor performance of the cotton crop in the case of the control object, a greater amount of labor was required in field to achieve the attained yields. The Bonitet value for bright spots farmers was significantly higher than the control objects suggesting that overall the former group of farms were on higher quality soils and hence a great productive capacity (Table 1.1.13). This may in part explain the better performance of bright spot farms in terms of cotton productivity. In order to verify this, the yield per Bonitet value was calculated for both groups and compared before and after privatization (Table 1.1.14). The results indicated that yields per Bonitet of both groups did not significantly differ prior to privatization suggesting that both groups were operating at the same level. However, upon privatization the bright spot farmers were able to significantly increase their yields per Bonitet value (Table 1.1.14). If one assumes that there were no changes between the groups with respect to Bonitet values pre and post-privatization, it could be argued that in the case of both groups yields of cotton were constrained by factors other than soil quality and that with privatization the bright spot farms were able to take greater advantage of these changes than the control object. No significant differences in selected soil chemical attributes were observed between the two groups again suggesting that soil quality may not be a limiting factor in the enhanced performance of the bright spot group (Table 1.1.13).

Table 1.1.13. Selected characteristics of production systems and biophysical attributes for bright spot and control objects from Turkistan, Kazakhstan.

Attribute	Bright spot farmers	Control object farmers	Significance
Area per labor unit (ha/unit)	3.26 ± 1.05	2.37 ± 0.40	0.021
Land quality (bonitet value)	43.18 ± 3.37	38.64 ± 2.34	0.002
Soil organic matter (%)	1.02 ± 0.06	1.00 ± 0.00	0.341
Soil phosphorus (mg kg^{-1})	15.36 ± 2.73	15.91 ± 3.02	0.661
Soil potassium (mg kg^{-1})	262.73 ± 29.70	285.45 ± 23.82	0.062

Table 1.1.14. Changes in yield of cotton per Bonitet value before and after privatization of State farms in Turkestan, Kazakhstan.

Attribute	Bright spot farmers	Control object farmers	Significance
Cotton yield per Bonitet value before privatization (t/ha)	0.042 ± 0.01	0.040 ± 0.02	0.761
Cotton yield per Bonitet value after privatization (t/ha)	0.072 ± 0.01	0.065 ± 0.01	0.024

Livestock are certainly a major enterprise that has been positively affected through privatization (Table 1.1.15). Prior to privatization no significant differences in cattle and goat numbers were observed between the two groups although it should be stressed that there was significant variability in numbers within each group (Table 1.1.15). It is clearly evident that on average significant increases in animal numbers occurred in both groups with privatization (Table 1.1.15). However, the increase for BS farms from 7 head to 32 heads for cattle and 49 heads to 700 heads for sheep and goats are significantly higher than that of the control farms of 5 to 20 and 18 to 163, respectively. Moreover, both groups have acquired poultry after expansion the number of which also significantly differs

between the bright spot and control groups (Table 1.1.15). During the interviews the bright spot farmers indicated that they extensively apply manure generated from their livestock to their fields as a soil amendment. This would undoubtedly enhance the production of the cotton crop.

Table 1.1.15. Selected livestock composition before and after privatization of farms in Turkestan, Kazakhstan

Attribute	**Bright spot farmers**	**Control object farmers**	**Significance**
Cattle before	7.45 ± 2.25	5.09 ±3.42	0.073
Cattle after	31.91 ± 10.69	20.18 ± 9.48	0.013
Sheep/goat before	48.82 ± 55.99	17.91 ± 8.59	0.100
Sheep/goat after	700.00 ± 290.48	163.18 ± 136.35	0.000
Poultry after	94.82 ± 41.49	55.91 ± 35.20	0.028

In terms of economic indicators, the annual income per laborer and net profits from cotton production are significantly different between the groups, although, surprisingly, the production costs per ha (USD 395.13 for the bright spot farms and USD 374.21 for the control farms) and investment per ha (USD 357.74 for bright spot farms and USD 358.54 for control farms) made into the farm by both groups are almost identical (Table 1.1.16). Moreover, the investments that were made by farmers are mostly financed through own savings without support from outside sources. These results imply that bright farmers have better managerial skills than the other group since they had managed to obtain higher returns with similar investment on farms with larger land size and greater animal holdings. The possession of agricultural machinery indicates that although many farms have machinery for agronomic practices, their quantity is much higher in bright farms when compared to control farms (data not presented). This may indicate that efficiencies may be higher on bright spot farms due to greater availability of machinery compared to control objects.

Table 1.1.16. Selected economic indicators associated with the performance of bright spot and control farms in the production of cotton, Kazakhstan

Attribute	**Bright spot farmers**	**Control object farmers**	**Significance**
Annual income labour ($/laborer)	2696.40 ± 1299.24	1192.57 ± 390.22	0.003
Net profit ($/ha)	418.02 ± 3.33	21.09 ± 3.86	0.000
Net production cost ($/ha)	395.13 ± 24.82	374.21 ± 32.13	0.110
Investment ($/ha)	357.74 ± 53.00	358.54 ± 43.82	0.970

DISCUSSION AND CONCLUSIONS

The agricultural transition in the Former Soviet Union (FSU), particularly in Central Asia, has not been smooth. The reform efforts in the rural sector were thwarted by a lack of suitable markets and institutions. This resulted in increased barter trade, self-sufficiency policies and an increased role for the household in agriculture (Spoor, 2003). Therefore, the role of market forces in agricultural production is still very weak. The progress of agricultural reforms in Central Asia are dynamic and on going, quite complex in nature, and highly differentiated according to geographic locations (Spoor, 1997). The common signs of agricultural reforms in Central Asia are institutional vacuums, lack of supportive legal frameworks and an absence of effective extension services (Spoor, 2003).

Agricultural producers and policy makers are gradually realizing that through cooperation and collective action, rural communities can employ economies of scale, reduce transactions costs and improve their livelihoods. Moreover, not only for rural producer but also for agro-industry these steps are important in order to realize vertical integration and internalize costs. The notion of creation of agro-industry clusters (Porter, 1990 in Korea Rural Economic Institute, 2005) has been emerging as a focus of development policy in some countries, including Kazakhstan, in recent years.

In this respect, encouraging private farmers to reduce their transaction costs through collaboration, especially utilizing the concepts that are inherent in bright spots, can be viewed as one of the initial steps to realize this strategy. However, it is imperative that before embarking on such an approach there is a need to understand the way in which these bright spots are superior to others.

The results from this study demonstrate that there are clear differences in the performance of farmers who appear to face the same biophysical constraints. The dismantling of collective farms in Uzbekistan and to a less degree in Turkmenistan, has in part resulted in the enhanced performance of the agricultural sector, this being based on a comparison of the yields of wheat and cotton prior to and post-privatization. It is widely recognized that land reforms around the world have a political dimension (Ellis 1999) and are a key driver in enhancing productivity and land stewardship. One could argue that the expected benefits from agricultural transformation in FSU countries, especially in Central Asia, may only be realized once effective institutional and political changes take place that support private land ownership. Within the current environment there are, however, encouraging signs that farmers are responding to liberalization of the agricultural sector and are benefiting through high productivity levels, this certainly being the case in both of the target countries.
There are distinct similarities between the Uzbekistan and Turkmenistan in that they have approached land ownership in a cautious and phased approach, while retaining a planned agricultural sector based on wheat and cotton. In this study, we have deliberately focused on identifying bright spots in the most degraded (salinized) lands in each of the countries. This has the advantage of demonstrating the robustness of this approach and, more importantly, would add weight to the concept of 'induced innovation' as described by Boserup (1965) being a driver in the development of bright spots. There are certain elements of incentives being present in the two cases studied. In Uzbekistan, farmers that exceed the planned production levels for cotton and wheat are entitled to keep the excess and thus sell into an open market. This often takes the form of selling to neighbouring farmers who were unable to meet the plan at prices that are higher than that being offered by the State or to smuggle excess cotton across the border into Kazakhstan where prices are significantly higher and reflect world market prices. A further incentive is the threat of having their land reallocated to another owner if they are unable to meet the plan production levels successively. Indeed, in the current study, three of the control objects had had their land titles revoked by the state in 2006. In the case of Turkmenistan, the threat of being made landless due to revocation of leasehold titles is clearly a factor. There is also the possible incentive of being recognized as an elite farmer, *mulkdar*, by the President along with the leasehold entitlement for life that is not subject to confiscation if the plan is not met. Hence, the two cases show clear attributes that would fit with the concepts of 'induced innovation' that is effectively sponsored through what could be termed 'perverse' inducements that are State orchestrated. Here there is a distinct divergence from the concept of 'induced innovation' that was described by Boserup (1965).

Productivity and economic indicators clearly suggest that bright spots are operating at a significantly highly level than control objects and confirm the results from a limited number of cases reported previously (Ul Hassan *et al.*, 2005). It is also of note from an analysis of the entire population of farmers from which bright spots were identified in Uzbekistan, that 46% of farmers exceeded the 'plan' cotton yields (Figure 1.1.6) suggesting the potential for these farmers to benefit individually from the sale of this surplus.

In describing the requirements for the development of bright spots in Uzbekistan and Turkmenistan the overwhelming contributing factor is having the ability to access inputs that are critical to these production systems. In Uzbekistan having access to financial resources in order to purchase inputs and services appears to be a fundamental difference between the two groups. The mobilization of financial resource influences a farmer's ability to mobilize labor resources, reduced dependence on centralized services, increase production inputs allowing greater attention to infield operations. Similarly in Turkmenistan access to resources i.e. manure and attention to agronomic practices (i.e. deep ploughing in the case of wheat) all appear to be important in the development of bright spots. The overall strategy amongst the bright spot farmers seems to be that they have taken reforms and gradual privatization as an opportunity, and envisioned its continuity, and formulated their own coping and adapting strategies.

Uzbekistan had dismantled the collective and cooperative farms by late 2006, and turned their management over to the private individuals. Turkmenistan has taken a more staged approach to land reform and the development of an open market economy. What appears to be a common element of bright spot farmers in the two countries is that they exhibit entrepreneurial attributes that have enabled them to succeed. Moving from a collectivized system of production that assigned employees to specific tasks i.e. tractor driving to managing an entire farming enterprise is in itself a significant achievement in the case of the bright spot farmers. The question thus arises: How does one out-scale the successes of bright spots? This could best be achieved through two complementary approaches. Firstly, conventional extension services as commonly used to disseminate knowledge are not as yet evident in these countries and it is highly unlikely that resources will be forthcoming to establish formal extension and knowledge based platforms in both countries through centralized government systems within the foreseeable future. Innovative approaches in addressing this knowledge gap that links the products of research, and in this case 'induce innovation', with the majority of beneficiaries are required. This may take the form of creating linkages between farmers, researchers and markets through the formation of learning alliances. Indeed, this approach is currently being trialed in each of the countries with positive results.

Secondly, the development of enabling policies that address issues related to inequitable access to land and enable farmers to invest in land resources. For example, in Uzbekistan, farm sizes associated with the initial stages of privatization were too small to be viable enterprises. Subsequent changes to policy have resulted in larger farm units being allocated to individuals in 2006. Further, the provision of incentives which trigger private investments in rehabilitating lands and reversing salinity could also potentially stimulate individuals into addressing resource degradation. Such incentives may not necessarily tax state finances. For example, if farmers were allowed to withdraw cash from the banks, they would be able to pay their labor and service suppliers swiftly, which will ensure timely farm operations, such as maintenance of irrigation and drainage infrastructure. Likewise, reducing the prevailing monopoly of the state service companies, such as machine parks, fertilizer providers, etc., would not only bring in private investments and increased service levels, but will also generate employment in rural areas.

What appears to be a logical model for countries in transition, such as Uzbekistan and Turkmenistan, for reversing land degradation is that both the pace of liberalization as well as the depth of such reforms needs to be balanced and widened. While the pace has already been accelerated through privatizing the management of all lands in Uzbekistan, it is highly desirable that instead of tailoring complicated procedures for strict compliance, and evaluating farmer's performance against procedural steps, the authorities should evaluate farmer's performance against livelihood generation and sustaining the environment. By adopting such an approach, farmers will not have to spend significant amounts of effort on addressing administrative constraints, but rather they would be in a position to invest time in devising and implementing strategies for remediation of bio-physical and environmental constraints and enhancing productivity and profitability of farms.

Contrasting Uzbekistan and Turkmenistan, Kazakhstan has privatized fully land under cotton production and created opportunities for farmers to choose the crops to grow and trade them on an open market. It revised the land purchasing and leasing policy that are having a profound effect not only on agricultural production but also the livelihoods of farmers in the Southern Kazakhstan. The results from this study clearly demonstrate that there are farmers who are outperforming others through better managerial and agronomic skills. In addition, through diversification of their production systems by the introduction of a livestock component, has undoubted enhances these farmers potential even further.

It seemed important to spread the best practices of bright spot farmers to others in the community, as these are 'tried and tested' practices that work under local conditions. Within the scope of the project, it was attempted to link bright spot farmers with neighboring farmers to share their experiences and improve the productivity of the latter. This was undertaken in 2006 on a one to one basis. In other words, 11 bright spot farmers each were formally linked with a neighboring farmer. Due to the length of the project, it was not possible to generate solid quantitative results on the improvements of neighboring farmers who started using the bright spot practices in their fields. However, at the end of the project in 2007 many farmers in the community have expressed their

willingness to be part of this process and become linked with the best farmers increasing the number of farmers from 11 to 42 proving that collaboration among farmers is creating an impact on their productivity and livelihoods. This also demonstrates the potential of using superior farmers in an extension role that by passes traditional services.

Implementation of an industrial cluster strategy in Kazakhstan is putting pressure on farmers to form cooperatives. Given the painful experience of collectivization during Soviet times, farmers are reluctant to join such associations. Hence, gradual collaboration among farmers such as linking best farmers with others can be a step forward to realizing the cluster strategy. Through collaboration, farmers can also reduce their transaction costs in purchasing inputs as well as marketing their products. However, in implementing this collaboration the support of local authorities as well as the willingness of farmers to participate is vital. Moreover, the institutional support for such incentives needs to be put in place.

1.2. NATIONAL ROUNDTABLE DIALOGUES – EXPANDING THE PROJECT RESULTS TO DECISION MAKERS.

BACKGROUND

A key element is the out-scaling of the results generated within the context of this project and in particular the concepts associated with bright spots. Achieve this end policy dialogues were convened in the three target countries in the final year of the project. The focus of these meetings was on policy instruments that would allow up-scaling and adoption of project methods and strategies for incorporating promising outcomes from the diverse array of research activities into a policy framework. It would presumptuous to expect that policy makers would undertake the necessary reforms and changes within the life of the project, however, a process of engagement has been initiated and appreciated by all parties that will in the long term result in change. The specific objectives of these roundtable dialogues were:

1) Present project results to policy makers and other stakeholders
2) Generate discussion on possibilities of up-scaling and adopting the approaches identified as having a high degree of effectiveness, namely the promotion of bright spots and rehabilitation of highly saline and abandoned land through bio-remediation.
3) Produce a clear picture on the adoption process.

In Uzbekistan and Turkmenistan the focus of these roundtable dialogues were on elements from Component 1 (undertaken in June and August 2007) whilst in Kazakhstan the focus was on elements generated in Component 2 (September 2007). A list of participants at each of the dialogues is presented in Annex 1.1.

OUTCOMES FROM DIALOGUES

To facilitate discussions at the roundtable convened in Uzbekistan a policy brief was drafted that specifically focussed on the rehabilitation of abandoned saline/sodic land through the use of licorice (Annex 1.2). This was deemed to be an excellent example of how a simple cost effective approach could be used to rehabilitate abandoned irrigated lands. Further the dialogue presented the outcomes of research efforts into bright spots and the process of farmer alliances using the concepts described in Component 3. The main points discussed during the meeting in Uzbekistan were:

1. On the dissemination of bio-remediation of abandoned soils, major question raised was the feasibility of this technology in CA especially its adaptability by farmers. Mr. Pulat (MP) raised the issue that before considering government incentives and policy changes, they would be interested to know the economic and social viability of these technologies. Other issue is that how many farmers are actually interested in the adoption of licorice as a way to reclaim abandoned soils. In response it was argued that it was still early to assess the economic viability of this approach since the farmer alliance established to grow licorice at the start of the project on 100 ha of abandoned land at Galaba had yet to harvest their first crops. However, preliminary estimates of the economic viability of growing licorice had indicated that there were significant economic returns on investments (See session 2.4.1.2 of this report).
2. Generally the role of bright spots in taking these messages to farmers was lauded however stakeholders were of the opinion that more needs to be done in this regard.
3. There was general agreement that incentives to assist farmers to rehabilitating abandoned land were nonexistent. Farmers need incentives from the government to improve their productivity and livelihoods. Although the Government announced that agriculture related credits are available to farmers, in reality it is very difficult for a farmer to obtain them. The same situation is applied to marketing of agricultural products. So there was agreement that there had to some concrete changes to make these options available to farmers.
4. Added to this the Government has recently passed a resolution to increase number of animals in the country. However, there is little work done to increase the production of fodder. Halophytes grown on abandoned land, especially licorice, may become a valuable

source of fodder to facilitate this expansion and therefore should be considered in the mix of options available to farmers.

5. If a farmer improves his yields, officials will reassess the incumbent's requirements to meet 'planned' outputs for wheat and cotton by increasing his/her state quota. Consequently there is no incentive for farmers to improve his/her yields and land quality.
6. There was also a strong voice that farmers should be given more rights in terms of crop selection e.g. growing halophytes on abandoned land and support their livelihoods.
7. It was mentioned in the meeting that draft amendments to the Land Code of Uzbekistan are to be considered by the Government before Oct 1st 2007. The main objective of this amendment is to give some basic incentives to farmers to maintain/improve their land quality. One of the options being considered is that if a farmer maintains and improves his land quality on a continuous basis he will be exempt from the land tax. For example, increasing 10 points of land fertility will give him 10 years of tax waiver.
8. The old style grading of land is becoming an outdated method for assessing land quality, so there is a need to introduce more efficient assessment techniques for land classification. Work currently being undertaken in the region within the context of this project and other activities in assessing soil salinity using GIS/RS techniques may assist in assessing land quality and made the case that this could pave the way for this type of analysis in future.
9. Bio-remediation is a good option for rehabilitating land, however there is a need to study specifics of where to grow which varieties of halophytes.
10. Publication and dissemination of project results to the wider public especially farmers in Uzbek language is essential.
11. There was also a suggestion to undertake more work on the rehabilitation of high Mg soils in Uzbekistan.
12. The need for involving Academia and farmers, besides the Government, in solving issues related to salinity and abandonment of land was also stressed.

The overall conclusion of the round table meeting in Uzbekistan was that the project is making a valuable contribution and tackling the most important issues faced in agricultural sector of Uzbekistan. However, there is a great need to continue this project to obtain tangible results, and to disseminate these results. Additional discussions/talks need to be generated between policy makers, farmers, and scientist to determine what kind of legislative framework is required to implement bio-remediation in Uzbekistan, what role can farmers play in it and to increase the number of bright spots farmers in the region.

In the Turkmenistan dialogue a key focus of discussions was on the introduction of new salt tolerant crop varieties that were introduced through Component 2. Added to this the work on bright spots as they relate to Turkmenistan was discussed. The outcomes of these deliberations were as follows:

1. Participants agreed that the initiative of linking *mulkdars* (bright spots) with relatively poor performing farmers called '*arendators*' is important as the best practices of *mulkdars* can be taken up by others.
2. There is a need to work more closely with the local authorities and promote agronomic practices of *mulkdars* as an interim measure until the planting materials and seed of the newly introduced varieties are bulked and promoted to the wider community.
3. Regarding data collected within framework of Component 2.1. "Crop Selection" policy makers suggested that the following points should be further investigated:
    - Seed data collection and seed quality both under laboratory and field conditions;
    - Nutritional values and mineral composition of selected salt tolerant crops and halophytes;
    - Animal feeding systems by mixing fodder crops such as sorghum, pearl millet, maize with halophytes;
    - Salt tolerance limits of tested plant material at the Akdepe Site;
    - New approaches for the classification of crops according to the level of their tolerance have to be established since all Central Asian countries are located in the arid desert zone.
4. Farmers are interested in growing salt tolerant crops on abandoned land as the experience of the project showed. Farmers of plots neighboring the experimental plot have been surprised by the plant growth in the experimental plot, as this was abandoned land, and have taken

seed from the project agro-specialist to try to cultivate some salt tolerant crops on their owner lands.

5. Irrigation with saline water, there needs to be a clear report on when, how much, how long, for which plants this water can be used. There is a need to conduct further experiments using saline water for cotton production, as this is the main crop grown in the area. The project can produce hydro-modules for the local area. The local authority can provide meteorological data for this.
6. The project should have included a water specialist from water management department.
7. There are many different views on the effect of using mineralized water for irrigation. Instead of using saline drainage water, it would be best in Turkmenistan to promote bio-drainage, water saving technologies and use of drip and sub-soil/surface irrigation. It was suggested that scientists from international centers involved in the project could help in identification of appropriate water saving and bio-drainage technologies and determination of water requirements of different cash and fodder crops under saline conditions.
8. Farmers are using excessive amount water for irrigation, which is the primary cause of salinity. Hence, work on awareness building on the effect of excessive use of irrigation water and promotion of water saving technologies need to be widely implemented.

1.3. DISSEMINATION OF BRIGHT SPOTS.

INTRODUCTION

Since the existence of formal extension services as a conduit of research results and technologies that could assist farmers in enhance the performance of their production systems are still at a fledgling stage in each of the target countries innovative approaches were adopted that included the formation of knowledge alliances. In this respect, bright spot farmers were linked to neighbouring control farmers and an alliance was established that facilitated the transfer of information between the two groups. The 'potential' bright spot farmers were selected based on the following criteria:

- Willingness to involved in this activity
- Demonstrating aspirations to change
- In close proximity to the bright spot farmer
- Similar characteristics of soil quality attributes as determined by the Bonitet values.

The process of dissemination of practices used by bright spot farmers was achieved through discussion group exercises and the distribution of leaflets outlining the bright spot farmers successful practices and methods. In each of the three countries the following alliance groups were formed:

Uzbekistan. Small knowledge alliances were created around each of the bright spot farms. Two potential BS, one in 2006 and a further participant in 2007 were linked with the bright spot farms making a total of 30 farms in the project.

Kazakhstan. The total number of farmers in the knowledge alliance was 22 in 2006 (11 bright spot farms and 11 'potential bright spots). The number of satellite farms has risen to 42 in 2007 as many farmers were willing to participate in the initiative and improve their farm performances.

Turkmenistan. 8 farmers producing wheat and 5 farmers producing cotton were each linked with the bright spot farmers giving a total of 26 farms in the project.

2. OUTCOMES

Following the linking of 'potential' bright spot farmers, monitoring has been undertaken to assess the progress with respect to improvements in agricultural production. Whilst it is still very premature and that definitive conclusions cannot be drawn, there is evidence to suggest that the formation of these alliances have contributed to increasing productivity (Figure 1.1.9). Clearly the productivity of 'potential' bright spot farmers has increased as evidenced from data collected on wheat and cotton yields in Uzbekistan.

Overall, results of this dissemination process have been positive and should be encourage as a possible dissemination mechanism. Farmers in the alliances have been cooperating on use of machinery, mutually helping in cultivation and harvesting of crops through the organization of *hashar* – a form of collective action widespread in countries of Central Asia. Moreover, a number of farmers came forward and expressed their interest in joining the knowledge alliances themselves on top of those identified by the project in 2007.

Annex 1.1

List of participants in the dialogues undertaken in each of the target countries in 2007

UZBEKISTAN		
1.	Dr Sh. Hamraev	First Deputy Minister for Agriculture and Water Resources Ministry for Agriculture and Water Resources
2.	Dr A. Hanazarov	Director of the Scientific-Production Centre of the Republic of Uzbekistan
3.	K. Ishanov	Leading Specialist, Cabinet of Ministers of the Republic of Uzbekistan
4.	N. Sheraliev	Department of Water Resources Management, Ministry of Agriculture and Water Resources
5.	S. Arabov	Director of the Institute, UzGeodezCadastre
6.	A. Abduazizov	Chairman of the State Committee for Land Resources, Geodesy and Cartography
7.	Dr P. Reimov	Member of the Parliament, Legislative
8.	Dr A. Qureshi	Project manager, IWMI
9.	Dr S. Beniwal	Head of PFU-CAC
10.	Prof T.Hudaiberdiev	Rector of TIIM
11.	Dr K. Toderich	ICBA
12.	Prof U. Tashkenbaev	Rector, Gulistan University
13.	S. Arabov	Director, Institute 'Uzdaverloyiha'
14.	Prof R. Kuziev	Director, Soil Institute
15.	A. Mistanov	Acting Head of the Agricultural and Water Resources Division Of Syrdarya Province
16.	O.Maharov	Head of Land Resources and Land Cadastre Division of Syrdarya Province
17.	4 Farmers	Bright spots and Potential Bright Spots
18.	3 farmers	Galaba farmers - Licorice
19.		
20.	Prof G. Bezborodov	National Coordinator, Cotton Institute
21.	Prof S.Avezbaev	Project socio-economist, TIIM
22.	Dr H.Kushiev	Project plant scientist, Gulistan University
23.	Dr A. Karimov	IWMI
24.	Dr T.Gunchinmaa	IWMI
25.	A. Mirzabaev	ICARDA
26.	I. Yusupova	IWMI
27.	T. Yuldashev	ICARDA
28.	I. Khudaibergenov	ICARDA
29.	A. Tashmatov	IWMI
30.	I. Sultanova	Media

Continuation of Annex 1.1

TURKMENISTAN		
1.	Dr A. Saparmuradov	Head of the Scientific Department of the Ministry of Agriculture
2.	Dr E. Mamedov	Head of the Laboratory of the Desert Institute, specialist on halophytes
3.	S. Ruziev	National Coordinator
4.	Dr K. Redjepbaev	Project soil specialist
5.	B. Kariev	Deputy Head of the Agricultural Department of Dashaguz province
6.	K. Hudaiberdiev	Deputy Head of Seed inspection unit of Dashaguz Province
7.	A. Durdiev	Head of water management department of Dashaguz porvince
8.	Dr K. Toderich	ICBA
9.	Dr T.Gunchinmaa	IWMI
10.	T. Yuldashev	ICARDA
11.	I. Yusupova	IWMI
12.	R. Hekimov	Socio-economist of the project
13.	D. Nurmedov	Project agronomist
14.	F. Redjepov	Project agronomist
15.	A. Annaev	Farmer ‘mulkdar’
16.	A. Hodjiev	Farmer ‘mulkdar’

Annex 1.2.

Rehabilitating abandoned saline land: A case study from Uzbekistan with policy implications.

Large expansion of the irrigated area in the Aral Sea Basin has exerted a substantial toll on land and water resources in the Basin. Elevated water tables due to poor irrigation management and the development of non-functional drainage infrastructure associated with a lack of financial resources, has resulted in significant salinization of crop lands that threatens irrigated agriculture in the region. In the worse cases this hascaused the abandonment of land due to declining wheat and cotton yields.

It is estimated that annually between 2-3% of the irrigated area of the Hunger Steppe (Mirzachul) in Uzbekistan becomes unfit for production due to salinization. Around 30,000-50,000 ha of irrigated land are annually abandoned in Aral Sea Basin area due to salinity (Dukhovny, 2004). The conventional approach to rehabilitating these salinized areas requires major technical expertise and investments that are beyond the means of the national budgets as well as farmers' investment capacity in these emerging economies.

An alternative approach to the reclamation of abandoned saline soils that encompasses the concept of bioremediation using licorice (*Glycyrrhiza glabra*) was assessed over a 4-year period before the land was reverted back to a wheat cotton rotation. Results indicate that after 4 years of continuous licorice, the water table was maintained below the critical level of 2.5 m. Before the experiment cotton and wheat yields in these fields were 1.1 ton/ha and 0.87 ton/ha respectively. After the growing of licorice cotton and wheat yields increased to 1.89 t ha^{-1} and 2.42 t ha^{-1}, these production levels exceeding the district average.

Bioremediation is an attractive low cost option in the rehabilitation of abandoned salinized lands that would be utilized by farmers themselves. It may be necessary to adjust certain policies to harness this opportunity. By encouraging individuals to invest in the rehabilitation of these lands, positive outcomes in addressing this insidious and vexing problem could be achieved. An example of a pilot approach currently being implemented by farmers from Galaba farm with the support of local authorities is presented. It is suggested that selected pilot studies similar to that being undertaken by farmers in Galaba be established to assess the feasibility and effectiveness of this approach.

Uzbekistan a country in transition

The economy of Uzbekistan is based primarily on agriculture and agricultural processing, with cotton being the major export crop. This dependence of the economy on agrarian based activities is unlikely to change in the foreseeable future as the country embarks on a staged process of market liberalization. The government of Uzbekistan has committed itself to promote a voluntary transition of farming enterprises from the public to the private sector.

With the breakup of the former Soviet States and their independence, economies in several of Central Asian countries have faced associated socio-economic, environmental and food security issues. After independence, the Uzbek government retained the Soviet system of agricultural production planning for major agricultural products for the following main reasons: a) to ensure a continual supply of essential agricultural products, i.e. meat, grains, fruits and vegetables to domestic markets in order to protect people from food deficits; b) to enhance aggregate agricultural production by dictating yields and area targets for major crops; and c) to increase rural employment; and to increase agricultural exports and decrease imports. Since 1995, the planned system was eliminated for the majority of agricultural commodities except for the broad acre crops, cotton and wheat.

Crisis associated with land abandonment

Water logging and salinization are major problems affecting all cotton and wheat growing regions of Central Asia. The predominant reasons for their development are poor irrigation water management and inadequate drainage, rising groundwater tables and associated mobilization of primary salts within the soil profile. Bucknell *et al.* 2003 report that "*….approximately 600,000 ha of irrigated cropland*

in Central Asia have become derelict over the last decade due to water logging and salinization. It is estimated that approximately 20,000 hectares of irrigated land in Uzbekistan is lost to salinity and invariably abandoned every year. The proportion of irrigated land that is salinized to some extent has risen from 48% in 1990 to approximately 64% in 2003. In some downstream provinces of Uzbekistan (Navoiy, Bukhara, Surkhondaryo, Khorazm and Karakalpakstan) 86 to 96 % of irrigated lands are said to be salinized." Saline areas are generally found in poorer areas of the region with per capita incomes 30% lower than average national indicators and unemployment levels 40% higher.

Soil salinity and waterlogging are a heavy burden for resource poor farmers who are located in such land-degraded zones. Farmers are required to produce state planned cotton and wheat and in addition have the responsibility of preventing further degradation of their lands as part of there lease agreements. Failure to achieve both of these could result in financial penalties and the revoking of the lease by authorities and confiscation of the land. To avoid the aforementioned, farmers located in land-degraded zones are applying different strategies in order to remediate or prevent further salinization and waterlogging. The dominant strategy applied by farmers that are situated in water abundant areas is heavy salt leaching of affected lands in the winter season. The annual water usage associated with these leaching regimes often exceed 5,000 - 6,000 m^3 ha^{-1}, that in total account for a staggering 5-6 km^3 of water resources delivered per annum just for salinity mitigation (Khamraev, 2002). However, heavy salt leaching without effective and functional drainage infrastructure to remove the leached salt is counter productive and results in elevated ground water levels and further secondary salinization. This is a vicious circle that further compounds the problem resulting in further deterioration of land and water productivity (Razakov, 2000). Other approaches that some farmers are applying to manage salinity and waterlogging include strictly controlling irrigation regimes; attempting to control ground water levels; introducing organic matter into soils and using plastic mulching to reduce evaporation from the saline soils.

Abandoned land within an irrigation command area due to salinity is a point source of salt that has a negative impact on surrounding irrigated lands. Every season thousands of tones of salt are moved by wind and water from these abandoned saline areas to adjacent irrigated lands thereby increasing the threat of salinization.

There is no doubt that individual farmer efforts, and especially their collective action, in salinity remediation is an important precondition to addressing this issue. However, the enormity of the problem in Central Asia, and in particular in Uzbekistan, requires the assistance and efforts of the wider community. For the past 5 years, the Government of Uzbekistan (GoU) has taken concrete steps in improving irrigation and drainage infrastructure, in order to avoid excessive water losses and to facilitate the transport of drainage water from irrigated areas (CACILM, 2005). The focus of the government's efforts is concentrated on major elements of the irrigation and drainage systems with scant attention being paid to on farm systems that directly affect the individual farmer.

Most of the abandoned irrigated lands have irrigation and drainage infrastructure, although often it is in a derelict state. The government is scheduling to return on an annual basis 10,000 – 15,000 ha of abandoned land back into production through reconstruction/rehabilitation of irrigation and drainage infrastructure (CACILM, 2005). This approach requires huge investments from the government budget and therefore, the speed of rehabilitation of abandoned lands through government funds is slow and a long-term process.

Role of plant mediated reclamation of abandoned saline soils

The role of plants in the remediation of saline and sodic soils is an emerging low cost approach in the reclamation of abandoned irrigated lands. In this respect, the creation of highly productive fodder systems through the establishment of palatable halophytes has been shown to remediate saline / sodic soils as well as provide an income to resource poor farmers. Halophytes are ecologically and physiologically specialized plants that are capable of producing high yields under saline conditions. The introduction of the halophyte *Glycyrrhiza glabra*, (commonly referred to as Licorice) in the reclamation of saline soils and the subsequent restoration of irrigated cropping systems has been demonstrated in several studies in the region but quantification of the impact of reclamation on subsequent crops was not the focus of these previous studies. The recently completed study endeavored to assess this aspect.

Licorice belongs to the family leguminous (*Fabaceae L.*) and is one of 13 species in this family. It is a perennial shrub species that grows to a height of 1.5 m. The plant has a fusiform root system with numerous suckers that often grow to more than 1 m in depth. However, in many cases roots of an individual plant often reach 17 m in depth in arid areas in order to access deep ground water. The roots of this species are in high demand due to two main reasons: some varieties of licorice root are fifty times sweeter than sugar and may be chewed or eaten as a sweet, making it a useful component of candies and flavorings; and licorice has for thousands of years been sought after for its reputed medicinal qualities. In addition, glycyrrhizic acid is extracted from the root and used as a flavoring in food, tobacco, alcohol, and cosmetics.

The study site and treatments

A field experiment was established on two adjacent fields of 10 and 13 hectares on the shirkat (collective farm) "Navbahor", Bayauut district of Syr Darya province, Uzbekistan, in the Mirzachul valley, Hungry steppes (40º8' N and 69º52' E). The region is characterized by a sharp continental climate, with hot and long summers and cold and wet winters. Mean annual rainfall for the region is 300 mm that falls almost entirely as snow during the winter months. The temperatures fluctuate throughout the year with summer temperatures reaching 46ºC and winter temperatures dropping to below -46ºC. Soil surface temperatures during the summer often exceed 50ºC. The two fields were on land that had been abandoned due to the presence of high salinity. The control field was established on a 10 ha field whilst licorice (treated) was established on 13 ha.

The control treatment was left in its abandoned state throughout the duration of the study. In contrast, all 13 ha of the treated plot was established to licorice in October 1999 and kept under the same crop until 2003. At the end of the summer growing season in 2003, two 1 ha plots in the control and treated fields were prepared for the establishment of winter wheat and cotton.

Yields of licorice during the rehabilitation phase

The first crop of licorice fodder was harvested in 2001 and yielded 3.6 t ha^{-1} of dry matter with a protein content of 12%. Over the intervening two years, 2002 and 2003, forage yields from the plot progressively increased and reached a maximum of 5.11 (±0.17) t ha^{-1} (Figure 1.3.1). In addition, root harvests undertaken in 2002 and 2003 resulted in yields 5.6 and 8.5 t ha^{-1}. During the rehabilitation process the crop of licorice has the potential to generate an income for farmers through the production of quality forage for feeding livestock and the sale of root material at plough-out that can be used in drinks and medicinal preparations, resulting in a net positive income stream for farmers.

After 4 years under licorice the field was reverted back to a cotton / wheat rotation. The yields of both crops were significantly higher than crops grown on adjacent saline fields (Figure 1.3.2). Yields of wheat after licorice increased from 0.87 t ha^{-1} on saline fields to 2.42 t ha^{-1} – a 2.8 fold increase. Similarly, cotton yields increased from 0.31 t ha^{-1} to 1.89 t ha^{-1} – a 6 fold increase due to the remediation affects of licorice. The average yields of wheat and cotton for the Hungary Steppes is 1.75 and 1.5 t ha^{-1} respectively clearly demonstrating the potential of licorice to increase the productivity of these abandoned saline fields thereby generating increased incomes for farmers.

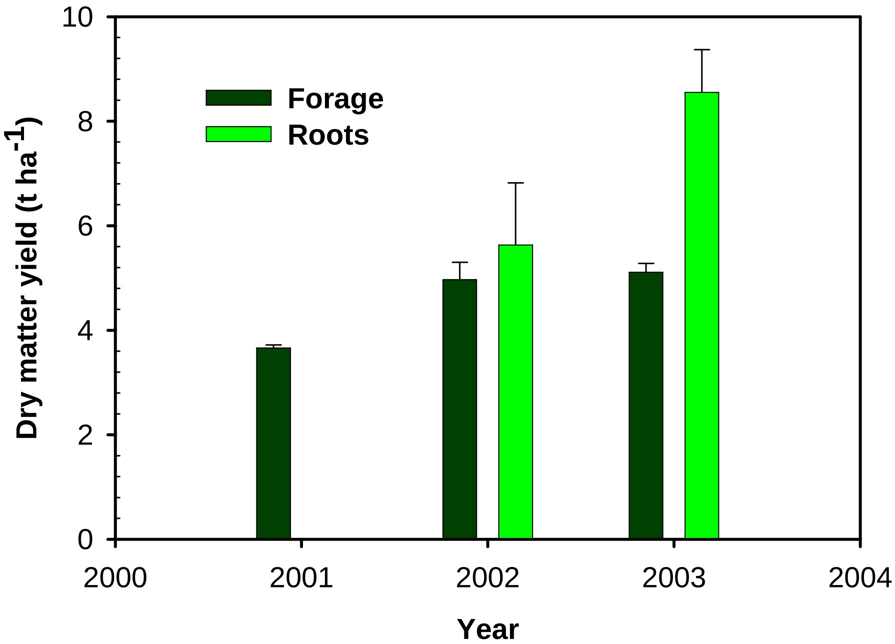

Figure 1.3.1. The dry matter yields of forage and roots over the 4 years that the Licorice was grown on an abandoned saline soil (Kushiev *et al.*, 2005).

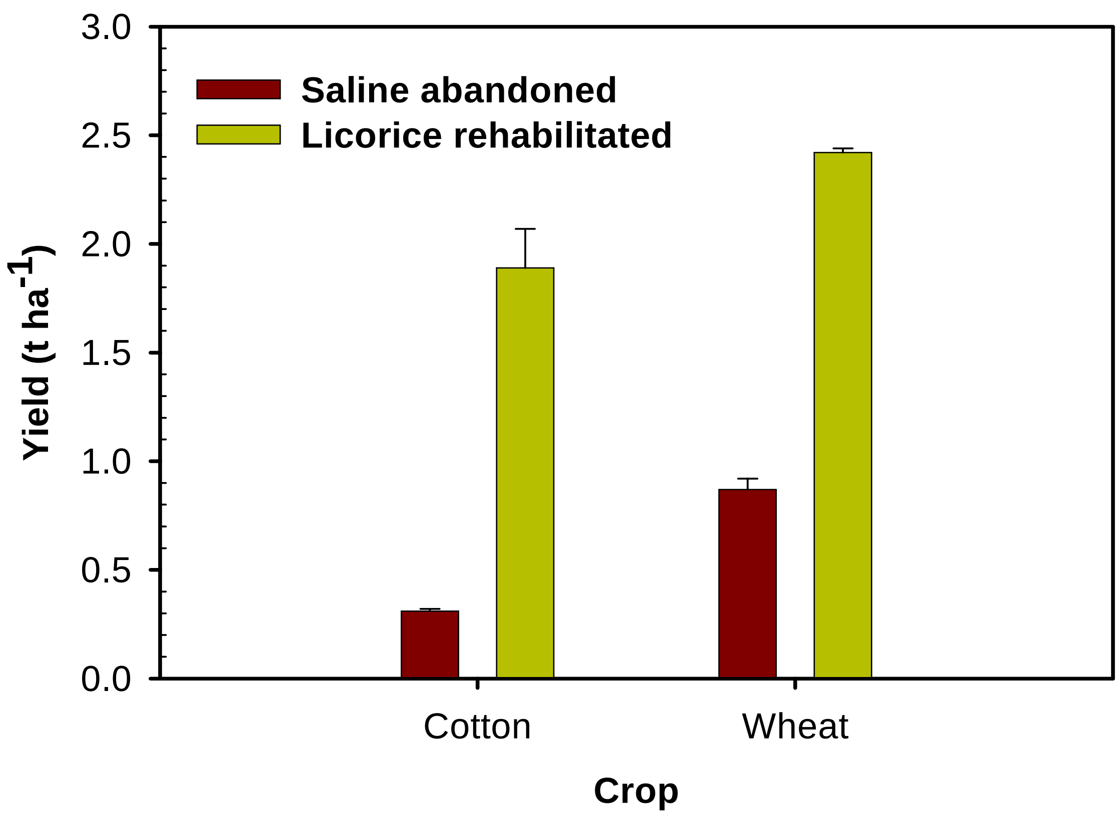

Figure 1.3.2. Yields of cotton and wheat after of 4 years of growing licorice compared to an adjacent saline field (Kushiev *et al.*, 2005).

The reasons for the enhanced productivity following licorice.
There are three main factors that have contributed to converting these abandoned saline soils back into economic production.

1. Lowering the water table. Through over irrigation and inadequate in-field drainage elevated water tables commonly develop in fields resulting in the mobilization of profile salt. There are seasonal fluctuations in the depth to water table in Central Asia in irrigated fields, with levels being closer to the surface during the winter months (January – April) and decreasing during the summer growing season reaching a maximum depth in September, at the end of the growing season. At the start of the study, the water table for both the licorice and adjacent saline field were at the same depth, which was below the 'critical' level of 2.5 m (Figure 1.3.3). After the first year under licorice the water table was maintained at below the 'critical' level and by September 2003 had fallen to below 3.0 m. These changes in water table height are attributed to the extensive root and prolific rooting system of licorice and the perennial nature of crop. By lowering the water table the risk of salt transfer through capillary rise to the soil surface is minimized thereby reducing the risk of upward movement of salt. The depth to water table of treatments in September for each year between 2000 and 2003 clearly shows the water table moving closer to the surface in the control treatment when compared to the licorice plot (Figure 1.3.3). As both fields had inadequate in-field drainage infrastructure, the effect of licorice in maintaining if not decreasing the level of the water table, is clearly evident.

The impact of establishing licorice on the quality of ground water was assessed by determining the concentration of total dissolved salts (TDS) on composite samples collected from piezometers on a monthly basis. The TDS of the ground water in the control plot increased from 5.19 to 6.11 g l^{-1} over the period 2000 to 2003 indicating that there had been mobilization of salts from the profile associated with the rising water table. Under the licorice treatment the TDS declined over the same period from 6.35 to 3.99 g l^{-1} indicating that salts had been lost from the system. This may in part be attributed to downward movement of salts and/or re-precipitation within the profile. The critical depth and TDS of the ground water for Hungary Steppe that would diminish the risk of salinization of surface horizons are 2.5 m and 4.5 g l^{-1}. In the case of the licorice treatment both of these critical levels were achieved prior to the establishment of the wheat and cotton crops.

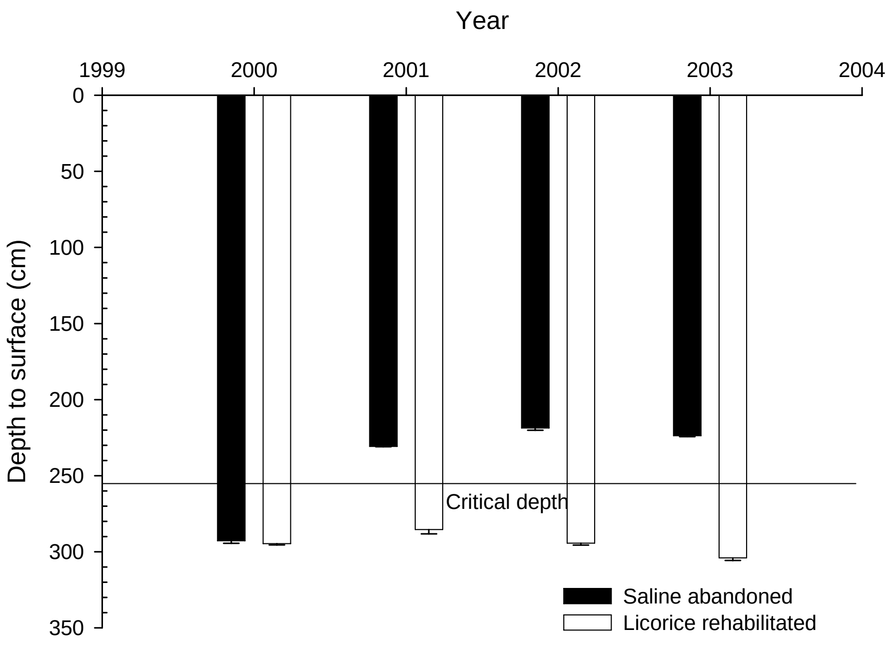

Figure 1.3.3. Changes in the mean depth of water table from the surface measured in September of each year between 2000 and 2003 for saline abandoned land and adjacent licorice rehabilitated field (Kushiev *et al.*, 2005).

2. Reduced salt in the profile: An assessment of the salt content within the profile over the 4 year period prior to the establishment of wheat and cotton is presented in Figure 1.3.4. The initial total salt content in the top 2 m depth of soil in 2000 in the licorice plot was estimated to be 215 t ha^{-1} (Figure

1.3.4). By 2003 the total salt content had declined to 185 t ha^{-1} or a 14% decline in total salt. In contrast, on the abandoned control plot that underwent a routine leaching phase in the winter where 350 mm was applied, the total salt content increased by 31% from 210 t ha^{-1} to 305 t ha^{-1} between 2000 and 2003 (Figure 1.3.4). These results clearly indicate the ameliorative effect of establishing licorice on the total salt balance for the plot, but more importantly, the ineffectiveness of the commonly prescribed annual leaching program that farmers routinely undertake in the absence of a functional drainage system. Moreover, it would appear that in the latter case the situation has been exacerbated with greater levels of salt accumulation in the profile.

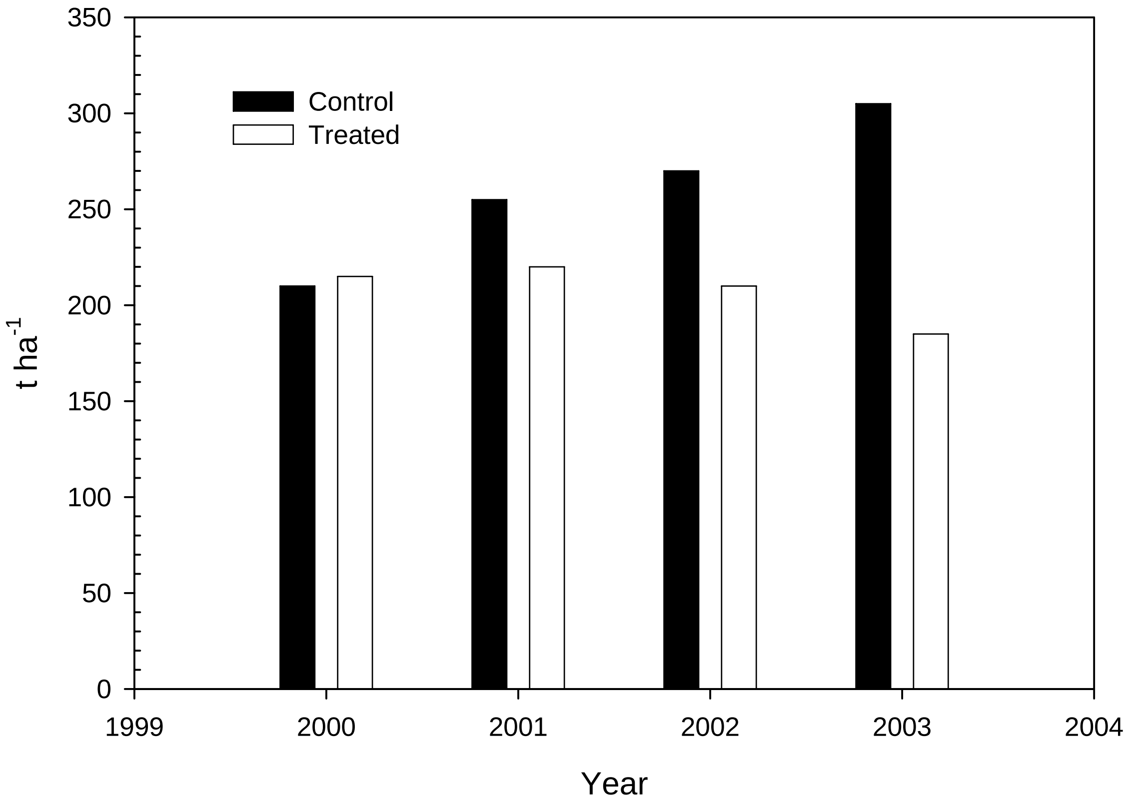

Figure 1.3.4. Estimated salt content for the 2m depth interval on an annual basis for the control and treated plots (Kushiev *et al.*, 2005).

3. Changes in organic carbon content: Organic carbon has an important role in maintaining the structural stability of soils thereby increasing several soil physical properties. Soil organic matter levels were measured routinely during the period under licorice for both the control and treated plots (Figure 1.3.5). Composite samples for the 0 – 50 and 50 – 100 cm were collected and the organic matter content determined. Organic matter contents remained unchanged for both sampling depths in the control treatment over the intervening 4 year period from 2000 to 2003 which is to be expected as the plot remained devoid of any vegetation. Contrasting this, the licorice plot showed substantial increases in organic matter over both sampling depths between 2000 and 2003 (Figure 1.3.5). This is attributed to the prolific and extensive root system of the species and possibly organic exudates associated with root growth. The positive impact of higher organic matter on soil properties, including aggregate stability and hydraulic conductivity, would significantly enhance the amelioration process. In addition, high organic matter would also facilitate improvements in the biological component of these soils promoting the overall health of the soil.

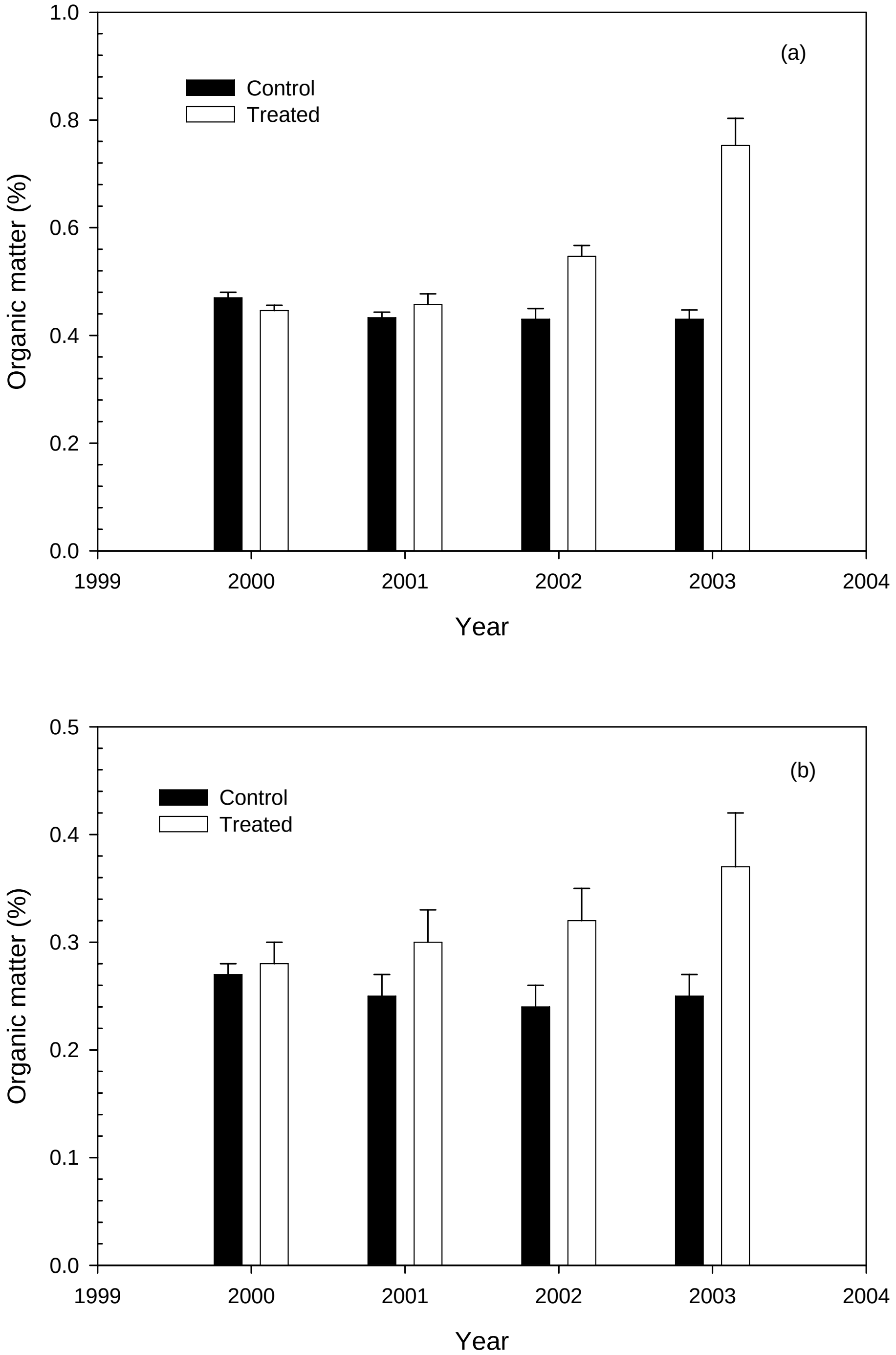

Figure 1.3.5. Percent organic matter content of the 0 – 50 cm (a) and 50 – 100 cm (b) depth interval over the course of 4 years for the control and treated plots. (Kushiev *et al.* 2005)

Addressing salinity through strategic interventions

Technical strategies for arresting salinity are invariably capital intensive and are often beyond the means of the national budgets of the governments. In Uzbekistan alone, between 45 – 50% of $261 million water management related funding is channeled into rehabilitating degraded drainage infrastructure clearly showing the commitment of the Uzbek government in addressing this issue. The approach demonstrated in the current study provides an alternative strategy to addressing the issue of reclaiming abandoned saline soils through vegetative bioremediation. Results clearly demonstrate that after a 4 year period under licorice, indicators of salinity, namely water table height and soil and water salinity levels, declined significantly and allowed the site to be returned to a

productive wheat / cotton rotation. In addition, the subsequent productivity of wheat and cotton crops was greater than the regional average suggesting increases in incomes to farmers. It should be noted that this approach to remediation does not negate the need for effective irrigation water management and functional drainage.

Bioremediation through Licorice is cheaper compared to capital approaches

The construction of sub-surface drainage infrastructure to lower water tables and facilitate the leaching of soluble salts from salt affected profiles is estimated to cost US$ 2,000 ha^{-1} whilst the implementation, operation and maintenance of a vertical drainage system cost approximate US$ 2,500 ha^{-1} yr^{-1}. In contrast the costs associated with the establishment and maintenance of a single crop of licorice was estimated to be approximately US$130 ha^{-1}. In addition, the crop has the potential to generate income for farmers over the remediation period through the production of high quality forage for feeding to livestock and the sale of root material at plough-out that can be used in drinks and medicinal preparations, resulting in a net positive income stream.

It should be noted that the role of bioremediation as demonstrated in this study does not negate the role of effective and functional drainage infrastructure in the management of salinity, but more importantly, offers an important alternative to the remediation of abandoned saline lands and an interim measure in the management of saline soils. However, there are potential negative impacts associated with the introduction of plant species in the process of bioremediation that need to be considered. In the case of licorice it has all the attributes common to an invasive weedy species. Its extensive root system with the ability to sucker makes this species difficult to control without the use of herbicides (i.e. glyphosate).

Creating incentives for the rehabilitation of abandoned saline lands.

A broader view of the problem of land abandonment associated with salinity in Uzbekistan shows that it is a significant issue that has resulted in, and is likely to contribute to, the continued contraction of irrigated areas; reduced aggregate agricultural output; and increase dislocation of rural communities. These negative impacts could be offset through job creation in the non-farm based sector of the economy and through out-migration or through further expansion of the irrigation area by bringing new land into production. The latter is unlikely to occur due to costs associated with infrastructure development and the former would require significant increases in job creation outside of the agricultural sector in an economy that is struggling to achieve minimal GDP growth.

Encouraging farmers to invest in rehabilitation
In a pilot study with 10 farmers in the Galaba community, Syrdarya Province a 100 ha block of abandoned saline land has been established to licorice in the fall of 2005. With the approval and active participation of the Provincial Hakymyat the block was released to the farmers to establish the crop under prevailing production practices. With technical support, these farmers have invested their own resources in establishing and maintaining the crop.

Through mobilization and capacity building activities, this group of farmers has become what is termed a permanent Learning Alliance (LA). The main reason of the LA formation was to deploy farmers themselves in the land rehabilitation process through the establishment of licorice. The advantage of building functional LA groups is that these groups will remain active even after project completion and the withdrawal of support. What is unique to these LA groups is that they do not only represent farmers but also representatives of provincial government, local businesspersons (i.e. licorice traders), and researchers from Gulistan University. The LA held 3 meetings where information and discussions related to the growing of licorice was highlighted, work plans were prepared and responsibilities of different parties were agreed upon. The formation of LA is an attempt to institutionalize land rehabilitation efforts within local communities.

Whilst individual resource investments by farmers are to be encouraged, often this is beyond the means of most farmers and farming communities. In addition, the decision to invest ones own limited resources within a risk averse environment is by no means taken lightly. Farmers need to be

assured that their investments in such an undertaking will yield positive financial benefits in the short run. In a recently completed study of selected drivers associated with the adoption by farmers of new technologies, 'quick and tangible' benefits associated with adoption were ranked highly amongst the 10 drivers (Noble *et al.*, 2008). Hence, there is a need to create an enabling environment whereby farmers can perceive direct positive benefits to themselves through their own investments in the rehabilitation of abandoned saline lands. Such an enabling environment could take the form of investment incentives and/or policy changes that would encourage individuals to invest their own resources in the rehabilitation process.

The current initiative with a small group of farmers in Galaba community in collaboration with Provincial officials offers an insight into how this may occur. The release of abandoned saline lands to farmers for rehabilitation may offer an opportunity in bringing these lands back into production with positive benefits for all actors. It will require the development of policies specific to the lands that would encourage individuals to invest their resources in rehabilitating these lands. It is suggested that the formulation of such incentives / changes in policy should be undertaken with the full participation of all actors, including state officials and farmers in order to encourage buy-in from all parties. Once there is agreement on the form and structure of such incentives/policy changes, these should be assessed in pilot study sites in a number of areas for their effectiveness.

Concluding Remarks

The bioremediation of abandoned saline lands is just one of a number of strategies that can be employed to bring these lands back to their full production potential. This approach should not be viewed as a substitute to technical interventions (i.e. improved water management, effective drainage infrastructure etc) but rather as a phase in the rehabilitation process.

Some countries formulate legal acts and procedures to oblige farmers to undertake rehabilitation. It needs to be noted however, that in many cases around the world, "*the effectiveness of legislation alone for land conservation and rehabilitation was overshadowed by agricultural production price support schemes for domestic and export needs, land settlement and land development schemes, rather than for ecological objectives. Thus, legislation alone might not provide needed solutions unless complemented by appropriate incentives for farmers and private sector to invest in land rehabilitation*" (Second International Conference on Land Degradation and Desertification, 1999).

There are opportunities to involve individual farmers in the process of rehabilitation as is being trialed at Galaba. However, fundamental to encouraging individual investments in the rehabilitation of abandoned land is the provision of technologies/incentives/policies that will result in direct benefits to the individual. In this case licorice offers a potential solution to rehabilitating abandoned saline lands. However to harness this opportunity incentives/policy changes may be required to facilitate individual investments that will have positive financial implications. Such policies might relate to nature and security of property rights to land and right of access to natural resources (Sherr and Yadav, 1997).Since salinization of land and water resources is a national issue, the government of Uzbekistan should consider providing special incentives to farmers that may include the granting special leases for these lands, tax and quota exemption for a given period, provision of soft loans and other such incentives that would facilitate the involvement of farmers in the rehabilitation / recovery of these lands. An interesting example of farmer-government co-investment is in practice at Border Rivers-Gwydir Catchment Management Agency (www.brg.cma.nsw.gov.au/IncentivesBrochure.pdf), where interested farmers can seek assistance from the agency in assessing the cost of the project, alternative approaches to rehabilitation, and then the farmer submits a bid for "how much investment he would be willing to make". The agency then comes up with the balance of investment.

COMPONENT II. PLANT PRODUCTION ON SALT AFFECTED SOILS[4]

INTRODUCTION

Soil salinity and sodicity affects 53% of the arable lands in the Central Asian countries. The annual losses in Uzbekistan due to salinization have been estimated at US$ 31 million, while withdrawal of highly salt affected lands out of agricultural production costs an estimated US$ 12 million annually (World Bank, 2002). Most of the irrigated lands in Aral Sea Basin are subjected to salinity due to sharp continental arid climate with aridity coefficient from 0.12-0.3 (Chembarisov et al., 1989). Initial sources of the accumulated salts in soil profiles are irrigation water. The risk of salinization is further increased due to the rising water table associated with poorly managed drainage systems.

Waterlogging and salinization are major problems affecting all cotton and wheat growing regions of Central Asia placing a heavy burden upon resource poor farmers, who are located in the most land-degraded areas of the region. In these areas, per capita income is 30% lower than average national indicators and unemployment levels are 40% higher. Awareness of farmers on soil/water conservation and management of marginal lands is also poor. Measures for the reclamation of salt prone marginal lands and irrigation scheduling are still based on the Soviet approaches.

Cultivation of most agricultural crops on salt-affected soil requires inputs of chemical fertilizers and costly leaching and intensive drainage. This strategy, however, increases the risk of re-salinization in the root zone and the leaching process has to be repeated each cropping season in order to avoid the build-up of high salt concentration within the effective rooting zone. In this regard, efficient water use for irrigation coupled with the introduction of modern bio-remediation technologies can help to define the best management practices for crop production under saline environments (Yensen et al., 2000; Toderich et al., 2006). Over the last decade, a number of plant species have been evaluated in Central Asia for their tolerance to salinity (Nazariuk, 1968; Kamalov, 1997; Shevelukha et al, 2000; Shamsutdinov et al., 2003; Guz Gintzburger et al, 2003; Toderich et al., 2007, 2008). These species have shown to be highly productive with excellent digestibility characteristics; palatable to animals; and highly nutritious. With proper screening and evaluation, these species can become an integral component of farm production systems of Central Asian countries under saline environments. However the rehabilitation of soils affected by salinity in the Central Asian region requires significant inputs and investment. Smallholder farmers have limited capacities to combat salinity and increase cotton yields under prevailing economic conditions.

Other alternative agricultural production systems may assist in the process of utilizing these marginal resources, provide economic returns and environmental benefits to the farmers. The introduction of new salt tolerant crop varieties/improved lines into marginal areas require a comprehensive understanding of alternative mechanisms of cultivation and seed multiplication of highly productive and adaptive varieties to poor-nutrient and salt stress environments in smallholder farming systems. Selection and evaluation of appropriate plant species to match the environment, in particular the salinity level and the type of production system for different ecological zones in Uzbekistan, Kazakhstan and Turkmenistan were evaluated in this component.

[4] This component was led by ICBA. NARS partners include in Turkmenistan : Mr. Serdar Roziyev, National Coordinator, Ministry of Agriculture of the Republic of Turkmenistan; Dr Mr. Kadyrbek Redjepbaev, soil scientist, and Mr. Durdybek Nurmedov, agronomist.
In Uzbekistan: Dr Khabib Khushiev; Nasim Suleimanov and Tadjiddin Kuliev, Gulistan State University; Dr Dzhura Alimov and Gulbakhor Alimova, Plant Industry Institute; Professor Surat Yusupov, Drs Abdullo Rabimov, Tolib Mukimov and Batyr Bekchanov, Institute of karakul Sheep Breeding and Desert Ecology in Samarkand;
In Kazakhstan: Drs Galina Lyubina and Nurullo Balgabaev, Institute of Irrigation in Taraz, southern Kazakhstan

COMPONENT 2.1. EVALUATION OF SALT-TOLERANT FORAGES, FIELD CROPS, MEDICINAL AND AROMATIC PLANTS

CROP SELECTION

The main focus of this activity was to introduce and evaluate native wild halophytes and conventional and non-conventional salt tolerant crops, the development of management options to increase productivity and income generation on salt-affected and waterlogged soils. This was achieved through field-based trials in the three target countries (Kazakhstan, Turkmenistan, and Uzbekistan) of Central Asia. This component was implemented by the International Center for Biosaline Agriculture (ICBA), UAE, in collaboration with NARES of the participating countries.

The main objectives of the crop selection activity were as follows:

- Selection of appropriate plant species and improved lines of non traditional salt tolerant crops to match the environment, in particularly the salinity level and the type of production system for different ecological zones in Uzbekistan, Kazakhstan and Turkmenistan; and

- Development of agronomic practices (crop management, seedling establishment, growth, plant density, fertilizer application, time of planting, yield capacity, etc).

It was envisaged that the diversification of cropping systems under prevailing saline conditions could sustain agricultural production from salt affected areas and increase profits of farmers. Introduction of new species and varieties of forage crops, grasses, legumes and tree/shrub species could contribute to reducing water-logging and to the restoration of degraded soil.

Experimental Sites:

Various trials on forage production were established under different eco-agro-climatic zones that differed significantly in soil salinity level. Experiments were conducted under the following soils environments:

- Low or slightly (EC 1.5-3.5 dS m^{-1}) saline serosems (Plant Industry Institute, Tashkent region); salt-affected sandy desert soils (Kyzylkesek site, Navoi region) in Uzbekistan;

- Moderately saline (EC 6-8 dS m^{-1}) at Galaba Farm, Syrdarya province (Uzbekistan) and Makhtaral Experimental Plot (South Kazakhstan). Under these saline environments farmers continue to cultivate salt tolerant conventional and non-conventional crops;

- Highly saline soil with EC 8-14 dS m^{-1} at the Akdepe Experimental site, Dashauz Province (Turkmenistan) and partially Kyzylkesek Site, Central Kyzylkum, Uzbekistan. Usually farmers obtain very low yields of cotton and wheat, and sometimes there are complete crop failures depending upon the severity of the problem. The location of experimental trial sites are presented in Figure 2.1.1.

Figure 2.1.1. Experimental sites for the evaluation of halophytes, legumes, sorghum and pearl millet for grain and forage production in the three Central Asian countries.

MATERIALS AND METHODOLOGY

PLANT SPECIES EVALUATED

More than 70 improved lines, forage crops, legumes and tree/shrubs species were studied during 2005-2007 in Kazakhstan (Makhtaral and Besagash sites), Turkmenistan (Akdepe site) and Uzbekistan (Experimental Plot at the Gulistan State University, Plant Industry Quarantine Plots; Galaba Farm in Syrdarya province and Kyzylkesek Site, at Madaniyat Sherkat Farm of the Uzbek Research Institute of Karakul Sheep Breeding Institute). Randomized design trials were selected for evaluation of wild tree/shrubs halophytes, 14 improved lines of sorghum; 27 of pearl millet; two salt tolerant alfalfa; and 4 fodder beet varieties of ICBA germplasm along with local varieties. New germplasm of halophytes and salt tolerant crops received from ICBA and tested at selected sites are given in Table 2.1.1.

Table 2.1.1. Introduced germplasm of halophytes and salt tolerant crops evaluated.

S.No	Species	Accessions/Varieties	S.No	Species	Accessions/varieties
1	*Sorghum*	Speed feed	39	*Pearl Millet*	Dauro Genepool
2		Sugar graze	40		Eraj Pop
3		Super dan	41		Guerinian-4
5		Pioneer 858	42		HHVBC Tall
6		ICSV 745	43		ICMS 7704
7		ICSV 112	44		ICMV 155 Brist
11		SP 47529	45		ICMV 155 e,el
13		SP 39105	46		ICMV 155 original
19		SP 47105	47		SRBC
20		ICSR 172	48		Sudan Pop III
21		ICSB 682	49		MC 94 C2
23		SP 39262	50		Wraj Pop
24		ICSB 405	51		Sudan Pop I
25		SP 40516			
26	*Pearl Millet*	Nutrifeed	52	*Fodder beet*	Blaze
27		IP 3616	53		Blizzard
28		IP 6101	54		Maestro
29		IP 6104	55		Turbo
30		IP 6105	62		Eureka
31		IP 6106	63		Sceptre
32		IP 6107	68	*Acacia*	*A. ampliceps*
33		IP 6109	70	*Atriplex*	*A. nummularia*
34		IP 6110	71		*Amnicola*
35		IP 6112	72		*undulata*

In the assessment of sorghum and pearl millet acccessions 51 treatments with three replications in each was undertaken. The general layout of the trials is described in the guidelines developed by ICBA (2005).

In order to identify the most salt tolerant and highly productive varieties for fodder and green manure production, ICBA germplasm was evaluated using the following agro-biological characters: time of planting, seed germination under field and laboratory conditions, seedling emergence, survival rate, plant density, flowering rate, fresh and dry biomass and seed yield. Seeds of introduced lines/species and local varieties of *Sorghum bicolor*, *Pennisetum glaucum* and alfalfa were broadcasted in an area of 0.2 ha. Alley-cropping strips of 6 m long and 60 cm inter-row distance was used at the Galaba Farm and at the Kyzylkesek sites in Uzbekistan.

Seedlings of *Acacia ampliceps* were obtained from seeds both by direct sowing in the field (February 2006) and in the plastic bags. Jiffy-7 pots have the advantage of promoting rapid seedling emergence under green house conditions. A significant increase in height and plant canopy was observed, when seedlings were transplanted in late April (Temperature of soils – 12-15 ^{o}C). Investigations were conducted that included the measurement of relative growth rate (RGR) and survival percentage (SP) of multipurpose tree/shrub species. All trials were undertaken with three replications. The trial establishment and crop studies were carried out according to the guidelines distributed by ICBA during the first training course (2005).

Representative soil samples were collected from the study area at the following depths: 0-0.15 m, 0.15-0.30 m, 0.30-0.60 m, and 0.60-1.00 m. The sampling was undertaken before the implementation

of any treatments (initial soil condition). The collected samples were air-dried and processed for the analyses. The physical attributes consisted of particle-size analysis (from one randomly selected sample from 4 depths (0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m), field capacity (from one randomly selected location in each treatment), infiltration rate (from one randomly selected location in each treatment), saturated hydraulic conductivity (from one randomly selected location in each treatment), bulk density (from one randomly selected location in each treatment), and moisture content (from one randomly selected location in each treatment).

The samples collected from different soil depths were subjected to chemical analyses, which consisted of pH, electrical conductivity (ECe in dS m^{-1}), soluble cations including calcium (Ca^{2+}) by titration procedure, magnesium (Mg^{2+}) by titration procedure, sodium (Na^+) and potassium (K^+) by difference. The soil samples were also analyzed for soluble anions that included carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated from the values of soluble Ca^{2+}, Mg^{2+}, and Na^+. The sampling was undertaken before the implementation of the treatments (initial soil condition) and after harvest of crops. Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. The water samples were analyzed for the following parameters: pH, EC, cations such as Ca^{2+} and Mg^{2+} by titration procedure, and Na^+ and K^+ by difference. These samples were also analyzed for anions such as CO_3^{2-}, HCO_3^- and Cl^- by titration procedure and SO_4^{2-} by precipitation as barium sulfate.

Following soil leaching, 6 months and 1-year-old seedlings of 13 multipurpose tree and 5 shrub species (50 seedlings per species) were planted at the Akdepe (Turkmenistan) and Kyzylkesek (Central Kyzylkum, Uzbekistan) sites on an area of approximately 0.09 hectares. Seedlings of introduced halophytic species were produced at the Akdepe experimental station, at the nursery of the Plant Industry Institute, Uzbekistan, and at the Reserach Institute of Irrigation, Taraz, Kazakhstan. Seedlings were transplanted into the field in the fall period by using appropriate management (ICBA Guidelines 2005; Toderich et al. 2006). Seedlings were planted between the ridge and bottom of the irrigation furrow at a spacing of 3.5 m x 3.5 m, half way from the furrow bottom. This large spacing between rows/plots was introduced to minimize possible competition of different tree species in the root zone from horizontal extension of the root systems due to the high groundwater table. The prepared furrows were about 40 cm deep and 70 cm wide. Each plot consisted of two rows with 25-30 randomly planted trees. Biometric parameters and survival rates were determined at each site. It was found that the optimum target density should be around 900-1200 trees ha^{-1}.

KAZAKHSTAN

I. Makhtaral Experimental Sites

Experiments were established on a private farm, located in close proximity of the Institute of Cotton Production, Southern Kazakhstan. The annual precipitation in the area varies from 157 to 296 mm. As presented in Figure 2.1.2, rainfall is abundant in April and contributes to an increase in soil moisture that stimulated good seed germination for the majority of crops.

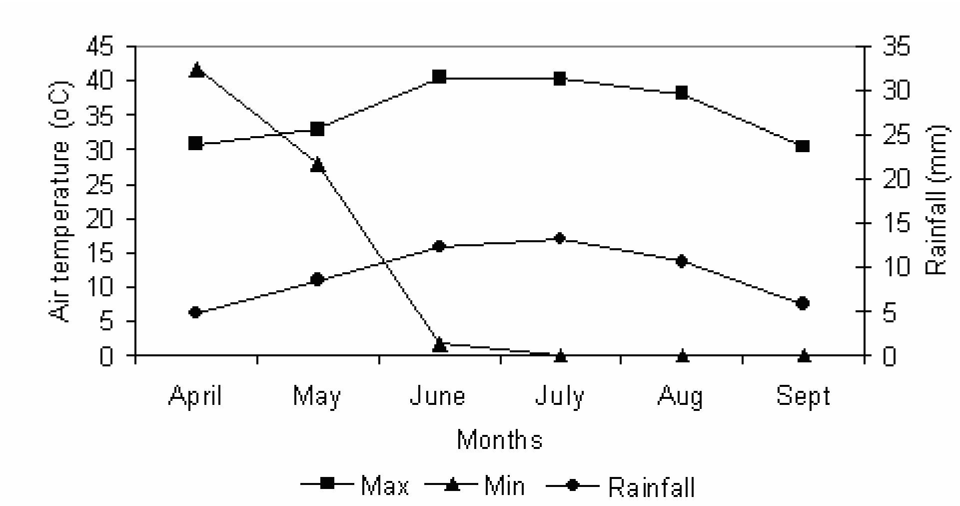

Figure 2.1.2. Climatic parameters at the Makhtaral Site (average data for 2005)

Maximum annual precipitation (120.3 mm) and minimum air temperature (22.2°C) during thr crop season was observed in 2005. The average air temperature during the crop season was lower in 2005 and precipitation higher than in 2006 (22.2°C vs 22.1°C and 59.8 mm vs 34.6 mm). The highest air relative humidity (75.59%) and plentiful precipitation (110.8 mm) was noted in April and May 2007. The period with average daily temperature above 10°C was from 26 March to 1st November, with an average annual air temperature of 14°C. During June and July, maximum temperature both of air and soil were observed.

Tested crops on the Makhtaral experimental plot were irrigated three times with a total volume of 2550 m^3 ha^{-1}. Irrigation was stopped during flowering and seed maturation stage for all evaluated crops. TDS of irrigation water was relatively low (1200 ppm) with a relatively higher concentration of Ca^{2+}. The soil at Makhtaral station is loamy; varying from medium to heavy textured at soil depths from 0-100 cm and has a low salinity level (Table 2.1.2).

Organic matter varied between 0.50-0.84% with low nitrogen content in soil as compared to phosphorus and potassium. The depth to the water table during the vegetative phase of crops varies from 1.2 to 2.5 m. Quantitatively, the average data obtained in 2005-2006 indicated low organic matter contents of 0.653% (0-0.15 m), 0.541% (0.15-0.30 m), 0.325 (0.30-0.60 m) and 0.215% (0.60-0.90 m). The pre-experiment soil salinity levels (for two seasons 2005 - 2006) in terms of total soluble salts (TSS) at different soil depths extending up to 1.0 m were in the range of 5210 mg L^{-1} to 7370 mg L^{-1} (Table 2.1.3). Low soil moisture contents in the top soil during the crop germination stage, may have contributed to the low seedling emergency of fodder beet and two varieties of Sorghum (Figure 2.1.3).

Table 2.1.2. Variation in chemical composition of soil samples taken at the Makhtaral station (average for 2005)

Soil depth	pH	EC1:5	Solid residual	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	SAR
(cm)		dS m^{-1}	mg L^{-1}							mmolc L^{-1}	
0-15	7.55	1.32	5210	40	22	15.85	1.15	4	7.2	67.8	2.85
15-50	7.6	1.68	6490	59	29	9.98	1.02	4	6.8	88.2	1.5
50-100	7.55	1.47	5480	39	23	21.35	0.25	3.6	10.8	69.2	3.83

Table 2.1.3. Selected soil composition at the Makhtaral Experimental Station (2005-2006)

Soil Depth, (cm)	Content of Nutrient Elements							
	Organic Matter (%)		N (mg/kg)		P (mg/kg)		K (mg/kg)	
	2005	2006	2005	2006	2005	2006	2005	2006
0-50	0.79	0.65	5	5.12	21.8	22.01	291	294
50-100	0.54	0,52	8.12	8.09	13.9	13.5	263.5	273.2
0-50	0.73	0.71	2.8	2,89	20.3	21	250	261
50-100	0.57	0.43	Trace amount	Trace amount	14.1	14.9	241	249.5
0-50	0.77	0.7	5.94	6.01	22.3	22,5	245.1	247.3
50-100	0.59	0.56	5.31	5.65	18.9	18,93	228.3	230
0-50	0.77	0.75	5	4.89	24.4	24.9	275.3	276.1
50-100	0.58	0.52	Trace amount	Trace amount	19.1	19.87	201.4	203.1
0-50	0.77	0.74	10.38	11,02	23.6	23	246.3	248.1
50-100	0.5	0.47	Trace amount	Trace amount	18.1	18.9	240.1	241.9
0-50	0.79	0.81	5.63	5.93	24.4	24.8	285.3	289.8
50-100	0.5	0.47	Trace amount	Trace amount	14.4	14,7	240.3	245.1
0-50	0.78	0.86	6.56	6,89	19.3	20.1	255.6	158.4
50-100	0.58	0.59	3.8	3,96	13.3	13.9	240.3	253
0-50	0.81	0.83	6.25	7.01	18.3	18.8	261.4	264.3
50-100	0.54	0.58	Trace amount	Trace amount	13.9	14.2	231.4	236.3

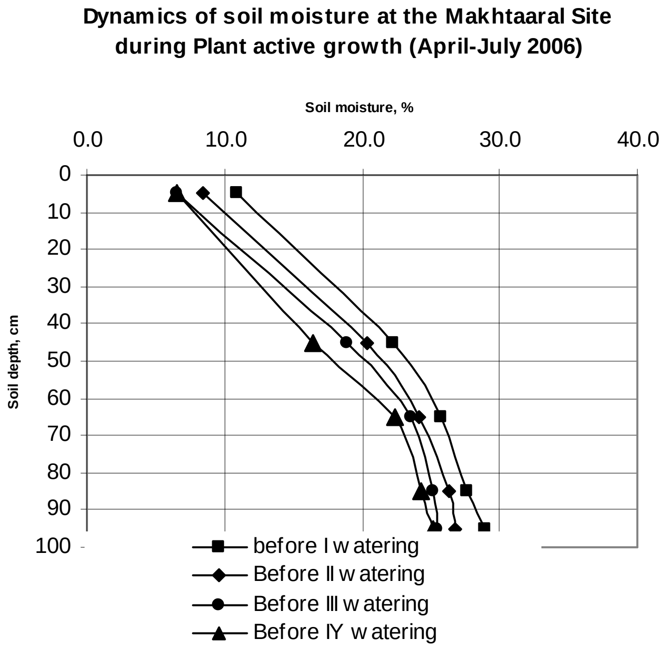

Figure 2.1.3. Dynamics of soil moisture at the Makhtaral Station (average data for 2005-2006)

PLANT GROWTH AND DEVELOPMENT UNDER SALINE ENVIRONMENT

Sorghum germplasm received from ICBA was characterized by various seed germination capacity. Percentage of seed germination and survival of seedlings/adult plants was significantly higher for the Daura Genepool, IP 19586, IP 6104, IP6101, Sudan pop III and Nutri Feed accessions. Low seed germination under field conditions was evident for accessions ICSV 745, SP 40516, SP 3905, while seed germination values of Sorghum bicolor varieties that included Super Dan, Pioneer 858, Sugar Graze, Speed Feed and SP 40516 varied from 75-95%. No germination was observed in accession ICSR 172, as well as for all local varieties of sorghum and pear millet.

The same tendency was noted with respect to plant survival. Figure 4 indicates that SP 47105, ICSV 112, SP 3905, Pioneer 858, Sugar Graze, Super Dan accessions had early seedling emergency; whereas, samples SP 47529, SP 40516, ICSB405, Speed Feed, SP 39262, ICSV 745, ICSV 682 were characterized by a late seed germination.

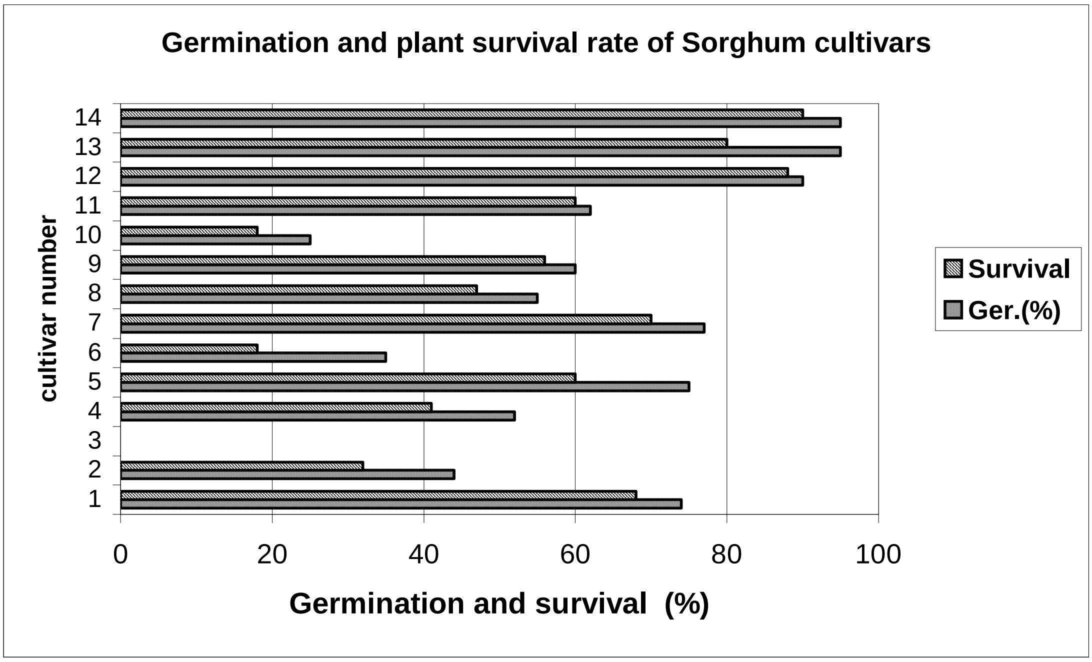

Figure 2.1.4. Germination and survival rate of Sorghum cultivars. Accession/improved line numbers corresponds as following: 1- ICSV 745; 2- ISCV 112; 3- ICSR 172; 4- ICSV 682;5- SP 3905; 6- SP 40516;7- ICSB405; 8- SP 47529; 9- SP 47105; 10- SP 39262;11- Pioneer 859: 12- Sugar Graze; 13- Super Dan: 14- Speed Feed

After 80 days of plant growth almost all varieties reached flowering and reproductive maturity stage, except for *Sorghum bicolor* Speed feed, SP 47105, ICSB 405 and Sugar Graze accessions. Based on the above-cited peculiarities a phenological spectrum of Sorghum germplasm was developed (Table 2.1.4) for southern Kazakhstan, which sharply differs from those at the Akdepe Site in Turkmenistan. Under climatic and edaphic conditions of Makhtaral district, seed bedding of sorghum and pearl millet should be done much earlier (at least in 2-3 weeks) than what was practiced in 2006.

Table 2.1.4. Phenologic spectrum of sorghum germplasm from ICBA (Makhtaral Site, South Kazakhstan, 2006)

Plant ontogenetic development stage	April	May	June	July	August	September	October
Seedling emergence	■						
Growth and accumulation of green biomass	■	■	■	■			
Tillering		■	■				
Panicle initiation		■	■	■	■		
Flowering			■	■	■		
Heading				■	■	■	
Seed maturation				■	■	■	■

Many accessions of Sorghum (Super Dan, Nutri feed, Pioner 858 SP 39269) showed adequate re-growth and seed maturation ability as late as September-October, 2006. The agro-biological data collected for the evaluated accessions of sorghum are summarized in Table 2.1.5.

Table 2.1.5 presents seed germination, morphological parameters of vegetative and reproductive phases, plant density and dynamics of plant height during vegetative period, which allow characterizing of the biological potential of sorghum. Based on the above data, the screened cultivars were classified as dwarf 102-122 cm (ICSV 112, SP 39105, ICSV 745 and SP 47529) and tall 195-280 cm (Super Dan, Sugar Graze, Speed Feed, Pioneer 858, SP 47105) samples. The remaining samples showed intermediate growth habits. Number of basal tillers among tested sorghum germplasm varied between 3-5 (ICSV 112, Pioneer 858) and 11-28 (Speed Feed, Super Dan, Sugar Graze and ICSV 745).

Based on the observations, the rate of growth of 14 sorghum varieties from ICBA germplasm were classified as follows:

Fast growing (Speed Feed, Super Dan, Sugar Graze, Pioneer 859) accessions;
Slowly growing (ICSV 112, SP 39105, SP 47529) accessions.
The remaining varieties/improved lines showed intermediate growth rates. It was found that plant productive longevity significantly varied among tested accessions and positively correlated with the sum of effective temperatures. As it is shown in Table 2.1.6, Sugar Graze, Speed Feed, Pioneer 858, and ICSV 745, SP 39105 sorghum populations/lines belong to the most early-maturation accessions.

According to flowering patterns of sorghum from the ICBA germplasm, the following early-flowering genotypes were identified: SP 39105, Pioneer 858, ICSV 745, Speed Feed, Sugar Graze; and late-flowering samples: SP 39262, ICSV 745, ICSV 682, Super Dan. Accumulation of green biomass was related to plant height and increased with the application of fertilizer and irrigation. The values of fresh and dry biomass for the tested sorghum accessions at Makhtaral site is presented in Table 2.1.7. Under farmers' field conditions of south Kazakhstan, green fodder production in top-yielding sorghum varieties/lines varied from 97.0-113 t ha^{-1} and dry matter ranged between 16.0-27.0 t ha^{-1}. Similarly, the top-yielding populations/lines of sorghum yielded 2.0-2.5 times higher than the grain yields of local varieties. As shown in Table 2.1.8, Sugar Graze, Pioneer 858, ICSV 682, Super Dan, SP 39105 lines of *Sorghum bicolor* (ICBA germplasm) should be considered as one of the most promising lines for seed (grain) production under moderately saline conditions of southern Kazakhstan.

Table 2.1.5. Agrobiological characteristics of the sorghum (Makhtaral Site, September 2006)

Name of Varieties/ Improved lines	Seed germination	Height of plant (maturing stage)	Size of leaves		Number of tillers	Size of panicle		Plant density
			length	width		Length	width	
	%	cm	cm	cm		cm	cm	per m^2
ICSV 745	74	148	57	14.8	11-May		stay -green line	68
ICSV 112	44	122	38	12.6	4-Mar	28	6.7 (multiflowered,friable)	37
ICSV 682	52	129	30	9.7	7-Jun	30	5.8 (friable)	41
SP 39105	75	168	22	8.9	9-Jul	32	6.1 (compact)	59
SP 40516	35	152	25	5.9	3	23	4.1	42
ICSB 405	77	130	25	4.8	5		no inflorescence	70
SP 47529	55	110 (rough stemmed)	30	3.9	6-Apr	28	30% (heading stage) small-tall/midjet	50
SP 47105	60	(thin-stemmed. friable)	25	2.9	8-May	18	no inflorescence	54
SP 39262	25	195	29	3.8	7-May	37	5.8	28
Pioneer 858	62	158	22	3		48	4.1	61
Sugar Graze	90	258 (thin stemmed)	31	3.2	11-Sep	37	6.1 friable, ramified	113
Super Dan	95	280	40	2.8	27		no inflorescence	105
Speed Feed	95	288	25	2.9	28-Nov	40	4.6	135

Table 2.1.6. The vegetation stage of different accessions/lines of tested Sorghum germplasm depending on sum of effective temperatures

Name of Varieties/Improved lines	Seed germination		Plant Flowering		Longevity of vegetation	Sum of effective temperatures during vegetation cycle
	Days after sowing	Rate (%)	month	rate (%)	(days)	(⁰ C)
ICSV 745	24	74	YI-YII	90	96-110	2095 – 2925 / early-maturing
SP 39105	15	75	YI-YII	90	98-114	2146 – 2925 / early-maturing
Pioneer 858	15	72	YI-YIII	60	95-135	2072 – 3646 / early-maturing
Sugar Graze	15	90	YI-YII	100	85-115	1886 – 3034 / early-maturing
ICSV 112	15	44		58	120-135	3172 – 3646
ICSR 172	0	0		0	0	
ICSV 682	26	52	YII-IX	40	120-148	3172 – 3854
SP 40516	26	38	YI-YIII	100	80-110	1869 – 2925
ICSB405	21	77	YIII-IX	10	120-150	3172 – 3907
SP 47529	22	55	YI-YII	50	115-135	3058 – 3646
SP 47105	15	60	YIII-IX	35	120-160	3172 – 4095
SP 39262	24	45	YIII-IX	40	120-150	3172 – 3905
Super Dan	15	95	YIII-IX	80	120-148	3172 – 3854
Speed Feed	21	95	YI-IX	20-30	105-136	2826 – 3668

Table 2.1.7. Fresh and dry biomass of 14 sorghum varieties/improved lines (Makhtaral site)

Name of Varieties/Improved Lines	Plant density	Fresh Biomass	Dry Biomass
	'000/ha	t/ha	t/ha
ICSV 745	68.0	58.0	12.0
ICSV 112	27.0	37.0	8.5
ICSR 712		0.0	0.0
ICSV 682	41.0	45.0	13.9
SP 39105	59.0	36.0	11.2
SP 40516	42.0	74.0	18.0
ICSB 405	70.0	55.0	13.5
SP 47529	50.0	82.0	13.7
SP 47105	54.0	41.0	10.9
SP 39262	28.0	93.0	13.5
Pioneer 858	61.0	102.0	27.0
Sugar Graze	133.0	113.0	25.0
Super Dan	125.0	108.0	22.0
Speed Feed	165	97.0	16.0

Table 2.1.8. Seed production of 14 accessions of Sorghum (Makhtaral Site)

Varieties/Lines	Plant density	Number of panicles	Weight of seeds/5 panicles	Weight of seeds /plant	Weight of seeds
	th.plant/ha		cm	g	t/ha
ICSV 745	68.0	seed maturation was not observed			
ICSV 112	37.0	5	141	28.2	1.41
ICSR 712	0	0	0	0	0
ICSV 682	41.0	6	291.2	48.3	2.89
SP 39105	59.0	7	283.2	41.6	2.91
SP 40516	42.0	8	196.7	35.4	2.83
ICSB 405	70.0	8	178.1	24.5	1.96
SP 47529	50.0	7	116.2	25.4	1.77
SP 47105	54.0	6	349.3	19.3	1.16
SP 39262	28.0	5	382.7	69.9	3.49
Pioneer 858	61.0	11	379.3	34.8	3.82
Sugar Graze	133.0	10	262.2	37.9	3.79
Super Dan	125.0	7	180.4	37.4	2.62
Speed Feed	165.0	9	448.3	49.8	no seeds
Control	seedlings emergence was not observed				

Screening of pearl millet germplasm indicated that accessions/varieties/lines IP 6112, IP 19612, ICMS 7704, IP 6110, IP 19586, ICMV 155 Brist, HHVBC tall, MC 94 C2, and Dauro Genopool, Sudan Pop III have good green biomass accumulation. Yields of fresh biomass at the end of plant vegetation varied from 10.2 to 12.3 kg m^{-2} with a plant density of 65-120 plant m^{-2}. Height of plant was 165-280 cm and number of basal tillers varied from 9-32, respectively.

These germplasms can also be characterized as early blossoming and fast ripening. For example more than 75% of inflorescences of IP 19612, ICMS 7704, ICMV 155 Brist, Dauro Genopool, Sudan Pop III, HHVBC tall were at the stage of seed maturation at the end of July. The length of panicle for majority of above-mentioned accessions/varieties/lines varied from 18.9-39 cm.

Under saline soil conditions at Makhtaral Experimental plot, 11 top accessions/varieties/lines of sorghum ICBA germplasm were identified (Figure 5).

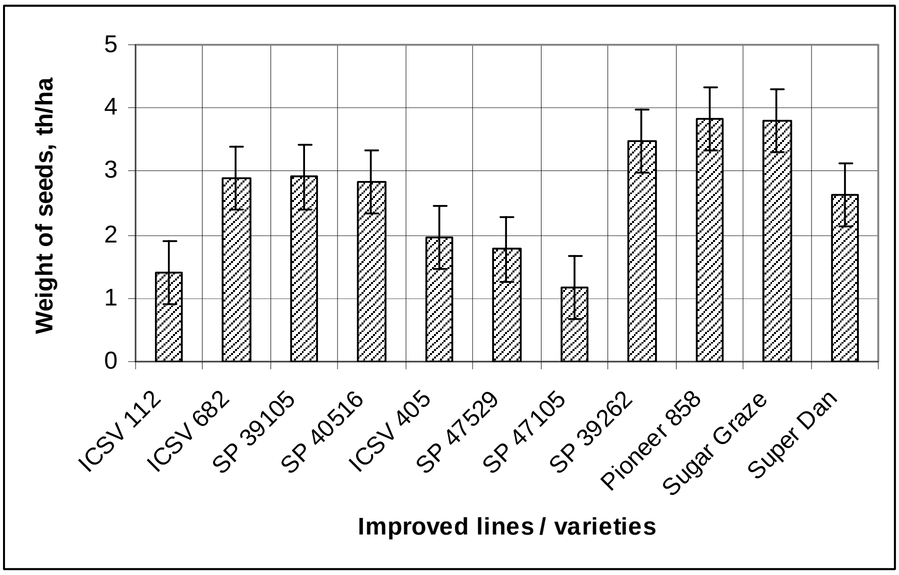

Figure 2.1.5. Seed production in top 11 Sorghum accessions/varieties/lines grown under field condition in Kazakhstan (ICSV 112, ICSV 682, SP 39105, SP 40516, ICSV 405, SP 47529, SP 47105, SP 39262, Pioneer 858, Sugar Graze, Super Dan)

The highest value of seed production was observed for Sudan Pop III (3.85 kg m^{-2}) and ICMS 7704 (3.38 kg m^{-2}). Low plant performance of fodder beet varieties (only 45% of plant survival) at the Makhtaral Experimental farm was mainly due to inadequate soil moisture and inappropriate seeding techniques.

Seedlings emergence for non conventional shrubby halophytes *A. nummularia*, *A. amnicola* and *A. undulata* were tested in the plastic bottles. *A. nummularia* and *A. undulata* showed almost 50% seed germination, although only 35 seedlings of *A. undulata* were well developed in the plastic bags and were transplanted to the open field at the end of August 2006.

ii. Beshagach experimental site

Field work survey undertaken in 2007 in Kazakhstan indicated that almost all territories of Assa-Talas River Basin are used to grow pastures for horse and sheep breeding. However, due to increasing soil salinization and rising groundwater table, the majority of the irrigated lands in these areas have gradually been removed from cultivation of conventional agricultural crops. Data of soil and water from various sources (open canal, drinking water and collector-drainage water) during the last decade indicates significant increases in salinity levels.

Besagash, which has been selected as a demonstration site for halophytes and up-scaling of high producing varieties of sorghum, pearl millet, fodder beet, alfalfa and other salt tolerant legumes is located approximately 25-30 km south to Djambul city near Kazakh-Kyrgyz border that geographically represents the foothill semi-desert of Tyanshan mountains system.

The climate of this region is characterized as dry continental with hot summer and severe winter. Average air temperature in summer varies from 16-19^{o}C with an absolute maximum of 43^{o}C during the summer season. The first frosts occur at the end of October. The annual amount of precipitation received as snow and rain on the lowland of south part of Djambul district varies between 210-380 mm with mean annual precipitation of 362 mm. About 160 mm rainfall occurs when the air temperature is less than 10^{o}C. Annual number of days when the air temperature does not exceed 0^{o}C is 170.

Soil at Besagash site is meadow light sierozem and moderate clay loam with medium mechanical composition at 0-100 cm soil depth. Soil moisture and field capacity did not show any variation with respect to the soils collected from two different points of the experimental plot however, soil infiltration rate differed significantly. Field capacity in the upper 0.15 m depth was 24.18% and 23.45% at 0.15-0.30 m depth. At 0.30-0.60 m and 0.60-0.90 m depths field capacity was 23.34% and 20.96%, respectively. Infiltration rate was relatively low (18.40 mm h^{-1}), being a consequence of the high levels of Mg^{2+} on the cation exchange complex, which effectively results in these soils exhibiting similar properties to Na^{+} dominated soils, i.e. sodic soils that are easily dispersed when wet. Soil bulk density increased with depth and ranged from 1.52 to 1.67 g cm^{-3} (Table 2.1.9).

Table 2.1.9. Physical properties of the field site in Besaghash site

Soil characteristics	Unit	Soil depth (m)			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
Sand (0.05-2.0 mm)	%	26.78	21.44	22.53	21.23
Silt (0.002-0.05 mm)	%	58.40	54.27	56.31	59.40
Clay (<0.002 mm)	%	26.81	24.29	27.16	24.37
Soil Texture (method USDA)	—	silt loam	silt loam	silt loam	silt loam
Field Capacity	%	24.18	23.45	23.34	20.96
Infiltration rate	mm h^{-1}	18.40			
Soil Bulk Density	g cm^{-3}	1.32	1.57	1.67	1.67
Soil moisture (May 2005)	mm	52.10	50.40	104.10	105.20

Bulk density varied from 1.32-1.67 g cm^{-3} at both sites and at different depths. Organic matter content in top soil is less than 1% and ranged between 0.50-0.84 with low nitrogen content in soil as compared to

phosphorus and potassium. Depth of ground water table varies with season and ranges between 1.5 - 2.8 m with TDS ranging from 3000-7190 mg L^{-1}.
Soil salinity and sodicity remained low with high concentration of Ca^{2+} and low concentrations of K^{+}. Among the anions, $SO_4{}^{2-}$ was dominant having maximum concentration of 88.4 $mmol_c$ L^{-1} at the upper 0.15 m depth with a slightly increasing trend from top to deeper horizons. Chemical analyses of soil showed higher concentration of Ca^{2+} followed by Na^{+} among cations (Table 2.1.10)

Table 2.1.10. Variation in chemical composition of soil at the Besagach site and adjoining areas.

Name of site (Site sampling)	**pH**	**TSS mgL-1**	**Soluble cations ($mmol_cL^{-1}$)**			**Soluble anions ($mmol_cL^{-1}$)**			
			Ca^{2+}	**Mg^{2+}**	**Na^{+}+K^{+}**	**$CO_3{}^{2-}$**	**$HCO_3{}^{-}$**	**Cl^{-}**	**$SO_4{}^{2-}$**
Besagach point 1 (near Cotton processing Plant)	7.6	1010	4.00	4.00	6.00	-	8.00	2.4	3.6
Besagach point 2 (near cementary)	7.95	4420	2.00	5.00	57.00	9.6	14.40	6.40	33.6
Besagach point 3 (along the main irrigation channel)	8.4	8760	2.00	4.00	120.0	14.40	15.60	6	90
Besagach point 4 (near Kazakh-Kyrgyz border)	7.95	7360	3.75	5.00	28.10	trace	5.60	2.16	88.4

The concentration of Cl^{-} was much lower than that of $SO_4{}^{2-}$ and ranged from 2.40 to 6.40 $mmol_c$ L^{-1} at different soils depths. Among the cations, Na^{+} was dominant at the soil surface followed by Mg^{2+} and Ca^{2+}. The concentration of Mg^{2+} in the upper 0.15 m depth was 4-5 $mmol_c$ L^{-1}. The concentration of Ca^{2+} was almost equal or less to the Mg^{2+} concentration at the different soil depths and ranged from 2.0 to 4.0 $mmol_c$ L^{-1}. The soil has a slightly alkaline reactivity with soil pH in water ranging from 7.60 to 8.4. Irrigation water analyzed in early summer season from the Besagash channel had a TDS value of about 1190 mg L^{-1} (Table 2.1.11).

Table 2.1.11. Chemical contents of irrigation water (from Assa River, near Kazakh-Kyrgyz border)

Name of site	**pH**	**TDS (mg/L-1)**	**Soluble cations ($mmol_c$ L^{-1})**			**Soluble anions ($mmol_c$ L^{-1})**			
			Ca^{2+}	**Mg^{2+}**	**Na^{+}+K^{+}**	**$CO_3{}^{2-}$**	**$HCO_3{}^{-}$**	**Cl^{-}**	**$SO_4{}^{2-}$**
Besagash channel	8.25	1190	5.0	2.5	2.3	-	6.8	1.84	11.60

CROP EVALUATION

Data collected in April 2007 showed high seed germination rate under field conditions followed by good seedling emergence, plant survival and growth performance, both for introduced and local sorghum varieties. Results are summarized in the Table 2.1.12.

A single cut of above-ground biomass at the 10 cm height was done for fast-growing, thin stemmed and tall forage sorghum lines, such as Pioneer 858, Super Dan, Sugar Graze and Uzbek-5 as control variety firstly introduced from Uzbekistan. Re-growth of the shoots after cutting performed well.

Similarly, the top-yielding populations/lines of sorghum (ICSV 112; ICSR 172; ICSV 745; SP 47105; SP 47529; SP 39105) for grain production were identified, which showed non-significant differences in seedling emergence and plant height to that of local variety Karlik, Uzbekistan (Figure 2.1.6).

Table 2.1.12. Evaluation of introduced and local sorghum germplam at Djambul region

Improved lines/varieties	Date of sowing	Date of seedling emergence	Plant height (cm)			Leaf size (mm)		Number of tillers
			36 days	72 days	End of vegetation	Length	Width	
High-yielding grain sorghum varieties*								
SP 47105	13.04.2007	24.04.2007	12.3	62.7	165	45.1	6.6	1.3
SP 47529	13.04.2007	24.04.2007	11.6	57.7	188	40.3	4.8	2.2
ICSV 172	13.04.2007	24.04.2007	12.3	62.2	155	43.9	6.6	1.7
ICSV 112	13.04.2007	23.04.2007	14.1	93.3	163,3	47.9	6.5	2.4
SP 39105	13.04.2007	23.04.2007	11.5	70.1	215	44.8	4.7	1.5
ICSV-745	13.04.2007	24.04.2007	10.6	62.3	190	32.5	4.4	
Uzbek Karlik (standard)	13.04.2007	24.04.2007	7.8	62.8	135	43.3	6.3	1.5
Top-yielding sorghum varieties for forage and grain*								
Sugar Graze	13.04.2007	22.04.2007	12.3	59.9	278	40.8	4.5	4.2
Super Dan	13.04.2007	25.04.2007	12.8	70.1	283.5	40.1	3.8	7.4
Pioneer 858	13.04.2007	24.04.2007	14.2	71	280.4	43.5	3.5	5.5
Speed Feed	13.04.2007	23.04.2007	13	69.5	279.8	54.2	4.8	6.2
Uzbek -5	13.04.2007	25.04.2007	12	56.1	230.8	46.9	5.7	5.6

* Best varieties selected from previous year screening for up-scaling and seed production on one-farm level.

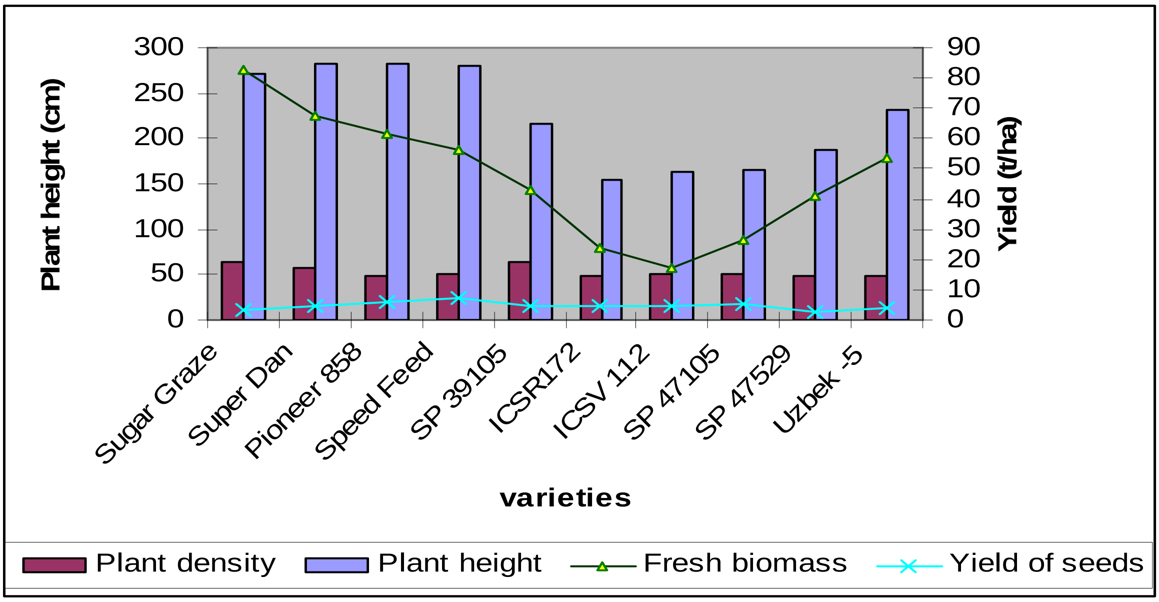

Figure 2.1.6. Yield of seeds and fresh biomass of high yielding sorghum lines in relation to plant height at the Besagash Site (2007)

Screening of pearl millet germplasm by using of the same agro-biological traits indicates that IP 6110, Guerinian-4, IP 3616, ICMS 7704, IP 6110, HHVBC Tall, MC 94 C2, Daura Genopool, Sudan Pop III assessions showed best results in terms of green biomass accumulation (yield of fresh biomass at 50% of plant heading varies from 6,200 up to 10,400 kg/m^2 with a plant density of (65-94 plant/m^{-2}), height of plant as 250-296 cm and number of basal tillers: 4.9-6.8 respectively); highest rate of seasonal growth and plant survival (Table 2.1.13).

Table 2.1.13. Growth characteristics of high productive pearl millet lines, at the grain maturity stage on sodic-alkaline soils

Improved lines/varieties	Date of sowing	Date of seedling emergence	Plant Height (cm)			Leaf Size (mm)		Number of tillers
			36 days	72 days	End of vegetation	Length	Width	
HHVBC tall	14.04.07	25.04.07	10.2	67.5	259.5	40.9	2.2	6.2
IP 3616	14.04.07	24.04.07	11.9	57.6	270	42.9	2.8	
Guerinian 4	14.04.07	23.04.07	7.7	55.3	250	39.1	2.6	
Sudan Pop III	14.04.07	23.04.07	10.6	60.2	254.8	52.5	2.8	6.8
IP 6110	14.04.07	24.04.07	11.1	69.3	296	54.5	2.3	4.9
ICMS 7704	14.04.07	22.04.07	11	67.9	269	46.8	3.1	6.4
MC 94 C2	14.04.07	24.04.07	10	75.1	296.3	47.7	3.6	5.6

These improved lines could also be characterized as early-blossoming and early-maturing varieties. For example more than 75% of inflorescences of ICMS 7704, Dauro Genopool, Sudan Pop III, IP 6110 and HHVDBC Tall were at the stage of seed maturation. The length of panicle for majority of above mentioned cultivars varies between 20.9-38.4 cm.

Significant increase in yield of seeds is associated with the panicle size, weight of seeds/panicle and weight of 1000 seeds showed IP 3616, Sudan Pop III, HHVBC Tall\, Gurenian -4, MC 94 C2, and ICMC 7704 as improved lines. Alfalfa varieties Eureka and Sceptre from ICBA are recommended for cultivation in large scale on abandoned alkaline soils for seed production. Field screening of these varieties showed significant growth rate (Figure 2.1.7) for Eureka cultivar (both parent and first reproduction lines) when compared with local varieties.

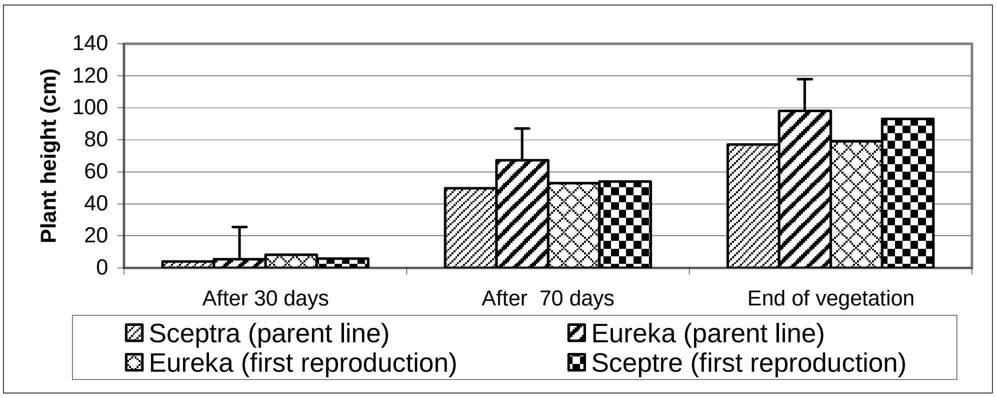

Figure 2.1.7. Variability in plant height of alfalfa (of different origin) at 36; 72 days and at the end of vegetation at the Besagash site (July 2007).

As a result of adequate soil moisture in early spring time at the site and appropriate seeding techniques, about 95% plants of fodder beet varieties survived with good establishment. Maximum plant height was observed for cultivar Turbo (Figure2.1. 8).

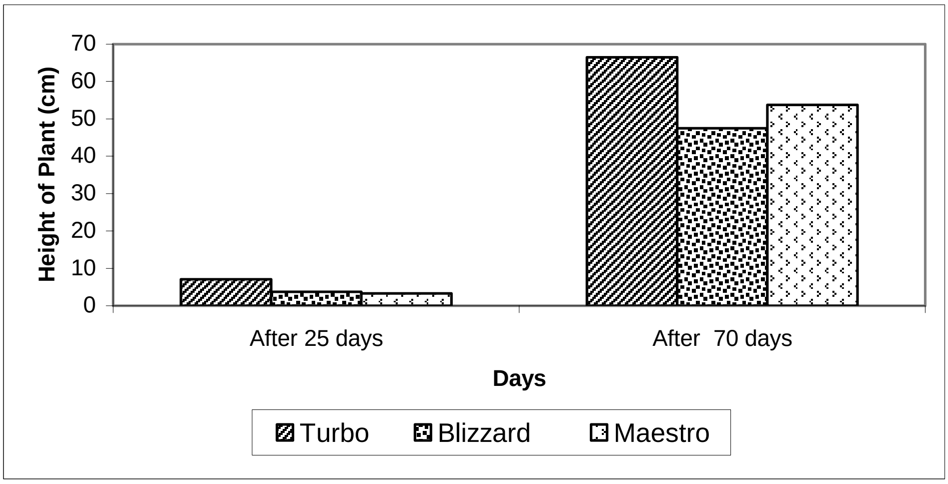

Figure 2.1.8. Plant growth of three introduced varieties of fodder beet (ICBA germplasm) at the Besagash experimental plot (August, 2007)

Evaluation of non-conventional tree and shrubs relative growth rate and green biomass accumulation

Pre-seed sowing treatment and seedling emergence developed earlier at the Akdepe site and Plant Industry nursery for non-conventional halophytes *Acacia ampliceps* and *Atriplex* spp. showed very promising results in the southeastern Kazakhstan. As is shown from Figure 2.1.9, the highest relative plant growth value was observed for *Acacia ampliceps* and *Atriplex amnicola*, while *Atriplex undulata* with a medium growth rate had highest survival rate and frost tolerance.

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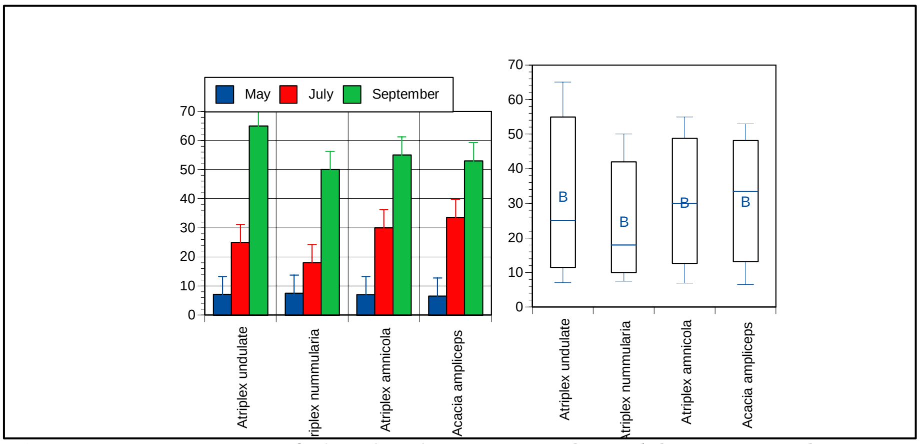


Figure 2.1.9. Dynamic of plant height (cm) *Atriplex undulata*, *A.amnicola*, *A.nummularia* and *Acacia ampliceps*. X-axis shown the varieties of Atriplex and Y-axis shown height of Plant (cm).

B. TURKMENISTAN

The studies were carried out at Akdepe site located in Akdepe district of Dashauz province, northern part of Turkmenistan.

Forage crops and shrubs studied at the Akdepe experimental Site were as follows: Sorghum (14 varieties/lines), Pearl Millet (27 accessions/cultivars), Fodder Beet (4 varieties), Alfalfa (2 varieties), Acacia ampliceps and Atriplex (3 species). General layout of the trail was established accordingly the guidelines developed by ICBA (2005).

The studies on tree survival on saline environment were carried out from 2005-2007. The growth and survival rate of following tree and shrubs were studied at the site: Poplar, Thuya, Quince, Mulberry, Dog-rose and Black currants. Agronomic practiced applied were as follows:

I. Different salinity levels, with and without leaching
II Reduced irrigation

- 80% irrigation (only three per vegetation season)
- Full irrigation (five times during the vegetation period).

Irrigations were applied twice, first in April after crop seed sowing followed by three consequent irrigations in June and August. Saplings of tree species were irrigated only in 2005 - 2006 growing seasons with a volume of 1200 m^3 ha^1, when pre-irrigation soil moisture content was at 60% of field capacity.

Data related to maximum air temperature, average air temperature and precipitation near the Akdepe farm of Dashauz province is given in Figure 2.1.10. Relative humidity increased from 38 to 52% during the experimental period in 2007.

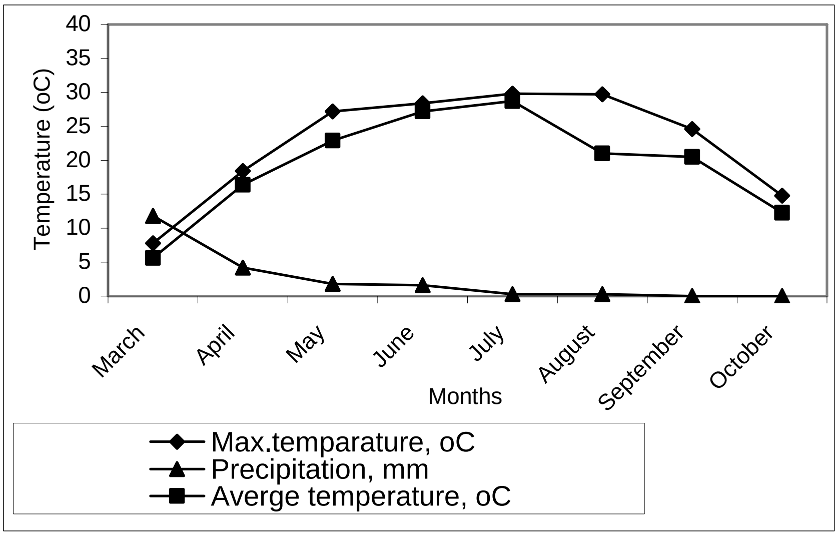


Figure 2.1.10. Meteorological data for the Dashauz province site.

On an area of 0.9 ha, pits for planting of shrubs and trees were prepared. Sapling tree species from the previous year's experiments were irrigated with a volume of 1200 m^3 ha^{-1}, when pre-irrigation soil moisture content was at 60% of field capacity. Pits for the planting of new species of *Acacia ampliceps* and *Atriplex undulata* were prepared in 2007. *A. undulata* was planted directly by seeds. The plants were sown on 14-15 April at air temperature ranging between 14.5 to 17.7°C; soil temperature ranging between 2 to 5°C; air humidity at 56%; and monthly rainfall of 7.1 mm. Agronomic practices applied to the site are presented in Table 2.1.14.

Table 2.1.14. Agronomic measures applied for the trial at Akdepe site in 2006

Farming Practices	Dates	Implements	Additional information
Land leveling	11/11/2005	Tractor MTZ-80, land leveler	Three passes (lengthwise, transversal, diagonal)
Laying out	15-30 /11/2005	Manual	Laying and to dig a hole
Cleaning and weeds control	February-March,2006	Manual	
Planting	14-15 April	Manual	
Organic Fertilizer		Manual	
N (ammonium nitrate), kg/ha	Beginning of April 2006; and two times in June	Manual	100

Soils of this area have silt loam texture in all sub-plots. Field capacity of soil varied from 18-23% at 0-90 cm soil profile depth. Soil N, P and K content showed low amounts of N when compared to P and K in top and sub-surface profile depth (Figure 2.1.11). Top soil layer (0-30cm) was characterized by poor soil-

nutrient stocks; organic matter was in range of 0.4-0.68% and 0.45-0.56 at the 60-90 cm depth and severe secondary soil salinization. Over the two growing seasons, the ground water table (GWT) averaged 2.5 m and 0.5 m below the soil surface, respectively. The mean electrical conductivity of the groundwater was 3.3 and 6.9 dS m^{-1}. Chemical analyses of soil done at transplantation of plants showed moderate salinity and sodicity levels. Sulfate remained the dominant ion in all sub-plots followed by Cl^- (Figure 2.1.11, 2.1.12)

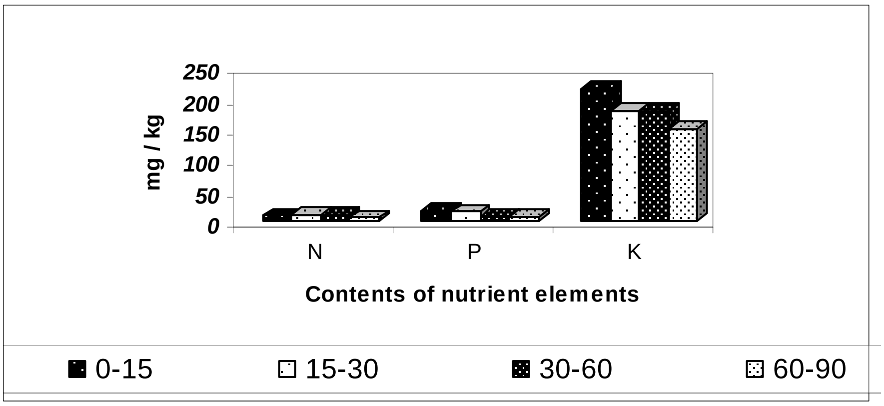


Figure 2.1.11. Contents of nutrient elements in the soil

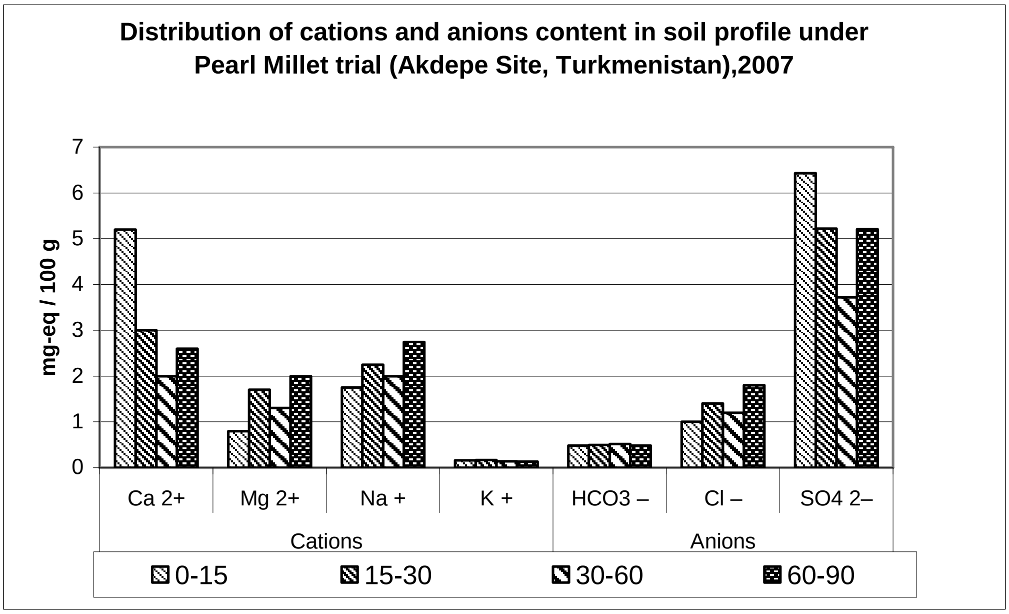


Figure 2.1.12. Distribution of cations and anions in soil profile.

The amount of salts at the end of growing season (September 2006-2007) showed an increasing trend up to 60-90 cm under sorghum-pearl millet crops. The 32% increase in soil salinity under tree plantation can be associated with shallow groundwater table depth and higher ground water salinity. Ground water table was at 0.98-1.28 m at the end of April and gradually lowered to 2.92-3.17 m in September due to evaporation and transpiration. The maximum decline in ground water table depth up to 3.06 m was observed under tree plantation (average data for two grown seasons). A gradual reduction in the ground water table level was marked under alfalfa and *Atriplex undulata* trials.

Ground water had a high salinity level varying from 7032-10722 mg L^{-1} (~ EC_{iw} 10-15 dS/m). Irrigation water had TDS value about 2000 mg L^{-1} (~ 1.80 dS/m) with Ca^{2+} and Na^{+} of almost similar values. Salinity of drainage water in November was at 4043 mg L^{-1}.

GROWTH AND PRODUCTIVITY OF SALT TOLERANT PLANTS

Experiment 1: Evaluation of salt tolerance and plant performance of annuals and biannual crops
The difference in phenospectrum of seedling emergence and plant development for both ICBA and local germplasms of sorghum and pearl millet at the Akdepe Experimental Site indicated that almost all ontogenic stages were reached 5-10 days earlier than those at the Makhtaral Site in the southern Kazakhstan (Figure 2.1.13).

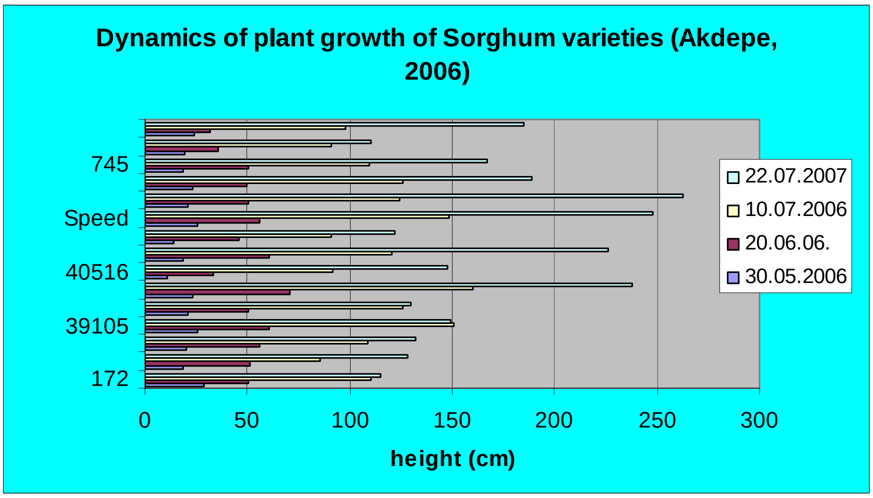


Figure2.1. 13. Dynamic of plant growth Sorghum varieties (Akdepe, 2006)

Among tested sorghum varieties/improved lines from ICBA namely Speed Feed, Super Dan, Sugar Graze, Pioneer 858, SP 40516 and SP 39269 showed significant advantages both in seasonal growth rate and plant height when compared to local variety (Table 2.1.15).

Table 2.1.15. Growth parameters and seed production of 14 varieties/improved lines of Sorghum bicolor from ICBA, tested under saline environments in Akdepe, Turkmenistan

Varieties/Improved lines	Height of plant at seed maturation stage, cm	Green biomass, t/ha	Dry biomass, t/ha	Yield of seeds, g/m²
ICSR 172	140	28	13.3	266
SP 47105	142	28.2	13.3	400
ICSV 112	140	21	10.8	400
SP 39105	181	18	10.3	266
SP 47529	170	10	5.0	66
Pioneer 858	260	46	23.7	133
Sp 40516	105	30	13.0	-
Sugar Graze	181	80	27.3	333
ICSB 405	101	50	20	-
Speed Feed	210	74	26	500
Super Dan	190	70	20	100
Sp 39269	200	28	10	300
ICSV 745	194	28	10.6	300
ICSB 682	110	50	20	-
Local variety		16	8.5	233

Among tested Sorghum from ICBA, Speed feed, Super Dan, Sugar Graze, Pioneer 858, SP 40516 and SP 39269 accessions showed significant advantages both in seasonal growth rate and plant height in

comparisons to local varieties. The above mentioned varieties were also characterized by highest yield of fresh biomass varying between 70.0 t/ha (Super Dan), 74.0 (Speed feed) up to 80.0 (Sugar Graze) and 46.0 (Pioneer 858) respectively, while the yield of green biomass of Sorghum sernum (local variety) was only 16.0 t/ha (Table 2.1.15). Majority of low –growing and late-maturing specimens of sorghum, such as ICSV 112, SP 3905, SP 712 are characterized by thick succulent stems and long and ramified panicles that make these varieties useful both for forage (silage) and grain production (0.26-0.48 kg/m²).

The top performing 8 (Sugar Graze, ICSB 405, Speed Feed, Super Dan, Pioneer 858, ICSR 172, ISCV 112 and ISCV 745) varieties/improved lines of sorghum germplasm showed an average dry matter production of 13.3-27.3 t/ha tested in field conditions under different seasonal ranges of soil salinity. These values could be recommended for the development of local breeding program and seed production and dissemination among farmers under saline environments in Turkmenistan (Figure 2.1.14).

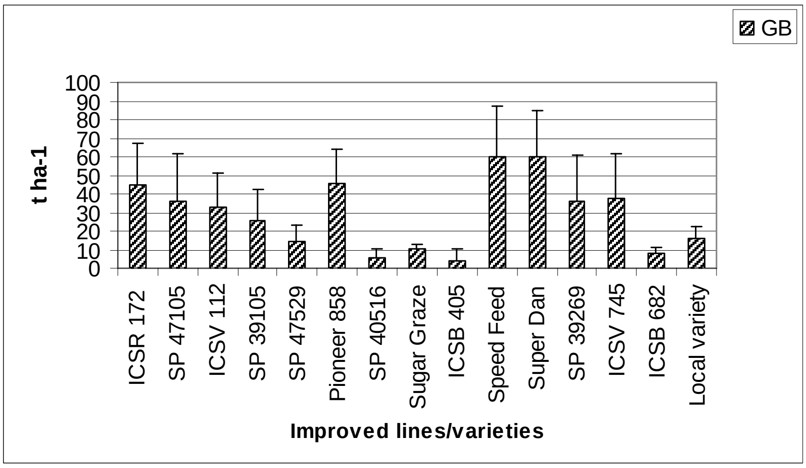


Figure 2.1.14. Fresh biomass production of 14 varieties of sorghum from ICBA. (Akdepe, 2006)
GB- average of green biomass

Majority of low-growing and late-maturing specimens of sorghum, namely ICSV 112, SP 3905, ICSR 172, ICSV 745 are characterized by having a thick succulent stem and long and ramified panicles that make these varieties useful both for forage (silage) and grain production.

Based on the series of agrobiological parameters, including field germination capacity, growth and seasonal rate, as well as leaves area (photosyntethic activity), panicle size and values of fresh biomass (at the stage of plants flowering), 26 varieties of pear millet from ICBA were conventionally divided into three categories (Table 2.1.16). The most economical and highly adaptive varieties to the saline soil and saline irrigated water were found to be ISCMS 7704 (a very fast-growing and early ripening cultivars with a yield of fresh biomass 4,200 kg/m² and plant density of 116 plants m^{-2}); IP 6105 which showed a fast growth rate with almost simultaneous development (panicle excretion and seed maturation) of all plants.

Significant increases in plant height and fresh biomass was also characterized for MC 94 C2, IP 19612, IP 6109, Sudan Pop III, Gurenian-4 and HHVBC tall varieties. Based on biomass production and seed yield, a group of 6 to 8 high productive pearl millet accessions/lines/varieties were identified and selected for further cultivation under highly saline conditions of Turkmenistan. Pearl millet germplasm from ICBA showed about 30% more dry fodder yield and 25% seeds as compared to local varieties. The most economically promising and highly adaptive to the saline soil were: ICMS 7704 (a very fast-growing and early ripening cultivar with a yield of fresh biomass 4.2 kg m^{-2} and plant density of 116 plants per m²; IP 6105, which had a rapid growth rate with almost simultaneous development (panicle initiation and seed maturation) of all plants. Significant increases in plant height and green biomass was also observed for MC 94 C2, IP 6112, IP 6109, Sudan Pop III, IP 22269, Gurenian-4 and Dauro Genepool varieties. Comparative studies of fresh biomass of high yield pearl millet varieties for two seasons (2006-2007) confirmed the selection of above-mentioned lines (Figure 2.1.15). Dwarf forms of pearl millet such as Eraj Pop, Nutrifeed, SRBC, IP 3616, and ICMV 155 have a low plant height and are characterized by thin-stemmed delicate forage. The majority of the above cited varieties have high plant density that makes them useful for cultivation in early spring-summer as animal forage.

Table 2.1.16. Growth parameters and seed production of 25 accessions/lines/varities of Pennisetum glaucum from ICBA, tested under saline lands in Akdepe, Turkmenistan

Accessions/varieties/ lines	Height of plant at the full seed maturation stage (cm)	Green biomass (t/ha)	Dry biomass (t/ha)	Yield of seeds (t/ha)
Nutreefeed	171	88.0	26.6	1.2
MC 94 C2	235	38.0	11.6	2.95
IP 19612	260	45.6	14.8	1.87
IP 6105	211	30.1	10.3	2.91
Eraj Pop	210	21.3	8.3	1.47
IP 3616	235	34.9	14.3	1.30
ICMV-155 Original	215	30.3	10.6	1.10
Sudan Pop III	250	46.0	13.7	1.37
SRBC	195	10.7	2.7	5.6
ICMV 155 e,el	210	16.9	6.4	3.0
ICMV 155 Brist	210	18.5	6.0	-
IP 6109	250	33.8	11.6	1.9
IP 22 269	215	38.5	12.2	0.5
IP 6101	230	23.4	10.3	2.8
IP 19586	235	21.8	8.3	1.40
IP 6106	240	38.6	16.7	5.85
IP 6107	220	21.7	7.7	3.1
IP 6112	220	23.9	10.0	4.0
Sudan Pop I	205	20.1	9.3	4.7
IP 6110	225	40.6	13.7	1.98
Dauro Genepool	220	13.0	4.9	1.27
HHVBC tall	220	16.8	6.7	6.0
ICMS 7104	190	30.6	10.3	8.9
Guerinian-4	200	40.5	13.7	4.30
Wraj Pop	160	21.9	10.1	1.41
Control	185	16.0	8.5	-

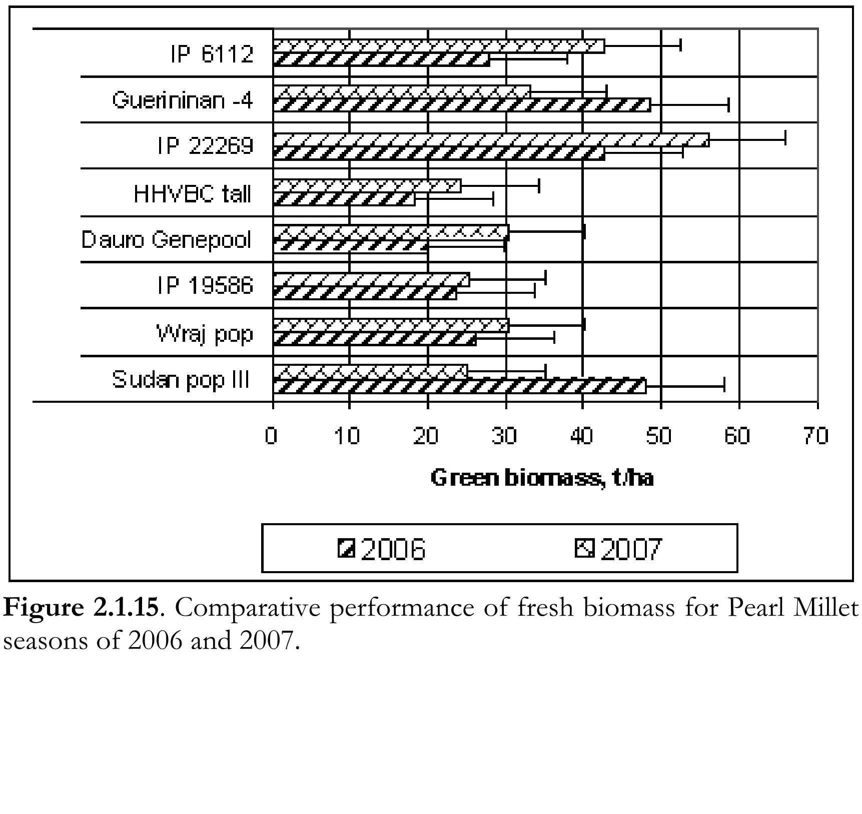


Figure 2.1.15. Comparative performance of fresh biomass for Pearl Millet accessions during the growing seasons of 2006 and 2007.

They can also be included as an inter-cropping system established in the inter-space area between trees, Glycyrrhyza plantations etc. Densely covering the salt-affected lands, they contribute to the soil improvement and moisture holding that should be taken into consideration when determining crop rotations.

EVALUATION OF SALT TOLERANT ANNUAL AND BIANNUAL CROPS

A good re-growth rate and high canopy crop of alfalfa (ICBA germplasm) was observed for those planted in 2006 and 2007. Majority of individual plants during mid May 2007 were in the flowering and/or beginning of seed maturation stages, with plant height varying between 89.6–121.6 cm and plant density of 280-330/m². Up-scaling technology for seed multiplication of alfalfa (ICBA second regeneration) 0.06 ha of farmer fields gave good results. Size of each experimental plot varied between 15 x 40 m and 15 x 100 m. Seeding was done through broadcasting, and seed germination varied between 85-90%.

At the Akdepe Site, very promising results were obtained for ICBA alfalfa Eureka and Sceptre varieties when compared with local varieties. Height of plant and fresh green biomass was higher for Eureka variety compared with local Khivinskiy variety (Figures 2.1.16 & 2.1.17). It was found that both varieties from ICBA were well distinguished from local variety "Khivinskii" not only by growth rate, but also by the length of generative sprouts, number of inflorescence, size and number of pods and seed per one pod, which in combination determine high seed productivity of introduced Medicago varieties.

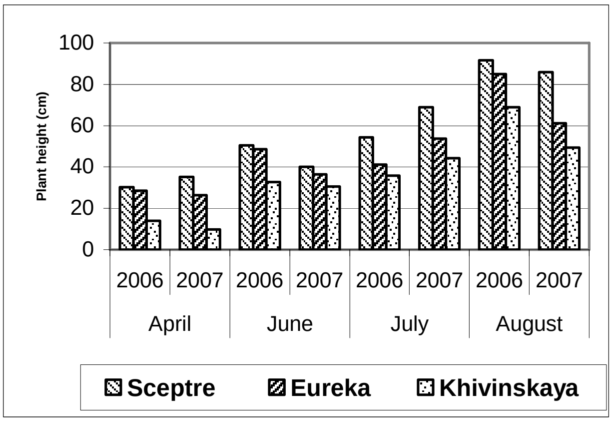


Figure 2.1.16. Annual plant growth dynamics of ICBA alfalfa compared with local varieties at the Akdepe site (Turkmenistan)

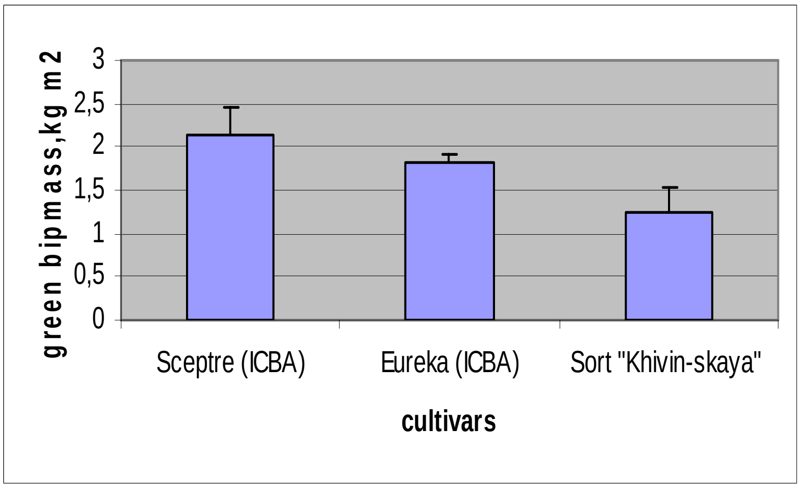


Figure 2.1.17. Average seasonal fresh biomass production of ICBA alfalfa compared with local varieties at the Akdepe site.

Being sown manually by seed in April 2006 both alfalfa varieties produced seedlings in one week while local variety germinated after three weeks. Marked differences in the flowering period and seed maturity were observed with the ICBA varieties. Additionally, the two ICBA introduced alfalfa along with local Kyzylkumskaya (from Uzbekistan) varieties tested both in Turkmenistan and Uzbekistan also showed high tolerance to soil salinity (Figure 2.1.18). ICBA and Kyzylkumskaya alfalfa varieties could tolerate high soil salinity without decreasing of green biomass.

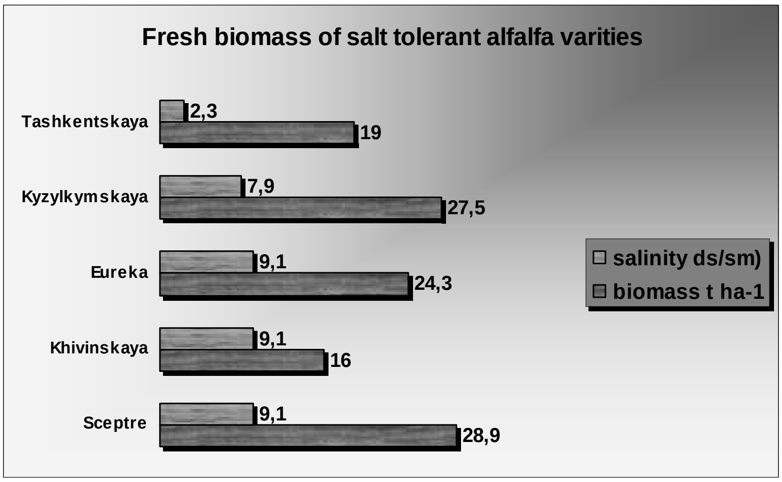


Figure 2.1.18. Fresh biomass of top-yielding alfalfa varieties depending on soil salinity

Productivity of fodder beet cultivars from ICBA grown at the Akdepe site

Fodder beet varieties Turbo, Maestro, Blizzard and Blaze planted under high saline environments of Dashauz province, Turkmenistan (ECe of ground water: 5.6-21.1 dS/m) showed good performance and productivity. It should be noted that during 2006-2007, adequate plant growth for the four fodder beet varieties from ICBA was only obtained at the Akdepe farm. These varieties should be sown when the soil moisture in the surface layers is approximately 23-28% and the temperature of the soil is at 10-12 ^{o}C. Plant density at the period of formation of tubercle was in range of 21 plants per m^2 for Blizzard cultivar; 18-for cultivar Maestro; 16- for Blaze and 12 - for Turbo variety, respectively (Table 2.1.17).

Table 2.1.17. Agrobiological parameters and tuber production of fodder beet cultivars from ICBA at the Akdepe site, Turkmenistan

Varieties	Plant density (ind./m^2)	Color of tubercle	Average weight of 1 tubercle with above ground biomass (kg/plant)	Average of weight of 1 tubercle without leafy tops (kg/plant)	Weight of tuber with leafy tops kg/m^2	Tuber production (kg/m^2)
Turbo	12	White	4.3	3.7	51.6	44.4
Blizzard	24	White	3.1	2.7	74.4	64.8
Maestro	18	Yellow	4.5	4.2	81.0	75.6
Blaze	16	Red	4.6	4.2	73.0	67.2

Total tuber production is shown in Figure 20 ranged from 44.4 (variety Turbo) up to 75.6 kg m^{-2} (Maestro cultivar).

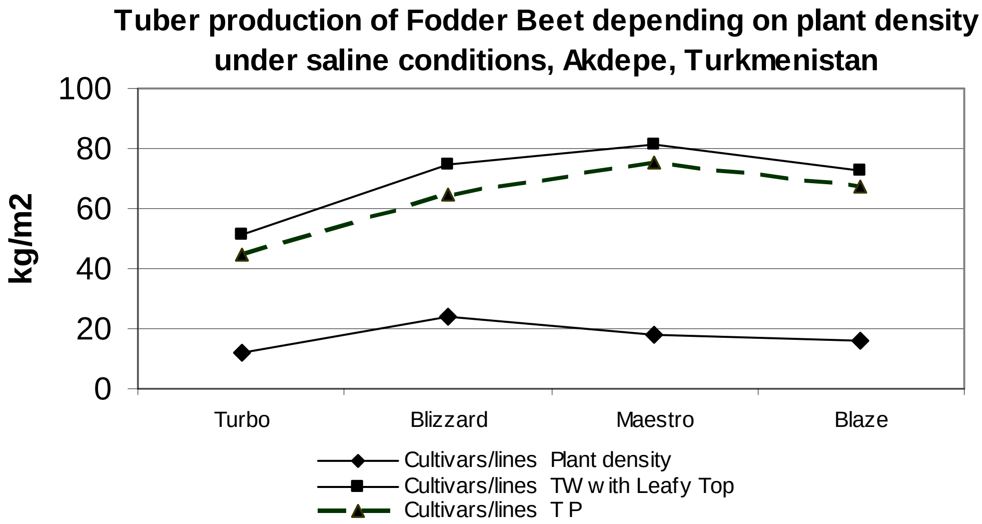


Figure 2.1.20. Tuber production of fodder beet depending on plant density under saline conditions, Akdepe, Turkmenistan

The highest biomass was observed in Maestro with green foliage plus weight of tubercle amounting to 81.0 t/ha.

Despite the encouraging results obtained for the sugar beet accessions from ICBA there is a need to develop agro-techniques for the establishment and cultivation of this crop on salt affected soils. A surplus of fertilizers and excessive irrigation may cause the breakdown of tubercle, as well as the appearance of various pests, which was observed at the Akdepe site in fall 2006.

EXPERIMENT 4. EFFECTS OF LEACHING ON CROP YIELDS

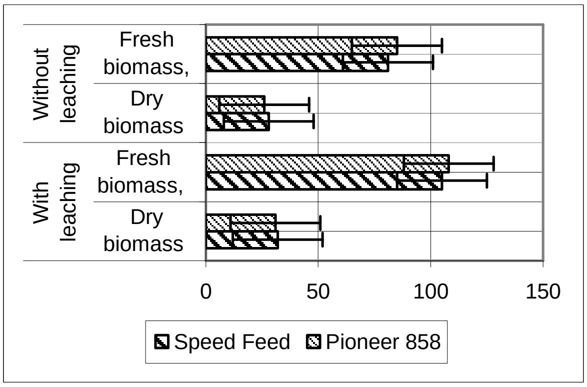
Soil leaching is one of the main agricultural techniques to keep salinity of the soil priofile below the harmful level for crop production. In 2007 at the Akdepe site we investigated the leaching impact on the plant performance and productivity of ICBA introduced germplasm. Table 18 shows the effect of leaching on seedling emergence and plant growth at the early stages of development for all tested salt tolerant species/varieties of alfalfa, sorghum and pearl millet. Significant delays of about 14 days was marked in seed germination rate for all tested crops under the non leaching treatment (Table 2.1.18)

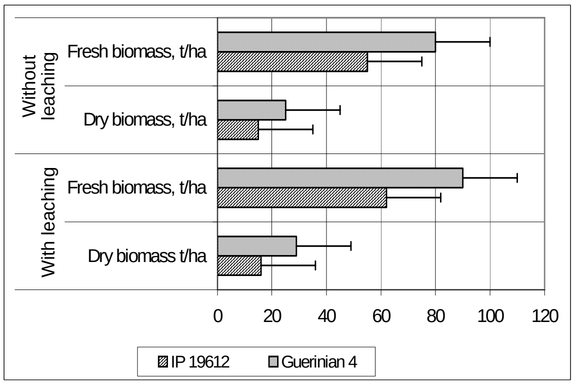
Table 2.1.18. Plant height and growth stages of alfalfa under different soil treatments

Varieties/improved lines	**Numbers of days after seed sowing**		**Plant Height (cm)**		**Development Stage**	
	A*	**B****	**A**	**B**	**A**	**B**
Alfalfa Sceptre variety	6	20	34.5	8.7	budding	seedling emergence
Alfalfa Eureka variety	6	20	39.6	11.2	budding	-
Peerl millet (IP 19612)	9	24	29.8	5.8	tillering	-
Pearl millet (Guerinian -4)	9	23	33.9	3.9	tillering	-
Sorghum (Pioneer 858)	9	22	43.4	4.1	tillering	-
Sorghum (Speed Feed)	9	23	46.2	6.9	tillering	-

A*- without leaching; B** - soil leaching done in early April 2007

The same tendency has been manifested until the beginning of seed maturation stages, i.e., effect of leaching resulted in a relatively good growth rate of plants and crop yield productivity both for sorghum, pearl millet and alfalfa cultivars (Figures 2.1.21-2.1.22 a,b).





Figures 2.1.21 and 2.1.22a. Relative growth rate (3 months period) and forage biomass production for two high productive accessions of sorghum and pearl varieties under and without leaching treatment

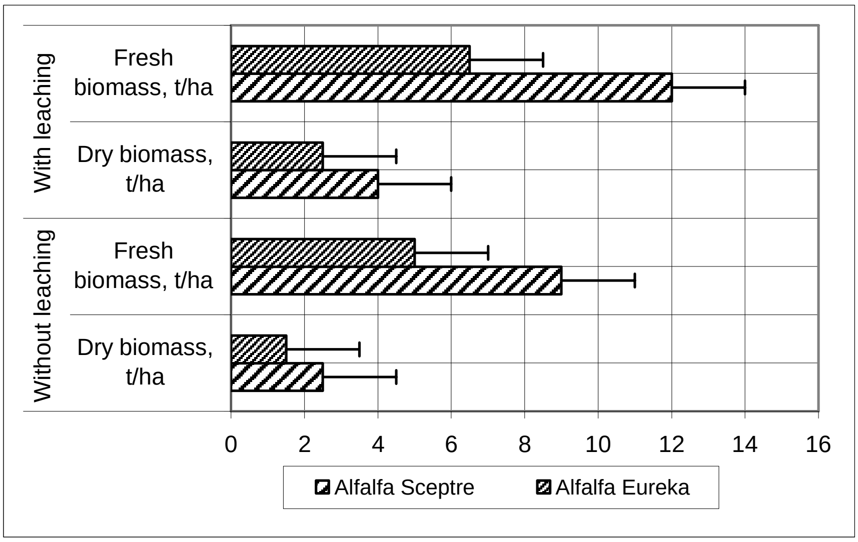


Figure 2.1.22 b. Differences in crop yield of two varieties of alfalfa with or without soil treatment.

Like other crops, leaching improved the growth and biomass production significantly in both the alfalfa varieties. Var. Eureka showed higher productivity as compared to Sceptre for both leaching treatments.

EXPERIMENT 5: EVALUATION OF TREE/SHRUBS PLANTATION FOR REHABILITATION OF SALT PRONE LANDS

The rapid expansion of irrigated agriculture in Central Asia has greatly affected the natural deserts, riparian and foothill forests that also contributed to exacerbating desertification and contributing to secondary salinization and waterlogging. Conventional solutions to combat waterlogging and salinity still are confined to horizontal subsurface drainage systems, consisting of horizontal buried pipes and deep open drains. Previous experiences, however, had shown that these systems although having distinct advantages create several problems such as disposal of the drainage water, maintenance and high cost of drainage infrastructure (Abrol et al, 1988, Djalalov et al., 2005). Elsewhere, afforestation has proved to be effective in re-vegetating saline landscapes, providing valuable products to farmers from marginal degraded land, and make use of otherwise unproductive land and lower elevated groundwater table (GWT) via biodrainage (Heuperman et al., 2002; Marcar and Crawford, 2004). However, to ensure effective and sustainable outcomes, afforestation of marginal lands must be preceded by a comprehensive evaluation of appropriate both native and introduced tree species.

The assessment of tree performance in the region during the first three years on marginal land showed high growth rates, which were comparable to those reported for trees on irrigated agricultural land, despite the increase of the root-zone salinity from low to high.

.

The afforestation of saline marginal lands by using native tree/shrubs species is dependent on available groundwater resources. The salinity level of the groundwater (8.0-16.5 dS m^{-1}), though inappropriate for the common local agricultural crops, did not restrict growth of these tree species. Due to shallow groundwater table and irrigation (although applied at deficit rates), the trees tolerated the strong soil salinity without inhibition in survival and growth rate.

From our studies at the Kyzylkesek site (Uzbekistan) and Akdepe site (Turkmenistan) the leading tree species with regards to survival rate, growth characteristics and adaptability to high saline natural environment proved to be *Haloxylon apphyllum*, *Salsola paletzkiana*, *S. richteri* at a saline-sandy sites, followed by *E. angustifolia*, *P. euphratica* and *P. nigra* var. pyramidalis, *Robinia pseudoacacia*, *M. alba*, *Morus nigra* whereas fruit species such as *Cydonia oblonga*, *Armeniaca vulgare*, *Prunus armeniaca* and species of genera Malus. These plant species though desirable from a farmer's financial perspective, showed low bio-drainage potential. Above-ground DM production for 2006-2007 seasons were in the order of *Acacia ampliceps* >*E. angustifolia* > *M. alba*, *M. nigra* > *P. euphratica* > *Robinia pseudoacacia* > *Thuja occidentalis*, among the species tested (Table 2.1.19). These species showed fast growth with a moderate ability to develop leaf biomass rapidly, have characteristics of feed quality to be used during the off-season. Genus Tamarix, with high absolute values of above-ground biomass, were very tolerant to saline-alkali soil with pH values of up to 8.5.

The overall ranking of the trees, weighing all parameters concurrently shows that species of genus Tamarix and *E. angustifolia* have the highest potential for growing on both loamy and sandy soils, which represent the dominant soil textures in the region. As a result, at marginal sites where a shallow, slightly-to-moderately saline groundwater is available throughout the growing season, *Elaeagnus angustifolia*, *Robinia pseudoacacia* and newly introduced *Acacia ampliceps* showed the fastest growth and highest water use. This indicates the suitability for planting on low fertility saline lands. Preliminary outcomes of the study on salt affected soils have also indicated that tree plantations with *E. angustifolia*, *Populus*, *Morus spp.*, have potential for increasing the soil organic matter due to the relatively rapid leaf litter decomposition. *Morus nigra* and *Cydonia oblonga* showed reasonable DM production on degraded land, with high biomass allocation towards the root fraction. Among tree species, Poplar (*Populus alba*, *P. nigra* var. piramidalis and *P.euphratica*) showed maximum growth for all parameters studied followed by mulberry (*Morus nigra*). *Populus diversifoilia* which displayed high rates of leaf and wood production appeared to be the most sensitive to salinity on sandy-soil. Similarly, it had slow longitudinal root growth and low root DM production at sandy site while exhibiting superior below-ground development at the sandy-loamy soils.

Table 2.1.19. Performance indicators of native and introduced species of tree and shrubs under condition of Akdepe (Turkmenistan) compared with Kyzylkesek (Uzbekistan)

Parameters species	Growth rate (at first years)	Root establishment	Reproduction	Above ground DM	Biodrinage potencial; feed and firewood value	Soil salinity level	Winter frost tolerance	Rate survival (%)
Haloxylon aphyllum	+	+	a.b.c	+	+	+	+	+
Tamarix hispida		+	Invasive	+	+	+	+	+
T. androsovii	+	+	Invasive	+		+	+	+
Populus alba	+	+	a.b	+		+	+	+
P.nigrav var. pyramidalis	+	+	a.b	+	+	+	+	-
P.euphratica	+	+	a.b	+	+		+	-
Salix babylonica	+	+	a.b.c	+	+	+	+	-
Hyppophae ramnoides	+	+	a.b.c	+	+	+	+	+
Elaeagnus angustifolia	+	+	a.b.c	+	+	+	+	+
Robinia pseudoacacia	-	+	a.b.c	+	+	_	+	+
Morus alba	+	+	a.b	+	-	+	+	+
Morus nigra	+	+	a.b	+	+	+	+	+
Malus domestica	+	+	a.b	+	+	-	-	+
Malus silvestris	+	_	a.b	+	+	+	+	+
Cynadon oblonga	+	+	a.b	+	+	+	-	+
Armeniaca vulgare	+	+	a.b.c	+	+	+	-	+
Thuja occidentalis	-	_	b	-	-	-	+	-
Acacia ampliceps	+	+	a.b.	+	+	+	+	-
Roza canina L.								
Atriplex undulata	+	+	a.b.c	-	+	+	+	+

+ =high potential; + = medium potential; - = low potential

Introduced coniferous species *Thuja occidentalis* was the only species that showed poor growth under furrow irrigation at the Dashauz province and in the second year died due to its high sensitivity to frost.

Evaluation of survival rate, performance and productivity including biomass and seed production of non-conventional tree/shrubby halophytes was undertaken for first time in Central Asian. *Acacia ampliceps*, *Atriplex nummularia*, *A. undulata* and *A. amnicola* showed high potential for the reclamation of salt affected marginal lands. All species tolerated average root-zone salinity of 8-16.8 dS m^{-1}. Seedlings of *Acacia ampliceps* were obtained from direct seed sowing in the field (February 2006) and through the establishment in plastic bags. The growth rate was very fast at 12-18 cm/month at the rooting stage and 25-30 cm/month, when the basal stems develop a woody character. Plant growth of *Acacia ampliceps* raised from direct seeding was much higher than with similar plants grown after transplanting by seedlings (from plastic bags). The higher accumulation of green biomass in both cases was observed from August to September, reaching maximum under conditions of Turkmenistan.

Among shrubs *Atriplex spp*., dog rose and redberry showed a high seed germination and survival rate. Among *Atriplex spp*., highest seed germination (approximately 89%) under field conditions was observed for *Atriplex undulata*, which showed a rapid growth rate and accumulation of biomass. having been grown at a high plant density of 10-12 plants/m^2 (normal density of this shrub is 4 plants/m^2) in the first year, this species with its large canopy can occupy the inter-row spaces forming a dense mono-component halophytic pasture. The biomass produced in 1.5 years was 5.6 kg /m^2 and was readily browsed by cattle and small ruminants. Biomass of *Atriplex undulata* at the Akdepe Experimental site increased with high density level of plant per square meter (5.0-5.8 thousand plant/ha). Replacement of 30% of individuals has been done in August 2006 in order to maintain the stand and decrease plant density.

Low seed germination of about 55% was observed in *Atriplex nummularia* and *A. amnicola* (only 4 shrubs of the latter plant survived). Comparative studies on seasonal plant performance, accumulation of green biomass in *Acacia ampliceps* and *A. nummularia*, *A. amnicola* and *A. undulata* was observed after transplanting into the field (Table 2.1.20).

Table 2.1.20. Data for tree and shrub species tested under saline environments at the Akdepe experimental site (June, 2005-2007)

Name of Tree Species	Plant Height (cm)	Number of Branches	Length of Branch	Crown Diameter	Developmental Stage
Poplar	242	20	93	-	Green biomass accumulation
Mulberry	172	15	89	107	Flowering/fruit maturation
Quince	126	9	49	-	Biomass accumulation
Dog rose	41	4	21	-	Seed maturation
Redberry	131	6	45	-	Fruit maturation
Atriplex undulata	121	28	-	126	flowering

Plant growth showed positive results for *Atriplex undulata*, *A. amnicola* and *Acacia ampliceps*, under conditions of Turkmenistan and Uzbekistan (Gulistan State University Experiemntal plot) (Table 2.1.21). In addition to plant height and plant diameter (D1), ratio of *Atriplex undulata* with respect to different types of reproduction and soil salinity showed that plant growth through vegetative propagation resulted in better establishment (Figure 2.1.23). This method will be more convenient for farmers.

Table 2.1.21. Growth of *Acacia ampliceps* and *Atriplex spp.* after transplanting into the open field (data for Akdepe and Gulistan Experimental Sites)

Species	Height of plants Akdepe*	Gulistan**	Stem diameter Akdepe	Gulistan	Leaf area Akdepe	Gulistan	Fresh weight Akdepe	Gulistan
	cm	cm	cm	cm	mm^2	mm^2	kg/m^2	kg/m^2
Apr-06								
Acacia ampliceps	6.9	15.6		29.22	0.16	12.59	no data	no data
Atriplex nummularia	5.8	12.1	2.01	2.16	0.03	2.46	no data	no data
A.amnicola	4.9	9.1	0.6	4.8	0.04	0.48	no data	no data
A. undulata	6.7	8.6	0.9	2.9	0.25	1.05	1.6	0.9
Nov-06								
Acacia ampliceps	117.9	88.6	72.9	84.6	92.82	91.02		
Atriplex nummularia	77.3	65.4	22.6	14.8	8.75	2.04	1.2	0.9
A.amnicola	68.2	51.6	57.4	56.9	1.8	1.05		
A. undulata	115.5	109.2	58.4	65.7	3.38	3.41	2.4	1.32

* site located in Dashauz province of Turkmenistan
** site located in Syrdarya province of Uzbekistan

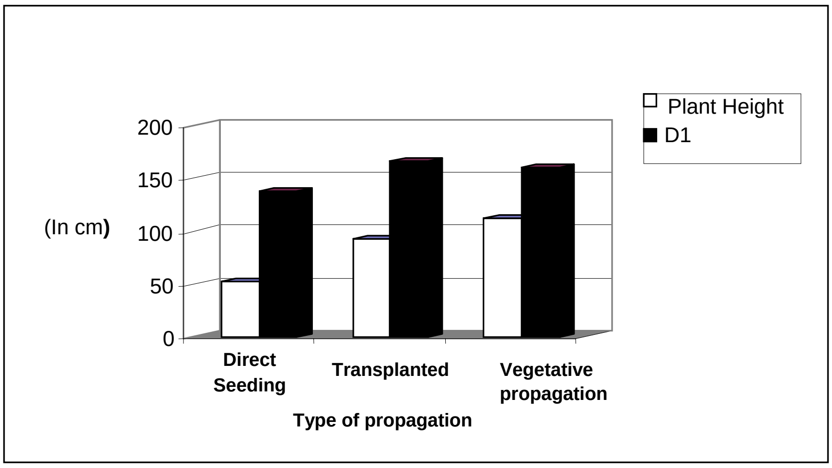


Figure 2.1.23. Plant growth of *Atriplex undulata* using different methods of propagation (Gulistan University experimental plot (September 2007)

Comparative studies of plant vigour and response to strong frosts that were marked at the end of 2006 and beginning of 2007 showed that *Atriplex undulata* performed very well as compared to *A. nummularia*, *A. amnicola* and *Acacia ampliceps* grown under the similar saline environments over the same time (Table 2.1.22).

Table 2.1.22. Plant performance of non-conventional halophytic trees and shrubs (from ICBA) under different saline and arid environments.(Galaba Farm compared with Akdepe site trials, 2006-2007)

Date of observation	Plant height (cm)		Average air temperatures		Plant vigor (%)	
	A*	B**	A	B	A	B
Acacia ampliceps						
16-Aug-06	25.4	78.5	28	31.2	100	100
1-Sep-06	39.5	96.7	22	20.7	100	100
1-Oct-06	51.5	120	10.7	0 - +5;	100	100
1-Nov-06	98.2	-	+5; -2 – 8;	-10	0	0
22-Dec-06	-	-	-11.8	-14.9	0	0
Jan-07	-	-	-14***	-17.5	0	0
Atriplex undulata						
Aug-06	32	42.1	34.4	31.2	100	100
Sep-06	56.6	63.6	26.3	20.7	100	100
1-Oct-06	82	136.2	10.7	0 - +5;	94	100
1-Nov	91.6	136.2	+2; -6	-10	90	98
22-Dec-06	no changes	no changes	-11.8	-14.9	90	90
Jan-07	no changes	no changes	- 14.0;	-15	86	90
Feb-07	no changes	no changes	-3 ; -6	-16	86	90
Mar-07	re-growth	re-growth	2.64	-3	86	90
Atriplex nummularia						
Aug-06	38.1	31.1	28	31.2	100	100
1-Sep-06	62.7	40.9	22	20.7	100	100
1-Oct-06	71	68.4	10.7	0 - +5;	100	100
1-Nov-06	72.8	68.4	+2; -6	-2 – 8	0	0
22-Dec-06	died	died	-14.8***	-16.9***	0	0
Atriplex amnicola						
Aug-06	28.3	33.9	28	31.2	100	
1-Sep-06	48.6	54.7	22	20.7	100	100
1-Oct-06	75.6	68.3	10.7	0 - +5;	100	100
1-Nov	89.9	71	+2; -6	-10	0	0
Dec-06	died	died	-14.8***	-14.9	0	0

A* -Gulistan University Experimental site; B** Akdepe site; *** a strong frost up to (-20 ^{0} C) has been noted once at Akdepe site, Turkmenistan

Earlier data collected in 2006 and late 2007, showed a low frost tolerance of *Acacia ampliceps* and two species of Atriplex (*A. nummularia* and *A. amnicola*). The maximum temperature at which the plants survived was -12^{o}C. However, *A. undulata*, survived (95%) the strong winter frost (20-25^0 C) and at the beginning of March showed good regeneration. *Atriplex undulata* seems to be frost tolerant, most widely adapted and a high yielding species under high saline environments. *Acacia ampliceps* and *A. nummularia* were also among the high yielding and fast-growing species that were tested, but with lower frost tolerance.

Mixed establishment of *Atriplex undulata* and alfalfa in rows on saline lands (without any tillage or leaching) at the Akdepe experimental site was initiated in 0.25 ha of farmer's land during May 2007. *A.*

undulata plants were raised through vegetative propagation (one year cutting) and at the end of October produced seeds of good quality, which have been distributed to Tajikistan and Kyzylorda, Kazakhstan. Three varieties of fodder beet tested in 2006 showed good growth in the field, while Turbo variety entered into the flowering stage. The first lot of seeds was collected in July 2007.

UZBEKISTAN

These studies were carried out at the Gulistan State University experimental farm in Syrdarya Province.

1. Evaluation of salt-tolerant crops and forage species in saline environment

In 2006 the following crops were evaluated on the Experimental plots of the Gulistan State University:

- Four species/varieties of oil crops: *Helianthus cultus* Wenzl, *Arachis hypogaea* ssp. vulgaris, *Carthamus tinctorius*, *Sesamum indicum* L;
- Eight species/varieties for fodder crops: *Zea mays* L., var. indentata, *Sorghum technicum*, *Phaseolus aureus* Piper, *Sorghum sudanense* stapf., *Beta vulgaris* L. var. crassa, *Medicago sattiva*, *Panicum miliaceum* L., *Hordeum vulgare* L.
- Ten varieties of safflower (*Carthamnus tinctorius*); 10 accessions of *Hordeum vulgare*, 3 cultivars of *Sorghum bicolor* (Grif 612; Grif 619 and IS 29781), as well as one accession of *Pennisetum glaucum*;
- Four varieties of alfalfa Anand-2; alfalfa Anand-3 from ICARD and Sceptre and Eureka from ICBA.
- Cultivars for double cropping after harvesting winter wheat were Maize (fast-ripening); Sunflower (fast-ripening); mung bean.

2. Optimizing productivity of the selected two varieties of crops (maize, sorghum, sunflower)

Agronomic treatments evaluated at Gulistan State University (GSU) site were as follows for maize, sunflower and sorghum crops:

100 and 50% dose of mineral nutrition and irrigation water
These crops were also grown without any irrigation and nutrition.

3. Studying efficiency of Azolla

In 2005-2007 comparative studies on *Azolla karoliniana* as a fertilizer on plant growth and yield capacity of some salt tolerant crops were performed at the Gulistan State University experimental plot and at the Galaba farm, Syrdarya province. The following Azolla treatments were tested:

Maize + azolla	(2 and 4 kg/10 m^2)
Sunflower + azolla	(2 and 4 kg/10 m^2)
Sorghum + azolla	(2 and 4 kg/10 m^2)

EXPERIMENTAL RESULTS

Though temperature remained high during the early periods of plant establishment (June onwards), but precipitation ranged between 13-15 mm.. The maximum precipitation occured in spring with a decrease crops harvest period. Ground water table remained shallow (1.05-1.72 m) during seed sowing season, when the area received about 20-23 mm precipitation. In 2005 crop season the total dissolved solids increased from 5262 ppm to 15370 ppm. K^+ content remained very low, whereas, Ca^{2+} content was high followed by Na^+ among cations; sulfate remained the dominant anions (Table 2.1.23).

Table 2.1.23. Chemical properties of ground and drainage water at GSU site (May2005).

Groundwater	Chemical Properties									
Depth	pH	TDS	Soluble cations			Soluble anions			SAR	SAR adj
			Ca^{2+}	Mg^{2+}	Na^{+}	HCO_3^-	Cl^-	SO_4^{2-}		
(m)		mg/l						$mmol_cL^{-1}$		
1.05	7.5	6031	31.2	33.4	25.2	12.6	16.2	64.4	4.43	5.02
1.09	7.4	6195	32	34.6	26	13.3	15.8	66.2	4.51	5.10
1.04	7.4	6253	32.6	35	25.4	13.8	15	67.2	4.37	4.95
1.24	7.4	4365	20.4	21.6	24.4	7.8	10	48.62	5.32	6.02
1.22	7.3	4334	20.6	19.2	26.8	7.2	10.4	49	6.01	6.78
1.2	7.4	4842	20	21.3	24.2	7.2	9.8	48.6	5.33	6.02
1.36	7.5	5838	37.8	35.9	23	13.1	15.4	68.2	3.79	4.30
1.38	7.45	6073	39.6	36.4	24.2	13.4	16.8	70	3.93	4.46
1.3	7.4	5904	38.5	35.6	23.2	13.4	16.8	67.2	3.81	4.33
1.28	7.3	5262	36.4	31.2	18.7	10.8	12.8	62.6	3.22	3.67
1.18	7.4	5365	37.6	30.4	19.4	10.8	12.8	63.8	3.33	3.79
1.22	7.4	5645	38.2	32.6	20.8	10.82	16.4	64.3	3.50	3.98
1.55	7.5	5925	37.2	33.8	21.6	11.9	14.2	66.5	3.63	4.12
1.6	7.4	6238	37.8	35.4	22.4	11.68	16.2	67.8	3.70	4.21
1.72	7.5	5895	36.2	33.2	20.4	11	13.4	65.4	3.46	3.94

Chemical composition of the irrigation water used for crops cultivation at the Gulistan State University site is characterized by low salinity levels (EC varied 0.46-2.05 dS/m) with a total dissolved salts of 1204-1694 mgL-1(Table 2.1.24).

Soil properties in the study area (Table 2.1.25) is characterized as loam to silt loamy. Infiltration rate of water at two different plots showed insignificant difference.

Table 2.1.24. Chemical properties and ions composition of the irrigation water at the Gulistan Site (average data for 2005-2006)

Replication	Date of observing	Chemical Properties										
		pH	Electrical conductivity	TDS	Soluble cations			Soluble anions			SAR **	SAR adj
					Ca^{2+}	Mg^{2+}	Na^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}		
			dS/m	g/l	$mmol_cL^{-1}$			$mmol_cL^{-1}$				
1	6/7/2005	7.1	1.85	1485	8.32	8.42	6.24	2.32	4.44	16.24	2.16	2.48
2	6/7/2005	7.2	1.93	1485	8.3	8.41	6.21	2.3	4.43	16.19	2.15	2.48
3	6/7/2005	7.1	2.03	1694	10.81	8.39	6.88	2.34	4.41	19.22	2.22	2.56
1	7/19/2005	7.12	1.74	1322	6.49	5.83	7.39	3.2	4.43	12.08	2.98	3.40
2	7/19/2005	7.2	1.8	1305	6.38	5.92	7.28	3.25	4.44	11.89	2.94	3.35
3	7/19/2005	7.1	1.68	1298	6.43	5.87	7.33	3.28	4.43	11.92	2.96	3.38
1	7/30/2005	7.1	1.82	1284	6.49	6.01	6.45	3.2	4.01	11.74	2.58	2.96
2	7/30/2005	7.11	1.75	1204	5.49	4.53	7.8	2.49	3.5	11.82	3.48	3.97
3	7/30/2005	7.21	1.85	1296	5.99	5.51	7.65	2.9	3.5	12.76	3.19	3.64
1	8/13/2005	7.2	1.98	1436	6.94	7.75	6.88	3.08	4.16	14.35	2.54	2.91
2	8/13/2005	7.22	2.05	1431	7.05	7.64	6.94	3.26	3.5	14.86	2.56	2.94
3	8/13/2005	7.18	2	1422	7.25	7.46	6.85	3.12	4.16	14.28	2.53	2.90

Table 2.1.25 . Soil textural analyses at the GSU experimental site.

Plant Species	Soil Depths (cm)	Soil Texture (Method USDA)				Soil Texture (Kachinskyi method)
		Distribution of soil particles (%)			Soil Texture (USDA)	
		Sand (0.05-2.0 mm)	Silt (0.002 mm)	Clay (<0.002 mm)		
Sorghum sudanse	0-15	45.8	45	9.3	Loam	Light loam
Sunflower "ok semechka"	0-15	42.4	40.4	17.2	Loam	Light loam
Maize+Azolla	0-15	42.3	39.8	17.9	Loam	Light loam
	Average	43.5	42.1	14.8	Loam	Light loam
Sorghum sudanse	15-50	11.1	75.9	12.6	Silt loam	Heavy loam
Sunflower "ok semechka"	15-50	10.2	71	18.8	Silt loam	Heavy loam
Maize+Azolla	15-50	9.6	72.6	17.8	Silt loam	Heavy loam
	Average	10.3	73.2	16.4	Silt loam	Heavy loam
Sorghum sudanse	50-100	9.6	70.8	19.6	Silt loam	Heavy loam
Sunflower "ok semechka"	50-100	8.1	68	23.9	Silt loam	Light clay
Maize+Azolla	50-100	8.1	66.8	25.1	Silt loam	Light clay
	Average	8.5	68.6	22.5	Silt loam	Light clay

Field capacity at different stages of crops development from different points of the experimental plot ranged from 24.85 to 26.22 %. Soil bulk density remained almost the same at the both sampling periods. Soil moisture varied from 16-27% at the 0-15cm and 30-33% at 50-100 cm of soil depths (Table 2.1.26)

Table 2.1.26. Soil properties at the GSU experimental site (average data for 2005).

Plant species	Soil Depths (cm)	10/6/2005				15/10/2005			
		Bulk density	Average soil moisture (%)	Amount of moisture		Bulk density	Average soil moisture (%)	Amount of moisture	
		g/cm3	vol/vol	mm	m3/ha	g/cm3	vol/vol	mm	m3/ha
Fodder crops	0-15	1.38	16	24	242	1.38	16.1	24	242
	15-50	1.47	26	89	894	1.47	25.3	89	894
	50-100	1.49	32	162	1624	1.49	31.8	159	1591
Oil crops	0-15	1.36	16	24	236	1.36	15.7	24	236
	15-50	1.49	27	94	936	1.459	26.8	94	936
	50-100	1.47	32	162	1616	1.47	32.3	162	1616
Maize + Azolla	0-15	1.37	16	23	233	1.37	15.5	23	233
	15-50	1.48	24	84	836	1.48	23.9	84	836
	50-100	1.48	33	165	1653	1.48	33.1	165	1653
Fodder crops	0-100					1.47	27.3	273	2727
Oil crops	0-100					1.46	27.9	279	2789
Maize + Azolla	0-100					1.46	27.2	272	2722

High level of soil salinity were observed in the upper soil profile (0-15cm) compared to 50-100 cm depth. However, in maize + azolla sub plot, it remained same at all soil depths. Among cations Ca^{2+} dominated and SO_4^{2-} among anion respectively (Table 2.1.27).

Table 2.1.27. Chemical properties of soil at different soil depths during the plant vegetation period

Plant species	Soil Depths	Chemical Properties									
		pH	EC	TDS	Soluble cations			Soluble anions			SAR **
					Ca^{2+}	Mg^{2+}	Na^{+}	HCO_3^-	Cl^-	SO_4^{2-}	
	cm		dS/m	mg/l						mmolcL-1	
		7.06.2005									
Fodder crops	0-15	7.4	2	10280	65.9	46.1	36.5	0.9	2.0	12.9	0.92
	15-50	7.2	1.8	8310	53.9	39.5	30.0	0.8	1.1	10.5	0.84
	50-100	7.3	1.16	4650	34.4	16.5	15.7	0.6	0.6	5.5	0.71
Oil crops	0-15	7.1	1.26	12620	78.3	62.5	49.6	13.1	25.4	151.9	0.99
	15-50	7.2	0.97	9700	68.0	43.0	25.6	2.1	4.1	130.3	0.98
	50-100	7.3	0.97	4750	36.5	16.5	15.8	5.5	5.4	58.0	0.75
Maize + Azolla	0-15	7.4	2.65	1314	7.0	5.6	3.9	1.5	2.8	12.1	1.58
	15-50	7.5	2.19	1083	6.1	4.7	3.0	1.0	2.0	10.8	1.27
	50-100	7.4	1.28	534	4.2	2.1	2.5	0.6	1.1	7.0	1.39
		15.10.2005									
Fodder crops	0-15	7.4	2.24	10980	69.8	55.7	39.1	15.5	28.2	120.9	0.94
	15-50	7.3	1.9	9120	60.9	46.8	29.6	9.8	19.7	107.7	0.9
	50-100	7.4	1.4	5890	41.7	21.0	24.5	6.2	11.3	69.8	0.77
Oil crops	0-15	7.4	2.65	13140	95.8	60.1	44.3	12.8	28.2	159.1	1.18
	15-50	7.5	2.19	10830	67.9	50.2	46.4	9.7	22.5	132.3	0.92
	50-100	7.4	1.28	5340	37.4	22.2	18.2	6.1	19.7	52.1	0.72
Maize + Azolla	0-15	7.4	2.3	11150	70.1	51.5	46.3	10.2	19.7	138.0	0.94
	15-50	7.5	2.16	10380	71.2	49.8	32.0	9.4	19.7	128.9	0.99
	50-100	7.4	2.28	11040	66.9	65.8	33.4	17.1	11.3	138.0	0.9

EVALUATION OF SALT TOLERANT CROPS AND FORAGE SPECIES UNDER SALINE ENVIRONMENT OF MIRZACHULI STEPPE (SYRDARYA PROVINCE)

Evaluation of salt tolerant crops at the Gulistan University experimental Plot and Galaba collective farm under arid/semiarid saline environments of Mirzachuli steppe showed good performance of sunflower and safflower local varieties when compared to peanut and sesame. As seen from the data presented in Tables 28 and 29 fresh biomass of peanut and sesame at the end of plant vegetation stage in 2006 sharply decreased.

However, among tested oil-bearing crops two varieties of safflower (*Carthamus tinctorius*), obtained from ICBA germplasm and cultivated on the Gulistan State experimental trial showed high seed germination, growth rate, yield capacity (both fresh and dry biomass), as well as the weight of seeds. Newly introduced cultivars were also superior for early flowering and seed maturity. Significant differences were also observed in biomass and grain yield of fast growing and early maturity Sorghum Grif 619 and IS 29781 varieties. The small tall sorghum varieties were characterized by higher productivities (both fresh and dry biomass) at the stage of full maturity (Table 2.1.30). In addition these identified varieties (Grif 619 and 1S 29781) had a short–term and uniform flowering.

Relative growth rate, biomass and grain production of high productive pearl millet lines of ICBA germplasm introduced as dual-purpose crop at the Gulistan Sate University site gave yields 2.0-2.5 times higher than that of local variety (Figures 2.1.25 and 2.1.26). The same trend was also observed for the top yielding ICBA sorghum selected lines (second seed reproduction), which performed very well under moderately saline soils of the Mirzachiuli steppe showing high values of both fresh and seed production, when compared with local variety (Figure 2.1.24 a,b).

Table 2.1.28. Comparative studies on plant performance, biomass production and seed yield for some oil-bearing crops

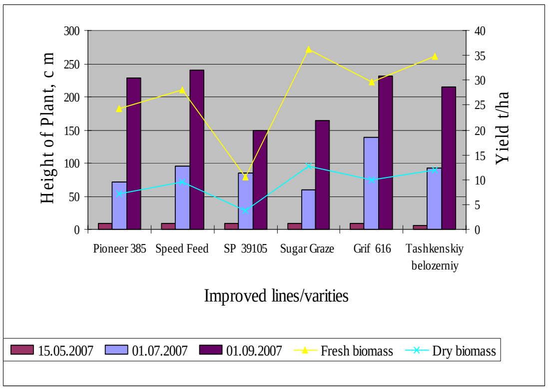
Height of plant	Size of leaves		Date of flowering	Yield of Biomass before seed maturation		Weight of seeds/plant	Yield of seeds	Biomass at the end of vegetation		Plant density
	Length	Width		fresh	dry			fresh	dry	
cm	cm	cm		t ha-1	t ha-1	g	T ha-1	t ha-1	t ha-1	th.plants per m-2
Peanut										
12.2	3.4	1.3	19.07.06	2.72	0.95	4.2	0.84	1.25	0.56	20
11.3	3.6	1.5	18.07.06	5.31	1.86	3.9	1.36	1.11	0.49	35
13.4	3	1.2	17.07.06	4.53	1.58	3.1	1.67	0.89	0.4	54
Sesame										
56	13.5		29.05.06	5.57	2.23	0.3	1.4	8.8	3.96	80
35	13.6		02.06.06	2.09	0.84	0.2	1.41	7.75	3.48	70
45.5				3.83	1.54	0.3	1.88	8.28	3.72	75
Safflower										
57.8	5	2.1	10.06.06	7.72	6.08	1.1	7.15	25.3	7.8	65
38.9	5.2	7.5	12.06.06	6.52	2.6	1.3	9.1	27.3	10.4	70
35.2	6.8	8.1	13.06.06	4.21	1.62	1.2	6.96	22.6	7	58
Sunflower										
132	6.5	7.7	07.07.06	15.3	4.89	27.7	23.54	29.7	13.36	85
	6.9	8.9	08.07.06	14.4	4.61	18.1	14.48	28	12.65	80
141	9.5	10.5	04.07.06	17.46	5.58	26.7	25.89	33.9	15.25	97

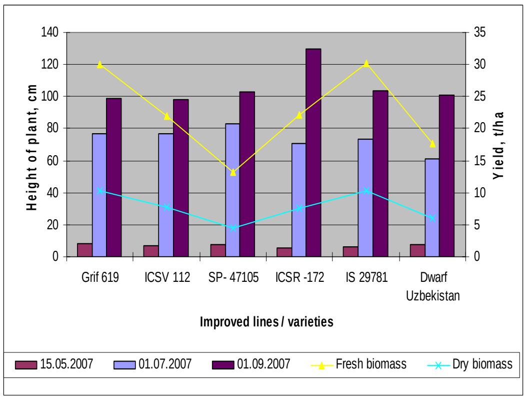
Table 2.1.29. Plant growth parameters and yield of biomass and seeds of safflower (Gulistan site)

Number of cultivars	Height	Date of flowering	Biomass during flowering stage		No. of / capitules	Weight of one capitule	Yield of seeds	Biomass at the end of vegetation		Plant density
			fresh	dry				Fresh	Dry	
	cm		t ha^{-1}	t ha^{-1}		G	t ha^{-1}	t ha^{-1}	t ha^{-1}	per m^{-2}
ICBA-1	45	07.06.06	26.2	9.2	3	1.5	0.09	2.28	0.9	20
ICBA-2	70.2	24.06.06	67.7	23.7	7	1.8	2.77	7.42	2.97	22
ICBA-3	48.8	05.06.06	36.7	12.8	4	1.7	1.91	3.31	1.32	28
ICBA-4	51.8	09.06.06	56.6	19.8	5	1.2	1.5	4.66	1.86	25
ICBA-5	53.8	11.06.06	53.8	18.8	4	0.9	0.93	4.1	1.64	26
ICBA-6	50	11.06.06	30.6	10.7	5	0.4	0.42	2.46	0.98	21
ICBA-7	31.8	10.06.06	21.2	7.42	6	0.9	1.4	1.68	0.64	26
ICBA-8	41.6	15.06.06	24.9	8.7	4	1.3	1.42	1.89	0.54	27
ICBA-9	35.2	03.06.06	35.8	12.5	4	1.8	2.01	2.51	0.2	28
ICBA-10	57.4	05.06.06	52	18.2	5	1.48	1.77	4	1.6	24
Local variety	35.2	13.06.06	42.1	16	4	1.2	2.78	22.6	7	58

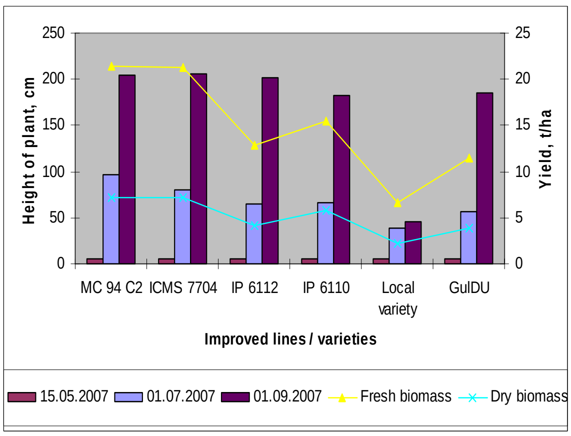
Table 2.1.30. Growth features and yield productivity for Sorghum and Pennisetum varieties (Gulistan site selected from the 2005-2006 experiemnts)

Number of cultivars	**Date of flowering**	**Biomass at the flowering stage**		**No. of panic-les**	**Weight of seeds/inflo-rescence**	**Weight of seeds/ plant**	**Biomass at the end of vegetation**		**Plant density**
		fresh	**dry**				**Fresh**	**dry**	
		t ha^{-1}	t ha^{-1}		g	g	t ha^{-1}	t ha^{-1}	th.plant per m^{-2}
Sorghum bicolor									
Grif 612	08.07.06	11.0	4.95	2	36.7	73.4	9.54	4.29	8
Grif 619	27.07.06	14.0	7.7	4	55.7	222.8	11.0	4.95	10
1S 29781	20.07.06	14.6	6.55	6	62.5	375.0	12.0	5.62	11
Local variety	16.07.06	10.4	3.84	4	19.5	78.1	8.5	5.7	155
Pennisetum glaucum									
ICBA-1	12.07.06	95.40	42.90	12	25.6		38.7	17.4	514
Local variety	22.05.06	45.80	21.90	5	0.90		72.0	39.6	903





Figures 2.1.24 a,b . Dynamics of growth rate, forage biomass and yield of seed for top-yielding Sorghum selected lines (September 2007)



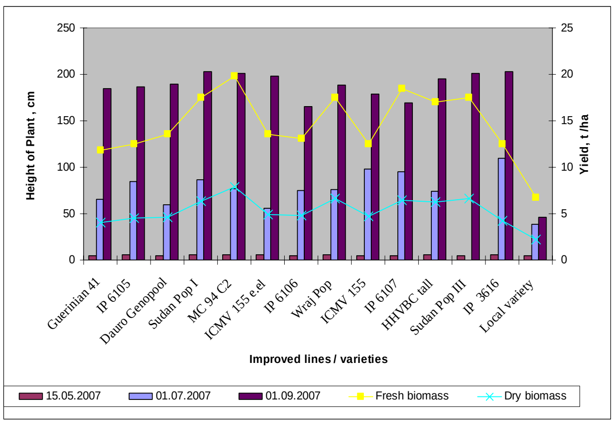


Figure 2.1.25. Comparative data on relative growth, forage and grain yields of top-yielding pearl millet lines (at the Gulistan University site, 2007)

Figure 2.1.26.Comparative data on relative growth, forage and grain yields of top-yielding pearl millet (at Glaba Farm, 2007)

STUDYING THE EFFECT OF AZOLLA ON YIELD OF CROPS

Data on biomass of maize, sunflower and sorghum as affected by application of Azolla is given in the Table 2.1.31.

Table 2.1.31. Biomass of oil and fodder crops as affected by application of Azolla

Treatment	Seed germination	Plant density	Biomass at the milking stage		Biomass at fruit maturation stage		Weight of seeds/ inflorescence
			fresh	dry	fresh	Dry	
	%	th.plant per m^2	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	g
							Maize
Zea +Azolla 2 kg m^{-2}	73	85.0	17.2	6.9	15.4	6.9	38.23
Zea +Azolla 4 кg m^{-2}	75	88.0	13.3	5.3	7.2	1.0	10.1
Zea + no Azolla	70	91.0	8.6	1.8	6.1	2.7	6.83
Sunflower							
Helianthus + Azolla 2 kg m^{-2}	71	87.0	23.9	8.1	41.3	18.9	45.84
Helianthus + Azolla 4 kg m^{-2}	74	87.0	15.7	5.0	29.8	13.4	24.17
Helianthus + no Azolla	80	94.0	13.5	3.9	6.8	3.1	24.03
Sorghum							
Sorghum + Azolla 2 kg m^{-2}	74	145.0	9.7	3.6	13.6	6.1	11.82
Sorghum + Azolla 4 kg m^{-2}	78	147.0	6.9	2.6	10.9	4.9	6.7
Sorghum + no Azolla	70	147.0	4.4	1.6	5.4	2.4	3.17

Azolla treatment had a negative effect on sunflower germination rate and biomass accumulation, but on the other hand, was compensated by the final weight of seeds. Based on this trial, the optimal norm of Azolla treatment at 2 kg m^{-2} is recommended to be the best for all tested crops (Figure 2.1.27).

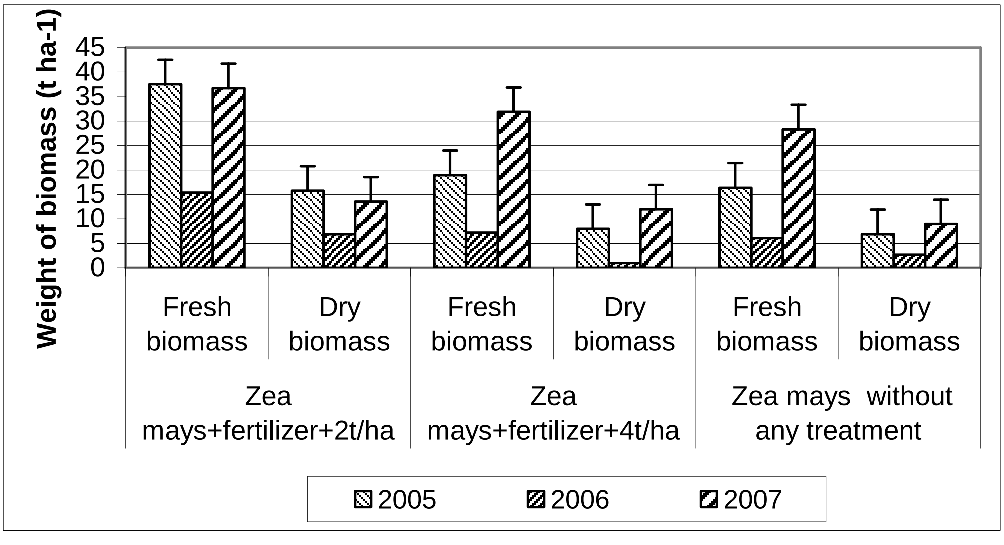


Figure 2.1.27. Biomass of oil and fodder crops as affected by application of Azolla

EVALUATION AND IDENTIFICATION OF LOCAL AND INTRODUCED SALT TOLERANT GERMPLASM IN INTERCROPPING LIVESTOCK-CROPS FEEDING PRODUCTION ON SALT AFFECTED MARGINAL LANDS

Potential of mixed cropping of earliness cereals with legumes, cultivated between strips of saltbushes (Atriplex)

Fabaceae species represent about 9.8% (Korovin, 1961, Granitov, 1964) of the overall flora of arid/semiarid zones of Uzbekistan. Preliminary field trials, exhibited their potential use in the rehabilitation of degraded arid and semiarid lands (Erejepov, 1978, Halilov, 1993, Kamalov, 1995, Mavlyanov, 1997, Ashurmetov et al., 1998, 2002, Toderich et al., 1998, Kushiev et al., 2006). Preliminary results show that the family is genetically rich with potential for drought and salt resistance. Many native legumes Acacia, Astragalus, Alhagi, Glycyrrhyza, Melilotus, Cicer, Vicia, Lathyrus of Central Asian desert flora, that may be sometimes rhysomatous, are remarkably drought/salt tolerant and capable of sustaining relatively heavy grazing (Ashurmetov et al., 2002, Gintzburger et al., 2005, Toderich et al, 2008). They grow well in association with other wild arid plant communities and often provide severe competition to perennial species both in natural and sowing pasture plant communities on saline soils and on disturbed mine contaminated sites (Toderich et al, 2006). This material is still available, but many taxa are at the verge of disappearance due to grazing abuse and may become an irreversible loss of mankind biodiversity resources.

Under the current state order system for cotton and wheat production in Uzbekistan and Turkmenistan, small-scale farmers are not able to apply adequate levels of fertilizer to other crops due to their high costs. As a nitrogen-fixing salt tolerant plant, legumes are expected to enhance soil fertility. In addition, majority of above cited legumes are deep-rooted crops that extracts water from different depths, thereby, decreasing elevated groundwater levels in waterlogged soils. In this regards, present studies included evaluation of annual and perennial, mostly wild legumes such as *Mellilotus album*, *Mellilotus officinalis*, *Vicia angustifolia*, *Lathyrus sativus*, *Lotus corniculatus*, *Lens culinarius* along with of two local and ICBA's alfalfa (Medicago sativa) varieties both in pure and mixed sowing with Triticale and ICBA's barley (*Hordeum vulgare*) varities. All mentioned species were established by direct broadcasting seeding between wide–space forage shrubs hedgerows, i.e. between rows of *Atriplex undulata*. It was anticipated that this system would provide:

- the suitable and efficient water use: shrubs having a deep rooting system use moisture not available for annual crops;
- short-term vegetation of annual frost tolerant winter legumes and cereals will provide with additional high protein forages in early spring time; additionally being planted in dense standing biomass these crops significantly decrease the water table level and evaporation that simultaneously decrease the salinization of upper soil profile;
- early-maturating legumes can be left as green manure in the field before of the sowing of cotton;
- the combination of energy-rich and protein-poor stubble of graminous crops could be complemented by the energy –poor, but nitrogen rich shrubs.

A trial was conducted in an area of 0.25 ha at farmer's field in Galaba Farm under silt loam saline dry environments at the Syrdarya province with a combination of barley-alfalfa and triticale-alfalfa cropping systems between rows of Atriplex undulata.

Preliminarily results on evaluation of inter-cropping fodder legume mixed with salt and frost tolerant barley and Triticale showed a positive effect in increasing fodder biomass per unit land area (Table 2.1.32).

Table 2.1.32. Agronomic characteristics of salt tolerant crops cultivated under alley-cropping system by using salt tolerant crops and wild halophytes.

№	Treatments/Crops	Height of Plant, cm	Date of harvest (first cutting)	Fresh Biomass (g/m²)	Fresh Biomass (t/ha)	Dry Biomass (t/ha)
1	Alfalfa Anand-2 (pure stand)	58.0	20.04 07	520	5.20	1.60
2	Alfalfa ICBA germplasm (pure stand)	55.3	20.04.07	400	4.00	1.20
3	Barley (pure stand)	66.2	20.04.07	1050	10.50	3.20
4	Alfalfa "Kyzylkumskaya" (pure stand)	76.0	20.04.07	720	7.20	2.10
5	Alfalfa + barley			1450	14.50	4.40
6	Triticale (pure stand)	94.0	20.04.07	1030	10.30	3.09
7	Alfalfa+ Triticale		20.04.07	1640	16.40	4.98

Fresh biomass of alfalfa (first seasonal cutting) in pure stand was 7.20 t/ha, while mixed sowing with Triticale increased to 16.40 t/ha. Experiments suggest that *A. undulata* mixed with various short–terms (*Vicia angustifoilia* and *Onobrychis chorsanica* Bge) and long term vegetation legumes like alfalfa, *Melilotus officinalis*, *Lathyrus sativa* may be successfully integrated into a farming livestock feeding system. This will provide alternative winter-spring forage with efficient protein- energy balance. We have found that barley-Triticale-alfalfa yields were 20% higher in alley-cropping system as compared to traditional barley-fallow system. Growing salt-tolerant high-yielding alfalfa in combination with cereals, alternated by strips of *Atriplex undulata* could assist farmers in producing highly nutritional value forage (both fresh and as hay). For each of the cereals an analysis was undertaken to determine whether there are significant differences in the yields of these cereals under different alfalfa varieties (Figure 2.1.28)

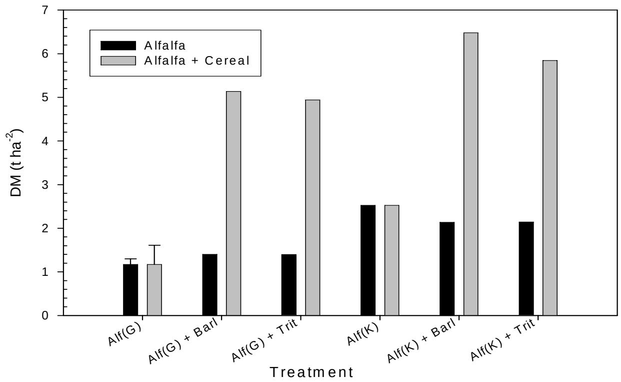


Figure 2.1.28. Differences in yields of alfalfa intercropped with early maturing cereals

No significant differences in yields for both barley and triticale were observed with respect to the variety of alfalfa, hence the yield increases associated with mixed cropping of barley and triticale with alfalfa is associated with the superior yield potential of local Kyzylkumskaya alfalfa variety.

There are significant differences in biomass and grain yield of fast growing and early maturating Sorghum Grif 619 and IS 29781 varieties/lines adopted from ICBA. Late maturating varieties of pearl millet from ICBA showed 2.0-2.5 times higher values of green biomass and grain production as compared to local variety. The optimal rate of Azolla (a bioorganic fertilizer) was found at 2 kg m^{-2} for all tested crops. There are significant advantages in growing mixed cereal/annual/perennial legumes alternated by strips of halophytes. This practice will increases fresh forage and grain yields and improves the quality of the soil on the degraded, abandoned farmer lands of Syrdarya province, Uzbekistan.

2.1.3 TESTING SEED MATERIAL OF SALT TOLERANT NON CONVENTIONAL CROPS

UZBEKISTAN

A. Evaluation of growth and development of salt tolerant crops

Medicago sativa – two alfalfa varieties (Eureka and Sceptre) from ICBA were sown on 25.08 2005 at the quarantine experimental plot of Plant Industry Institute. Seedling establishment was observed at the end of October 2005 and in February 2006 there was evidence of re-growth of plants. Comparative studies of plant growth, accumulation of green biomass and seed production of different varieties of *Medicago sativa* showed an advantage of two varieties of alfalfa from ICBA (Tables 2.1.33-2.1.35)

Table 2.1.33. Growth and development of alfalfa from ICBA under saline environments of Turkmenistan and Uzbekistan

Parameters	Sceptre (ICBA)		Eureka (ICBA)		Tashkent region	Kyzylkum Site	Sort "Khivinskaya"
	UzRIPI	Akdepe	UzRIPI	Akdepe			
Seed germination before sowing(%)	92	78	86	65	80	85	30
Date of seed bedding	31.08.05	14.04.06	31.08.05	14.04.06	20.04.05	30.03.2005	12.03.06
Date of seedling emergence	10.09.05	21.04.05	12.09.05	23.04.06	08.03.06	re-growth on 14.02.06	4.04.06
Date of flowering	09.05.06	07.06.06	01.05.06	17.06.06	07.06.06	05.05.06.	No data
Height of plant (cm)	104.6	75.8	101.8	97.1	68.7	97-102*	61.2
Number of flowers/sprout	24-29	22-26	24-26	21-27	16-21	20-28	21-24
Size of leaves(cm)	2.4-0.9		2.2/1.1		1.8/0.7	2.7/08	1.7/0.5
Size of inflorescence (cm)	7.8	6.9	5.1	7.4	3.6	6.7	2.9
Number of pods	16-10	14-Dec	13-16	13-Nov	9-Jul	15-Nov	9-May
Number of seeds/pod	11-Aug	11-Jul	9-Jul	13-Jul	11-Jul	18-Sep	7-May
Yield of fresh biomass, kg m^{-2}	2.23	1.8	2.9	1.6	1.9	2.4	1.6
Yield dry biomass, kg m^{-2}	0.89	0.45	0.96	0.38	0.89	1.1	0.21
Yield of seed, kg ha^{-1}	835	260	860	240	220	310.2	189.1
Plant density, th.plants per m^{-2}	24.8	19.8	20.7	18.6	19.1	25.6	-

Table 2.1.34. Vegetation cycle and seed maturation of Sorghum varieties/lines

Plant Industry Institute , Uzbekistan , October 2006

Name of varieties/lines	Date of seed bedding	Seed germination (%)/Seedling emergence		Day of flowering	Seed maturation	Vegetation period
		%	days		(days)	(days)
Uzbekistanskyi (local)	30.04.06	48	18-24	72	76	140-148
Speed Feed	30.04.06	90	*14-20	65"*	70	106-135
Sugar Graze	30.04.06	85	14-16	68	48	105-126
Super Dan	30.04.06	90	18-24-	120	40	136-140
Pioneer 858	30.04.06	92	10-16	78	77	118-145
ICSV 745	30.04.06	50	20-26	120	63	120-183
ICSV 112	30.04.06	0	0	0	0	0
SP 47529	30.04.06	40	24	78	51	110-129
SP 39105	30.04.06	0	12-18	0		
SP 47105	30.04.06	60		63	59	106-112
ICSR 172	30.04.06	0		0		0
ICSR 682	30.04.06	32	16-28	63	0	0
SP 39269	30.04.06	5		0	0	0
ICSB 405	30.04.06	20	20-22	63	57	108-120
SP 40516	30.04.06	0		0	0	0

* -first seedlings appeared on 08.05.06; **- early flowering (25.06.06)

Table 2.1.35. Seed production in different varieties/lines of Sorghum ICBA germplasm grown under conditions of Tashkent region

Number of catalog	Name of varieties/lines	Size of panicle		Density of plants	Weight of 1000 seeds	Weight of seeds/ plant	Yield of seeds
		length	width				
		cm	cm	th.plant per m^{-2}	g	g	t ha^{-1}
	Uzbekistanskiy (local)	20,1	6,8				
4732	Speed Feed	40.4	15.6	12	20	99.5	1.94
4733	Sugar Graze	35.4	11.2	16	70	100	1.68
4734	Super Dan	25.8	7.9	15	10	4.5	0.67
4735	Pioneer 858	30.8	11.7	16	20	15.5	2.48
4736	ICSV 745	21.5	9.7	9	29	9.6	0.86
4737	ICSV 112	0	0	0	0	0	0
4738	SP 47529	27.8	7.4	11	20	33.6	3.69
4739	SP 39105	30.7	8.2	15	30	6.1	0.91
4740	ICSR 172	27.8	9.1	17	33	32.2	3.47
4741	ICSB 682	35.1	10.8	9	Seed maturation has been not observed		
4742	SP 39262	40.8	13	11	20	36.6	4.03
4743	SP47105	42.5	20.4	10	0	0	0
4744	ICSV 405	25.7	10.9	14	35	4.7	0.66
4745	SP 40516	30.1	9.8	12	0	0	0

Pearl millet sown on 20 April 2006 entered flowering stage on 7-9 June, the formation of panicle lasting on average 7-9 days was observed at the end of June. Flowering was noted 2-3 days after initiation of panicle formation. The longevity of flowering process depended on the cultivar and lasted between 20-28 days.

The highest seed production as shown in the table 36 was noted for the HHVBC Tall, MC 94 C2, Guerinian-4, ICMV 155 Original, Daura Genopool and ICMV 7704 under low soil salinity at the Tashkent region. Seeds of the above mentioned high productive pearl millet lines has been collected and stored for further dissemination in Uzbekistan.

Table 2.1.36. Seed production of the tested accessions/lines of pearl millet from ICBA at the Institute of Plant Industry Site

Catalog number	Population/lines	Size of spike		Weight of seed/plant	Weight of 1000 seeds	Yield of seeds
		Length	Width			
		cm	cm	(g)	(g)	t/ha
4706	Nutrifeed			no seeds	0	0.00
4707	IP 3616			4.3	10.6	0.60
4708	IP 6101	16.8	4.2	12.1	9.5	1.33
4709	IP6104	-	-	7.1	10.2	0.71
4710	IP6105	-	-	9	10.7	0.81
4711	IP76106	25.4	3.6	2.5	9.5	0.20
4712	IP6107	18.6	4.4	6.7	10.8	0.73
4713	IP6109	11.9	4.5	7	10.4	1.19
4714	IP6110	-	-	10	10.7	1.61
4715	IP6112	13.7	15.2	5.1	9.5	1.17
4716	IP19586			1	10.3	1.10
4717	IP19612	22.5	4.3	6.1	10.8	0.61
4718	IP22269	-	-	10.5	10.6	1.08
4719	Daura Genopool	25.5	2.8	16.1	10.5	1.93
4720	Wraj Pop	19.8	3.5	9.1	9.4	1.18
4721	Guerinian-4	40.6	4.3	23.8	10.6	3.33
4722	HHVBC Tall	38.4	4.5	28.2	11	6.12
4723	ICMV 7704	45.6	4.4	26.6	11.2	2.92
4724	ICMV155 Brist	50.1	3.5	16.1	9.8	1.75
4725	ICMV155 e,e 1	26.9	3.3	12.2	11.4	1.61
4726	ICMV155 Original	35.6	4.1	30.5	9.6	2.95
4727	SRBC	18.2	3.5	20.5	10.8	2.09
4728	Sudan Pop III	40.2	3.6	18.7	10.5	2.24
4729	MC 94 C2	-	-	4.3	11.4	4.31
4730	Wraj Pop	-	-	0.5	9.6	0.52
4731	Sudan Pop I	-	-	0.4	8	0.68

Various pre-treatments of seeds of Acacia were applied, the most effective among them was found to be short-term emersion of seeds in the boiled water for less than 1 min, and then into fresh water for 1-2 hours. This resulted in an average seed germination rate of 82%. About 86% of seeds germinated after scarification (gently grinding of seeds between the folds of a sand paper), i.e. after breaking of the impervious layer of the seed coat. A significant delay of seed germination was observed for the first term sowing on the 6.02.06, this possibly being due to the low room temperature. Seed germination under

laboratory conditions makes 50-70% (First term of seed bedding) and 50-82% (for the second terms 20.02.06).

Seed germination in plastic bags and Jiffy-7 pots comprising of compressed peat showed rapid seedling emergence under green house conditions. Acacia ampliceps is a light-sensitive species. Ideally, conditions for seedlings transplantation into the field are in April-May, when air temperatures reach 18-22^{o}C. Irrigation (along furrows or around root zone of each plant) should be undertaken during the initial rooting stage to ensure good plant survival. The survival rate of plants in the field according to the experiments of Institute Plant Industry is approximately 90% using the aforementioned practices.

A remarkable increase in height and plant canopy was noted for Acacia ampliceps, when plants were transplanted into the open field in early spring 2006. Plant height measured in mid-May was approximately 9.8 cm; however by mid-July plant height had increased to more than 65.3cm. Development of branches and new leaves occurred rapidly if plants are enough irrigated. The total number of branches on 15.07.07 was 20-24. About 350 seedlings of *Acacia ampliceps* at various stages of development were prepared and transplanted into the open field at Akaltyn and Galaba farms; on experimental Plot at the Gulistan State University site, as well as in the Western and Central Kyzylkum on sandy saline soils has been established and monitored in 2007.

Different times and ecological edaphic conditions for plant transplantation have been applied for field testing at the Experimental plots of Gulistan State University and Kyzylkum Site. Amongst the tested species of salt bushes, *Atriplex undulata* and *Atriplex nummularia* showed high levels of seed germination both under laboratory (86%) and field conditions (92%). A considerably lower percentage of seed germination and lower rate of plant growth and development were observed for Atriplex amnicola (Table 2.1.37). Under the prevailing climate and edaphic conditions of the Tashkent region, this plant has a prostrate growth habitat.

Table 2.1.37. Plant growth of *Acacia ampliceps* and Atriplex species under field conditions.

Species	**Height of plant**	**Stem diameter (cm)**	**Leaf area (mm^2)**	**Fresh Biomass (t/ha)**
April 15 2006				
Acacia ampliceps	25.66	39.22	25.91	no data
Atriplex nummularia	8.9	11.9	12.6	-
A. amnicola	9.4	9.8	3.2	-
A. undulata	10.2	10.5	14.3	-
November 15 2006				
Acacia ampliceps	107.92	74.6	103.12	
Atriplex nummularia	98.7	48.3	98.6	-
A. amnicola	53.7	92.6	14.9	-
A. undulata	102.3	56.1	87.9	16.9

More than 480 seedlings of *A. undulata* and 325 seedlings of *A. nummularia* and 180 *A. amnicola* transplanted in fall 2006 under saline environments in Syrdarya and Navoi regions showed fast growing and accumulation of green biomass. However frost tolerance of these introduced halophytes should be further investigated under the temperate zones of the southern Part of Uzbekistan.

2.1.5. DOMESTICATION AND PRODUCTION OF HALOPHYTES USING GROUND MINERALIZED WATER FOR IMPROVEMENT PRODUCTIVITY OF DEGRADED DESERT RANGELANDS

Degradation of desert rangelands, throughout the whole desert/semidesert zones of Uzbekistan has reached an alarming degree, calling for prompt action. Increasing human population and expanding agricultural areas throughout foothills towards sandy desert have resulted in heavier grazing pressures on pastures in spite of the increasing role of crop residues and grains in livestock production (Nordblom et al., 1997, Gus Gintzburger et al., 2003, 2005). As a result of erratic cropping in low rainfall zones, overgrazing of the good rangelands, and cutting of shrubs by the local population for firewood, the natural vegetation of these desert areas is under pressure from anthropogenic degradation factors. Salinization is one of the major ecological and production problems currently facing the agricultural and agropastoral sectors in these areas. Secondary salinization (human induced) is increasing rapidly and crop production under these conditions is becoming less sustainable. Drought and salinity can have a far greater effect on food security in Central Asia than in other areas (Goldshtein, 1997, 2000, Toderich et al., 2001, 2002, 2004a, b, 2006; Aparin et al., 2006). As a result, the formerly highly productive livestock system has deteriorated and livelihoods of the people have dramatically declined. It was estimated that areas of rangelands seriously affected by salinity in Kyzylkum desert cover about 1.7 mln ha (UNDP Report, 2007). Accumulation and migration of soils throughout soil profiles in these areas induced the irreversible degradation of vegetation and decreasing of botanic diversity of main plant communities. As a result, the virgin psammo and xerophytic desert plant communities were replaced by halophytes (salt loving plants). Such a phenomenon leads to the eradication of useful, endemic or rare desert plant species and to the reduction of rangelands productivity. Both local and introduced germplasms for initially lowering water table, followed by management practices to cultivate salt-tolerant forage and crops, and halophytes, can help to improve the livelihood of the poor agropastoralists in the remote desert areas.
Introduction of a range of deep rooted annuals and perennials forage species, legumes, chenopod and tree species can be used in a demonstration plot to monitor the changes in soil and water. Among desert flora of Uzbekistan there are a number of untraditional native and exotic halophytes both C_3 and C_4 plants suitable for reclamation of arid and semi-arid, salt/affected and waterlogged lands, that have been proven very useful in demonstration/cultivation trials, but have not been widely used as part of the arid forage production system in Uzbekistan by the pastoralists and farmers (Akgigitova,1982, Shevelukha et al, 2000, Ashurmetov, 2003, Toderich et al, 2002, 2007, Gus et al, 2003, 2005). Previous studies have shown that many wild halophytes and salt tolerant crops grow well in association with a variety of plants and often provide severe competition to perennial species, both in natural and introduced pastures on saline and disturbed mine sites (Toderich et al.2007, Annual Report ICBA-CAC, 2007, Toderich et al., 2008) .

Another appropriate option for improving the productivity of degraded/patchily saline arid rangelands in the Kyzylkum sandy deserts is to make use of the huge resources of underground low saline water. The artesian waters could be used for development of arid fodder production systems, in addition to vegetable production (melon and watermelon) and other purposes through management practices. The establishment of highly productive livestock-feeding systems will ensure the safety of natural habitat and increase the income levels of the rural poor farmers and pastoralists. However, using the saline artesian water for long-term sustainable crop production needs propose management to avoid environmental degradation.

Based on last year data we have found that the demand for seeds of salt-tolerant species has increased and a number of farmers are keen to test the biosaline agriculture technology, as an alternate option for their farms. Innovative selection programs, elaboration and introduction of suitable modern technologies are needed to multiply seeds of wild halophytes and traditional salt tolerant crops to establish them within the natural plant communities, needed in other ecosystems. We have expected that native halophytes would grow well in association with a variety of species and often provide severe competition to perennial species, both in natural and introduced pastures on saline and disturbed mine sites. However, many of the germplasm are at the edge of disappearance due to over grazing and may become an irreversible loss of biodiversity resources. Most of populations of the desert halophytes within flora of the Uzbekistan are local and small, sometimes fragmented. They frequently have incomplete life cycles with little ability to reproduce, low indices of renewal and replacement.

Therefore a demonstration trial to test different options of improving the productivity of degraded rangelands was established in 2006 under saline environments at the Kyzylkesek Site, Kanimekh district, Navoi region in Central Kyzylkum.

Spatial distribution (zonation) of natural desert vegetation in relation to soil salinity was studied in an area of about 25 ha, located between two artesian hot springs (Figure 2.1.29 a,b)

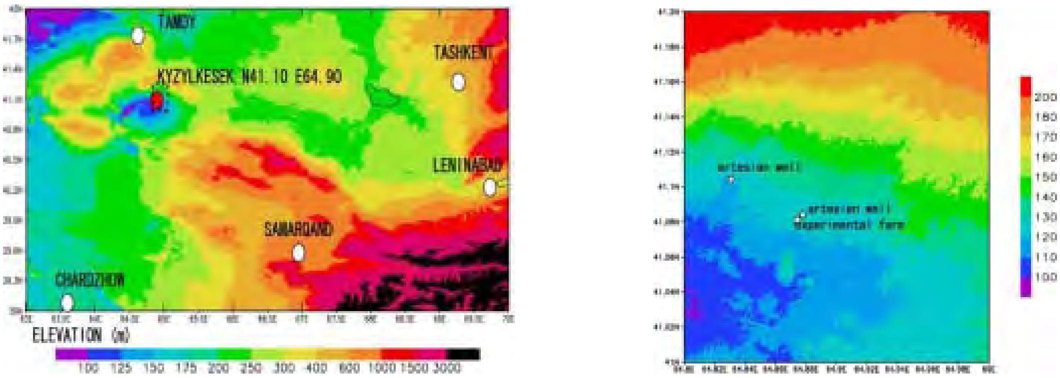


Figure 2.1.29 a,b. Spatial distribution (zonation) of natural desert vegetation

Representative soils samples were collected seasonally, prior to seed sowing (spring time) and after crops harvesting (late autumn) under native and non-conventional salt tolerant crops. Soils samples were collected at different depths from 0-100 cm.

I. Agro-climatic conditions and chemistry of soils and underground water.

The agro-climatic environments and availability of water sources for cultivation of crops on the salt-affected soils are radically different from the agricultural irrigated areas. Climatic conditions for the Kanimekh agro-ecological zone, Navoi region (Central Kyzylkum), which has been chosen as biomonitoring site of salinity trends and halophytic botanic diversity changes, is shown in Figure 2.1.30,2.1.31.

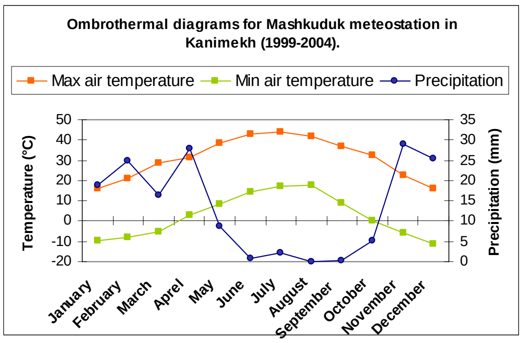


Figure 2.1.30. Climatic conditions for the Kanimekh agroecological zone (Central Kyzylkums, Uzbekistan).

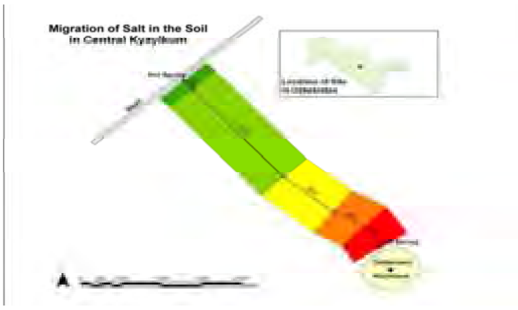


Figure 2.1.31. Spatial distribution of different desert landscapes according salinity gradient: low salinity in the virgin desert Artemisia rangelands (green color); moderate salinity under artificial Haloxylon aphyllum forest (yellow) and high salinity (salt marshes solonchaks with Tamarix, Halostachys and Aeluropus plant community (orange and red)

Target area (experimental Plot of sherkat farm "Madaniyat", Kanimekh district, Navoi region) constitutes a salt depression formed by freely-flowing saline hot artesian water (vertical drainage water), which is the only water source available for cultivation under sandy Kyzylkum desert conditions. Spatial and temporal distribution (zonation) of natural vegetation of 8 visually divided zones accordingly soil salinity level were studied based on plant vegetation type and soil salinity level (Table 2.1.38).

Table 2.1.38. Geographical coordinates of study zones for different soil types

	Studied zones	coordinate	Soil type	Biotopes
1	1 hot spring	N 041^0 06'231" E 064^0 50'927" Elevation 120 m	Salt affected lands (secondary salinization)	Haloxerophytes
2	Climate station	N 041^0 05'654" E 064^0 51'925" Elevation 126 m	Grey-brown with high content of gypsum	Xerophytes with domination of xerogysophytes
3	Transit zone Halopxylon plant community	N 041^0 05'052" E 064^0 52'510" Elevation 126 m	Sandy and clay loamy soils/	Xeropsammohalophytes
4	Alhagi plant community		Sandy and clay loamy soils/	Xerohalophytes
5	Agricultural plots	N 041^0 04'797" E 064^0 52'520" Elevation 118 m	Sandy and clay loamy soils	Introduced halophytes and salt tolerant crops
6	Drainage canal	N 041^0 04'373" E 064^0 52'825" Elevation 117 m	Shallow soils/sodic alkaline soils	Dominated by typical halophytic plant communities (Salicornia, Tamarix, Aeleoropus etc.)
7	Solonchaks	N 041^0 02'976" E 064^0 52'544" Elevation 106 m	Salt-marshes	Hyperhalophyte

EVALUATION OF SALT TOLERANCE AND PRODUCTIVITY OF BIANNUAL AND ANNUAL CROPS BY IRRIGATION WITH ARTESIAN SALINE WATER

Evaluation of strips-alley cropping system

This approach include improvement of degraded natural rangelands alone (mixture of perennial fodder shrubs/semishrubs and annual grasses) or mixed with farming systems. Fodder trees and/or shrubs like Haloxylon apphyllum, Salsola paletzkiana, S. richteri, P. alba, Populus nigra var. pyramidalis, P. euphratica, Eleagnus angustifolia Salix babilonica, Morus album,M.nigra, Hippophae ramnoides, Tamarix hispida, T. well associated with wild halophytes and salt tolerant crops, such as sorghum alfalfa fodder beet, triticale and pearl millet. Wild halophytes fodder species were established in widely spaced patterns (15-25m) to allow for easily mechanical cultivation and harvesting of moderately salt tolerant grass and cereals. Agronomic practices were as follows: rough tillage on the area of 0.5 ha; field leveling; cutting parcels and furrows. Flooding irrigation has been used. Manual seeding on the small parcels of the following species were made:

Kochia scoparia-	400 м^2
Atriplex nitens	300м^2
Agropyron desertorum	50м^2
Atriplex canescens	50м^2
Climacoptera lanata	300м^2
Beta vulgaris	75м^2
Zea mays	
Hippophae ramnoides	
Suaeda arcuata	
Salsola orientalis	
Camphorosma lessingii	
Alhagi pseudoalhagi	

Various species of trees, legumes, including licorize (Glychyrryza glabra)

Soils of the surveyed area are silt-sandy loam up to the depth of 60 cm. The soil is highly saline in the top soil and in the lower layers, where high content of gypsum is observed. The predominant salinity type is

sulphate-chloride. Ground water salinity varies: 2000-8200 mg/l. Sodium and magnesium are the dominating ions. Groundwater table fluctuates from 0.5-2.5 m during May-July at the dry solonchaks and experimental agricultural plot and up to 5-8 m in the virgin desert degraded rangelands area. Dynamics of soil moisture under different plant communities, which are mostly distributed in the degraded rangelands, is shown in Figure 32,33.

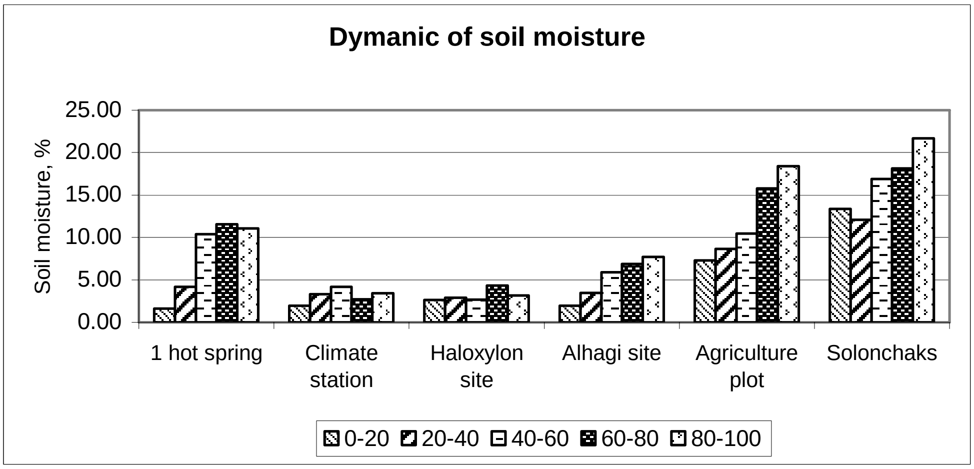


Figure 2.1.32. Dynamic of soil moisture at all investigated zones including agricultural ICBA plot (spring 2006).

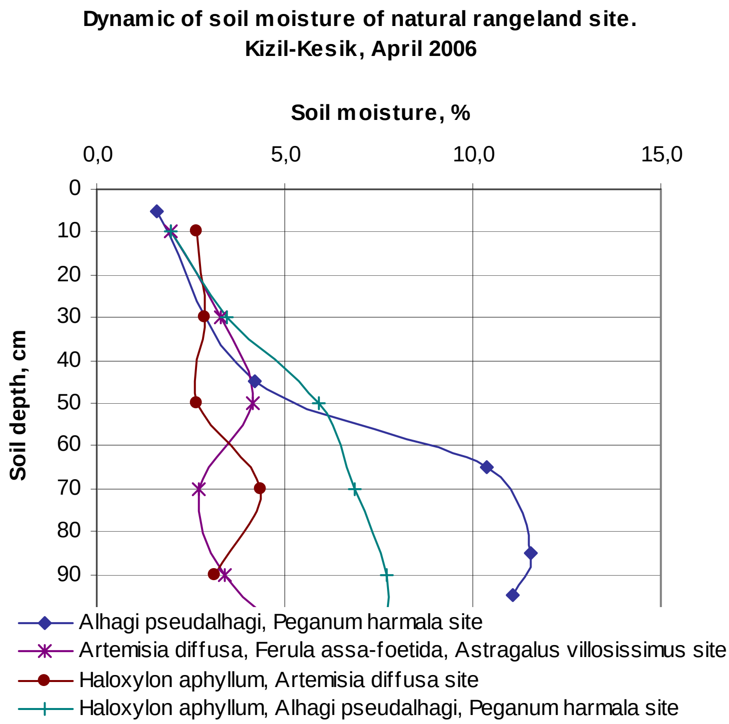


Figure 2.1.33. Dynamics of soil moisture under main desert plant communities, located in the vicinity with Agricultural ICBA Plot (spring 2006).

Due to low transpiration capacity, Alhagi plant communities promote retention of soil moisture in the top soil. The same situation is also observed on saline areas near agricultural plots where Climacoptera and others annual Salsola's species dominate. Additionally the high evaporation rates are drying the ponds in summer, making them as evaporation ponds. Poor natural drainage system of marginal cropping irrigated lands has caused an increase in the salt content at the superficial crust and groundwater that induces secondary salinization of the soils. A very intensive process of soil salinization occurs in the area located in the vicinity of the artesian wells (1 hot spring and solonchak zones). Therefore the introduction of salt-tolerant wild halophytes has supported studies of groundwater with reference to salinity sources and irrigation management. Average electric conductivity of the irrigation water (artesian hot spring 1 and 2) varies between 2.30 to 8.1 dS/m; pH value is between 7.3 to 8.1. The dominant cation is Na^{+} and SO_4^{2-}

among anions (Table 2.1.39). Drainage water is ≈3.5 times more saline than irrigation water. Micro element composition for the Kyzylkesek water is distributed as follows: Sr> Ba> Ti> Mn> Cr> Ni> Cu> Mo> Pb.

Table 2.1.39. Chemical properties of the drainage and ground water at the Kyzylkesek Site (observations are for August 2006 period)

Site ID	**Chemical Properties**									
	pH	**EC**	**Soluble cations ***					**Soluble anions ***		
			TDS	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**
		dS/m	mgL-1				mgL-1			mgL-1
Drainage water (head part)	7.93	18.1	8800	584	365	1778	7	269	1997	3696
Drainage water (middle sream)	7.85	17.8	8750	574	353	1789	7	262	1997	3607
Drainage water (lower stream)	8.1	12.5	9000	592	371	1777	7	262	2197	3697
Artesian irrigation water (well 1)	7.4	10.9	2654	184	91	565	8	177	621	1015
Well 2	7.3	9.9	2716	184	85	574	8	165	621	1018
Well 3	7.4		2826	190	94	586	8		621	1079

Chemical analyses of soil samples from the target area showed that dominating ions are calcium-sodium and hydrocarbonate-sulfate. Analysis from each zones separately demonstrated significant differences of content of cations and anions. Three zones (Climate station site, Haloxylon forest and Alhagi sites) with less content of soil moisture is characterized by significant amount of Ca^{2+} and HCO^{3-} ions and the less content of Na^+, Mg^{2+} and Cl^- compared with other sites. Site 1 with the hot spring and Agriculture plot (2-d hot spring) occupied an intermediate place according to soil moisture and content of majority ions (Na^+, Mg^{2+}, K^+, SO_4^{2-}, Cl^-). Na^+ in this site is almost 20 times more than in the Climate station site and the Haloxylon site, Cl^- is 10 times higher and SO_4^{2+} is about 2 times highert.

II. FLORISTIC COMPOSITION OF VEGETATION OF SALT AFFECTED RANGELANDS, MINERAL CONTENT AND EVALUATION OF HALOPHYTIC GERMPLASM

Studies in the region have shown presence of different ecological habitats and high plant diversity along the Zarafshan River Valley (old agricultural zone as a case of Navoi region) and Kyzylkum Desert (Akjigitova, 1982; Goldstein et al., 2000, Toderich et al., 2001; Shamsutdinov et al., 2000, Gus Gintzburger et al, 2003). During the present survey more than 380 species of different groups of salt loving plants (wild halophytes representing 19 taxonomical families) were described. The study areas show a high endemism in plants (bout 3.4% from total species). Most noticeable is the relative richness of the Chenopodiaceae with nearly 33%, equivalent only with Australia chenopods. It is also quite rich in Asteraceae (20%), Poaceae (11%); Fabaceae and Brassicaceae (about 11%). Species belonging to Polygonaceae, Plumbaginaceae, Zygophyllaceae, Cyperaceae account for a smaller share (3-5%), whereas, Eleagnaceae, Plantagainaceae and Frankeniaceae make up an even smaller part (< 1.0%) of rangelands halophytic pastures. Among cited plant resources there are a number of native and exotic halophytes both C_3 and C_4 plants suitable for reclamation of arid and semi-arid, salt/affected and waterlogging areas that have been proven very useful in demonstration trials. These areas have not yet been widely used as part of the arid production system of Uzbekistan by the pastoralists and farmers.

The main goal of the Component 2.1.5 activity was to evaluate the sustainable development of saline-sandy desert degraded rangelands through optimal agricultural management practices to optimize growth of both native and introduced salt tolerant crops. Analysis of cover vegetation made during two 2006-

2007 seasons for each visually divided zone allowed determining the edificators and sub-edifiocators species. In the first zone, where there was a high soil mineral content, species of genus Salicornia, Halostahys, Halimocnemis, Climacoptera are widely distributed. The vegetation period begins fairly late because the marshes are under water for a long part of the year. The conventional salt tolerant crops (sorghum, pearl millet, fodder beet, safflower etc.) as seen in Figure 2.1.34, occupy an intermediate place between true halophytes and xero-halophytes.

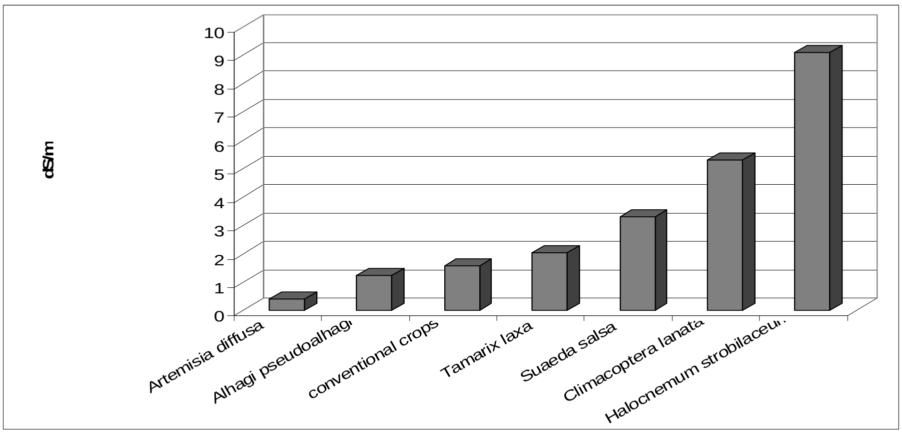


Figure 2.1.34. Ecological row of plant species distribution including conventional crops by increasing salinity in the irrigation water

Our investigation on chemical composition of desert plants for ions like Cl^-, SO_4^{2-}, HCO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, as well as phosphorus and iron, showed significant changes within different halophytic forage species. The naturally growing plants, e.g., Halocnemum strobilaceum, Tamarix hispida, Climacoptera, Halothamnus subaphylla contains higher Na^+ concentrations near the critical limit for livestock, while legumes (Alhagi pseudoalhagi) and some graminous fodder grass mostly accumulate K^+ (Figure 2.1.35).

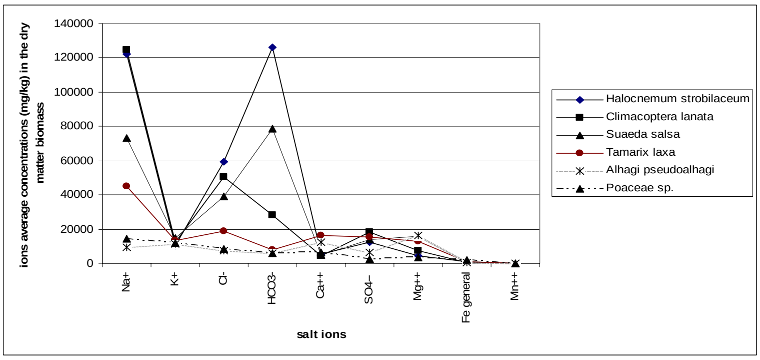


Figure 2.1.35. Changes in chemical composition of dry mater biomass of various halophytic forage species growing under sandy saline desert Environments

Concentration of salt ions, phosphorus and general iron in the dry matter biomass of all species varies depending on physical and chemical properties of soils and irrigation water as is shown at Figure 2.1.36 a,b,c,d for Alhagi pseudoalhagi, Tamarix laxa, Poaceae spp. and Climacoptera lanata, inhabiting the bio-monitoring points along the Zarafshan River and the Kyzylkum Desert. The highest concentration of K^+ was found in Kochia scoparia, closely followed by Atriplex nitens and Suaeda arcuata. Total mineral ions were highest in Halocnemum strobilaceum, followed by Climacoptera lanata, Suaeda salsa, Salsolas spp., Zygophyllum spp., Tamarix laxa, T. hispida and Haloxylon aphyllum. On the base of salt concentration of main cations (Ca^{2+}, Na^+, K^+, Mg^{2+}) and anions (SO_4^{2-}, Cl^-, HCO_3^-), Alhagi pseudoalhagi, Poaceae spp. , Artemisia diffusa having a minimum concentration of mineral ions, and could be categorized as relatively more palatable as forage plants. However, the fresh biomass of Alhagi pseudoalhagi from highly saline habitats sharply decreases with the increasing gradient of salinity. Alhagi pseudoalhagi, Poaceae spp. and Artemisia diffusa are more suitable as animal fodder than other salt tolerant plants. These species can be recommended for direct grazing or feeding. Salt bushes also maintained relatively higher Ca^{2+} and Mg^{2+}. In spring 2006 we have started our activity by creation of artificial agrophytocenoses combined with high

palatable wild halophytes, grasses and palatable salt tolerant crops both native introduced species. Data of growth parameters of some investigated species are given in the Table 2.1.40.

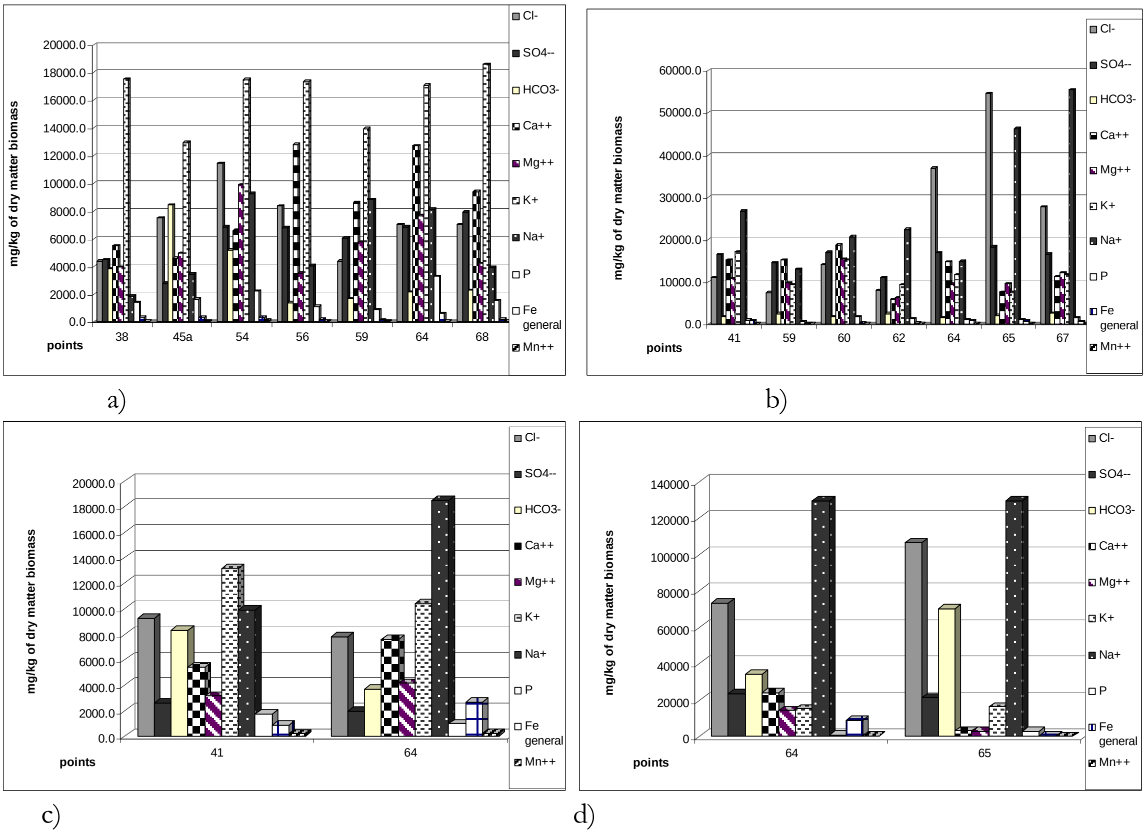


Figure 2.1.36 a,b,c, d. Concentration of salt ions, phosphorus and general iron in the dry matter biomass of (a) Alhagi pseudoalhagi, (b) Tamarix laxa, (c) Poaceae spp. and (d) Climacoptera lanata.

Table 2.1.40. Parameters of plant growth of tested halophytes and salt tolerant crops at the Kyzylkum Experimental Site in spring 2006

Name of species	Date of sowing	Duration of plant performance (days before flowering)*	Plant survival (%)	Height (cm)
Atriplex canescens	14.03.2006	82	40	15.1+0.2
Agropyrum desertorum	14.03.2006	82	90	21.4+0.2
Kochia scoparia	14.03.2006	82	95	105+0.9
Atriplex nitens	25.02.2006	105	97	121+3.9
Climacoptera lanata	25.02.2006	105	64	48.4+0.9
Glycyrrhiza glabra	25.02.2006	105	30	48.6+1.4
Salix songarica	13.03.2006	83	95	32.2*+2.2
Populus eupharatica	13.03.2006	83	85	51*+2.1
Morus alba	6.04.2006	65	85	25.6*+1.6
Fodder beet (Beta vulgaris)	13.03.2006	83	70	15+0.2
Alfalfa (Medicago sativa)	25.02.2006	105	95	110+1.9
Zea mays	8.04.2006	71	95	120+1.9
Sorghum effesum	8.04.2006	71	95	71.6+1.4
Sorghum contractum	8.04.2006	71	93	101.3+3.0
Fodder beet (Beta vulgaris var sacchorifara)	8.04.2006	71	84	15+0.4
Fodder beet (Beta vulgaris)	8.04.2006	71	80	13+0.3
Hippophae ramnoides	8.04.2006	63	65	8.1+0.1

*- from seedling stage up to flowering; **- length of annual sprouts

Table 2.1.40 shows that the annual species of Atriplex nitens (seeds from Karakalpakstan) sown in two different term perform better. Additionally, the productivity of degraded salt affected pastures could be improved by sowing annual and perennial wild halophytes (seed material has been collected from different eco-geographical desert zone of Uzbekistan) in 2004-2005 mixed with moderately salt tolerant crops like Sorghum, Zea mays, and legumes. Data on plant performance, yield of fresh and dry biomass and yield of seed was summarized and shown in table 2.1.41 & 2.1.42.

Table 2.1.41. Plant growth and productivity of annual halophytic pastures under irrigation by artesian saline water, (Kyzylkum Site, 2006)

Name of species/number in the collection	Date of seed bedding	Number of plants	Yield of fodder mass		Yield of seeds (t/ha)	Period of vegetation (days)
			Fresh	Dry		
		th.plants per ha	t ha-1	t ha-1	t ha-1	days
Kochia scoparia						
K-599	14.03.06	26.29	29.5	14.6	1.19±4.6	82- 96
	14.03.06	23.13	21	11	1.37± 2.4	80-85
K -598	14.03.06	24.46	41.5	16.2	2.92± 2.8	78-80
Control/Kyzylkum population	Self-reproduction	30.14	15.6	7.8	0.75-1.34	80-101
Atriplex nitens						
K-550	14.03.06	67.8	21.0± 5.8	9.6± 3.8	2.9± 3.6	
K-632	Self-reproduction	59.1	19.0 ± 4.1	9.1 ± 3.2	2.08± 4.3	
K-620	Self-reproduction	61.6	11.0±7.1	9.69±5.8	2.96±5.6	
Climacoptera lanata						
K-621	25.02.06	173.3±2.5	5.88	1.17	0.09-0.45	180-220
K-602	25.02.06	113.3±3.7	21.4.6±2.3	2.11	1.43-1.56	190-232
Climacoptera + Sorghum+ irrigation with mineralized water		146±3.8*	17.5±6.9	8.85±4.6	8.48±3.9	190-235
	14.04.06.	62.0±3.7**	22.33±2.6	13.4±4.9	6.85±5.1	125-136
Climacoptera + Sorghum+ saline/w+fertilizer		174.5± 3.8	9.68± 2.9	6.17± 3.4	1.69 ± 4.2	180-210
	10.04.04	138±5.1	68.0±10.1	23.8±9.3	12.47±8.3	110-125
Climacoptera + Zea maize + irrigation with mineralized water		135±4.6	6.16 ± 2.1	3.04± 3.6	1.92± 3.6	180-210
	10.04.06	212±3.0	13.5±4.6	25.5±7.1	7.22±6.4	95-130
Climacoptera + Zea maize + saline/w. +fertilizers		153.3±4.1	15.0±6.9	8.2±5.6	13.2±4.9	195-205
	10.04.06	234±5.1	42±8.1	19.8±4.9	10.2±5.4	85-110
Salt depression (control) Climacoptera pure stands	Self-reproduction (15.02.06)	51.1±1.5	6.22	1.15	0.8-1.0	210-235
						Suaeda arcuata
Salt depression	Self-reproduction	15.3	54.4	13.6	0.57-1.09	170-190

*- value for Climacoptera; **- value for traditional crops

Table 2.1.42. Plant growth and productivity of perennial halophytic pastures under irrigation by artesian mineralized water, (Kyzylkesek Site, 2006)

Name of species	Date of seed bedding	Number of plants	Height of plants	Yield of fodder mass		Yield of seeds	Period of vegetation
				Fresh	Dry		
		t ha-1	cm	t ha-1	t ha-1	t ha-1	days
Salsola orientalis	Self-reproduction (II-III)	9.296-12.3	155-75	2.0-2.8	1.0-2.2	0.05-0.15	250-254
Halothamnus subaphylla	20.10.05	9.250-10.28	109-150	1.9-2.06	1.24±2.1	0.90-0.93	235-250
Kochia prostrata	Self-reproduction	17.22	94-103	2.6-3.09	2.06-2.16	0.3-0.67	250-260
Camphorosma Lesingii	Self-reproduction (II-III)	14.98	88-92	1.6-2.07	1.2-1.6	0.02-0.21	230-235
Atriplex canescens K-4773	14.03.06 (seedlings)	104	35.1+0.2	6.19±5.3	2.05+0.2	no seeds	220-238
Agropyron desertorum*	14.03.06	812	125-157	0.8-1.5	0.4-0.6	No seeds	105-108
Alhagi pseudoalhagi	Self-reproduction (II-IY)	960/1004	58-161	0.85-2.40	1.24-1.60	0.1-0.19	218-225
		Glychyrriza glabra					
K-609 Karakalpakstan ecoptype	25.02.06	231-345	45-110	7.9 ±4.1	1.27 ±3.1**	0.79±0.9	216-220
K-603-Mirzachuli steppe	25.02.06	380-416.0	60-150	8.4	3.46	0.46	190-205
Hippophae ramnoides K-656	25.02.06	280-310	68-105	-	-		205-220

* Agropyron –Kochia scoparia mixture produce up to 1.3 t DM ha^{-1}; ** Expected yield of dry roots 2.5 t ha^{-1}

Majority of investigated halophytes and salt tolerant crops are well grazed by all livestock and can serve as high palatable forage for winter feed, when softened by rain or snow. Additionally a proportion of 70 (crops residues):30 halophytes (in kind of silage or hay) are recommended for the preparation of concentrated forage production in remote desert areas. However a well equipped technologies and trained specialists on hay making and granular fodder production should be developed for the region.

Introduction of non conventional salt-tolerant crops and native wild halophytes with reference to water salinity control and irrigation management.

The introduction and cultivation of native promising fodder species of halophytes and their involvement into a crop-livestock feeding system were tested on large scale (0.5-1.5 ha) on farmer's degraded lands. A range of naturally occurring halophytes were tested with the following treatments:

a. without irrigation;
b. 80% irrigation (only three, seasonal per plant cycle vegetation)

High field seed germination (78-94%) was observed for Atriplex nitens, Kochia scoparia, Ceratoides ewersmanniana, Halothamnus subaphylla and Salsola orientalis. All of the mentioned species showed good self-reproduction from last year's seed (in situ seed bank). Cuttings of Glychyrryza glabra, Hippophae ramnoides and Alhagi pseudoalhagi showed 90-98% survival rate. During May, Agropyron desertorum, Alhagi pseudoalhagi, Kochia scoparia, Atriplex nitens and Glychyrryza glabra

(Karakalpakstan and Gulistan varieties) under irrigation started flowering and fruit maturation in 2-3 weeks earlier than under its natural habitats (Galaba farms Mirzachuli, Syrdarya province). Green biomass harvested at flowering stage showed positive correlation with plant height and their density per one square meter (Figure 2.1.37).

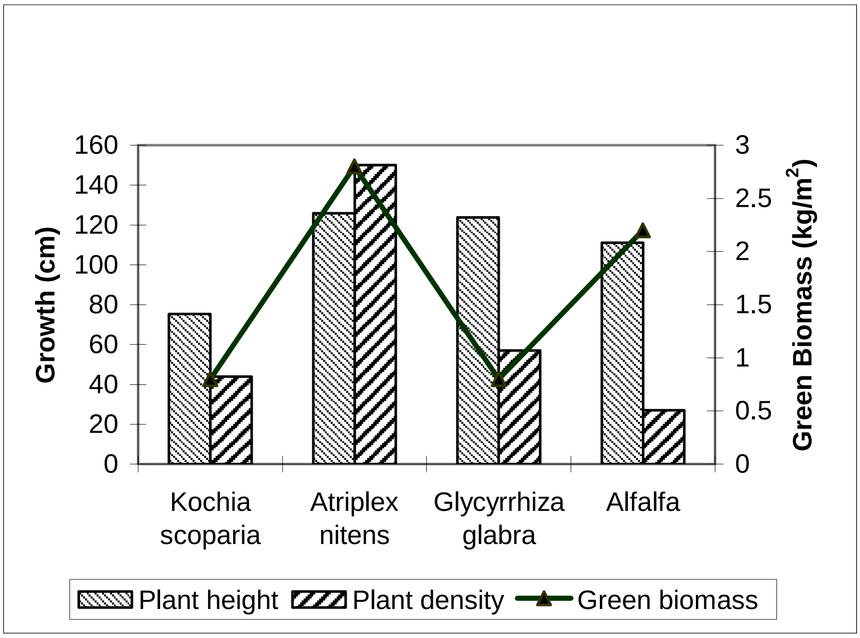


Figure 2.1.37. Green biomass of salt tolerant species grown under sandy saline desert irrigated by artesian saline water

Evaluation of strip-alley cropping system: Natural halophytes mixed with traditional crops including sorghum, Zea mays, annual and perennial legumes

Trial for strip-alley livestock-farming system was established in March 2007 in an area of 0.02 ha on farmer field. Strips of different forage crops (Triticale, sorghum and pear millet - both native and ICBA germplasm lines) were cultivated, each of them separated by a row of wild native halophytes likes Climacoptera lanata, Kochia scoparia, Atriplex nitens and Alhagi pseudoalhagi. The strips were separated by a row of Populus nigra, P. alba, var. piramidilis, Halothamnus subaphylla, Salsala rigida, Ceratoides ewersmanniana, Camphorosma lessingii and Atriplex undulata. Fodder trees and shrubs were planted to retain soil (reduce soil erosion), provide feed from late summer to early winter and use rain water (early spring) efficiently. A strip of annual and perennial legumes Medicago sativa (both native and introduced from ICBA varieties) were alternated with native halophytes aimed for grazing in spring/early summer was also established. However, establishment of Lens culinaris, Melilotus officinalis and Lathyrus sativa under sandy saline environments was very low (5-10%). Better plant performance (with a density of 210-380 thousand plants ha^{-1}) was observed for alfalfa, both Kyzylkesek and ICBA varieties (seeds from parent germplasm and first Turkmenistan reproduction)

Growth and productivity of conventional and non-conventional salt tolerant crops

Sorghum and pear-millet improved lines were sown at a depth of 3-4 cm apart in 60 m rows. Before seeding, soil samples under sorghum and pear millet cultivation were collected for mineral analysis. Two sowing terms in early spring (29.03.07 and 12.05.07) were tested for the all top-yielding sorghum lines evaluated last year. Both sowing periods have showed high seed germination (85-96%), seedling vigor and plant performance in the field (Table 2.1.43).

Table 2.1.43. Growth characteristics (useful agro-economic traits) of sorghum ICBA Gerplasm, grown under different sowing period at Kyzylkesek (May, 2007).

Improved lines/varieties	Date of Seed Bedding		Seedling Emergence				Seed Germination, %		Height of Plant (cm)	
	1st sowing	2nd sowing	1st sowing	2nd sowing	1st sowing	2nd sowing	1st sowing	2nd sowing	1st sowing	2nd sowing
Karlik Uzbekistana (St)	1/19	1/24	1/30	1/31	1/5	¼	85	96	30.5	5.2
ICSV-745	1/19	1/24	1/1	1/1	1/4	1/6	89	94	33.2	6.1
ICSV-112	1/19	1/24	1/1	1/1	1/6	1/5	92	95	34.1	6.6
ICSV-172	1/19	1/24	1/30	1/31	1/5	¼	90	94	36.5	4.9
SP-39105	1/19	1/24	1/30	1/31	1/5	¼	89	93	37.4	4.7
SP-47529	1/19	1/24	1/1	1/31	1/5	1/3	89	94	35.7	8.2
SP-47105	1/19	1/24	1/30	1/31	1/5	¼	91	96	36.5	7.7
Tashkentsky Belozernyi	1/19	1/24	1/2	1/31	1/6	1/5	90	95	32.8	5.5
Sugar Graze	1/19	1/24	1/2	1/1	1/5	¼	95	95	48.6	5.1
Pioneer 858	1/19	1/24	1/30	1/31	1/5	¼	92	90	47.9	5.8
Uzbekistan -5 (St)	1/19	1/24	1/1	1/31	1/6	¼	86	94	23.3	7.3
Super Dan	1/19	1/24	1/2	1/1	1/7	¼	89	95	49.8	7.8

Eighteen top-yielding lines of pearl millet were planted in 3 row plots of 6 m length in randomized complete block design replicated three times with 65-70 cm spacing between the rows and 12-15 cm between plants within the rows. One month after establishment intensive growth for all tested lines of sorghum was observed. Height of plant taken at the end of May for both local and ICBA sorghum germplasm varied between 23.3-49.8 cm, while those sown two weeks later had only between 4.7-7.79 cm. Field observation taken during mid July 2007 showed a rapid growth for the sorghum and pearl millet lines sown during late March. Data is summarized in Table 2.1.44. After 107 days of plant growth, almost all varieties of sorghum and pearl millet reached flowering and reproductive maturity stage, which sharply differs from those at the Akdepe Site in Turkmenistan and Makhtaral site in Kazakhstan tested in 2006.

Table 2.1.44. Variability of plant height (in cm) of varieties of pearl millet and sorghum compared with local improved standards sown in early spring period under sandy saline Kyzylkum desert (July 2007)

Evaluated varieties/lines	Average Plant Height (cm)	Max Plant Height (cm)	Min Plant Height (cm)
IP-6112	224.0	280	190
ICMV-155 Original	229.8	250	140
IP-6107	223.8	270	180
IP-6105	212.6	290	110
ICMV-155 e.el	213.2	250	165
Gueranian-4	186.4	230	140
Wraj Pop	192.8	250	140
MC 94 C2	210.8	250	150
IP 3616	199.7	240	165
SP-47105	180.8	200	140
SP-39269	182.2	215	140
Speed Feed	186.6	240	145
Pioneer 858	181.6	205	130
Uzbekistan-5	205.6	275	180
Dwarf Uzbekistan	190.6	230	150

This indicates that early spring seed sowing was better for seedling establishment and plant vigor. The efficient use of soil moisture and winter-spring rainfall combined with minimum land preparation and involvement of high productive Sorghum genotypes is innovative for saline desert environments. It was found that some varieties of Sorghum both local and ICBA germplasm showed high sensitivity to pest, especially lines growing under wet salt marshes soils.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Pearl millet accessions/varieties, Sudan Pop III, Guerinian -4, IP 6110, IP 6107, Eraj Pop and MC 94 C2 exhibited 30% dry fodder yield and 25% seeds more than local varieties. These lines are promising for further dissemination for grain production in northern part of Turkmenistan.

Dwarf forms of pearl millet such as Eraj Pop, Nutrifeed, SRBC, IP 3616, and ICMV 155 have a low plant height and are characterized by thin-stemmed delicate forage. The majority of the above cited varieties have high plant density that makes them useful for cultivation in early spring-summer as animal forage. They can also be included in an inter-cropping system established in the inter-space area between trees.

Agronomic techniques evaluated for cultivation of salt tolerant varieties of alfalfa from ICBA, showed advantages both in green biomass and seed production than local variety. Highest biomass production was observed in fodder beet variety Maestro (yield of green foliage plus weight of tubercle was 81.0 kg m^{-2}). However a proper practice of irrigation and norms and rates of fertilizers use should be developed.

Methodologies for direct seeding of *Acacia ampliceps* and *Atriplex undulate* and their seedlings establishment were elaborated that can be successfully used in large-scale saline enviroinmnets in Turkmenistan and Uzbekistan. Late summer and early autumn time should be considered as the optimal period for transplanting of all the above mentioned non conventional halophyte species. Introduction of strip-alley livestock-farming system increased the productivity of rangelands by 2.0 to 2.5 times and decrease further degradation of rangelands. The proposed system of creation of agro-phytocenosis by mixture of natural halophytes (list of plants was developed by the present studies) with salt tolerant crops, fodder legumes and grass allow getting forage for animal almost all around the year.

Salt tolerant crops cultivated by using strips alley cropping system benefits from the improvement of soils and microclimatic conditions provided by the shrubs. A considerably reduction in wind speed and potential evaporotranspiration, buffered temperatures and decrease in the intensity of sand storms was observed. First screening of wild halophytes for their gradual domestication should be done based on the following criteria: ash composition of forages; nutritional values and needs of farmers.

Integrated Biosaline Agriculture Program for sustainable use of marginal mineralized water and salt-affected soils for food-feed crops and forage legumes developed will assist to improve food security, alleviate poverty and enhance ecosystem health in smallholder crop-livestock systems. Such diversification of agro-ecosystems and development of new agricultural capacities could increase income source of rural poor and farmers which so far are often dependent on two major crops (e.g. cotton and wheat). Furthermore, the activities proposed here will also contribute to large scale biomass production, which will build up the soil organic matter. It will thus also contribute to make the poor farmers more resilient against climate change. The evaluation, domestication and large scale utilization of native and introduced halophytes and salt tolerant plant resources in sole or mixed farming system would have a significant impact on salinity control and remediation as well as on the and economic development of arid/saline lands commonly observed in the whole Aral Sea Basin.

One of the most promising steps in introducing uses of halophytes and other salt- tolerant crops is the production and conservation of important seeds germplasm of important seeds. The demand for seeds of salt-tolerant species has increased and a number of farmers have become interested to apply biosaline agriculture techniques as a feasible option for their marginal land resources. An innovative selection program and development of suitable modern agro-technologies were suggested to multiply seeds of valuable salt tolerant species and establish them within natural plant communities where they are suitable in different ecosystems. However, the outline of the general strategies for salt affected and degraded

rangelands regeneration and management in new human changing desert/semi-desert environments and socio-economic systems should still be developed and modeled.

Our findigs from the screening of the 16 multipurpose tree species offer a spectrum of options for afforesting degraded land. In order to implement afforestation of marginal patches of irrigated land in Kyzylkesek site (Kanimekh district, Navoi region, Uzbekistan), lower reaches of main Central Asian Rivers Amydarya River Delta (Khoresm region in Uzbekistan and Dashauz province from Turkmenistan), the ideal multipurpose tree species should combine a number of features such as: high survival rate, quick growth, halophytic and xerophytic characteristics, and high utility value of firewood and/or foliage. Salt tolerant trees and/or shrubs e.g., *Populus euphratica*, *P. pruinosus*, *Salix babylonica*, *P. nigra* var. Pyramidalis, *Elaeagnus angustifolia*, *Morus alba*, *M. nigra*, *Ulmus densa*, *Robinia pseudoacacia*, *Tamarix hispida*, *T. androsowii*, *Salix babylonica*, *S. songorica*, *Haloxylon aphyllum*, *Cydonia oblonga*, *Armeniaca vulgare*, *Malus domestica*, *Hippophae ramnoide*s, *Acacia ampliceps* and various perennials species shrubs, such as species of genus Atriplex, *Hippophae ramnoides, Ribes niger* and *Rosa canina* (exceptional under arid continental with subtropical elements climate) established on good deep soils have good potential as part of the silvi-agropastoral production system.

Fodder shrubs were associated with the cereal farming system, including native rangelands halophytes alone, or mixed with various traditional salt tolerant fodder crops. As part of the desert land re-vegetation and/or rangeland improvement saltbushes *Atriplex canescens*, *A. canescensnitens*, *A. undulata*, *A. nummularia* and *A. amnicola* were recently introduced at the saline sandy desert zones of low-lying salt affected areas of Central Asian River deltas. Our preliminary results showed that the establishment of trees/shrubs plantations requires limited irrigation during the initial stage of growth before sole reliance on available groundwater resources can become possible. Since the availability of irrigation water on marginal lands is limited, there is a need for the assessment of the groundwater budget, root zone salt accumulation control and studying the adoption of water saving irrigation techniques, which has been applied for tree plantation in other arid regions of the world (Andreu et al., 1997; Levy et al., 1999).

It was found that the high productivity of *T. androssowii*, *T. hispida*, *Salix babylonica*, *Haloxylon aphyllum*, *E. angustifolia* and *Atriplex undulata* makes them the most promising candidates for afforestation of highly degraded saline habitats with immediate economic benefits. However, species of genus Tamarix, spp. and *Elaeagnus angustifolia* and Salix are often referred to as aggressive colonizers since they tend to invade natural habitats and push out other less salt tolerant species (Cleverly et al., 1997). Species of the generaus Tamarix, *Salix babylonica songorica*, S. *babylonica* and *E. angustifolia* showed a high ability to self-propagate by vigorous sprouting, and thus intensive control is recommended (Tesky, 1992, Le Houerou, 2000, Toderich et al, 2006,. Khamzina, 2006). Although these species have the capability to grow on saline soils, Tamarix plantations may not benefit the environment in the long run, since this halophytic shrub releases accumulated salts via salt glands and thus increases soil salinity (Forestry Compendium, 2000). Given these characteristics of Tamarix, this genus does not seem to have good potential for the afforestation of salt-affected land, although further investigation is necessary. Besides *E. angustifolia*, *Morus alba*, *M. nigra*, *Acacia ampliceps*, *Robinia pseudoacacia* and Atriplex species offer possibilities as supplementary feed to the low-quality roughages such as wheat stalks used throughout the off-season for all kind of animals.

Although *M. alba* shows good fodder potential, in arid/semiarid areas of whole Central Asian region it plays a major role in sericulture production, which leaves little room to expand its potential as a provider of fodder for ruminants. To determine the real feed /nutritional values of the examined trees, the feed intake and live weight increments of livestock should be studied in vivo. Although, the cultivation of trees requires a waiting period, the use of multipurpose species, as investigated in this study, promises the farmers a return from those areas of their land where crops are no longer profitable. The expansion and commercialization of non-timber forest products has the potential to increase the cash income of rural Uzbek households. No data on the economy of non-timber forest products in Central Asian countries were available at the time of this study, and providing such data will be imperative for economic studies. Another aspect that remains unstudied is the degree to which this type of afforestation effort can contribute, on a larger spatial scale, to carbon sequestration; however, methane emissions from unfertilized poplar plantations as well as natural Tugai vegetation are below the detection limit (Scheer et al. 2008). If carbon trading benefits can be added to the benefits from non-timber forest products, this would create a “win-win” situation from both an ecological and economic point of view (Gintzburger et al., 2005, Khamzsina, 2006).

Pilot studies indicate the cost effectiveness of up-scaling grain and sweet sorghum raw material for ethanol production in Central Asian region. Although sorghum production is still low and gives less value comparative to rice and maize, the crop is drought/salt tolerant and has good adaptability to grow on marginal salt-affected lands. These traits give benefit and supplement fodder resources to the poor farmers in remote desert areas of Central Asia. Sweet sorghum varieties indicated in this report are the most attractive for alternative uses of sorghum as bioethanol source. Future programs will bring new salt-affected marginal lands into production of sorghum. However, state support, strong research and coordination between processing small/large companies, research institutions and farmers should be developed for sorghum breeding, adoption of relevant technologies available for the process of ethanol production in Central Asia.

As a sugar-bearing crop, *Sorghum bicolor* has well emerged under moderately saline soils in Uzbekistan. The research infrastructure, however, that would support a rapid scaling- up of sugar-bearing varieties/improved lines of sorghum plantations in Central Asian countries is currently not in place. Achievable sugar content, stover and seed yields are still uncertain, and little is known about the incentive structures under which smallholder farmers would grow this plant for smaller/and larger companies, which would make investments in ethanol extraction. This agro-silvicultural model coupled with the diversification of cropping system under prevailing saline conditions could sustain agricultural productivity of salt affected areas and increase profits of farmers. Herbaceous fodder crops planted within the inter-spaces of salt-tolerant trees and shrubs that provide fodder in intensive agro-forestry plantations could solve the animal feeding problem in the degraded (both by overgrazing and salinity) desert and semi-desert marginal areas. In addition, wild halophyte species planted in widely spaced patterns allows for easy mechanical cultivation and harvesting of grass and cereals. Promising fodder salt tolerant crops being assessed in our studies include sorghum, pearl millet, and salt tolerant varieties of alfalfa, all of which are currently not grown extensively in the region. Yield data collected at the conclusion of the 2006-2007 growing seasons indicates considerable adaptability of introduced genetic material to saline soil conditions, when compared to local material.

2.2 MANAGEMENT OF SALT-AFFECTED SOILS

2.2.1 EVALUATING THE RATE AND TIME OF PHOSPHOGYPSUM APPLICATION ON HIGH-MAGNESIUM SOILS FOR IMPROVED CROP PRODUCTIVITY[5]

1. INTRODUCTION

Excess levels of magnesium (Mg^{2+}) in irrigation waters and/or in soils in combination with sodium (Na^{+}) or alone result in soil degradation through impacts on soil physical properties (Oster and Jayawardane, 1998; Qadir and Schubert, 2002). There are emerging examples from some irrigation schemes worldwide such as the Aral Sea Basin in Central Asia where irrigation water contains higher levels of Mg^{2+} than calcium (Ca^{2+}), suggesting Mg^{2+}:Ca^{2+} ratios greater than 1 (Qadir and De Pauw, 2007). The same applies to soil resources; excess levels of Mg^{2+} on the cation exchange complex result in soil degradation through impacts on soil physical properties (Vyshpolsky *et al.*, 2008; Karimov *et al.*, 2008). The major reason for the specific Mg^{2+} effect is that the hydration energy and hydration radius of Mg^{2+} are greater than Ca^{2+} (Bohn *et al.*, 1985). Thus, the soil surface tends to absorb more water than where exchangeable Ca^{2+} is present, resulting in weakening of the forces that keep soil particles together. This, in turn, decreases the amount of energy to break down soil aggregates (Oster and Jayawardane, 1998). At low levels of exchangeable Na^{+}, Mg^{2+} also enhances the effects of Na^{+} on clay dispersion and hydraulic conductivity (Qadir and Schubert, 2002). In addition, high Mg^{2+} levels in soils tend to increase surface sealing and erosion (Dontsova and Norton, 2002).

More than 30% of the irrigated area in southern Kazakhstan is represented by the soils that have exchangeable magnesium percentage (EMP) in the range of 25-45%, and in some cases, as high as 60% (Bekbaev *et al.*, 2005). With low infiltration rates and hydraulic conductivities, the soils containing elevated levels of Mg^{2+} are typically referred to as '*Takyr*' soils in the region. During drying-up post-irrigation phase, these soils form large clods, which impact water flow rate. The consequence of using high-Mg^{2+} soils and waters in agricultural production systems without suitable management practices has been a gradual decline in cotton (*Gossypium hirsutum* L.) yield in the region, which heavily relies on this crop (Bekbaev *et al.*, 2005).

The productivity of magnesium-affected soils can be enhanced by increasing Ca^{2+} on cation exchange sites to mitigate the effects of excessive exchangeable Mg^{2+} (Vyshpolsky *et al.*, 2008). This is accomplished by applying sufficient amounts of Ca^{2+} to the soil (Ghafoor *et al.*, 1992; Karajeh *et al.*, 2004). Phosphogypsum (PG) is a source of Ca^{2+} and major waste product of phosphorous fertilizer factories, which use phosphate rock as raw material (Alcordo and Rechcigl, 1993). Although PG contains variable amounts of ^{226}Ra and other radionuclide concentrations depending on source, studies have shown that its use as a soil amendment does not produce significant increases in the radionuclide concentrations in soils (Al-Oudat *et al.*, 1998; El-Mrabet *et al.*, 2003). Rather, an application of PG could contribute to diluting the radionuclide wastes, with additional value to farmers (El-Mrabet *et al.*, 2003; Vyshpolsky *et al.*, 2008).

Phosphogypsum is available in Central Asia as a byproduct of the phosphorous fertilizer industry. In addition to increasing the Ca^{2+} content of the soil, phosphogypsum supplies appreciable quantities of phosphorous to the soil (Alcordo and Rechcigl, 1993). Although the beneficial effects of PG application on enhancing the productivity of high-Mg^{2+} soils have been demonstrated in the region (Vyshpolsky *et al.*, 2008), there is no information available on the appropriate combinations of the rates and timings of the amendment application to mitigate high Mg^{2+} levels in soils in the region. With the participation of local farming community, a 2-year field study on a high-Mg^{2+} soil in southern Kazakhstan was undertaken to determine the effects of different rates and timings of phosphogypsum application on: (1) changes in the soil chemical properties, (2) irrigation efficiency and water productivity, (3) growth response of cotton, and (4) economics of the applied treatments were assessed.

[5] This component was led by ICARDA. NARS partners include F. Vyshpolsky, K. Mukhamedjanov, U. Bekbaev, and S. Ibatullin Kazakh Research Institute of Water Management, Ministry of Agriculture, Taraz, Kazakhstan.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND SITE CHARACTERIZATION

In collaboration with the local farming community, this on-farm study was conducted during the years 2005-2007 in southern Kazakhstan. Cotton is the main crop grown in the region covering about 95% of the cropped area in summer. The selected site was in the Old Ikan area within the command zone of Arys Turkestan Canal. Site characterization was undertaken in September 2005. The Old Ikan area has a smooth landscape with slopes from 0.002 to 0.0035. Long-term annual precipitation ranges from 50 to 250 mm, with 90% occurring during October through May. The average precipitation during the study period (May-September) was 18 mm. The area has high summer temperatures (30-40°C) during June, July and August. The temperature declines to as low as –10°C, with an average of 2°C, during the winter months. The air temperature during the study period ranged from 21°C to 28°C. The soils are heavy loam with about 1% organic matter in the surface layer and cation exchange capacity (CEC) in the range of 10.8 and 12.6 $cmol_c$ kg^{-1}. A soil bulk density 1.56±0.05 Mg m^{-3} and the pH varies narrowly from 8.1 to 8.2. The EMP levels usually vary in the range of 30 and 40%. The exchangeable sodium percentage (ESP) levels remain below 3%.

2.2. TREATMENTS

The following five treatments were established in a completely randomized block design with four replications with plot size of 1000 m^2.

1 Control (without PG application)
2 Soil application of PG in January 2006 (before snowfall) at PG requirement for 0.3 m depth (3.3 t ha^{-1}) (later referred to as $PG_{3.3\text{–}Jan}$)
3 Soil application of PG in January 2006 (before snowfall) at PG requirement for 0.6 m depth (8.0 t h^{-1}) (later referred to as $PG_{8.0\text{–}Jan}$)
4 Soil application of PG in April 2006 (after snow melt) at PG requirement for 0.3 m depth (3.3 t ha^{-1}) (later referred to as $PG_{3.3\text{–}Apr}$)
5 Soil application of PG in April 2006 (after snow melt) at PG requirement for 0.6 m depth (8.0 t ha^{-1}) (later referred to as $PG_{8.0\text{–}Apr}$)

The rate of phosphogypsum application (phosphogypsum requirement, later referred to as PGR) to the soil was calculated from the quantity of gypsum requirement (later referred to as GR) as given in Equation 2.2.1.1. The amendment was applied to the respective treatments once at the beginning either in January ($PG_{3.3\text{–}Jan}$ and $PG_{8.0\text{–}Jan}$) or in April ($PG_{3.3\text{–}Apr}$ and $PG_{8.0\text{–}Apr}$). No phosphogypsum was applied to any treatment in the subsequent years.

$$PGR = GR / 0.8 \qquad [2.2.1.1]$$

Where
PGR = Quantity of PG required (t ha^{-1})
GR = Quantity of gypsum required (t ha^{-1})
0.8 = Conversion factor between PG and gypsum
The gypsum requirement was estimated using Equation 2.2.1.2:

$$GR = 0.086\ (E_{Mg} - 0.3\ CEC)\ (100\ d_s)\ \varrho_b \qquad [2.2.1.2]$$

Where
E_{Mg} = Exchangeable Mg^{2+} level ($cmol_c$ kg^{-1} soil)
CEC = Cation exchange capacity of the soil ($cmol_c$ kg^{-1} soil)
d_s = Depth of soil amelioration (m)
ϱ_b = Soil bulk density (Mg m^{-3})

2.3. SOIL AND WATER SAMPLING AND ANALYSIS

After laying out the experiment plots, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Sampling was undertaken before the implementation of the treatments (initial soil condition) and after harvest of cotton in each cropping year. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations including Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate (EDTA), and Na^{+} and potassium (K^{+}) by flame photometry; and soluble anions including carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) by titration with sulfuric acid, chloride (Cl^{-}) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated using Equation 2.2.1.3 from the concentrations (C) of soluble cations Ca^{2+}, Mg^{2+}, and Na^{+}, expressed as mmol$_c$ L^{-1}.

$$SAR = C_{Na} / [(C_{Ca} + C_{Mg}) / 2]^{1/2} \qquad [2.2.1.3]$$

Soil samples were further analyzed for exchangeable cations including magnesium (E_{Mg}), calcium (E_{Ca}), and sodium (E_{Na}). Cation exchange capacity (CEC) was calculated as the sum of the exchangeable cations (E_{Ca} + E_{Mg} + E_{Na}). EMP was calculated using Equation 2.2.1.4 where E_{Mg} and CEC were expressed as cmol$_c$ kg^{-1}.

$$EMP = 100\,(E_{Mg}) / CEC \qquad [2.2.1.4]$$

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was assessed using one randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent. Field capacity was determined from a randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture in the following days up to the time (usually 3-5 days) when there was minimal change in moisture content at all the soil depths. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer ring diameter of 0.4 m and inner ring diameter of 0.3 m. Both rings were buried in the soil to a depth of 0.1-0.15 m. Soil bulk density was determined on undistributed soil samples collected from each soil depth using the core method. Soil moisture content was determined by gravimetric method.

In order to determine water quality, irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. Water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}).

2.4. EXPERIMENTAL PROCEDURE

The field was plowed with a tractor during the first week of January 2006. This was followed by soil application of PG at the rate of 3.3 and 8.0 t ha^{-1} to the respective treatments, i.e. $PG_{3.3-Jan}$ and $PG_{8.0-Jan}$. It was applied to the other treatments in early April 2006 ($PG_{3.3-Apr}$ and $PG_{8.0-Apr}$). As a part of the seedbed preparation, furrows were made in the plots on 22 April 2006. In order to facilitate the leaching of salts, particularly Mg^{2+}, a pre-sowing irrigation (800 m^3 ha^{-1}) was undertaken on 2 May 2006. Harrowing with a tractor was performed just before cotton sowing. Cotton variety C-4727 was sown in all the plots with a cotton seeder (Model: SPC-3.6) on 9 May 2006. The planting density ranged from 1.2×10^5 to 1.6×10^5 ha^{-1}. The cultural practices for cotton cultivation in the control and phosphogypsum plots were the same and in accordance with the prevalent system of agriculture used in the region (Umbetaev and Batkaev, 2000). Nitrogen in the form of ammonium nitrate (NH_4NO_3) was applied at the rate of 130 kg ha^{-1} on 9 June 2006. Nitrogen as bio-fertilizer (bio-nitrogen) was applied at the rate of 3 L ha^{-1} in late July 2006. Cotton was harvested in September 2006 and yield from each plot was recorded. In the subsequent year (2007), all the agronomic and fertilizer management practices were the same except that a greater volume of water (1400 m^3 ha^{-1}) was used for pre-sowing irrigation and leaching of exchangeable Mg^{2+}.

2.5. IRRIGATION MANAGEMENT AND WATER PRODUCTIVITY EVALUATION

Arys Turkestan canal water was used for irrigation. To estimate irrigation water entering to the experimental site, trapezoidal Ivanov's weirs [Model: SANIIRI weirs (WS) with side slope 1:1] were installed. In order to monitor irrigation water application to each treatment, triangle Thomson's weirs [Model: WT-50 with angle 90^o] were installed in the main irrigation furrows, which were up to 0.15 m deep and 0.30 m wide. In order to determine soil moisture content, plastic wells of Diviner 2000 instrument were installed to the soil depth of 1.5 m. The sensor technology of Diviner 2000 utilizes Frequency Domain Reflectometry (FDR) to measure soil moisture to a depth of 1.5 m at 0.1 m intervals. In order to calibrate soil moisture measurements estimated by Diviner 2000 and traditional thermostat gravity method, soil sampling was undertaken from the same horizons (soil depths) in each treatment. Total available soil water (TASW) was calculated using Equation 2.2.1.5 (Allen *et al.*, 1998):

$$TASW = 1000\,(\theta_{FC} - \theta_{WP})\,Zr \qquad [2.2.1.5]$$

Where: TASW = Total available soil water in the root zone (mm)
θ_{FC} = Water content at field capacity ($m^3\ m^{-3}$)
θ_{WP} = Water content at wilting point ($m^3\ m^{-3}$)
Zr = Rooting depth (m); in the study Zr was taken as 0.9 m

Irrigation efficiency (IE) in the different treatments was calculated in terms of percentage using Equation 2.2.1.6

$$IE = (NIR / GIR)\ 100 \qquad [2.2.1.6]$$

Where: NIR = Net irrigation rate ($m^3\ ha^{-1}$)
GIR = Gross irrigation rate ($m^3\ ha^{-1}$)

NIR was estimated using following Equation 2.2.1.7

$$NIR = GIR - PL - SR \qquad [2.2.1.7]$$

Where: PL = Deep percolation losses ($m^3\ ha^{-1}$)
SR = Surface runoff ($m^3\ ha^{-1}$)

Water productivity (WP) in different treatments was calculated using Equation 2.2.1.8

$$WP = Y / W \qquad [2.2.1.8]$$

Where: WP = Water productivity ($kg\ m^{-3}$)
Y = Yield of cotton ($kg\ ha^{-1}$)
W = Water applied ($m^3\ ha^{-1}$) to the field (gross irrigation + rainfall)

2.6. ECONOMICS OF APPLIED TREATMENTS

The total cost of production for the different treatments was calculated by differentiating cost components such as cultivation, which included plowing, furrow making, harrowing, chiseling, cottonseed, sowing operations, weeding and cleaning of field, harvesting, and transportation of the harvested material. Other costs for the treatments consisted of fertilizer purchase and application, irrigation management, labor charges, and farm machinery. The cost of phosphogypsum application in the respective treatments was reported for the first year of the experiment in 2006 because no amendment was applied in subsequent years. This cost included transportation and field application of the amendment. There was no cost for amendment application in the control. The values of all costs computed in Kazakh tenge were converted into US dollar, considering the currency exchange rate for the respective year.

In order to evaluate the economics of different treatments, marginal rate of returns (MRR) were calculated. The MRR is the ratio between the change in net benefit and the change in total cost and reveals the returns to the additional investment due to technology adoption. The data on the economic evaluation were analyzed using Microsoft Office Excel. MMR was calculated using Equation 2.2.1.9:

$$MRR = 100\,[(NB_i - NB_o) / (TC_i - TC_o)] \qquad [2.2.1.9]$$

Where: MRR = Marginal rate of return (%)
NB_i = Net benefit of PG applied in respective treatments (US\$ ha^{-1})
NB_o = Net benefit of control treatment (US\$ ha^{-1})
TC_i = Total cost for respective PG treatments (US\$ ha^{-1})
TC_o = Total cost for control (US\$ ha^{-1})

3. RESULTS AND DISCUSSION

3.1. PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the classification system of the United States Department of Agriculture (USDA) for particle-size distribution, the soil is silt loam in texture throughout the profile up to the depth of 0.90 m (Table 2.2.1.1). Field capacity in the upper 0.15 m depth was 23.13%; for the 0.15-0.30 m depth, its value was 22.15%. At the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were estimated at 21.33% and 21.16%, respectively. Infiltration rate of the pre-experiment soil was relatively low (16.5 mm h^{-1}), this being a consequence of the high levels of Mg^{2+} on the cation exchange complex, which exhibits similar properties to Na^{+} dominated soils, i.e. sodic soils that are easily dispersed when wet. Soil bulk density increased with depth and ranged from 1.53 to 1.64 Mg m^{-3} (Table 2.2.1.1).

Table 2.2.1.1 Physical properties of the field site before the implementation of treatments in October 2005.

Soil characteristic	Unit	Soil depth (m)			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
Sand (0.05-2.0 mm diameter)	%	23.78	21.44	20.53	19.23
Silt (0.002-0.05 mm diameter)	%	53.40	54.27	55.31	59.40
Clay (<0.002 mm diameter)	%	22.81	24.29	24.16	21.37
Soil texture (USDA classification)	—	silt loam	silt loam	silt loam	silt loam
Field capacity	%	23.13	22.15	21.33	21.16
Infiltration rate	mm h^{-1}	16.50	—	—	—
Soil bulk density	Mg m^{-3}	1.53	1.57	1.64	1.64
Soil moisture	mm	51.20	50.60	103.10	103.40

The pre-experiment soil salinity levels in terms of total dissolved salts (TDS) at different soil depths extending up to 0.9 m were in the range of 1030 mg L^{-1} to 1153 mg L^{-1} with the highest value observed in the upper 0.15 m (Table 2.2.1.2). The corresponding EC_e values were in the range of 1.44-1.61 dS m^{-1}. Among the anions, HCO_3^{2-} was dominant with a maximum concentration of 9.47 mmol$_c$ L^{-1} in the upper 0.15 m depth, which decreased with an increase in soil depth with the lowest values (6.80 mmol$_c$ L^{-1}) at the 0.6-0.9 m depth. The overall concentrations of SO_4^{2-} were less than that of HCO_3^{2-} and had a slightly increasing trend from surface to deeper horizons and varied in the range of 4.53 to 5.67 mmol$_c$ L^{-1}, the highest levels found at 0.6-0.9 m depth. The concentration of Cl^{-} was much less than that of SO_4^{2-} and ranged from 1.73 to 2.13 mmol$_c$ L^{-1} at different soils depths. Its concentration had small variations at different soil depths. The determinations of CO_3^{2-} were not in detectable concentrations in the soil.

Among the soluble cations in the pre-experiment soil, Mg^{2+} concentrations were higher at the soil surface than the other cations, Na^{+} and Ca^{2+} (Table 2.2.1.2). The concentration of Mg^{2+} in the upper 0.15 m depth was 6.00 mmol$_c$ L^{-1}. It also followed a pattern similar to the dominant anion (HCO_3^{2-}) as its concentration had a decreasing trend from top to deeper horizons and varied from 4.67 to 6.00 mmol$_c$ L^{-1}. Sodium concentrations did not differ substantially (5.07-5.80 mmol$_c$ L^{-1}) at different soil depths. Calcium

concentration ranged from 4.0 to 5.0 mmol$_c$ L^{-1}. The soil has an alkaline pH in water ranging from 8.03 to 8.15. The SAR levels had a slight increasing trend from top to deeper layers and were in the range of 2.19 to 2.79. Exchangeable magnesium percentage ranged from 36.08 to 43.88. It increased with the depth, with the highest levels in the 0.6-0.9 m depth.

Table 2.2.1.2. Chemical properties of the field site before start of the experiment in October 2005

		Soil depth (m)			
Soil characteristic	**Unit**	**0.0-0.15**	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
pH	—	8.13	8.15	8.03	8.10
EC$_e$	dS m^{-1}	1.61	1.50	1.45	1.44
Soluble Ca^{2+}	mmol$_c$ L^{-1}	5.00	5.00	4.00	4.00
Soluble Mg^{2+}	mmol$_c$ L^{-1}	6.00	5.00	4.67	4.67
Soluble Na^{+}	mmol$_c$ L^{-1}	5.13	5.07	5.73	5.80
Soluble HCO_3^{2-}	mmol$_c$ L^{-1}	9.47	7.73	7.07	6.80
Soluble Cl^{-}	mmol$_c$ L^{-1}	2.13	1.87	1.73	2.00
Soluble SO_4^{2-}	mmol$_c$ L^{-1}	4.53	5.47	5.60	5.67
Exchangeable Ca^{2+}	cmol$_c$ kg^{-1}	7.33	7.40	7.30	6.53
Exchangeable Mg^{2+}	cmol$_c$ kg^{-1}	4.20	4.43	4.53	5.20
Exchangeable Na^{+}	cmol$_c$ kg^{-1}	0.11	0.13	0.13	0.12
CEC	cmol$_c$ kg^{-1}	11.64	11.96	11.96	11.85
SAR	—	2.19	2.27	2.75	2.79
EMP	—	36.08	37.04	37.88	43.88

3.2. IRRIGATION AND GROUNDWATER QUALITY

The salt concentration in irrigation water ranged from 450 to 520 mg L^{-1} (EC_{iw} = 0.64-0.72 dS m^{-1}) during 2006 and from 427 to 474 mg L^{-1} (0.69-0.73 dS m^{-1}) in 2007 (Table 2.2.1.3). The pH was alkaline and ranged, with little variation, from 8.30 to 8.75 in 2006 and from 8.25 to 8.70 in 2007. The dominant cations were Mg^{2+} and Ca^{2+} with Ca^{2+} concentrations ranging from 1.76 to 2.65 mmol$_c$ L^{-1} in 2006 and from 1.80 to 2.55 mmol$_c$ L^{-1} in 2007. The concentration of Mg^{2+} ranged from 2.70 to 3.50 mmol$_c$ L^{-1} in 2006 and from 2.50 to 3.10 mmol$_c$ L^{-1} in 2007. The concentrations of Na^{+} varied from 1.10 to 1.80 mmol$_c$ L^{-1} in 2006 and from 1.50 to 1.86 mmol$_c$ L^{-1} in 2007. The dominant anion in irrigation water samples collected during the cotton season in 2006 was HCO_3^{2-} with small temporal variations in its concentrations, which varied from 3.36 to 3.69 mmol$_c$ L^{-1} in 2006 and from 2.10 to 4.00 mmol$_c$ L^{-1} in 2007 (Table 2.2.1.3). The concentrations of SO_4^{2-} were less than that of HCO_3^{2-} and ranged from 0.29 to 2.82 mmol$_c$ L^{-1} at different sampling times during both years. Similarly, Cl^{-} concentrations varied from 0.56 to 2.36 mmol$_c$ L^{-1}. No detectable concentrations of CO_3^{2-} were found in water samples collected over the two years. Levels of SAR were ≤ 2 and SAR_{adj} ranged from 0.58 and 1.31, suggesting non-sodic nature of irrigation water. However, the ratio between the ionic concentrations of Mg^{2+} and Ca^{2+} was more than 1 throughout the cropping season, revealing the dominance of Mg^{2+} over Ca^{2+} with implications for soil physical degradation, particularly in the form of impaired soil structure leading to low hydraulic conductivity and infiltration rate.

The salinity level in groundwater as represented by EC_{gw} was in the range of 2.39 and 2.90 dS m^{-1} in 2006 and 2.55 to 3.11 dS m^{-1} in May-September 2007. The corresponding salt concentrations in groundwater as represented by TSS ranged from 1799 to 2015 mg L^{-1} in 2006 and 1778 to 2112 mg L^{-1} (Table 2.2.1.4). The pH was alkaline in reaction and higher than that of irrigation water used at the experimental site and nearby area. It ranged from 8.69 to 9.34 in both the years. The dominant cations were Na^{+} and Mg^{2+}. The concentration of Na^{+} ranged from 16.20 to 20.05 mmol$_c$ L^{-1} in 2006 and from 16.18 to 22.91 mmol$_c$ L^{-1} in 2007. The Ca^{2+} concentration (1.44-3.10 mmol$_c$ L^{-1}) was almost half of the Mg^{2+} concentration (5.15-6.76 mmol$_c$ L^{-1}). The major anions in groundwater samples were found to be SO_4^{2-} (8.90-15.98 mmol$_c$ L^{-1}) and HCO_3^{2-} (7.66-12.55 mmol$_c$ L^{-1}).

Table 2.2.1.3 Composition of irrigation water used to grow cotton at the experimental site over two consecutive years.

Characteristics	Unit	2006			2007		
		May	July	August	May	July	September
pH	—	8.75	8.30	8.50	8.70	8.30	8.25
EC_{iw}	dS m^{-1}	0.64	0.72	0.68	0.69	0.71	0.73
Ca^{2+}	$mmol_c$ L^{-1}	1.76	2.65	2.30	1.80	2.55	2.00
Mg^{2+}	$mmol_c$ L^{-1}	3.50	2.70	3.45	2.50	3.10	2.60
Na^{+}	$mmol_c$ L^{-1}	1.10	1.80	1.10	1.80	1.50	1.86
HCO_3^{2-}	$mmol_c$ L^{-1}	3.36	3.55	3.69	3.20	2.10	4.00
Cl^{-}	$mmol_c$ L^{-1}	0.56	0.74	0.54	2.20	2.25	2.36
SO_4^{2-}	$mmol_c$ L^{-1}	2.44	2.82	2.62	0.29	2.81	0.34
Mg^{2+}: Ca^{2+}	—	1.99	1.02	1.50	1.39	1.22	1.30
SAR	—	0.68	1.10	0.65	0.45	0.89	0.45
SAR_{adj}	—	0.84	1.31	0.80	0.58	1.08	0.58

The levels of SAR and SAR_{adj} were greater than that of irrigation water. In addition, the ratio between the ionic concentrations of Mg^{2+} and Ca^{2+} was more than 1 approaching 4.69 in groundwater samples collected during May 2007. Salts of Mg^{2+} and Na^{+} mainly consisted of sodium sulfate (Na_2SO_4), magnesium bicarbonate ($MgHCO_3$), magnesium sulfate ($MgSO_4$), and sodium chloride (NaCl). The amounts of Ca^{2+} salts as calcium sulfate ($CaSO_4$) were much less than the amounts of Mg^{2+} and Na^{+} salts. These results support the earlier findings of the studies conducted in the Arys Turkestan area (Vyshpolsky *et al.*, 2008; Karimov *et al.*, 2008).

Table 2.2.1.4 Composition of groundwater at the experimental site over two consecutive years.

Characteristics	Unit	2006			2007		
		May	July	October	May	July	September
pH	—	9.14	9.06	8.69	9.34	9.04	9.03
EC_{gw}	dS m^{-1}	2.90	2.75	2.39	3.11	2.65	2.55
Ca^{2+}	$mmol_c$ L^{-1}	2.55	2.62	2.59	1.44	2.86	3.10
Mg^{2+}	$mmol_c$ L^{-1}	6.40	6.39	5.15	6.76	6.32	6.26
Na^{+}	$mmol_c$ L^{-1}	20.05	18.53	16.20	22.91	17.35	16.18
CO_3^{2-}	$mmol_c$ L^{-1}	1.50	1.57	abs	4.21	1.43	1.30
HCO_3^{2-}	$mmol_c$ L^{-1}	8.00	8.19	12.55	7.66	8.11	8.04
Cl^{-}	$mmol_c$ L^{-1}	3.52	4.02	2.41	3.42	3.57	3.11
SO_4^{2-}	$mmol_c$ L^{-1}	15.98	13.76	8.90	15.82	13.42	13.09
Mg^{2+}:Ca^{2+}	—	2.51	2.44	2.00	4.69	2.21	2.02
SAR	—	10.77	9.67	8.34	12.03	8.67	7.84
SAR_{adj}	—	12.09	10.86	9.38	13.49	9.75	8.83

3.3. SOIL SALINITY AND EXCHANGEABLE MAGNESIUM PERCENTAGE

Salinity determinations made on soil samples collected after harvest of cotton in both the years reveal an increase in EC_e with respective to pre-experiment levels. The increase in EC_e levels in different treatments was 1-31% over the respective initial levels (Table 2.2.1.5). There was no clear pattern for this variation, which was probably due of two reasons: (1) spatial variability in the soil in terms of salt distribution in the soil profile, and (2) dissolution of phosphogypsum that increased soil salinity, particularly in the upper 0.15 m soil depth. There were no significant differences in changes in soil salinity among the phosphogypsum treatments. These results are in line with several studies carried out on sodic soils where gypsum was applied as a source of Ca^{2+} to mitigate the effects of excess exchangeable Na^{+}. Although solute concentration did increase in the gypsum-treated soils, this increase was small and non-significant among the treatments where the amendment was applied at different rates (Shainberg and Letey, 1984; Sumner, 1993; Qadir *et al.*, 2001).

Data from soil samples collected from different soil depths after harvesting the first cotton crop revealed an overall decrease in EMP levels in all the treatments where phosphogypsum was applied at different rates and times (Figure 2.2.1.1). The relative decrease in EMP in post-cotton 2006 over the pre-experiment levels in the phosphogypsum treatments — expressed as percentage decrease in EMP over the initial levels at the 0.6 m soil depth — revealed small variation among the treatments. These findings suggest that there was no statistical difference among the phosphogypsum treatments where the amendment was applied either before the snowfall in January or after snowfall in April, just before the cotton growing season. A similar pattern was observed when EMP levels were determined in the post-cotton 2007 soil samples collected from different depths (data not presented). In general, the impact of the phosphogypsum treatments on decreasing EMP levels was reduced at the lower soil depths (data not presented).

The non-significant differences among the phosphogypsum treatments can be explained in part by the fact that the amendment was applied once to the respective treatments at the beginning of the experiment. The snowmelt and precipitation in March and April contributed to the dissolution of phosphogypsum to release Ca^{2+} in the soil solution. In addition, cotton pre-sowing irrigation and leaching contributed to the movement of part of the amendment to lower soil depths. The increased concentration of Ca^{2+} in the soil solution triggered the replacement of Mg^{2+} from the cation exchange sites. This is evident from the data presented in Figure 2.2.1.1 on EMP levels in the soil profile after the harvest of cotton in both the years. However, there was no additional effect of the snowmelt in the treatments where the amendment was applied before the snowfall events. This may be due to soil being frozen during snowfall events and subsequent snowmelt could not effectively increase the phosphogypsum dissolution.

In addition to supplying a source of Ca^{2+} to replace excess Mg^{2+} from the cation exchange sites, the application of phosphogypsum increased the phosphorus (P_2O_5) and potassium (K_2O) contents of the soil. The increases in P_2O_5 and K_2O levels provided an additional benefit of the amendment application in the form of enhanced nutrient availability in the soil. Previous studies have quantified that the application of phosphogypsum at 4.5 t ha^{-1} to high-magnesium soils increased P_2O_5 levels in the top 0.2 m soil layer from 82.3 kg ha^{-1} to 106.4 kg ha^{-1}, indicating an increase in P_2O_5 levels by 29% (Vyshpolsky *et al.*, 2008). There was a substantial increase of 60% in P_2O_5 levels in the same soil when phosphogypsum was applied at the rate of 8 t ha^{-1}. However, compared to the P_2O_5 levels in the same soil, the increase in K_2O levels was small (3-5 %) after the application of phosphogypsum to the soil.

Table 2.2.1.5 Soil salinity levels expressed as EC_e (dS m^{-1}) in the soil profile as affected by the application of phosphogypsum to the soil at different rates

Soil depth (m)	Initial soil (2005)	Post-cotton (2006)	Post-cotton (2007)
Control			
0-0.15	1.60	2.04±0.14[a] (+28)[b]	1.84±0.14 (+15)
0.15-0.30	1.56	1.72±0.12 (+10)	2.04±0.15 (+31)
0.30-0.60	1.48	1.52±0.11 (+3)	1.48±0.11 (0)
	$PG_{3.3–Jan}$		
0-0.15	1.80	1.88±0.13 (+4)	1.92±0.14 (+2)
0.15-0.30	1.56	1.84±0.13 (+18)	1.84±0.14 (+18)
0.30-0.60	1.52	1.56±0.11 (+3)	1.60±0.12 (+3)
	$PG_{8.0–Jan}$		
0-0.15	1.44	1.60±0.11 (+11)	1.52±0.11 (+5)
0.15-0.30	1.40	1.40±0.10 (0)	1.48±0.11 (+6)
0.30-0.60	1.32	1.36±0.10 (+3)	1.52±0.11 (+15)
	$PG_{3.3–Apr}$		
0-0.15	1.61	1.72±0.12 (+7)	1.83±0.18 (+14)
0.15-0.30	1.50	1.52±0.10 (+1)	1.72±0.13 (+15)
0.30-0.60	1.45	1.48±0.10 (+2)	1.53±0.11 (+6)
	$PG_{8.0.–Apr}$		
0-0.15	1.61	1.76±0.12 (+9)	2.04±0.15 (+27)
0.15-0.30	1.50	1.72±0.12 (+15)	1.52±0.11 (+1)
0.30-0.60	1.45	1.56±0.11 (+8)	1.52±0.11 (+5)

[a] Figures with ± represent standard error

[b] Figures in parenthesis indicate percentage increase (+) or decrease (–) over respective initial levels in 2005

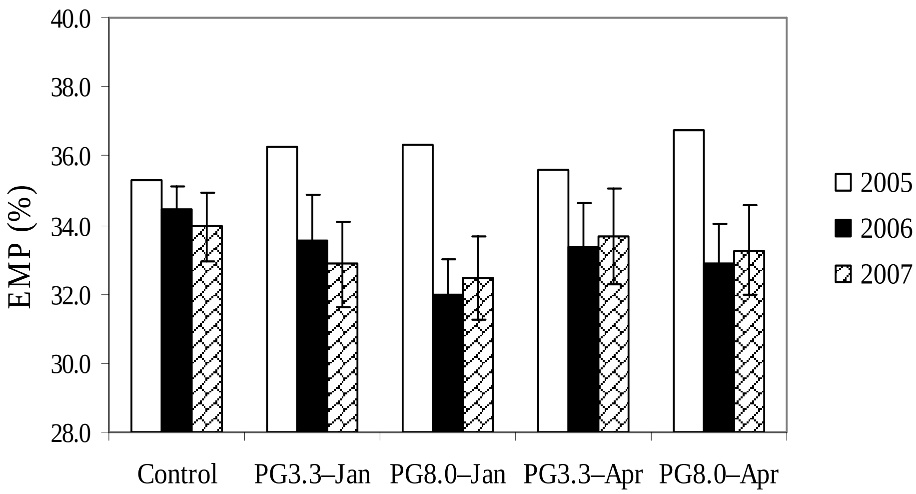


Figure 2.2.1.1 Exchangeable magnesium percentage (EMP) at the 0.6 m soil depth as affected by the rate and time of phosphogypsum application during 2006 and 2007. The bars for the year 2005 represent pre-experiment EMP levels in each treatment

3.4. AVAILABLE SOIL MOISTURE AND IRRIGATION EFFICIENCY

The soil moisture content in pre-experiment soil was 51.2 mm at the upper 0.15 m soil depth with small variation at the 0.15-0.30 m depth (50.6 mm). The moisture content doubled at the lower layers with levels of 103.1 and 103.4 mm at the 0.30-0.60 m and 0.60-0.90 m soil depths, respectively (Table 2.2.1.6). During the first cropping season (May-September 2006) the soil moisture content in different treatments varied with phosphogypsum treatments retaining more moisture than control (Table 2.2.1.6). The increase in soil moisture content may be attributed to Ca^{2+} released from the dissolution of PG, which improved the soil structure and hydraulic properties (infiltration rate and hydraulic conductivity) in the treatments where the amendment was applied. This enhanced water movement into and within the soil profile. In addition, higher water holding capacity of phosphogypsum also contributed to water storage in the soil. Similar findings have been reported by other researchers when they applied the amendment to the soil (Al-Oudat *et al.*, 1998; Shainberg *et al.*, 1989).

Table 2.2.1.6 Total available soil moisture (mm) in the 0.9 m soil profile determined at various time intervals as affected by different treatments during cotton growing season in 2006 and 2007

Date	Treatment				
	Control	**$PG_{3.3–Jan}$**	**$PG_{8.0–Jan}$**	**$PG_{3.3–Apr}$**	**$PG_{8.0.–Apr}$**
2006					
18.05.2006	60.2	85.1 (+41)[a]	93.4 (+55)	73.3 (+22)	72.8 (+21)
13.06.2006	32.6	36.2 (+11)	51.6 (+58)	38.2 (+17)	33.2 (+2)
21.06.2006	75.8	99.3 (+31)	103.2 (+36)	90.3 (+19)	84.1 (+11)
09.07.2006	43.9	59.8 (+36)	50.4 (+15)	50.3 (+15)	41.8 (–5)
15.07.2006	90.9	109.9 (+21)	96.5 (+6)	100.7 (+11)	98.9 (+9)
06.08.2006	16.9	27.1 (+60)	27.0 (+60)	14.7 (–14)	18.3 (+8)
12.08.2006	54.9	68.1 (+24)	72.7 (+32)	60.1 (+10)	60.1 (+10)
23.09.2006	–22.0[b]	–6.7 (+69)	–25.6 (–16)	–7.0 (+68)	–12.8 (+42)
Average	44.2	59.8 (+36)	58.6 (+32)	52.6 (+19)	49.6 (+12)
2007					
19.05.2007	15.6	38.5 (+147)[a]	13.3 (–15)	32.4 (+108)	36.0 (+131)
23.05.2007	77.1	116.3 (+51)	110.6 (+44)	99.1 (+29)	108.8 (+41)
27.05.2007	83.1	114.0 (+37)	113.8 (+37)	110.3 (+33)	125.1 (+51)
10.07.2007	39.7	51.2 (+29)	32.2 (–19)	37.5 (–5)	37.2 (–6)
19.07.2007	83.9	96.1 (+15)	86.6 (+3)	93.6 (+12)	91.0 (+8)
30.07.2007	29.4	46.3 (+57)	33.9 (+15)	33.9 (+15)	37.1 (+26)
07.08.2007	78.3	95.4 (+22)	90.1 (+15)	88.5 (+13)	92.1 (+18)
15.08.2007	28.3	38.7 (+37)	30.6 (+8)	25.6 (–9)	34.7 (+23)
20.08.2007	73.5	85.3 (+16)	81.1 (+10)	78.5 (+7)	86.2 (+17)
Average	56.5	75.8 (+34)	65.8 (+16)	66.6 (+18)	72.0 (+27)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over control
[b] Negative values indicate soil moisture below wilting point

In terms of cumulative response of the treatments to available moisture content during the whole cropping season in 2006, all the phosphogypsum treatments stored more water than the control (Figure 2.2.1.2). Among the phosphogypsum treatments, those applied in January ($PG_{3.3–Jan}$ and $PG_{8.0–Jan}$) stored greater amounts of water (32-36% over control) than those where the amendment was applied in April ($PG_{3.3–Apr}$ and $PG_{8.0–Apr}$). The later set of treatments stored 12-19% more water over control. In the following cropping season (2007), phosphogypsum treatments again had greater availability of soil moisture over the control. However, the differences among the two sets of phosphogypsum treatments diminished. The $PG_{3.3–Jan}$ and $PG_{8.0–Jan}$ treatments had 16-34% more average available moisture content than the control. The respective increase in available soil moisture in the $PG_{3.3–Apr}$ and $PG_{8.0–Apr}$ treatments ranged from 18 to 27%.

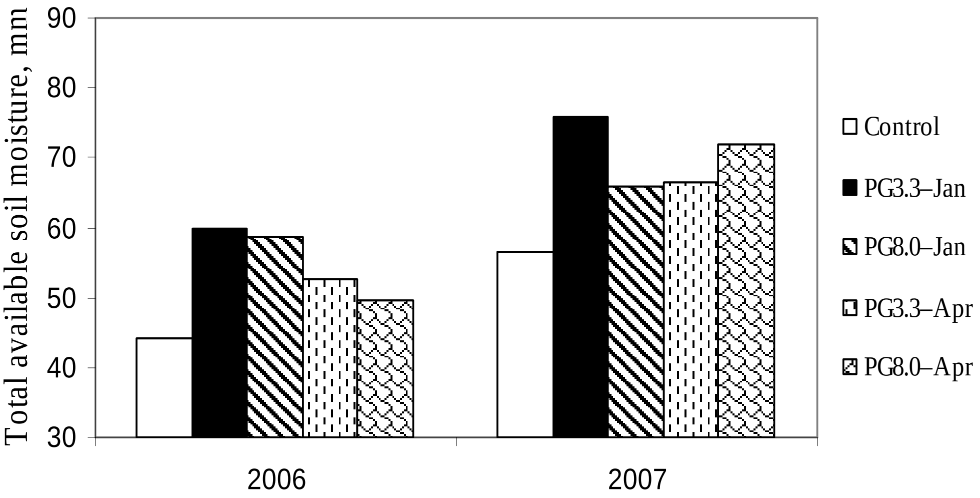


Figure 2.2.1.2 Average values of total available soil moisture (mm) in the 0.9 m soil profile (determined at various time intervals) as affected by different treatments during cotton growing season (May-September) in 2006 and 2007

3.5. IRRIGATION EFFICIENCY

Cotton was irrigated four times in both years. The first irrigation (1179 m^3 ha^{-1}) in 2006 was applied to treatments on 18 June 2006, which was followed by a second irrigation on 11 July 2006 applied at the rate of 848 m^3 ha^{-1}. The third irrigation (877 m^3 ha^{-1}) was applied on 25 July 2006. The final irrigation applied at the rate of 603 m^3 ha^{-1} on 7 August 2006 was the lightest among all the irrigation treatments (Table 2.2.1.7).

Table 2.2.1.7 Irrigation efficiency (%) as affected by the rate and time of phosphogypsum (PG) application (2006, 2007)

Irrigation date	Gross irrigation rate [a]	Irrigation efficiency [b]				
		Control	**$PG_{3.3–Jan}$**	**$PG_{8.0–Jan}$**	**$PG_{3.3–Apr}$**	**$PG_{8.0–Apr}$**
2006						
18.06.06	1179	43 (502)[c]	59 (701)	50 (586)	50 (590)	49 (579)
11.07.06	848	61 (521)	65 (552)	60 (511)	65 (554)	73 (621)
25.07.06	877	55 (481)	65 (568)	61 (531)	62 (546)	63 (552)
07.08.06	603	69 (419)	75 (450)	82 (497)	82 (494)	76 (457)
2007						
22.06.07	1169	43 (502)	60 (701)	50 (586)	50 (590)	49 (579)
16.07.07	957	46 (442)	47 (449)	57 (544)	58 (556)	56 (538)
02.08.07	853	57 (488)	57 (490)	65 (562)	65 (546)	64 (550)
18.08.07	827	55 (452)	56 (465)	61 (504)	64 (529)	62 (514)

[a] Gross irrigation rate (GIR) expressed as m^3 ha^{-1}
[b] Irrigation efficiency (IE) estimated by using the equation: IE = (NIR/GIR) 100
[c] Figures in parenthesis indicate net irrigation rate (NIR) expressed as m^3 ha^{-1}

The total amount of irrigation applied during 2006 was 3507 m^3 ha^{-1}. The same number irrigations were applied in 2007. The first irrigation (1169 m^3 ha^{-1}) was applied to the treatments on 22 June 2007, which was followed by 957 m^3 ha^{-1} second irrigation on 16 July 2007. The third irrigation (853 m^3 ha^{-1}) was applied on 2 August 2007, which was followed a 827 m^3 ha^{-1} fourth irrigation on 18 August 2007. The total irrigation in this year was 3806 m^3 ha^{-1} (Table 2.2.1.7). In 2006 the total amount of surface runoff under the control treatment was 1124 m^3 ha^{-1}, which was the maximum among for all treatments. It was 32% of the GIR. In the case of PG treatments, the total amount of surface runoff ranged from 576 to 670 m^3 ha^{-1} (16-19% of GIR). The total amount of infiltration was a minimum (460 m^3 ha^{-1}) under control (13% of GIR), while this value was much higher, ranging from 627 to 747 m^3 ha^{-1} (18-21% of GIR),

under PG applied treatments. The lower amount of surface runoff and greater infiltration into the soil under PG treatments suggest the beneficial role of the amendment in improving soil structure, thereby storing more water in the root zone for plant growth (Al-Oudat *et al.*, 1998; Shainberg *et al.*, 1989).

In the second year of the experiment, the total amount of surface runoff (1432 m^3 ha^{-1}) was observed in the control, which was the maximum (38% of GIR) among all treatments (Table 2.2.1.7). In the case of PG treatments, total amount of surface runoff ranged from 935 to 1271 m^3 ha^{-1} (24-33% of GIR). Data presented in Table 2.2.1.7 indicate that the application of PG increased irrigation efficiency by increasing share of irrigation water percolating into the soil and reducing surface runoff. Irrigation efficiency was higher in the beginning of the cropping season when the PG was applied before the snowfall as compared to the spring application of PG. Irrigation efficiency was higher under all PG applied treatments where its values ranged from 50 to 82 % in 2006 and from 49 to 65 % in 2007. Irrigation efficiency under control ranged from 43 to 69 % in 2006 and from 43 to 57 % in 2007 (Table 2.2.1.7).

3.6 CHANGES IN GROUNDWATER LEVEL

Monitoring the fluctuation of groundwater level reveals that water levels declined with time, i.e. from May to late September (Figure 2.2.1.3). The groundwater level was in the range of 1.20-2.51 m over the period 22 May 2006-12 September 2006 and in the range of 1.26-2.32 m during 28 May 2007-10 September 2007 (Figure 2.2.1.3-2.2.1.6). After the initial (18 June 2006), second (11 July 2006) and third irrigations (25 July 2006) groundwater levels rose to levels of 1.49-1.60 m, 1.26-1.57 m, 1.20-1.58 m, respectively There were not significant differences at the groundwater level after the fourth irrigation (07 August 2006).

The same trend in change of groundwater level was observed in 2007 after irrigation events. After first (22 June 2007), second (16 July 2006) and third irrigations (2 August 2007) groundwater levels rose to a level of 1.44-1.58 m, 1.51-1.65 m, 1.59-1.75 m, respectively There were not significant differences at the groundwater level after fourth irrigation (18 August 2006). Little differences in groundwater level after the last irrigation event in August 2006 and August 2007 could be explained by the lower amount of irrigation water applied. It is interesting note that groundwater level under PG application in the winter season ($PG_{3.3–Jan}$ and $PG_{8.0–Jan}$ treatments) were higher by 0.12-0.31 m (14 July -15 August 2006) in compare with $PG_{3.3–Apr}$ and $PG_{8.0–Apr}$ treatments where PG was applied after snow melting.

The beneficial role of the amendment was greater when PG application was undertaken in winter compared to spring. Phosphogypsum application before snowfall improved soil structure and infiltration rate, thereby promoting upward movement of groundwater level, which provided water to the plant roots by the capillary moisture. Crop yields under PG application in winter season ($PG_{3.3–Jan}$ and $PG_{8.0–Jan}$ treatments) were higher by 5-27% when compare with $PG3.3_{–Apr}$ and $PG_{8.0–Apr}$ treatments where PG was applied after snow melting. Water productivity under PG application before snowfall was also higher by 21-45% when compared with PG application after snow melting. In 2007 the differences in groundwater level among treatments were not significant.

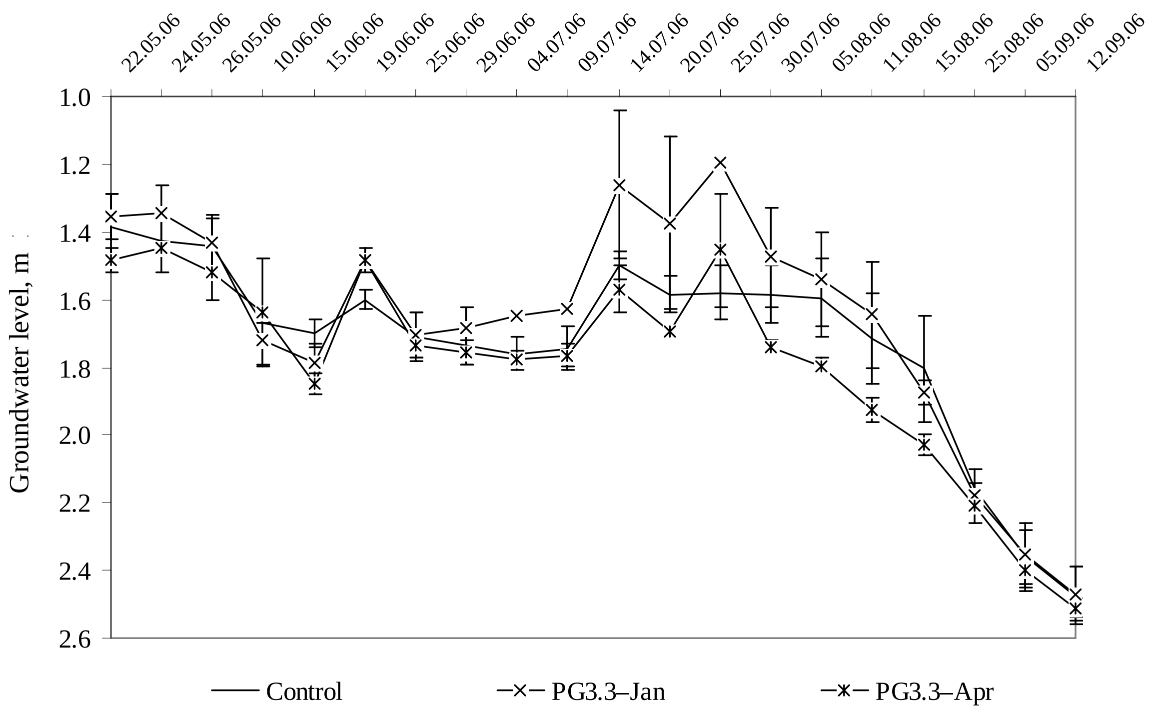


Figure 2.2.1.3 Variations in groundwater levels under PG application at the rate of 3.3 t ha-1 in winter and spring season ($PG_{3.3–Jan}$ and $PG_{3.3–Apr}$) and control during 2006

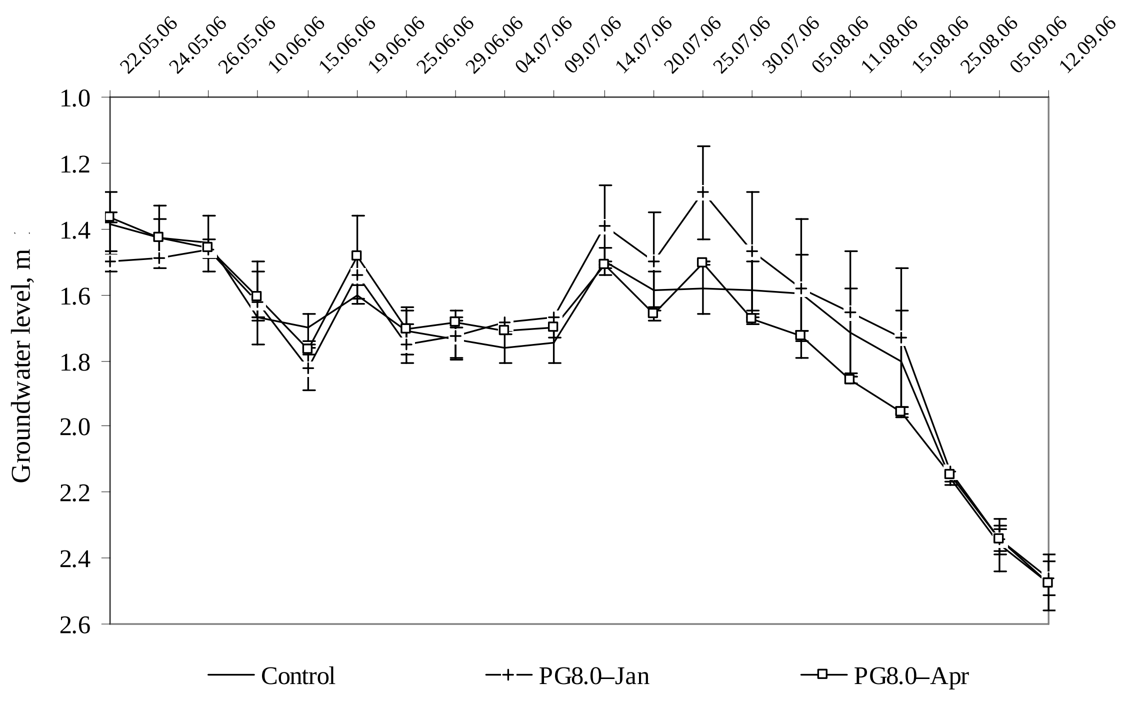


Figure 2.2.1.4 Variations in groundwater levels under PG application at the rate of 8.0 t ha-1 in winter and spring season ($PG_{8.0–Jan}$ and $PG_{8.0–Apr}$) and control during 2006

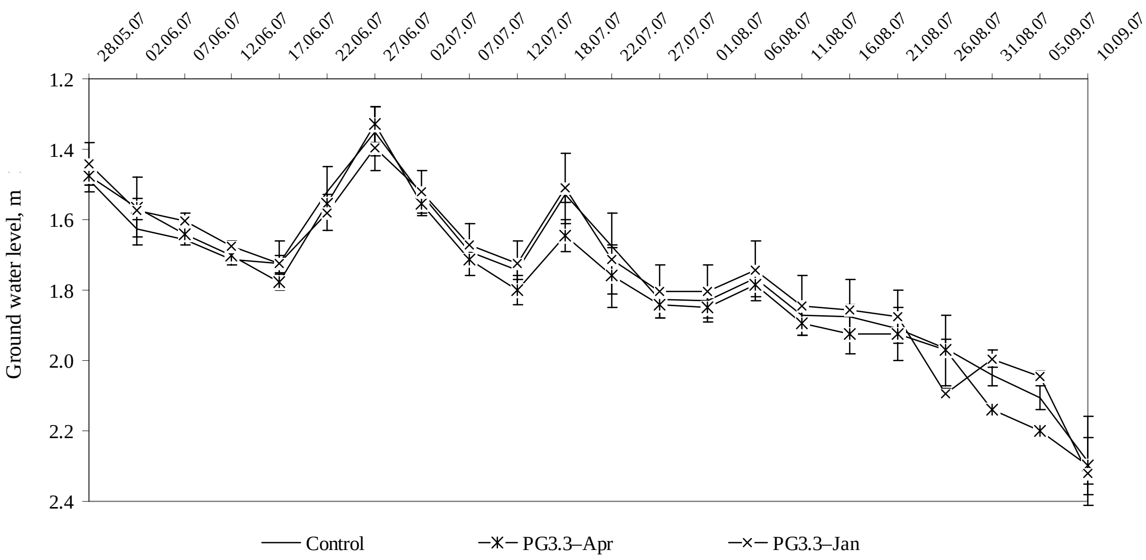


Figure 2.2.1.5 Variations in groundwater levels under PG application at the rate of 3.3 t ha^{-1} in winter and spring season ($PG_{3.3-Jan}$ and $PG_{3.3-Apr}$) and control during 2007

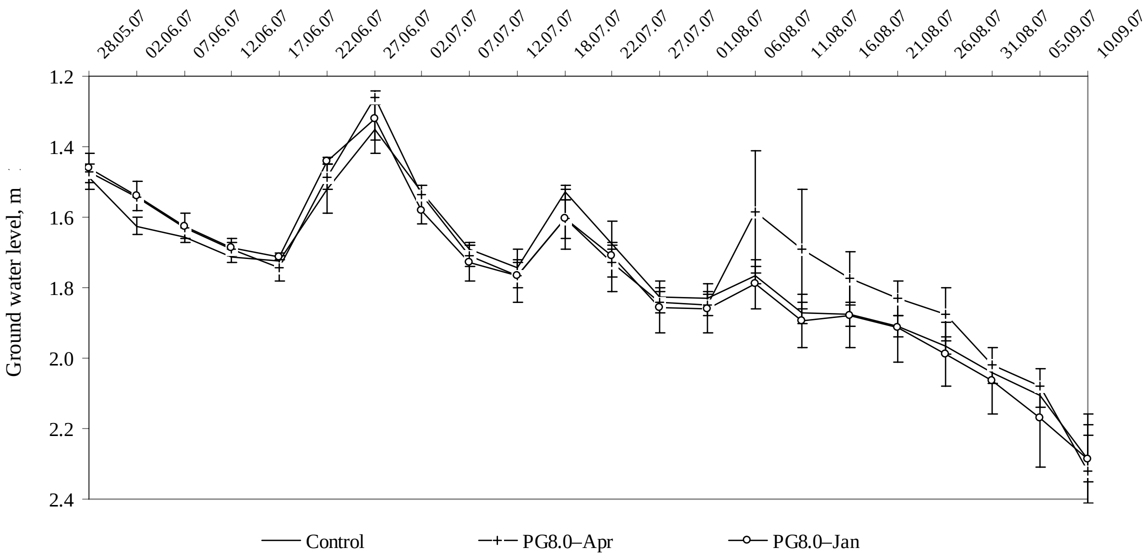


Figure 2.2.1.6 Variations in groundwater levels under PG application at the rate of 8.0 t ha^{-1} in winter and spring season ($PG_{8.0-Jan}$ and $PG_{8.0-Apr}$) and control during 2007

3.7. COTTON GROWTH AND YIELD

Plant density in the PG treatments was higher in comparison with the control suggesting that seedling emergence was enhanced through the beneficial effects of Ca^{2+} supplied through PG application. During June-August 2006, the highest average plant density was observed in the $PG_{8.0-Apr}$ treatment (134000-201000 ha^{-1}) followed by $PG_{8.0-Jan}$ (153000-182000 ha^{-1}), $PG_{3.3-Jan}$ (151000-170000 ha^{-1}), $PG_{3.3-Apr}$ (136000-165000 ha^{-1}), and control (121000-157000 ha^{-1}). In the subsequent year (2007), the highest average plant density was observed in $PG_{3.3-Jan}$ treatment (173000-185000 ha^{-1}) during July-September. Plant density in other treatments was in the order: $PG_{8.0-Apr}$ (168000-185000 ha^{-1}), $PG_{8.0-Jan}$ (156000-175000 ha^{-1}), $PG_{3.3-Apr}$ (146000-159000 ha^{-1}), and control (131000-150000 ha^{-1}).

Observations on the number of bolls in August 2006 indicated the maximum number under $PG_{8.0-Jan}$ treatment (627000 ha^{-1}), followed by $PG_{3.3-Jan}$ (618000 ha^{-1}), $PG_{8.0-Apr}$ (549000 ha^{-1}), and control (429000 ha^{-1}). The maximum number of bolls in August 2007 were observed under $PG_{8.0-Jan}$ treatment (529000 ha^{-1}), followed by $PG_{3.3-Apr}$ (457000 ha^{-1}), and $PG_{3.3-Jan}$ (455000 ha^{-1}). The lowest number of bolls was in

control (292000 ha^{-1}). Based on the number of bolls per unit area, the anticipated cotton yields were in the range of 2-3 t ha^{-1}. However, a hurricane with a wind velocity of 20-25 m s^{-1} occurred at the beginning of September 2006. Usual wind velocity in the region is around 2 m s^{-1}. The unexpected high velocity wind blew away cotton bolls with an estimated reduction in boll number to be 28-36%. This wind event impacted cotton yield, which was reduced by approximately 30%.

In 2006, the maximum cotton yield (2.08 t ha^{-1}) was recorded in $PG_{8.0\text{–}Jan}$ treatment, followed by $PG_{3.3\text{–}Jan}$ (1.87 t ha^{-1}), $PG_{3.3\text{–}Apr}$ (1.69 t ha^{-1}), $PG_{8.0\text{–}Apr}$ (1.63 t ha^{-1}) and control (1.30 t ha^{-1}) (Table 2.2.1.8). In the subsequent year (2007), the cotton yield trend was in the order: $PG_{8.0\text{–}Jan}$ (2.10 t ha^{-1}) ≈ $PG_{3.3\text{–}Jan}$ (2.10 t ha^{-1}) > $PG_{3.3\text{–}Apr}$ (2.0 t ha^{-1}) ≈ $PG_{8.0\text{–}Apr}$ (2.0 t ha^{-1}) > control (1.40 t ha^{-1}). The cotton yield data presented in Table 2.2.1.8 indicates the beneficial effects of applying PG to the soil in the form of (1) improved ionic balance in the soil in terms of the relative ratios of Ca^{2+} and Mg^{2+}, (2) enhanced nutrient availability status in the soil through increased levels of phosphorus and potassium, and (3) improved soil structure that facilitated water and nutrient availability to plant roots.

Table 2.2.1.8 Cotton yield as affected by different treatments in 2006 and 2007

Treatment	Cotton yield	Increase in cotton yield over control	
	t ha^{-1}	t ha^{-1}	%
2006			
Control	1.30	–	–
$PG_{3.3\text{–}Jan}$	1.87	0.57[a]	33.1[b]
$PG_{8.0\text{–}Jan}$	2.08	0.78	45.5
$PG_{3.3\text{–}Apr}$	1.69	0.39	22.8
$PG_{8.0.\text{–}Apr}$	1.63	0.33	19.4
2007			
Control	1.40	—	—
$PG_{3.3\text{–}Jan}$	2.10	0.70	36.5
$PG_{8.0\text{–}Jan}$	2.10	0.70	36.5
$PG_{3.3\text{–}Apr}$	2.00	0.60	31.3
$PG_{8.0.\text{–}Apr}$	2.00	0.60	31.3

[a] Increase in cotton yield over control in terms of t ha^{-1}

[b] Increase in cotton yield over control in terms of percentage

Least significance difference (LSD) for cotton yield at $p = 0.05$ was 0.24 t ha^{-1} in 2006 and 0.42 t ha^{-1} in 2007

3.8. CROP WATER PRODUCTIVITY

In 2006, the maximum water productivity of cotton (0.56 kg m^{-3}) was recorded in $PG_{8.0\text{–}Jan}$ treatment, followed by $PG_{3.3\text{–}Jan}$ (0.51 kg m^{-3}), $PG_{3.3\text{–}Apr}$ (0.46 kg m^{-3}), $PG_{8.0\text{–}Apr}$ (0.46 kg m^{-3}), and control (0.35 kg m^{-3}). In the subsequent year (2007), the crop water productivity was in the order: $PG_{8.0\text{–}Jan}$ (0.53 kg m^{-3}) ≈ $PG_{3.3\text{–}Jan}$ (0.53 kg m^{-3}) > $PG_{3.3\text{–}Apr}$ (0.50 kg m^{-3}) ≈ $PG_{8.0\text{–}Apr}$ (0.50 kg m^{-3}) > control (0.35 kg m^{-3}) (Figure 2.2.1.7).

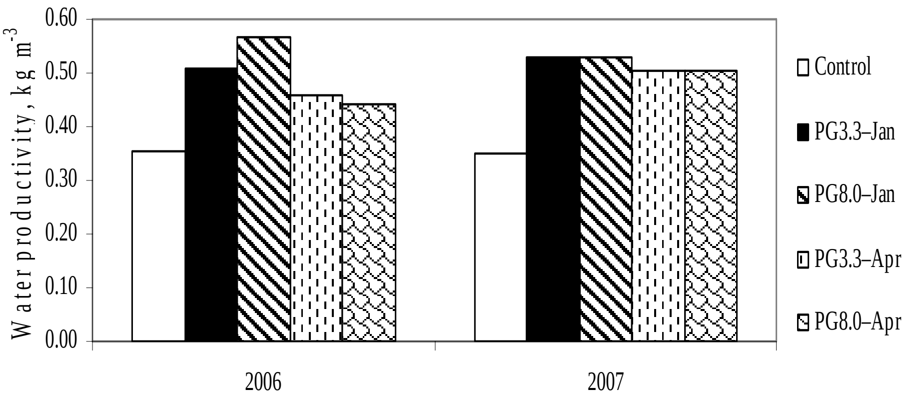


Figure 2.2.1.7 Average values of water productivity (kg m^{-3}) of cotton (lint+seed) as affected by different treatments during cotton growing season (May-September) in 2006 and 2007

3.9 ECONOMICS OF APPLIED TREATMENTS

The expenditures on fertilizer purchase and application as well as on water supply and irrigation application differed between the 2 years, but were the same for all treatments during 2006-2007 (Table 2.2.1.9).

Table 2.2.1.9 Major economic indicators of phosphogypsum application under different treatments during different years (except for benefit cost ratio and marginal rate of return, other parameters are expressed in US$)[a]

Expenditure/Income	Control	$PG_{3.3–Jan}$	$PG_{8.0–Jan}$	$PG_{3.3–Apr}$	$PG_{8.0–Apr}$
Year 2006					
Phosphogypsum [b]	—	104	251	104	251
Cultivation [c]	268	307	323	293	293
Fertilizer purchase and application	23	23	23	23	23
Water and irrigation	95	95	95	95	95
Total cost	386	528	692	514	662
Gross income [d]	473	694	776	606	600
Net income	87	166	84	92	–62
Benefit cost ratio	1.23	1.31	1.12	1.18	0.91
Marginal rate of return (MRR)		55	–1	3	–54
Year 2007					
Cultivation [c]	364.3	374.3	374.3	372.8	372.8
Fertilizer purchase and application	41.7	41.7	41.7	41.7	41.7
Water and irrigation	62.4	62.4	62.4	62.4	62.4
Total cost	468.4	478.4	478.4	476.9	476.9
Gross income [d]	700	1050	1050	1000	1000
Net income	232	572	572	523	523
Benefit cost ratio	1.49	2.19	2.19	2.10	2.10
Marginal rate of return (MRR)		42	42	22	22

[a] The expenditures and income determined in local currency (Kazakh Tenge) were converted to US$ with the currency exchange rate in the respective year

[b] Includes purchase, transportation, and field application costs of phosphogypsum during the first year of the experiment in 2006; No amendment was applied in the subsequent year

[c] Includes costs on plowing, making furrows, harrowing, chiseling, purchasing cotton seed, sowing, weeding, harvesting, and transportation of the harvest material

[d] Derived from the product of cotton yield and market price of cotton in the region in the respective year

The cost of producing cotton increased in the PG applied treatments because of the purchasing, transportation, and application costs of phosphogypsum during the first year of the experiment. In 2006, the maximum total cost incurred in $PG_{8.0–Jan}$ treatment (US$ 692), followed by $PG_{8.0–Apr}$ (US$ 662), $PG_{3.3–Jan}$ (US$ 528), $PG_{3.3–Apr}$ (US$ 514), and control (US$ 368). However, the increase in yield as a result of PG application increased the net income from the $PG_{3.3–Jan}$ (US$ 166), $PG_{3.3–Apr}$ treatments (US$ 92) whereas in control this parameter was 87US$. Limited differences in net income were observed under $PG_{8.0–Jan}$ treatment (US$ 84) and control (US$ 87) while net income was in the negative in $PG_{8.0–Jan}$ treatment (US$ –62). Benefit cost ratio under PG applied treatments in 2006 followed the same trend as net income and was in the order: $PG_{3.3–Jan}$ (1.31), $PG_{3.3–Apr}$ (1.18), $PG_{8.0–Jan}$ (1.12), $PG_{8.0–Apr}$, (0.91) while under the control this parameter was 1.23. The MRR from applying PG at 3.3 t ha^{-1} in January (before snowfall) against control was 55%. These results suggests the lower rate of PG application were more beneficial than the higher rate and its application before snowfall was more beneficial than that PG in spring season after snowmelt.

In 2007, total cost of the treatments were almost similar as it did not include items for the purchasing, transportation, and application costs of PG and were in the range of 476.9US$-478.4US$ under PG applied treatments whereas under control it was equal to 468.4US$. The overall economic benefits of the treatments were in the order: $PG_{3.3–Jan} \approx PG_{8.0–Jan} > PG_{3.3–Apr} \approx PG_{8.0–Apr} >$ control. The benefits from the amendment application in winter season were more than that with applications in spring (after snowmelt). These results suggest that the PG application before snowfall is optimal in this region.

4. CONCLUSIONS

The results of this 2-year field study on a high-Mg^{2+} soil in southern Kazakhstan have revealed the beneficial effects of phosphogypsum application in terms of improvement in soil chemical properties particularly EMP, irrigation efficiency, crop growth and crop water productivity. The amendment was applied to the respective treatments at two rates once at the beginning either in January ($PG_{3.3–Jan}$ and $PG_{8.0–Jan}$) or in April ($PG_{3.3–Apr}$ and $PG_{8.0–Apr}$). All the PG treatments performed better than the control in terms of (1) improved ionic balance in the soil with reference to the relative ratios of Ca^{2+} and Mg^{2+}; (2) decreased levels of EMP in the soil; (3) enhanced nutrient availability status in the soil through increased levels of phosphorus and potassium; (4) greater moisture storage in the upper soil depth for use by the plant roots; (5) improved soil structure that facilitated water and nutrient availability to plant roots; and (6) increased cotton yield. In the PG treatments, the cotton yields were by 19-46% higher than control.

Based on the cumulative effects, the amendment application before the snowfall improved soil properties to a greater extent compared with the application in spring after the snowmelt. At the end of the second year in the study economic benefits in terms of marginal rate of return from the amendment application at 3.3 t ha^{-1} were double those from the treatments where it was applied at 8.0 t ha^{-1}, suggesting that the lower rate is optimal. This rate of PG application is based on the phosphogypsum requirement of the soil for 0.3 m depth.

2.2.2 MANAGEMENT OF RICE-WHEAT CROPPING SYSTEM FOR SALINE SOILS[6]

1. INTRODUCTION

Before the mid 1980s, rice had been a traditional crop for farmers in the downstream reaches of the Amu-Darya River in Central Asia. After 1985, it was replaced by cotton-alfalfa and later by cotton-wheat crop rotations. As a result of new cropping pattern, the area of salt-affected soils has increased over the years, which has caused reductions in crop yields. Over exploitation of water and soil resources in the region with the concomitant desertification of the Aral Sea have resulted in serious economic, social and environmental consequences. At present more than 80% of irrigated lands in Turkmenistan, 60% in Uzbekistan and 25% in southern Kazakhstan are salt affected. Declining agricultural productivity associated with salinization and elevated groundwater levels have contributed to the development of endemic poverty in rural agrarian based communities in the region.

One of the main issues that confronted farmers when this new cropping system was introduced and found feasible and profitable, was the soil physical properties left after harvest of a puddled, transplanted rice crop. The effect of puddling reduced soil structure, especially stable soil aggregates, led to the formation of compacted layers. Soil cracking was higher under intensive puddling. Non-puddled direct seeded rice maintained the soil in a better physical condition, although yields were lower where weeds were not controlled. Farmers plowed their fields many times to obtain a suitable seed-bed for planting wheat. Plowing takes time and often results in late planting and decline in wheat yield potential along with many other negative effects (Hobbs and Gupta, 2004).

Tillage practices or new crop establishment techniques may cause substantial changes in the population/infestation of insect pests and natural enemies. In Pakistan no-tillage has been introduced for timely sowing, better crop stand, reduced cost of production, saving of water, higher productivity and increased income of the farming community in rice-wheat areas (Hobbs and Morris, 1996). The area under no-tillage technology increased rapidly and during the 2001-2002 the area under this technology in Pakistan and India was about 0.2 million ha.

A number of long-term experiments in Asia using modern varieties of rice and wheat have shown a range of response in terms of crop yield improvement – some rice varieties showed significant increase in yield (Dawe *et al*., 2000). Considering that rice could be reintroduced in rotation with winter wheat through sowing with no-tillage in downstream areas of Aral Sea Basin, studies were established in Turkmenistan for improved management of wheat-rice cropping systems to provide additional income for the farmers.

2. MATERIALS AND METHODS

This study was undertaken at Akdepe farm in Dashauz Province of Turkmenistan. The experimental area was 2.88 ha. The total number of experimental plots was 9 that consisted of 3 treatments and a similar number of replications. Each plot was 50 m × 50 m. The following three treatments were used:

Fallow (until July 2006)–rice (sown in July 2006 and harvested in October 2006)– (Control): Later referred to as FR

Winter wheat (sown in October 2005 and harvested in June 2006)–rice (sown in July 2006 and harvested in October 2006): Later referred to as WRAI

Winter wheat (sown in October 2005 and harvested in June 2006)–rice (sown in July 2006 and harvested in October 2006); traditional (flood) irrigation of rice as per farming practice in the area: Later referred to as WRTI

[6] This component was led by ICARDA. NARS partners include D. Nurmedov, K. Redjepbaev and Serdar Ruziev Turkmen Research Institute of Agriculture, Ministry of Agriculture, Ashgabat, Turkmenistan

2.1 SOIL AND WATER SAMPLING AND ANALYSIS

After laying out the experimental plots, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Sampling was undertaken before the implementation of the treatments (initial soil condition) and after the harvest of rice. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations such as Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions such as carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954).

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was done using one randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent. Field capacity was determined from one randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture in the following days up to the time (usually 3-5 days) when there was minimal change in moisture content at all the soil depths. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer ring diameter of 0.4 m and inner ring diameter of 0.3 m. Both rings were buried in the to a depth of 0.1-0.15 m. Soil bulk density was determined on undisturbed soil samples collected from each soil depth using core method. Soil moisture content was determined by gravimetric method. Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. The water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-}).

2.2. EXPERIMENTAL PROCEDURE

Land leveling was undertaken using a leveler pulled by a tractor (Model: MTZ-80) in first week of October 2005 followed by soil plowing to a depth of 0.25 m in the WRS and WRC treatments. Phosphorous fertilizer in the form of super phosphate was applied at the rate of 200 kg ha^{-1} on 9 October 2005. Just before sowing, harrowing was also undertaken. Winter wheat variety Yuna was sown by broadcasting at a seed rate of 200 kg ha^{-1} on 10 October 2005. Nitrogen fertilizer in the form of ammonium nitrate (NH_4NO_3) and super phosphate were applied at the same rate of 200 kg ha^{-1} in mid March 2006. Weeding was done manually in late April 2006.

Chiseling of the plot left for the rice seedlings nursery was carried out to 0.18-0.20 m depth, which was followed by land leveling in mid May 2006. The fallow field left for rice nursery was ploughed to a depth of 0.20-0.25 m in the last week of May 2006. Land leveling was carried out twice, the first leveling was undertaken immediately after plowing. The second land leveling was conducted just before sowing of rice (after the field was divided into two basin-checks and ridges were made between plots). Rice variety Avangard was sown at a seed rate of 500 kg ha^{-1} on the nursery area (0.3 ha) in late May 2006, which was followed by application of nitrogen in the form of Carbamid at the rate of 50 kg ha^{-1}. Winter wheat was harvested in last week of June 2006 and yield from each plot was recorded. After winter wheat harvesting, chiseling to a depth of 0.30-0.35 m was undertaken followed by land leveling. Thirty one-day-old rice seedlings were transplanted into the chiseled area. The rice seedlings from the nursery area (0.3 ha) were transplanted to the area after wheat harvest (2.5 ha). Nitrogen in the form of ammonium nitrate was applied to all rice treatments at the rate of 50 kg ha^{-1} in early July 2006. The rice was harvested in mid October 2006.

3. RESULTS AND DISCUSSIONS

3.1 PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the particle-size distribution of the USDA classification system, the soil is silt loam in texture throughout the profile to a depth of 0.90 m (Table 2.2.2.1). The pre-experiment soil salinity levels in terms of EC_e at different soil depths were in the range of 9.12 dS m^{-1} to 13.56 dS m^{-1} with the highest values being observed in the surface of 0-0.15 m, possibly reflecting salt accumulation at the soil surface due to capillary rise (Table 2.2.2.2). Among the anions, SO_4^{2-} was dominant having maximum concentration of 77.07 $mmol_c$ L^{-1} at the upper 0.15 m depth. The concentration of Cl^- had a decreasing trend from the upper to lower soil layers and varied in the range of 36.33 to 53.89 $mmol_c$ L^{-1}. The concentration of HCO_3^{2-} was much less than that of Cl^- and ranged from 4.62 to 4.89 $mmol_c$ L^{-1}. There was no detectable CO_3^{2-}in the soil.

Table 2.2.2.1 Physical properties of soil at Akdepe site

Soil properties	Unit	Soil depth (m)			
		0.0-0.15	0.15-0.30	0.30-0.60	0.60-0.90
Sand particles (0.05-2.0 mm)	%	34.75	34.10	41.23	37.14
Silt particles (0.002-0.05 mm)	%	50.82	51.19	46.22	49.15
Clay particles (<0.002 mm)	%	14.43	14.71	12.55	13.71
Soil texture	—	Silt loam	silt loam	loam	loam

Among the cations, Na^+ was dominant at the soil surface followed by Ca^{2+} and Mg^{2+} (Table 2.2.2.2). The concentration of Na^+ in the upper 0.15 m depth was determined to be 61.33 $mmol_c$ L^{-1}. It also followed a pattern similar to the dominant anion (SO_4^{2-}) as its concentration had a decreasing trend from top to deeper horizons and varied in the range of 61.33 to 44.61 $mmol_c$ L^{-1}. The concentration of Ca^{2+} was less that that of the Na^+ concentration at the different soil depths and ranged from 23.56 to 46.56 $mmol_c$ L^{-1}. The concentrations of Mg^{2+} did not vary substantially with soil depths and ranged from 21.00 to 25.89 $mmol_c$ L^{-1}. The soil was alkaline in reactivity with soil pH in water ranging from 8.63 to 8.74.

Table 2.2.2.2 Chemical properties of the field site before start of experiment (September, 2005)

Soil Characteristic	Unit	Soil depth (m)				
		0.0-0.15	0.15-0.30	0.30-0.60	0.60-0.90	0-0.90
pH	—	8.74	8.71	8.63	8.65	8.68
EC_e	dS m^{-1}	13.56	10.69	9.12	9.46	10.71
TDS	mmolc L^-	8683	6864	5594	6033	6794
Soluble Ca^{2+}	mmolc L^-	46.56	34.67	23.56	27.78	33.14
Soluble Mg^{2+}	mmolc L^-	25.89	24.00	21.56	21.00	23.11
Soluble Na^+	mmolc L^-	61.33	46.78	44.89	44.61	49.40
Soluble K^+	mmolc L^-	1.80	1.43	1.20	1.18	1.40
Soluble CO_3^{2-}	mmolc L^-	nd	nd	Nd	nd	nd
Soluble HCO_3^{2-}	mmolc L^-	4.62	4.89	4.84	4.58	4.73
Soluble Cl^-	mmolc L^-	53.89	41.67	38.22	36.33	42.53
Soluble SO_4^{2-}	mmolc L^-	77.07	60.97	43.68	53.66	58.85
SAR	—	10.19	8.64	9.45	9.03	9.33

3.1 IRRIGATION, DRAINAGE AND GROUNDWATER QUALITY

The salt concentration in irrigation water ranged from 742 to 2159 mg L^{-1} and did not change significantly during the winter wheat-rice crop season (September 2005-October 2006). The pH ranged from 6.75 to 8.3 was neutral in reaction (Table 2.2.2.3). The levels of SAR were in the range of 2.0 to 4.5, suggesting the

non-sodic nature of irrigation water. Groundwater was a highly saline, with TDS ranged from 17730 to 22874 mg L^{-1}. The dominant cation was Na^+ (Table 2.2.2.3)

The salt concentration in highly-saline drainage water ranged from 1562 to 10391 mg L^{-1} during September 2005 - October 2006; the pH level was in range of 7.35 - 8.25 or moderate alkaline in reaction. The levels of SAR were in the range of 3.85 and 15.35 during March–October, 2006 (Table 2.2.2.3).

Table 2.2.2.3 Chemical composition of irrigation, ground and drainage water during the cropping season in 2006

Characteristic	Unit	Irrigation water			Groundwater			Drainage water		
		mean	min	max	mean	min	max	mean	min	max
pH	—	7.40	6.75	8.30	7.86	6.64	8.90	7.89	7.35	8.25
EC	dS m^{-1}	1.72	1.12	3.27	34.39	29.01	36.76	9.28	2.38	16.93
TDS	mg L^{-1}	1130	742	2159	21228	17730	22874	5776	1562	10391
Ca^{2+}	$mmol_c$ L^{-1}	6.23	4.00	15.80	27.20	24.00	31.00	18.12	7.50	25.00
Mg^{2+}	$mmol_c$ L^{-1}	3.58	2.40	5.80	98.27	87.00	108.00	25.82	6.00	50.00
Na^+	$mmol_c$ L^{-1}	7.04	3.80	10.80	216.37	175.02	243.45	48.52	10.00	94.00
K +	$mmol_c$ L^{-1}	0.41	0.17	1.25	2.11	0.53	11.90	0.35	0.20	0.59
CO_3^{2-}	$mmol_c$ L^{-1}	abs	abs	abs	0.96	0.88	1.04	abs	abs	abs
HCO_3^{2-}	$mmol_c$ L^{-1}	2.43	1.76	3.04	8.54	6.64	11.28	5.43	3.12	6.80
Cl^-	$mmol_c$ L^{-1}	5.78	3.54	9.40	176.05	155.00	185.12	44.58	6.80	88.19
SO_4^{2-}	$mmol_c$ L^{-1}	8.98	5.23	20.29	159.50	119.35	191.51	42.74	12.80	74.83
Cl:SO4	—	0.68	0.46	0.80	1.13	0.81	1.52	0.90	0.36	1.39
Ca^{2+}: Mg^{2+}	—	1.73	1.07	3.29	0.28	0.22	0.33	0.91	0.48	1.55
SAR	—	3.18	2.00	4.50	27.34	22.63	31.97	9.52	3.85	15.35

3.2 SOIL SALINITY

In March 2006, the soil salinity (EC_e) levels at different soil depths extending to 0.9 m decreased in comparison with September 2005 and were in the range of 8.18 dS m^{-1} to 8.28 dS m^{-1}. The soil salinity data indicates lowering the concentration of Na^+, Mg^{2+}, Cl^- and SO_4^{2-} in the topsoil during the winter months. The soil has an alkaline reactivity with soil pH in water ranging from 8.18 to 8.28. The SAR levels indicate that the soil was saline in its characteristics and were in the range of 8.64-10.19 (fall 2005) and 4.36-10.87 (spring 2006). Soil was assessed as moderate saline with sulfate salinity type at the upper 0.30 m soil depth and highly saline with sulfate chloride salinity type at the 0.30-0.90 m depth.

Table 2.2.2.4 Soil salinity levels in dS m^{-1} as affected by wheat and rice rotations

Soil depth (m)	Treatment					
	FR		WRAI		WRTI	
	September	March	September	March	September	March
0-0.15	11.37	7.83 (-45)[a]	17.28	10.54 (-64)	12.02	7.64 (-57)
0.15-0.30	9.08	7.01 (-29)	13.59	9.62 (-41)	9.38	6.46 (-45)
0.30-0.60	8.42	8.89 (+5)	9.85	9.59 (-3)	9.08	6.08 (-49)
0.60-0.90	8.07	11.49 (+30)	12.18	11.96 (-2)	8.11	6.86 (-18)
0-0.90	9.24	8.80 (-10)	13.23	10.42 (-27)	9.65	6.76 (-43)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over September 2005

In March 2006 the soil salinity levels in comparison with September 2005 declined significantly by 27-43 % under WRTI and WRAI treatments (where the water level in the rice check basins was managed under wheat-rice cropping system). Fallow-rice cropping system brings soluble salts from the deeper horizons to the upper 0.30-0.90 m soil depth through the raised groundwater level. Reduction in soil salinity at 0-0.90 m soil depth under FR treatment was found to be 10% (Table 2.2.2.4).

3.3. IRRIGATION PARAMETERS

Winter wheat was irrigated three times (Table 2.2.2.5). First irrigation (1200 m^3 ha^{-1}) was applied to the all treatments in mid October 2005, which was followed by 500 m^3 ha^{-1} second irrigation on 11 April 2006. A third irrigation (500 m^3 ha^{-1}) was applied in late May 2006. The total amount of irrigation applied to winter wheat was estimated as 2200 m^3 ha^{-1}. Since short irrigations were applied for winter wheat, there was no significant difference between traditional and improved irrigation. The total amount of irrigation applied to rice seedlings was found to be 3980 m^3 ha^{-1} under nursery area (0.3 ha). The data given in Table 2.2.2.5 shows significant water savings being achieved using the the approach of transplanting of seedlings.

Table 2.2.2.5 Irrigation rates (m^3 ha^{-1}) of winter wheat and rice during crop season

Treatment	Irrigation					Total
	Wheat			Nursery	Rice	
	1	2	3			
FR	0	0	0	0	27730	27730
WRAI	1200	500	500	3980	13270	19450
WRTI	1200	500	500	3980	13490	19670

Monitoring fluctuations in groundwater level indicates that the water level increased from November to April. Groundwater level varied from 1.31-1.95 m (November 2005) to 0.67 m in April 2006. The negative effect of saline groundwater was suppressed by irrigations applied in April and May 2006 and drainage and high ET lowered the groundwater level up to 1.62 m below the soil surface in May 2006 (Figure 2.2.2.1).

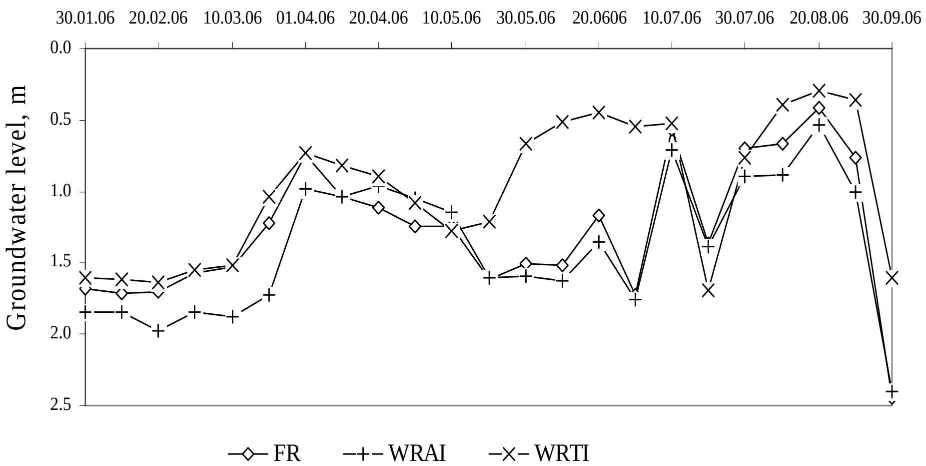


Figure 2.2.2.1 Changes of groundwater level as affected by wheat-rice irrigation

3.4 CROP GROWTH AND YIELD

The winter wheat sown on 10 October 2005 had excellent emergence resulting in an adequate plant density (263 plants m^{-2}) in early April 2006, which was reduced to 238 plants m^{-2} in late April 2006 (heading stage) due to high soil salinity level. Consequently plant height was relatively short and ranged from 0.09 m to 0.28 m during April 2006. In late May 2006, plant height was in the range of 0.44 to 0.60 m. At the grain ripening stage 40-50 grains per ear was observed in early June 2006. The winter wheat was harvested on July 20, 2006 and the yields data are presented in Table 2.2.2.6.

The second crop was rice sown in late May 2006 in a nursery area (0.3 ha). The rice seedling height had an increasing trend from 0.07 to 0.09 m (8th day after sowing) to 0.15-0.18 m (23rd day after sowing). Optimal period for rice seedling transplantation ranged from 25 to 35 days. Rice seedlings were transplanted in optimum time period (late June 2006). However, lack of irrigation from 8 to 28 July 2006 negatively affected the growth and development of rice seedlings. At the ripening stage 40-50 grains per panicle was observed in late September 2006. Rice was harvested in mid October 2006. The rice yields ranged from 0.31 to 1.15 t ha^{-1} (Table 2.2.2.6).

The maximum rice yield (1.15 t ha^{-1}) was obtained under WRAI treatment. Rice yield from other treatments was in the order: 0.53 t ha^{-1} (WRTI) and 0.31 t ha^{-1} (control). In terms of water use, WP of rice crop was the highest (0.067 kg m^{-3}) under WRAI treatment (Table 2.2.2.6). Water productivity from other treatments was of the order: 0.030 kg m^{-3} (WRTI) and 0.011 kg m^{-3} (FR). There was relatively little differences in winter wheat water productivity values under WRAI (1.123 kg m^{-3}) and WRTI (1.145) treatments (Table 2.2.2.6).

Table 2.2.2.6 Winter wheat and rice yields (t ha^{-1}) and water productivity (kg m^{-3}) under different treatments at Akdepe experimental site

Treatment	**Yield**		**Water productivity**	
	Wheat *a*	**Rice** *b*	**Wheat**	**Rice**
FR	—	0.31	—	0.010
WRAI	2.47	1.15	1.123	0.067
WRTI	2.52	0.53	1.145	0.030

[a]Least significance difference (LSD) for wheat at $p = 0.05$ was estimated as 0.22 t ha^{-1}
[b]Least significance difference (LSD) for rice yield at $p = 0.05$ was 0.52 t ha^{-1}

4. CONCLUSIONS

Considering that rice could be reintroduced in rotation with winter wheat in downstream areas of Aral Sea Basin, we carried out a field study in Turkmenistan to evaluate this strategy. The preliminary results reveal that a wheat-rice system using rice seedlings for establishment of rice may provide significant reductions in water use than current local traditional practices. Our results suggest that about 25-35% of irrigation water could be saved by transplanting 30-day-old rice seedlings instead of seeds. However, there would be a need for guarantied water supply, especially during transplanting the seedlings in July.

2.2.3. CROP-BASED MANAGEMENT OF SALINE AND WATERLOGGED SOILS [7]

1. INTRODUCTION

Irrigation has been an important factor in agricultural development. A major problem with irrigated agriculture is its negative environmental impacts. Irrigated agriculture, over the long-term, cannot avoid causing adverse off-site effects due to the drainage water it generates (van Schlifgaarde, 1994). The generation of drainage water by irrigation is a necessity to maintain soil salinity, through leaching, at acceptable levels for crop growth. One strategy for reducing downstream impacts of drainage effluent is to forego leaching and store salt in the lower portion of the root zone. Irrigating in small amounts with increased frequency may keep the water content high and salinity low in the upper root zone. However, a root zone of heterogeneous salinity may develop under irrigation without leaching, and yield reductions occur as salt accumulates first in the lower then the upper root zone (Jame *et al.*, 1984). For long-term productivity, perennial crops such as alfalfa must be able to adapt to increasing root zone salinity. The root zone of an established stand of alfalfa under irrigation extends to 2.5 m. It may be advantageous for deep-rooted crops such as alfalfa to exploit the lower average salinity of the upper root zone preferentially as salinity increases (Minhas and Gupta, 1993). Selection in the field for root traits in alfalfa under varying environmental conditions has had a positive effect on yield. Typically, non-dormant varieties of alfalfa are strongly tap-rooted (Smith, 1993), while increased dormancy is associated with greater branching of the tap root and greater fibrous root mass (Barnes *et al.*, 1988).

Under the current cotton and wheat production system in Uzbekistan, small-scale farmers are not able to apply adequate levels of cost-intensive fertilizers. As a nitrogen-fixing crop, alfalfa (*Medicago sativa* L.) has been shown to enhance the soil fertility. In addition, it is a deep-rooted crop which can extract water from the deeper soil horizons thereby decreasing elevated groundwater levels in the case of waterlogged soils. Introducing this crop into a cotton-wheat rotation could potentially improve the soil fertility of these degraded soils. Because of its ameliorative effect, alfalfa may even reduce the amount of water currently used for leaching.

Wheat-alfalfa cropping system is an appropriate rotation system since the crops are compatible (Caddel *et al.*, 2002). One can be plowed up in time to plant the other within a few months. Also, the array of diseases, insects, and weed pests on wheat and alfalfa are different; thus pest problems are not perpetuated. It is best to follow alfalfa with a non-leguminous species to take advantage of residual nitrogen left in the soil from alfalfa; however, little nitrogen is released from low density alfalfa stands that consist primarily of grassy weeds. Row crops such as maize, grain sorghum, and cotton generally contain few weeds that cause problems in alfalfa. When they are harvested and plowed in the fall, the land can be prepared for sowing alfalfa the following fall. This allows sufficient time to correct pH and fertility problems as well as land shaping to reduce drainage problems. Cultivation during the summer can help control perennial weeds. Soybeans and peanuts (both legumes) are not considered good choices to rotate with alfalfa because of similar pest problems and the loss of opportunity to use residual nitrogen. The current study aims to evaluate the potential of cultivating alfalfa as management option for saline and waterlogged soils.

2. MATERIALS AND METHODS

The study was undertaken at Galaba farm in Bayaut district, Syrdarya Province of Uzbekistan. In fall 2005, winter wheat variety Kroshka was sown on an area of 3.96 ha. At the same time, alfalfa was intercropped with winter wheat on an area of 2.59 ha (WA). The treatments applied were as follows:

Winter wheat (sown in October 2005 and harvested in June 2006)–fallow (later referred to as control)
Winter wheat + Alfalfa intercropping (both crops sown in October 2005, wheat harvested in June 2006 but alfalfa remains in field) (later referred to as WA)

[7] This component was led by ICARDA. NARS partners include L. Shurova, U. Toshbekov, and G. Bezborodov Tashkent Institute of Irrigation and Melioration, Uzbekistan.

2.1. SOIL AND WATER SAMPLING AND ANALYSIS

After laying out the experiment, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Sampling was undertaken before the implementation of the treatments (initial soil condition). The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations such as Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions including carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated from the concentrations of soluble cations Ca^{2+}, Mg^{2+}, and Na^+, expressed as $mmol_c\ L^{-1}$.

Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. The water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-}).

3. RESULTS AND DISCUSSIONS

3.1 PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the particle-size distribution of the USDA classification system, the soil is a silt loam in texture throughout the profile to a depth of 0.90 m. Field Capacity in the upper 0.15 m depth was 23.40%; for the 0.15-0.30 m depth, its value was 24.50%. At the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were estimated at 26.20% and 27.40%, respectively. The rate of infiltration was 8.70 mm h^{-1}. Soil bulk density had an increasing trend from top to deeper horizons and varied in the range of 1.35 to 1.50 g cm^{-3}. The soil salinity levels (February 2006) in terms of TDS at the different soil depths extending down up to 0.90 m were in the range of 4961 mg L^{-1} to 8020 mg L^{-1} (Table 2.2.3.1). The soil had a moderate alkaline reactivity with pH ranging from 8.4 to 8.5. The SAR levels were in the range of 1.82 to 2.16.

Table 2.2.3.1 Soil chemical properties of the experimental site

Soil Characteristic	Unit	Soil depth (m)			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
pH	—	8.44	8.46	8.48	8.49
EC_e	dS m^{-1}	11.45	9.49	8.1	7.3
TDS	mg L^{-1}	8020	6546	5616	4691
Soluble Ca^{2+}	$mmol_c\ L^{-1}$	58.61	40.83	32.78	27.22
Soluble Mg^{2+}	$mmol_c\ L^{-1}$	41.67	41.39	36.39	33.33
Soluble Na^+	$mmol_c\ L^{-1}$	12.92	11.8	11.35	11.88
Soluble K^+	$mmol_c\ L^{-1}$	1.37	0.84	0.55	0.53
Soluble CO_3^{2-}	$mmol_c\ L^{-1}$	abs	abs	abs	abs
Soluble HCO_3^{2-}	$mmol_c\ L^{-1}$	3.93	4.09	3.98	3.6
Soluble Cl^-	$mmol_c\ L^{-1}$	9.68	10.45	10.48	9.87
Soluble SO_4^{2-}	$mmol_c\ L^{-1}$	99.62	80.11	65.93	58.71
SAR	—	1.82	1.84	1.93	2.16

3.2 IRRIGATION, DRAINAGE AND GROUNDWATER QUALITY

The salinity of irrigation water was in range of 1121- 1252 mg L^{-1} (Table 2.2.3.2). The level of SAR was in the range of 1.65 to 1.76, suggesting that irrigation water was non-sodic in its characteristics. Salinity of drainage water was in range of 1135-2380 mg L^{-1}. The level of SAR was in the range of 1.12 to 1.4, suggesting that drainage water was also non-sodic in its characteristics. Groundwater salinity varied widely from 1230 to 12810 mg L^{-1}. The level of SAR was in the range of 1.44 to 13.11, suggesting that groundwater is of marginal quality.

Table 2.2.3.2 Composition of irrigation, ground and drainage water at the experimental site

Index	Unit	irrigation water			groundwater			drainage water		
		mean	min	max	mean	min	max	mean	min	max
EC	dS m^{-1}	1.91	1.76	2.05	4.65	1.50	11.00	3.00	1.96	3.29
TDS	mg L^{-1}	1186	1121	1252	4184	1230	12810	1919	1135	2380
Ca^{2+}	$mmol_c$ L^{-1}	6.76	6.39	7.14	17.31	5.22	29.94	13.36	8.73	16.37
Mg^{2+}	$mmol_c$ L^{-1}	7.56	6.74	8.39	14.94	5.32	27.63	12.19	6.88	15.79
Na^{+}	$mmol_c$ L^{-1}	4.56	4.35	4.78	14.07	4.35	52.17	4.28	3.91	4.57
K +	$mmol_c$ L^{-1}	0.17	0.15	0.2	0.18	0.13	0.25	0.13	0.08	0.15
HCO_3^{2-}	$mmol_c$ L^{-1}	1.85	1.03	2.68	3.22	1.57	5.99	3.13	2.06	4.19
Cl^{-}	$mmol_c$ L^{-1}	10.15	7.30	13	12.02	1.84	25.9	8.55	1.97	13.81
SO_4^{2-}	$mmol_c$ L^{-1}	7.03	2.37	11.7	35.86	6.77	93.69	18.78	3.41	29.2
Ca^{2+}:Mg^{2+}		0.89	0.95	0.85	1.17	0.82	1.67	1.10	1.27	1.04
SAR	—	1.70	1.65	1.76	3.79	1.4	13.1	1.23	1.12	1.40

3.3. IRRIGATION PARAMETERS

Three irrigations were applied for wheat/alfalfa intercropping before the wheat was harvested and two irrigations were applied for alfalfa during September after wheat harvesting (Table 2.2.3.3). There was no water available for irrigation of the crops during June – August, when farmers had limited water for irrigation of cotton which is the state controlled crop and some farmers had chance to apply water for rice which is most profitable crop for them in the region.

Table 2.2.3.3 Irrigation rates (m^3 ha^{-1}) of winter wheat and alfalfa

Treatment	Wheat irrigation rates				Alfalfa irrigation rates			Total
	15.11.05	17.03.06	24.04.06	Total	06.09.06	30.09.06	Total	
Control	800	900	560	2260	—	—	—	2260
WA	800	900	560	2260	1200	1000	2200	4460

Timings of irrigations applied for alfalfa were not optimal. The irrigations were applied during September twice. Poor recovery of alfalfa after wheat harvesting due to dry soil and the lack of irrigation had a limited effect on groundwater in the alfalfa treatment (Figure 2.2.3.1).

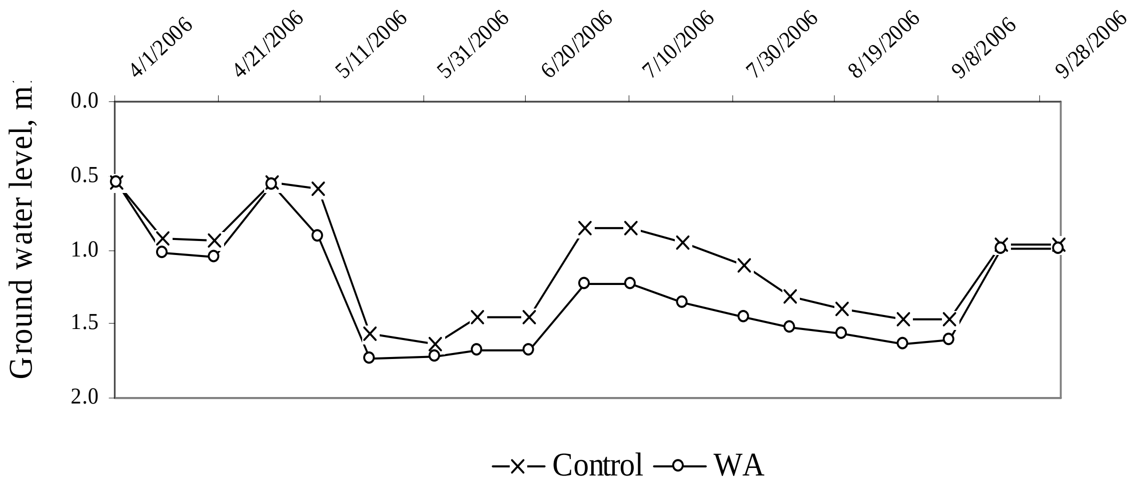


Figure 2.2.3.1 Changes in groundwater level under different treatments listed above

Even in these extreme conditions with poor recovery of alfalfa after harvesting wheat, there were indicating that the crop had a positive impact on groundwater height (Figure 2.2.3.1). The groundwater level under wheat/alfalfa intercropping was at the same depth as the control until March and April. Thereafter from mid June to mid August the difference between the treatments with alfalfa and no alfalfa was in the range of 0.21-0.40 m.

During the irrigation events, changes of groundwater storage indicated infiltration losses, while between irrigation - groundwater contributed to evapotranspiration (ET). Calculations indicated that the contribution of groundwater to ET was 2096 m^3 ha^{-1} under control and 2892 – 2580 m^3 ha^{-1} under the wheat and alfalfa intercropping treatment. Infiltration losses were estimated at 2641 m^3 ha^{-1} under control and 1870–1407 m^3 ha^{-1} under wheat/alfalfa intercropping. The data suggest that wheat/alfalfa intercropping increases the contribution of groundwater to ET and at the same time reduces percolation losses of irrigation water by 30-40%.

3.4. CROP GROWTH AND YIELD

Winter wheat was at the panicle emergence stage in early April 2006, bushing out stage on 20 April 2006, and flowering stage in early May 2006. Average plant density of wheat in the WA treatment was 318 plants m^{-2} in April 2006, while under control this parameter was equal to 265 plants m^{-2} . Average plant height of wheat under the WA treatment was 0.59 m. whereas it was 0.45 m under control. Yield data, presented in Table 2.2.3.4, suggest that the reduction of yield of winter wheat in wheat/alfalfa intercropping was 7% as compared to control, where wheat was sown without intercropping, but it was not statistically significant. Average plant density of alfalfa was 171 plants m^{-2} in early May 2006. After harvesting of wheat (mid June 2006), the height of residual alfalfa' stems was 0.32 m. Losses of the alfalfa green biomass were estimated at 96.35 g m^{-2} or 0.96 t ha^{-1}. Biological yield of alfalfa green biomass were estimated at 3.40 t ha^{-1} under the WA treatment (Table 2.2.3.4).

Table 2.2.3.4 Winter wheat and alfalfa plant density, plant height and yields

Treatment	Winter wheat			Alfalfa		
	Plant density	Plant height	Yield [a]	Plant density	Plant height	Yield
Control	265	0.45	2.60	—	—	—
WA	318	0.59	2.42	171	0.32	3.40

[a] Least significance difference (LSD) at $p = 0.05$ was estimated as 0.88 t ha^{-1}

4. CONCLUSIONS

Intercropping of alfalfa with wheat contributed to increase soil organic matter vis-à-vis soil fertility in the form of root biomass estimated at 3.4 t ha^{-1} in the soil during the first year. The cultivation of alfalfa caused a decrease in groundwater level by 0.21-0.40 m even when there was a water shortage that impacted the growth of the plant species for about 1-2 months. Lack of irrigation of alfalfa just after harvesting of wheat significantly affected to growth and biomass of alfalfa.

2.2.4 MANAGEMENT OF RICE-WHEAT CROPPING SYSTEM FOR SALINE SOILS THROUGH DIFFERENT TILLAGE OPTIONS [8]

1. INTRODUCTION

Rice-wheat rotation is one of the important cropping systems in Central Asia (Ryan *et al.*, 2004). The major rice cultivation area is in southern Tajikistan, Uzbekistan (three provinces: Syrdarya, Khorezm and Karakalpakistan), and southern Turkmenistan, and Kazakhstan (two provinces: Kyzyl-Orda and southern Kazakhstan). A major continuous part of the rice-wheat rotation is in the southern part of Kazakhstan and Uzbekistan. In the pre-independence era in Uzbekistan, wheat was cultivated mainly in rainfed areas, with yields usually lower than 1.8 t ha^{-1}, providing only 20% of the country's needs (AHT, 1999; Vlek *et al.*, 2002). Current estimates suggest that Uzbekistan needs to produce at least 4.2 million tons of wheat to meet domestic requirements. Since 1991, cultivation patterns have changed significantly. In 1999, cereals were cultivated on 1.72 million ha; 80% of this (i.e. 1.36 million ha) being under irrigation. Winter wheat, cultivated on 1.42 million ha (83%), is the most dominant among cereal crops. Wheat cultivation is undertaken now mainly at the expense of alfalfa. Other important crops are rice (164,000 ha), barley (59,000 ha), and maize (57,000 ha) (Mc. Quistion *et al.* 2000; Vlek *et al.*, 2002).

For centuries rice has been a traditional crop for farmers of Karakalpakistan. During the rice-growing period in the lower reaches of the Syr-Darya and Amu-Darya river basins, water consumption rates were high as traditional rice growing practices (including broadcasting and no mulching) were used. Direct sowing and poor land leveling demanded higher levels of water application under flooded irrigation regimes thereby increasing the overall amount of water diverted for rice cultivation. Under such management practices, the annual amount of water required for growing rice ranged from 26,000 to 30,000 m^3 ha^{-1} in the lower Aral Sea Basin. Between 1992 and 2000, the area under rice cultivation in Uzbekistan declined from 182,000 ha to 65,000 ha, equivalent to a 65% decrease in rice growing area with a concomitant decline in rice production (Wegerich, 2001). Growing irrigation demand in the middle reaches of the Syr-Darya and Amu-Darya resulted in significant reductions in irrigation water availability in downstream areas. For example, the total amount of water diverted from Amu-Darya to Khorezm Province has declined from 5.84 (in 1985) to 3.7 km^3 yr^{-1} (in 2000) in years of low water flows, and to Karakalpakistan from 9.36 to 8.87 km^3 yr^{-1}.

Both winter wheat and cotton have become the dominant components of farming systems in the region with farmers being obliged to grow the crops on saline and waterlogged soils in the lower reaches of Syr-Darya and Amu-Darya river basins. Current wheat production practices involve growing the crop over the fall and winter with a summer fallow, which results in the movement of salts to the surface due to capillary rise from a saline, shallow water table. Consequently, leaching of salts is undertaken in July-September when water demand for irrigation is at its peak for the production of cotton in the region.

Despite the reduction in area under rice, the extent of waterlogging in Khorezm Province with groundwater levels < 1.5 m has increased from 126,600 ha to 178,600 ha (41% increase in waterlogged area) with an associated increase in groundwater salinity to 3.5 g L^{-1} (Karimov *et al.*, 2006). Salt-induced land degradation and water quality deterioration have further compounded the situation. These factors have resulted in a significant decline in production levels of cotton and wheat with yields not exceeding 2.0 and 2.8 t ha^{-1} respectively. In order to facilitate the growing of cotton in the area, leaching (18,000 m^3 ha^{-1}) of accumulated salts within the root zone is undertaken annually. Such high levels of water consumption results in extremely low levels of water productivity. For example, raw cotton productivity is as low as 0.11 kg m^{-3}. Similar trends in water productivity have been observed in Dashauz Province of Turkmenistan, Kzyl-Orda Province of Kazakhstan, and Karakalpakistan in Uzbekistan.

Rice is a suitable arable crop for cultivation on saline soils and/or irrigation with saline water. Higher rates of water application for rice during its growth period also lead to leaching of salts from the root zone for the

[8] This component was led by ICARDA. NARS partners include R. Koshekov, G. Seitnazarov, and G. Bezborodov Uzbek Cotton Growing Research Institute, Ministry of Agriculture, Uzbekistan

subsequent crops. Such irrigation eliminates or minimizes the need for salt leaching from these soils. Recently some farmers in Khorezm have incorporated rice as a summer crop within the winter wheat monoculture system. This has been achieved through the transplanting of 35-40 day old early maturing rice varieties into flooded fields. The seedlings are established in a nursery that is sufficient in providing planting material for transplanting. The area under nursery is less than 10% of its transplanted area. By transplanting 'mature' rice seedlings, significant savings in water (20-25%) are achieved when compared to direct sowing of rice seed. Using such an approach, farmers in Gurlen and Shavat districts of Khorezm region have achieved wheat yields of 3-4 t ha^{-1} and rice yields of 5-6 t ha^{-1} (Karimov *et al.*, 2006). It is argued that significant improvements in this approach could be made to enhance the productivity and viability of this system.

A 3-year field study in the lower reaches of the Amu-Darya Basin in Karakalpakistan was undertaken to evaluate rice-wheat cropping system as a management option for saline and waterlogged soils to enhance crop productivity and provide additional income for the farming communities of the area.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND SITE CHARACTERIZATION

This on-farm study was carried out during the years 2005-2007 in Uzbekistan. The experiment was carried out in the Kzyl Uzyak farm of Chimbay district of Karakalpakistan. Long-term annual precipitation ranges from 50 to 220 mm, with 90% occurring during October through May. The period with temperature above 10^{o}C is 196 days and begins on 18 March and ends on 11 November. Average monthly temperature is below zero during winter months and exceeds 20^{o}C during May-August. Site characterization was undertaken in May 2005. The area has a smooth landscape with slopes from 0.002 to 0.0035. The average precipitation during April-September was in the range of 20-29 mm. The average precipitation during October-May (wheat grown period) was in the range of 68.9-124.8 mm. The source of irrigation water is Amu-Darya River. The concentration of soluble salts in water ranges from 500 to 1500 mg L^{-1}. The soils are heavy loam with about 1% organic matter in the surface layer. Soil bulk density is 1.36±0.17 Mg m^{-3} and the pH varies narrowly from 8.3 to 8.5.

2.2. TREATMENTS

The experimental treatments were designed based on the following factors: (1) *tillage* — comparing traditional tillage practices followed by broadcasting of wheat with no-tillage wheat sowing, i.e., zero tillage using a Brazilian seeder; (2) *land leveling* — comparing precision land leveling with no land leveling; and (3) *crop rotation* — cultivating rice and wheat alone and in rotation. There were seven treatments, details of which are given below and schematically in the cropping calendar that follows :

Fallow (until June 2006) – rice (sown in June 2006 and harvested in October 2006) – fallow (October to June 2007) – rice (sown in June 2007 and harvested in October 2007); flood irrigation practices for rice: Later referred to as FR
Same as in treatment 1 + land leveled: Later referred to as FR+LL
Winter wheat (sown in October and harvested in June 2006) – rice (sown in June and harvested in the end of September) – wheat (sown in October and harvested in June 2007) – rice (sown in June and harvested in October 2007) + zero tillage for winter wheat + land leveled: Later referred to as WR+ZT+LL
Same as in treatment 3 but without zero tillage + traditional tillage: Later referred to as WR+TT+LL
Same as in treatment 3 but without land leveling: Later referred to as WR+ZT
Same as in treatment 4 but without land leveling: Later referred to as WR+TT
Winter wheat (sown in October and harvested in June 2006) – fallow (from June to September) – wheat (sown in October and harvested in June 2007) – fallow (from June to September 2007) – winter wheat (sown in October and harvested in June 2008): Later referred to as WF

2.3. SOIL AND WATER SAMPLING AND ANALYSIS

After the delineation of plots, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Sampling was undertaken prior to the implementation of the treatments (initial soil condition) and after harvest of rice in each cropping years. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations including Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions including carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated using Equation 2.2.4.1 from the concentrations (C) of soluble cations Ca^{2+}, Mg^{2+}, and Na^+, expressed as $mmol_c\ L^{-1}$.

$$SAR = C_{Na} / [(C_{Ca} + C_{Mg})/2]^{1/2} \quad [2.2.4.1]$$

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was determined on a randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent.

Field capacity was determined from one randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture in the following days over a period of 3-5 days until stabilization was achieved at all the soil depths. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer ring diameter of 0.4 m and inner ring diameter of 0.3 m. Both rings buried in the soil to a depth of 0.1-0.15 m. Soil bulk density was determined on undistributed soil samples collected from each soil depth using the core method. Soil moisture content was determined by the gravimetric method. Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater levels were monitored each month. Water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-}).

2.4. EXPERIMENTAL PROCEDURE

In mid August 2005, land leveling was undertaken on the FR and FR+LL treatments with a land leveler attached to a tractor (model T-130). Winter wheat variety Chillaki was sown with a Brazilian seeder (Model: Zero-Till-Drill) at a seed rate of 200 kg ha^{-1} on the area under the FR and WR+ZT+LL treatments in mid September 2005. The field was plowed to a depth of 0.20 m (FR+LL, WR+TT+LL, WR+ZT treatments) in mid September 2005, which was followed by sowing of wheat variety Chillaki (WR+TT+LL, WR+TT). Wheat variety Polovchanka (local wheat variety, which is mostly used by farmers in the area) was sown by broadcasting in mid September 2005 (WF). Just before sowing, harrowing was undertaken with a harrow (Model: ZBS-1) pulled to a tractor (Model: MTZ 80). The fallow field for rice transplantation was ploughed to a depth of 0.20-0.25 m in last week of May 2006, which was followed by manual land leveling. Rice Nukus-2 variety was sown by manual broadcasting at a seed rate of 530 kg ha^{-1} in a nursery area of 0.15 ha on 28 May 2006. Rice of the same variety was sown by manual broadcasting at a seed rate of 180 kg ha^{-1} on control in early June 2006. Traditional farming practices were applied to the control treatment.

In the subsequent years (2006-2007), all the agronomic practices were the same except plowing was undertaken in early November in 2006 and late sowing of winter wheat (early November 2006 and late March 2007). In addition, in order to lower elevated groundwater levels, cleaning of collector drains was done on 4 February 2007. Due to higher soil moisture the sowing winter wheat was delayed for 2 months thereby influencing the growth of young wheat plants. Therefore, winter wheat was replanted and another wheat variety KKNIIZ-1 and was sown by broadcasting on 24 March 2007 in the WR+TT+LL, WR+TT, WF treatments.

Cropping sequence of experimental treatments

FR	Fallow								Rice				Fallow								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
FR+LL	Fallow								Rice				Fallow								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
WR+ZT+LL	Winter wheat								Rice				Winter wheat								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
WR+TT+LL	Winter wheat								Rice				Winter wheat								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
WR+ZT	Winter wheat								Rice				Winter wheat								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
WR+TT	Winter wheat								Rice				Winter wheat								Rice				Fallow		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											
WF	Winter wheat								Fallow				Winter wheat								Fallow						
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
	2005			2006												2007											

3. RESULTS AND DISCUSSION

3.1. SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the USDA classification system for particle-size distribution, the field soil is silt loam in the upper 0.60 m, and loam in the 0.60-0.90 m depth (Table 2.2.4.1). Field capacity in the upper 0.15 m depth was 20.15%; for the 0.15-0.30 m depth was estimated to be 21.85%. At the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were estimated to be 23.20% and 23.86%, respectively. The infiltration rate was relatively low at 2.91 mm h^{-1}, which may be a consequence of soil bulk density increasing from surface to deeper horizons and varied from 1.19 to 1.53 Mg m^{-3}.

Table 2.2.4.1 Physical properties of the experimental field in Chimbay district of Karakalpakistan

		Soil depth (m)			
Soil properties	**Unit**	**0.0-0.15**	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
Sand particles (0.05-2.0 mm)	%	25.86	25.59	32.47	36.47
Silt particles (0.002-0.05 mm)	%	55.84	54.66	51.36	46.21
Clay particles (<0.002 mm)	%	18.64	18.55	16.30	17.22
Soil texture (method USDA)	—	silt loam	Silt loam	silt loam	loam
Field capacity	%	20.15	21.85	23.73	23.86
Infiltration rate	mm h^{-1}	2.91	—	—	—
Soil bulk density	Mg m^{-3}	1.19	1.36	1.53	1.47

The pre-experiment soil salinity levels in terms of TDS at different soil depths extending to 0.90 m were in the range of 3872 mg L^{-1} to 10450 mg L^{-1} (Table 2.2.4.2). The corresponding EC_e values were in the range of 5.48-15.68 dS m^{-1}. Among the anions, SO_4^{2-} was dominant with a concentration of 93.69 $mmol_c$ L^{-1} in the upper 0.15 m depth. The concentration of SO_4^{2-} had a decreasing trend from surface to deeper horizons and varied from 37.77 to 93.69 $mmol_c$ L^{-1}. Chloride (Cl^-) concentration was less than that of SO_4^{2-} and ranged from 13.29 to 55.81 $mmol_c$ L^{-1} at different soils depths. Its concentration had a decreasing trend from the surface to deeper horizons. There were trace concentrations of HCO_3^{2-}, ranging from 3.78 to 4.90 $mmol_c$ L^{-1}. The soil has an alkaline reactivity with pH in water ranging from 8.45 to 8.49. The SAR levels had a decreasing trend from surface to deeper horizons and were in the range of 4.20 to 6.60.

Table 2.2.4.2 Chemical properties of the field site before start of the experiment

		Soil depth (m)			
Soil characteristic	**Unit**	**0.0-0.15**	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
pH	—	8.47	8.48	8.45	8.49
EC_e	dS m^{-1}	15.68	9.63	6.69	5.48
TDS	mg L^{-1}	10450	6580	4657	3872
Soluble Ca^{2+}	$mmol_c$ L^{-1}	69.40	40.42	26.43	22.38
Soluble Mg^{2+}	$mmol_c$ L^{-1}	37.68	25.95	17.50	13.81
Soluble Na^+	$mmol_c$ L^{-1}	48.30	28.85	22.11	17.85
Soluble K^+	$mmol_c$ L^{-1}	1.39	1.13	0.86	0.75
Soluble HCO_3^{2-}	$mmol_c$ L^{-1}	4.90	4.33	3.95	3.78
Soluble Cl^-	$mmol_c$ L^{-1}	55.81	31.84	17.11	13.29
Soluble SO_4^{2-}	$mmol_c$ L^{-1}	93.69	60.53	45.45	37.77
SAR	—	6.60	5.01	4.72	4.20

3.2. IRRIGATION, DRAINAGE, AND GROUNDWATER QUALITY

The source of irrigation water is Amu Darya River. The salt concentration in low-saline irrigation had a slightly increasing trend and ranged from 807 to 1161 mg L^{-1} (1.18-1.80 dS m^{-1}) during the cropping seasons of 2005-2007 (Table 2.2.4.3). The dominant cations were Na^+ and Ca^{2+} during 2005, Ca^{2+} and Mg^{2+} during 2006, Ca^{2+} and Na^+ over 2007. The concentrations of Na^+ varied from 3.13 to 4.93 $mmol_c$ L^{-1}. The concentrations of Ca^{2+} were in the range of 4.00 to 10.65 $mmol_c$ L^{-1}. The concentration of Mg^{2+} ranged from 2.75 to 5.04 $mmol_c$ L^{-1}.

The anionic concentration in irrigation water sampled during crop season 2005-2007 indicated SO_4^{2-} as the dominant anion having concentration of 6.73-7.90 $mmol_c$ L^{-1}. The concentration of Cl^- was less compared to that of SO_4^{2-} and was in the range of 2.47-7.51 $mmol_c$ L^{-1}. The levels of SAR and SAR_{adj} ranged from 1.39-3.07. The irrigation water has a low alkaline reaction, and is slightly saline. Irrigation conducted by applying this quality water is not expected to cause sodicity problems in the soil.

Table 2.2.4.3 Composition of irrigation water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{iw}	dS m^{-1}	1.18±0.30	1.34±0.08	1.80±0.24	1.44±0.18[a]
TDS	mg L^{-1}	807±248	874±61	1161±176	947±107
Ca^{2+}	$mmol_c$ L^{-1}	4.00±0.41	5.17±0.43	10.65±1.76	6.61±2.05
Mg^{2+}	$mmol_c$ L^{-1}	2.75±0.25	5.04±0.48	3.29±1.43	3.69±0.69
Na^+	$mmol_c$ L^{-1}	4.93±2.98	3.13±0.93	4.02±1.52	4.02±0.52
K^+	$mmol_c$ L^{-1}	0.10±0.02	0.10±0.03	Abs	0.1±0.002
HCO_3^{2-}	$mmol_c$ L^{-1}	1.99±0.14	2.52±0.35	2.53±0.22	2.35±0.18
Cl^-	$mmol_c$ L^{-1}	2.47±0.49	4.18±1.35	7.51±0.53	4.72±1.48
SO_4^{2-}	$mmol_c$ L^{-1}	7.36±2.79	6.73±2.22	7.90±2.12	7.33±0.34
Cl^-:SO_4^{2-}	—	0.39±0.05	1.19±0.86	1.05±0.19	0.87±0.25
Mg^{2+}:Ca^{2+}	—	0.69±0.04	0.97±0.02	0.35±0.20	0.67±0.18
SAR	—	2.68±1.59	1.39±0.44	1.52±0.58	1.86±0.41
SAR_{adj}	—	3.07±1.77	1.62±0.49	1.78±0.65	2.16±0.46

[a] Figures with ± indicate standard error of the mean

The salt concentration in drainage water sampled in 2005-2007 was in the range of 1383-2693 mg L^{-1}(2.05-3.96 dS m^{-1}) during the crop season of 2005-2007 (Table 2.2.4.4). The dominant cations were Na^+ and Ca^{2+} during 2005, Ca^{2+} and Mg^{2+} during 2006, Mg^{2+} and Ca^{2+} during 2007. The concentrations of Na^+ varied in the range of 9.31 to 10.85 $mmol_c$ L^{-1}. The concentrations of Ca^{2+} were in the range of 6.00 to 17.05 $mmol_c$ L^{-1}. The concentration of Mg^{2+} ranged from 3.50 to 12.75 $mmol_c$ L^{-1}.

The anionic concentration in drainage revealed that SO_4^{2-} as the dominant anion having concentration of 14.42-25.10 $mmol_c$ L^{-1} during 2005-2007. The concentration of Cl^- (3.10-12.0 $mmol_c$ L^{-1}) was much less than that of SO_4^{2-}. The concentration of HCO_3^- was less than the concentration of Cl^- with its values ranging from 2.50-5.72 $mmol_c$ L^{-1}. The levels of SAR and SAR_{adj} were in the range of 0.81 to 3.26, indicating that the drainage water was non-sodic in its characteristics.

The salt concentration in the ground water was in range of 2225 to 5116 mg L^{-1} (Table 2.2.4.5). The dominant cations were Na^+ and Mg^{2+} during 2005, Ca^{2+} and Mg^{2+} during 2006-2007. The concentrations of Na^+ varied over the range 8.69 to 33.79 $mmol_c$ L^{-1}. The concentrations of Ca^{2+} were in the range of 13.82 to 22.00 $mmol_c$ L^{-1}. The concentration of Mg^{2+} ranged from 11.18 to 25.67 $mmol_c$ L^{-1}. The anionic concentration in saline groundwater sampled indicated SO_4^{2-} as the dominant anion. The levels of SAR of the ground water were in the range of 2.43 to 7.80 suggesting that the use of such drainage water for irrigation without appropriate management practices may cause gradual increase in Na^+ levels in the irrigated soils.

Table 2.2.4.4 Composition of drainage water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{dw}	dS m^{-1}	2.05±0.60	3.96±0.48	3.71±0.53	3.1±0.60[a]
TDS	mg L^{-1}	1383±428	2693±431	2169±276	208±381
Ca^{2+}	$mmol_c$ L^{-1}	6.00±0.00	17.05±4.21	13.57±1.86	12.21±3.26
Mg^{2+}	$mmol_c$ L^{-1}	3.50±0.50	12.75±1.21	14.20±4.20	10.15±3.35
Na^{+}	$mmol_c$ L^{-1}	10.85±6.51	9.62±1.80	9.31±3.02	8.57±0.47
K^{+}	$mmol_c$ L^{-1}	0.12±0.01	0.14±0.03	Abs	0.13±0.01
HCO_3^{2-}	$mmol_c$ L^{-1}	2.50±0.50	5.72±0.44	4.64±1.09	4.29±0.95
Cl^{-}	$mmol_c$ L^{-1}	3.10±0.85	10.10±3.49	12.00±2.19	8.40±2.71
SO_4^{2-}	$mmol_c$ L^{-1}	14.42±5.58	25.10±8.74	16.69±2.60	18.74±3.25
$Cl^{-}:SO_4^{2-}$	—	0.23±0.03	0.70±0.33	0.72±0.09	0.73±0.16
$Mg^{2+}:Ca^{2+}$	—	0.58±0.08	0.85±0.17	0.96±0.21	0.93±0.11
SAR	—	2.86±1.87	0.81±0.54	2.50±0.91	1.69±0.63
SAR_{adj}	—	3.26±2.08	0.98±0.60	2.87±1.02	1.96±0.70

[a] Figures with ± indicate standard error of the mean

Table 2.2.4.5 Composition of ground water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{gw}	dS m^{-1}	8.19±3.34	3.45±0.59	3.87±0.28	5.17±1.51[a]
TDS	mg L^{-1}	5116±1980	2225±361	2235±163	3192±962
Ca^{2+}	$mmol_c$ L^{-1}	22.00±3.51	14.41±3.28	13.82±1.36	16.74±2.63
Mg^{2+}	$mmol_c$ L^{-1}	25.67±13.17	11.18±0.99	12.53±1.78	16.46±4.62
Na^{+}	$mmol_c$ L^{-1}	33.79±16.64	8.69±3.12	12.40±1.97	18.29±7.82
K^{+}	$mmol_c$ L^{-1}	0.39±0.14	0.18±0.04	abs	0.29±0.88
HCO_3^{2-}	$mmol_c$ L^{-1}	6.40±1.22	4.84±0.57	4.23±0.51	5.16±0.65
Cl^{-}	$mmol_c$ L^{-1}	30.92±15.13	10.11±2.86	12.42±0.95	17.82±6.59
SO_4^{2-}	$mmol_c$ L^{-1}	39.89±18.29	20.01±5.07	17.16±2.01	25.68±7.15
$Cl^{-}:SO_4^{2-}$	—	0.75±0.03	0.77±0.42	0.75±0.06	0.76±0.01
$Mg^{2+}:Ca^{2+}$	—	1.05±0.37	0.87±0.14	0.97±0.19	0.96±0.05
SAR	—	6.92±2.07	2.43±0.76	3.42±0.45	4.26±1.36
SAR_{adj}	—	7.80±2.31	2.79±0.85	3.89±0.50	4.83±1.52

[a] Figures with ± indicate standard error of the mean

3.3. SOIL SALINITY AND SODICITY

Salinity determinations made on soil samples collected after harvest of rice in 2006-2007 reflect an overall decrease in EC_e in the upper 0.15 m depth and overall increase in the 0.60-0.90 m soil depth with respective to the pre-experiment levels (Table 2.2.4.6). Only FR treatment increased the soil salinity level throughout the soil profile by 1-45% (2006) and 6-192% (2007) over initial level in 2005. The decreases in EC_e levels were 14-52% (2006), 41-52% (2007) over the respective initial levels at the 0-0.15 m soil depth.

Table 2.2.4.6 Soil salinity levels expressed as EC_e (dS m^{-1}) as affected by various treatments

Soil depth (m)	Initial soil (2005)	Post-rice (2006)	Post-rice (2007)
FR			
0-0.15	12.81	8.18(-36)	6.10 (-52)
0.15-0.30	7.95	8.20 (+3)	5.93 (-25)
0.30-0.60	7.69	6.82 (-11)	4.96 (-36)
0.60-0.90	6.15	6.02 (-2)	6.53 (+6)
FR+LL			
0-0.15	13.44	6.73 (-50)	7.67 (-43)
0.15-0.30	5.87	6.13 (+4)	6.33 (+8)
0.30-0.60	5.33	4.92 (-8)	11.79 (+121)
0.60-0.90	4.63	4.97 (+7)	7.40 (+60)
WR+ZT+LL			
0-0.15	10.05	6.65 (-34)	11.34 (+13)
0.15-0.30	6.22	7.76 (+25)	8.06 (+30)
0.30-0.60	5.19	7.93 (+53)	6.11 (+18)
0.60-0.90	4.52	9.18 (+103)	7.26 (+61)
WR+TT+LL			
0-0.15	23.02	10.96 (-52)	10.95 (-52)
0.15-0.30	15.4	4.47 (-71)	8.82 (-43)
0.30-0.60	8.3	8.30 (0)	8.17 (-2)
0.60-0.90	6.88	6.58 (-4)	9.08 (+32)
WR+ZT			
0-0.15	17.64	13.31 (-25)	10.43 (-41)
0.15-0.30	7.58	10.74 (+42)	9.03 (+19)
0.30-0.60	5.13	10.68 (+108)	6.70 (+31)
0.60-0.90	4.44	7.95 (+79)	5.70 (+28)
WR+TT			
0-0.15	20.07	17.32 (-14)	11.93 (-41)
0.15-0.30	15.16	12.78 (-16)	10.38 (-32)
0.30-0.60	8.09	9.79 (+21)	9.97 (+23)
0.60-0.90	6.64	4.67 (-30)	7.15 (+8)
WF			
0-0.15	12.69	13.23 (+4)	30.82 (+143)
0.15-0.30	9.26	9.37 (+1)	9.78 (+6)
0.30-0.60	7.1	8.38 (+18)	7.61 (+7)
0.60-0.90	5.08	7.36 (+45)	14.84 (+192)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over initial level (2005)

Maximum decrease in the soil salinity (52%) at the 0-0.15 m soil depth over the initial soil salinity level was observed under WR+TT+LL treatment in 2006-2007 (Table 2.2.4.6). At the same time, the average EC_e of the leveled plots (FR+LL, WR+ZT+LL, WR+TT+LL treatments) at the 0-0.15 m soil depth at the end of crop season in 2006-2007 was lower than that of the non-leveled plots (FR,WR+ZT, WR+TT, WF). The maximum reduction (60%) was observed in 2006, followed by 48% in 2007, whereas this parameter did not change significantly in 2005 (2%) as shown in Figure 2.2.4.2. It is indicated land leveling could significantly reduce the salt accumulation at the upper soil depth (0-0.15 m) in the first-two yeas.

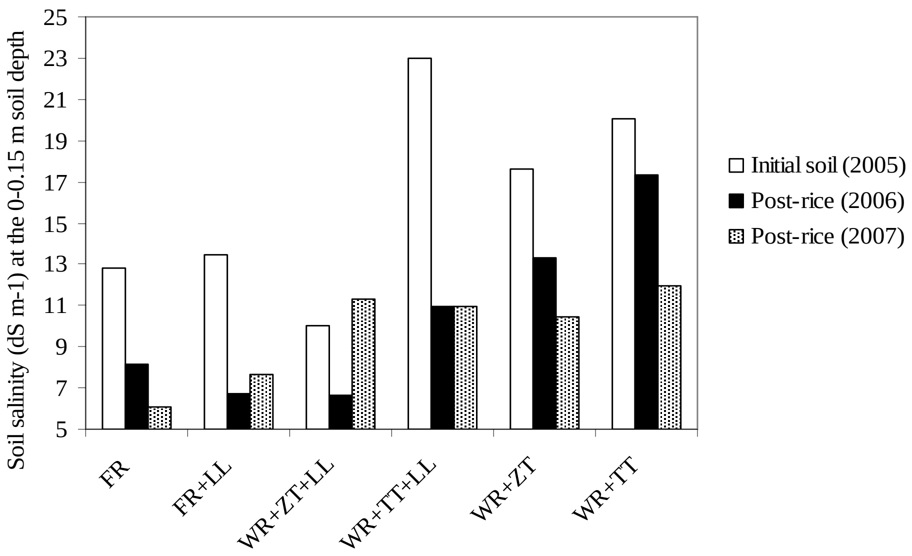


Figure 2.2.4.1 Soil salinity level as affected by different treatments in 2006-2007

Zero tillage technologies applied under winter wheat crop also reduced the soil salinity level as compared with traditional tillage technologies. The averaged the soil salinity levels under WR+ZT+LL and WR+ZT treatments were lower by 5-36% in comparison with traditional tillage applied treatments (WR+TT+LL, WR+TT). The maximum reduction (36%) was observed in 2005, followed by 29% in 2006, whereas this parameter did not change significantly in 2007 (5%) as shown in Figure 2.2.4.3. This suggests that Zero-tillage can significantly reduce the salt accumulation at the upper soil depth (0-0.15 m) in the first-two yeas.

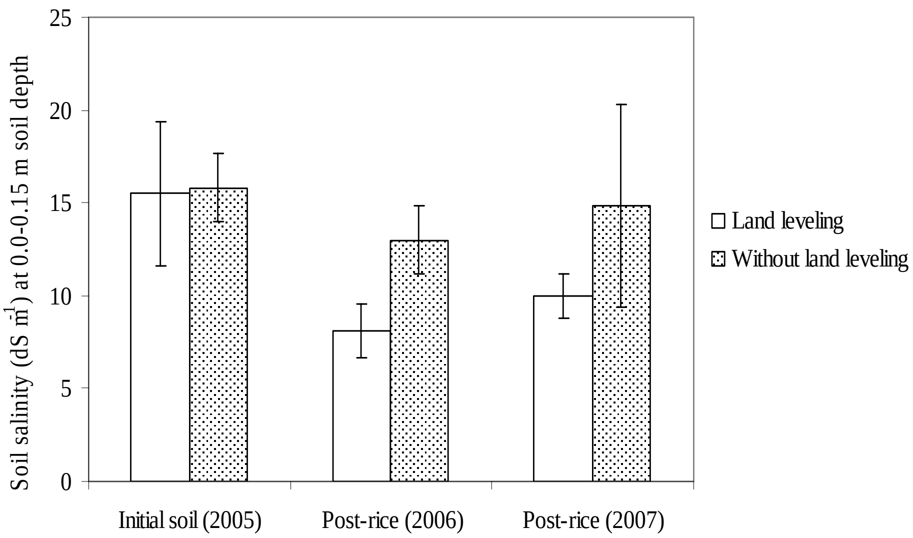


Figure 2.2.4.2 Effect of land leveling on salt accumulation after harvest of rice in 2006 and 2007

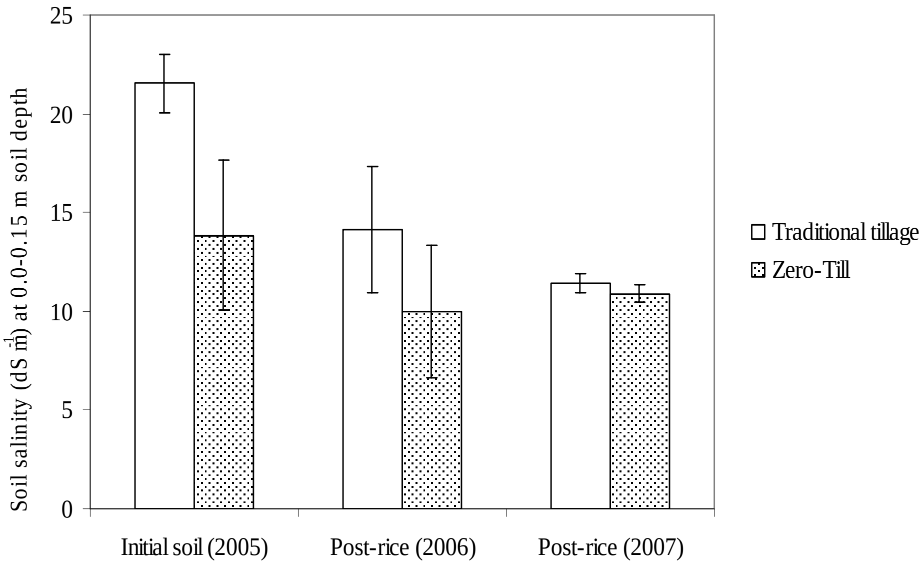


Figure 2.2.4.3 Effect of zero-tillage on salt accumulation after harvest of rice in 2006 and 2007

Sodium absorption ratio estimations made on soil samples collected after harvest of rice in 2006-2007 indicate an overall decrease in SAR at the upper 0.15 m depth with respective to the pre-experiment levels (Table 2.2.4.7). The decreases in SAR levels were 26-48% (2006), 33-61% (2007) over the respective initial levels at the 0-0.15 m soil depth

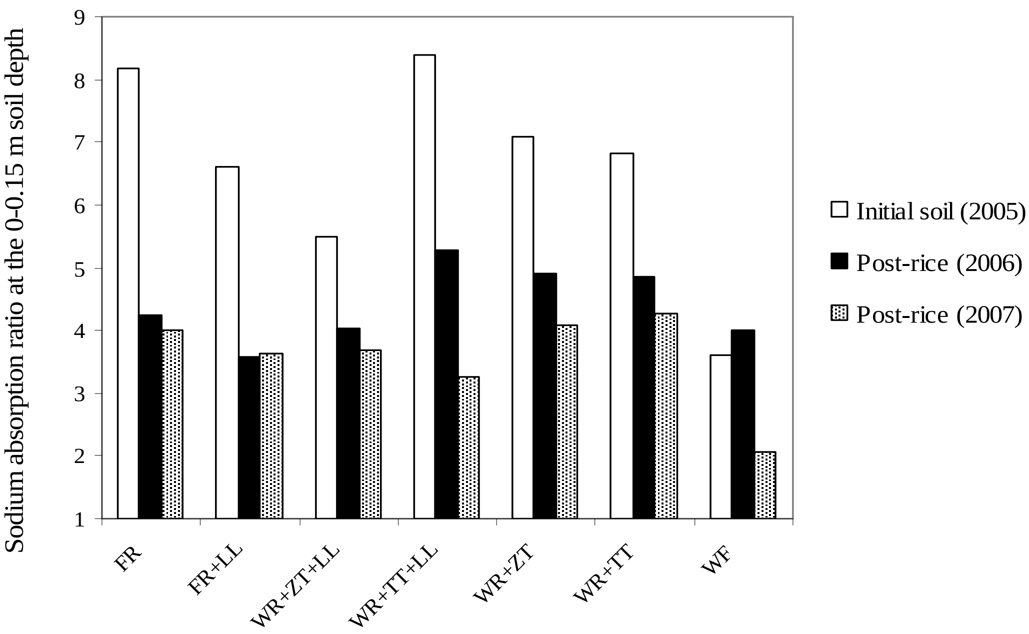


Figure 2.2.4.4 Sodium absorption ratio of the upper 0.15 m soil depth as affected by different treatments in 2006-2007

Table 2.2.4.7 Sodium absorption ratio (SAR) in the soil profile as affected by various treatments

Soil depth (m)	Initial soil (2005)	Post-rice (2006)	Post-rice (2007)
	FR		
0-0.15	8.17	4.25 (-48) [a]	4.01 (-51)
0.15-0.30	7.41	3.10 (-58)	3.49 (-53)
0.30-0.60	8.89	2.65 (-70)	3.52 (-60)
0.60-0.90	7.00	3.37 (-52)	3.65 (-48)
			FR+LL
0-0.15	6.61	3.58 (-46)	3.63 (-45)
0.15-0.30	5.69	3.59 (-37)	3.59 (-37)
0.30-0.60	4.97	3.59 (-28)	3.10 (-38)
0.60-0.90	5.49	3.02 (-45)	2.46 (-55)
	WR+ZT+LL		
0-0.15	5.48	4.03 (-26)	3.68 (-33)
0.15-0.30	3.43	3.91 (+14)	4.23 (+23)
0.30-0.60	3.38	4.07 (+20)	3.86 (+14)
0.60-0.90	2.75	4.38 (+59)	2.76 (0)
	WR+TT+LL		
0-0.15	8.38	5.29 (-37)	3.25 (-61)
0.15-0.30	5.24	3.25 (-38)	3.94 (-25)
0.30-0.60	4.03	4.17 (+3)	3.38 (-16)
0.60-0.90	3.20	3.34 (+4)	3.62 (+13)
	WR+ZT		
0-0.15	7.09	4.92 (-31)	4.07 (-43)
0.15-0.30	4.13	4.30 (+4)	4.17 (+1)
0.30-0.60	3.94	4.55 (+15)	4.00 (+2)
0.60-0.90	3.55	3.90 (+10)	4.06 (+14)
	WR+TT		
0-0.15	6.82	4.86 (-29)	4.27 (-37)
0.15-0.30	6.24	4.46 (-29)	4.13 (-34)
0.30-0.60	4.18	4.87 (+17)	3.96 (-5)
0.60-0.90	3.71	3.49 (-6)	4.60 (+24)
	WF		
0-0.15	3.61	4.01 (+11)	2.06 (-43)
0.15-0.30	3.63	4.49 (+24)	3.77 (+4)
0.30-0.60	4.23	3.98 (-6)	3.48 (-18)
0.60-0.90	4.40	3.91 (-11)	1.97 (-55)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over initial level (2005)

In October 2005-2007 the soil sodicity expressed in SAR at the 0.15 m soil depth under Zero tillage treatments was lowered by 12-17% in comparison with that under traditional tillage. The maximum reduction (17%) was observed in 2005, followed by 12% in 2006, whereas this parameter did not change significantly in 2007 (3%) as shown in Figure 2.2.4.5..

In general, the impact of the land leveling treatments on decreasing SAR levels (2-25%) was observed at the 0.30-0.90 m soil depth. The maximum reduction (25%) was observed in 2005, followed by 2% in

2006, 14% in 2007 as shown in Figure 2.2.4.6. It is indicated that land leveling could significantly reduce the salt accumulation at the 0.30-0.90 m soil depth whereas this parameter didn't significantly change in upper 0.0-0.30 m soil depth (5-9%) in the first-two yeas.

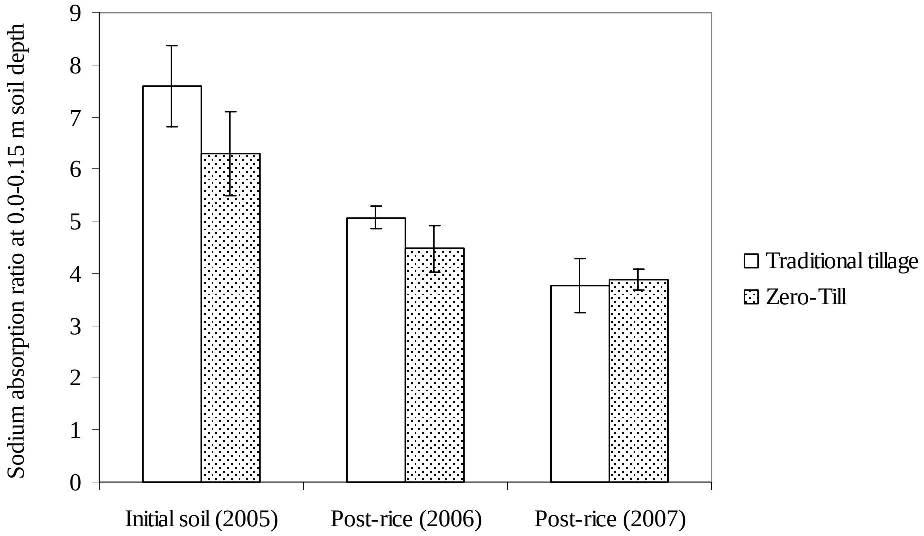


Figure 2.2.4.5 Effect of zero-tillage treatments on SAR level after harvest of rice in 2006-2007

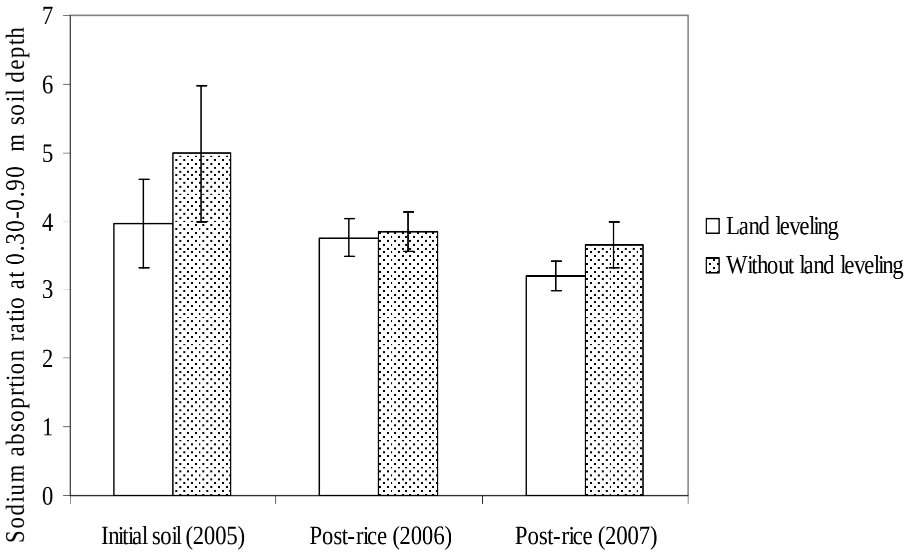


Figure 2.2.4.6 Effect of land leveling treatments on SAR level after harvest of rice in 2006-2007

3.4. IRRIGATION PARAMETERS

In 2005-2006 two pre-sowing leaching irrigations were applied to remove salts from the root zone and provide a suitable moisture regime for winter wheat. The first irrigation (800 m^3 ha^{-1}) was applied on 23 August 2005, which was followed by the 800 m^3 ha^{-1} second irrigation on 1st September 2005. The surface runoff losses were negligible during these irrigations due to the basin irrigation method. In the 2007, the only irrigation applied at a rate of 400 m^3 ha^{-1} was undertaken at the beginning of June before harvesting of wheat. There were no surface runoff losses during the irrigation. Total amount of irrigations applied for winter wheat and rice crops are presented in Table 2.2.4.8.

Table 2.2.4.8 Comparison of different treatments in terms of water saving (m^3 ha^{-1})

Treatment	Irrigation rate				Total water consumption		Amount of saved water	
	Wheat		Rice					
	2006	2007	2006	2007	2006	2007	2006	2007
FR			28300	20104	28300	20104		
FR+LL			28300	20120	28300	20120		
WR+ZT+LL	1,600	400	17870	14506	19470	14906	9880	5064
WR+TT+LL	1,600	400	17870	14871	19470	15271	9880	4699
WR+ZT	1,600	400	17870	17152	19470	17552	9880	2418
WR+TT	1,600	400	17870	17415	19470	17815	9880	2155
WF	1,600	400	—	—	1600	400		
			550[a]	550	550	550		

[a] Volume of water (550 m^3 ha^{-1}) applied to irrigate rice nursery

3.5. CHANGES IN GROUNDWATER LEVEL

Monitoring of ground water was conducted accordingly to the work program. During the study period the ground water level fluctuated from 0.01 to 1.25 m from October 2005 to September 2006 and from 0.04 to 1.23 m from October 2006 to September 2007. Poor drainage was a reason for the high groundwater level and waterlogging at the experimental site from November 2005 to March 2006 and from November 2006 to March 2007 (Figures 2.2.4.7 and 2.2.4.8).

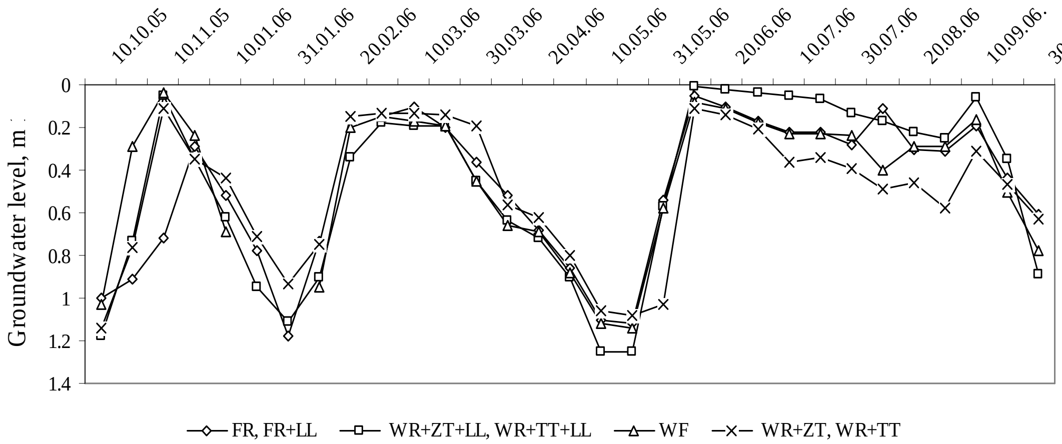


Figure 2.2.4.7 Changes of the ground water level at the experimental site during 2005 and 2006

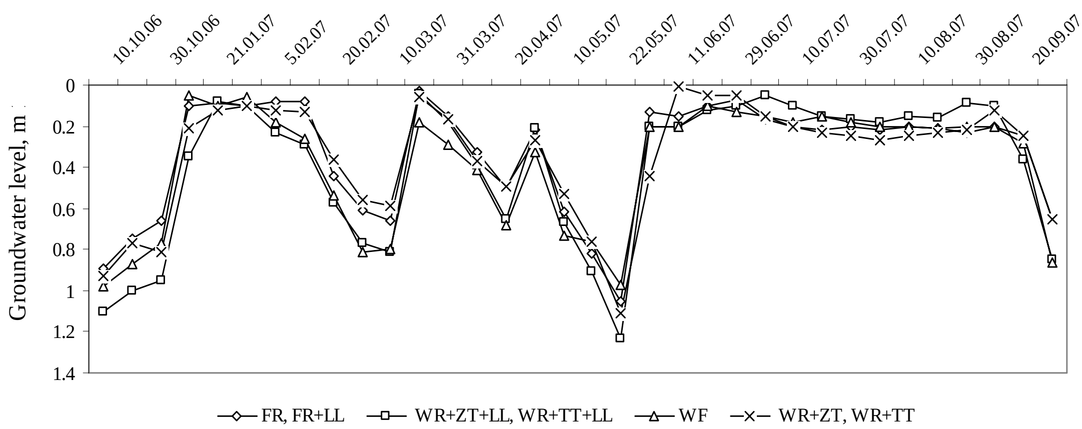


Figure 2.2.4.8 Changes of the groundwater level at the experimental site during 2006 and 2007

3.6. CROP GROWTH, YIELD AND WATER PRODUCTIVITY

The first crop was winter wheat sown in five treatments, viz. WR+ZT+LL, WR+TT+LL, WR+ZT, WR+TT and WF. On 13 October 2005, the maximum plant density of winter wheat was registered under WR+ZT+LL treatment (273 plants m^{-2}). In all treatments, wheat germination was adequate except WF treatment (154 plants m^{-2}). After one month plants density in all treatments was almost the same, and was in the range of 271 to 290 plants m^{-2}, excluding the WF treatment (239 plants m^{-2}). However, extreme cold weather and soil freezing negatively affected the crops status. Winter wheat yield harvested in the end of June 2006 was in the range of 0.5-1.0 t ha^{-1} with no significant differences between treatments (Table 2.2.4.9).

On 28 May 2007, the maximum plant density of winter wheat was observed in treatment WR+ZT+LL (210 plants m^{-2}). The plant density from other treatments was in the order: WR+ZT - 160 plants m^{-2}; WF - 80 plants m^{-2}; WR+TT+LL - 70 plants m^{-2} and WR+TT - 60 plants m^{-2}. Height of the plants in the treatment WR+ZT+LL, WR+ZT ranged from 55 to 60 cm during milky stage. Height of the plants in the treatment WR+TT was found to be 45-50 cm at flowering stage. Height of the plants in the treatment WR+TTL, WF was in the range of 18-22 cm at heading stage (28 May 2007). The winter wheat was harvested manually from each plot to determine the yield on 27 June 2007. The winter wheat yields from different treatments in 2007 are presented in Table 2.2.4.9. Yield of winter wheat in the treatments under using a Zero-Till-Drill manufactured in Brazil have produced higher yields in comparison with winter wheat sown by broadcasting treatments, namely, 2.15 t ha^{-1}, 2.03 t ha^{-1} under the treatments (WR+ZT+LL), and (WR+ZT), respectively. Contrasting this, the winter wheat yields under manual traditional sowing + plowing (WR+TT+LL, WR+TT, and WF) were 1.34 t ha^{-1}, 1.41 and 1.15 t ha^{-1}, respectively.

The second crop in the rotation was rice sown in late May 2006 and 2007 in a nursery area (0.3 ha). Rice was harvested manually from each plot in the first week of November 2006 and October 2007 and grain yields for the different treatments are presented in Table 2.2.4.9. In 2006-2007 the treatments under transplanted rice have produced significantly higher yields than control treatments, namely, 5.70-6.00 t ha^{-1}(WR+ZT+LL), 5.60-5.75 t ha^{-1}(WR+TT+LL), and 5.52-5.60 t ha^{-1} (WR+ZT). Contrasting this, rice yields under control treatments were following: 4.70-4.78 t ha^{-1} (WR+TT), 4.23-4.50 t ha^{-1} (FR) and 4.23-4.40 t ha^{-1} (FR+LL).

Table 2.2.4.9 Yield of rice and winter wheat as affected by the treatments in 2006 and 2007

Crop	FR		FR+LL		WR+ZT+LL		WR+TT+LL		WR+ZT		WR+TT		WF	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Rice	4.50	4.23	4.40	4.23	5.70	6.00	5.60	5.75	5.60	5.52	4.70	4.78	—	—
Winter wheat	—	—	—	—	1.00	2.15	0.80	1.34	1.00	2.03	0.50	1.41	0.50	1.15

Least significance difference at $p = 0.05$ for rice was estimated as 0.21 t ha^{-1} (2006)
Least significance difference at $p = 0.05$ for rice was estimated as 0.17 t ha^{-1} (2007)
Least significance difference at $p = 0.05$ for wheat was estimated as 0.12 t ha^{-1} (2006)
Least significance difference at $p = 0.05$ for wheat was estimated as 0.25 t ha^{-1} (2007)

In 2006-2007 in terms of water use, water productivity (WP) of rice was the highest (0.29-0.40 kg m^{-3}) under WR+ZT+LL treatment. Water productivity from other treatments was in the order: 0.29-0.38 kg m^{-3} (WR+TT+LL); 0.29-0.31 kg m^{-3} (WR+ZT); 0.24-0.27 kg m^{-3} (WR+TT) and 0.16-0.21 kg m^{-3} (FR, FR+LL). These results would suggest that wheat-rice systems enhanced WP by 29-90% in comparison with traditional fallow-rice treatments (Table 2.2.4.10).

Table 2.2.4.10 Effect of treatments on water productivity (kg m^{-3}) of rice

Year	FR	FR+LL	WR+ZT+LL	WR+TT+LL	WR+ZT	WR+TT
2006	0.16	0.16	0.29 (+81)[a]	0.29 (+81)	0.29 (+81)	0.24 (+50)
2007	0.21	0.21	0.40 (+90)	0.38 (+81)	0.31 (+48)	0.27 (+29)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over water productivity of FR treatment

In 2006-2007 in terms of water use, water productivity (WP) of winter wheat was the highest (0.44-1.30 kg m^{-3}) under WR+ZT+LL treatment. Water productivity from other treatments was in the order: 0.44-1.23 kg m^{-3} (WR+ZT); 0.35-0.81 kg m^{-3} (WR+TT+LL); 0.22-0.86 kg m^{-3} (WR+TT) and 0.22-0.70 kg m^{-3} (WF). One can conclude from this that wheat-rice treatments enhanced WP by 17-100% in comparison with traditional wheat-fallow treatment (Table 2.2.4.11).

Table 2.2.4.11 Effect of treatments on water productivity (kg m^{-3}) of winter wheat

Year	WF	WR+ZT+LL	WR+TT+LL	WR+ZT	WR+TT
2006	0.22	0.44 (+100)[a]	0.35 (+60)	0.44 (+100)	0.22 (0)
2007	0.70	1.30 (+87)	0.81 (+17)	1.23 (+77)	0.86 (+23)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over water productivity of WF treatment

4. KNOWLEDGE SHARING — FARMER TO FARMER

Some farmers in Khorezm region are using transplanting methods in their rice production systems. The study provided the opportunity for the local farmers in Chimbay district of Karakalpakistan region to learn from these experienced farmers the practices of transplanting rice. One of these farmers, Mr Saparboi Khudaybergenov from Khorezm, visited the experimental site and the farmers of the nearby area interested in rice-wheat cropping rotation one two occasions during the study. During each of these visits, the farmer shared his experience with the local farmers on transplanting the rice seedlings in the field after winter wheat harvesting. The farmer from Khorezm along with the local farmers started transplanting 30-day-old rice seedlings from the nursery to the field that previously was under winter wheat. Just before transplanting of seedling rice, harrowing (Harrow ZBS-1 on Tractor MTZ 80) and land leveling were done. The field was plowed manually to a depth of 0.15 m because of higher soil moisture. Mr Saparboi Khudaybergenov has visited the study area regularly and shared his knowledge with several farmers the technology of growing rice by transplanting rice seedlings.

5. CONCLUSIONS

With the major objective to evaluate rice-wheat cropping systems as a management option for saline and waterlogged soils to enhance crop productivity and additional income for the farming communities, this experiment addressed three interacting factors: (1) *tillage* — comparing traditional tillage practice followed by broadcasting of wheat with no-tillage wheat sowing, i.e., zero tillage using a Brazilian seeder; (2) *land leveling* — comparing precision land leveling with no land leveling; and (3) *crop rotation* — cultivating rice and wheat alone and in rotation. Comparison between the effects of the traditional tillage practice followed by broadcasting of wheat with no-tillage wheat sown using a Brazilian seeder indicated that zero tillage resulted in a better crop response. In the zero tillage treatments, rice yields were higher by 2-19% in comparison with traditional sowing method. The first-two year analyses reveal that zero tillage together with an increase in the rice yields enhanced crop water productivity. In 2006-2007, water productivity of the rice crop under zero tillage was higher by 48-90% over control (rice-fallow system), while that for winter wheat was higher by 77-100% over control (winter wheat-fallow system). Zero tillage technology applied under winter wheat crop also reduced the soil salinity level as compared with traditional tillage technologies. The average soil salinity levels under WR+ZT+LL and WR+ZT treatments were lower by 5-36% in comparison with traditional tillage applied treatments (WR+TT+LL, WR+TT). These results suggest that zero-tillage could also reduce the salt accumulation at the upper 0.15 m soil depth. Comparing precision land leveling with no land leveling indicates that land leveling enhanced rice yields by 2-20% over those treatments without land leveling. Land leveling enhanced water productivity by 29-81% over the control (rice-fallow system), while in case of winter wheat it was higher by 17-100% over control (winter wheat-fallow system). Another positive effect of land leveling was reduction in the salt accumulation at the upper soil depth (0-0.15 m) by 2-60% over non-leveled plots during 2006-2007. These results offer a range of options for increasing rice and wheat productivity on saline and waterlogged soils.

2.2.5 USE OF TREE PLANTATIONS AS BIOLOGICAL AMELIORANT FOR THE DEGRADED LANDS [9]

1. INTRODUCTION

Conventional solutions in the Aral Sea Basin to combating waterlogging and salinity are the use of horizontal subsurface drainage systems consisting buried pipes and deep open drains. The disposal of the marginal-quality effluent generated by conventional drainage systems is often considered as problematic. Where drainage effluent is reused for irrigation, salts are redistributed in the landscape. Where saline drainage effluent is disposed of into river systems, pollution of natural water bodies will occur (Heuperman, 2002). Starting from 1960 until 1980, costly drainage systems were constructed on irrigated lands in Uzbekistan. Previous experience had shown that these systems although having distinct advantages do pose several issues such as needs for proper disposal of drainage water, high maintenance cost and a significant amount of highly fertile land is taken out of production. Limited studies have been undertaken using the concepts of bio-drainage to control elevated level of groundwater.

Tree species and the agricultural crops possessing high transpiration capacity play an important role in the process of biological drainage.. Kiselyova has compared biological drainage systems in a cotton growing zone by evaluating alfalfa [*Medicago sativa* L. *subsp. varia*], willow [*Salix alba* L.], and poplar [*Populus alba* L.] plantations. During the vegetative stage of growth, alfalfa was reported to use water in the range of 4,000 to 20,000 m^3 ha^{-1}, while willow and poplar trees used 20,000 to 100,000 m^3 of water depending on age, groundwater level, soil texture, and density of crop. In general, the share of subsoil water consumed by the crop was of the order of 78 % (Kiselyova, 1985).

Bio-drainage reduces the need for disposal of saline water, limits negative environmental impacts and brings benefits to the farmers by producing wood for construction and fuel. The principal objective of these studies is to determine how effective trees are in regulating the groundwater level.

2. MATERIALS AND METHODS

2,1. STUDY AREA AND SITE CHARACTERIZATION

This on-farm study was carried out during the years 2005-2007 in Uzbekistan. Cotton is main crop grown covering about 90% of the cropped area in summer. The study site was in Syr- Darya district where irrigation waters are provided by the Syr-Darya River. Site characterization was undertaken in May 2005. The area has a smooth landscape with slopes from 0.002 to 0.0035. Long-term annual precipitation ranges from 100 to 300 mm, with 90% occurring during October through May. The average precipitation during the study period (April-September) was in the range of 43-106 mm. The area has high summer temperatures (26-30°C during June, July and August). The temperature decreases to as low as –6°C, with an average of 2°C, during the winter months. The air temperature during the study period ranged from 16°C to 28°C. The soils are medium loam with about 1.1 % organic matter in the surface layer. Soil bulk density remains 1.39±0.08 Mg m^{-3} and the pH varies narrowly from 8.1 to 8.3.

2.2. TREATMENTS

There are four treatments in the experiment:

1 Control (no tree plantation) — cotton [*Gossypium hirsutum* L.] field in 2006 and winter wheat [*Triticum aestivum L.*] in 2007 has been selected as a control (area of 1 ha)

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[9] This component was led by ICARDA. NARS partners include U. Toshbekov and G. Bezborodov
Gulistan State University, Ministry of Agriculture, Uzbekistan
Tulkun Yuldashev, Ph.D. student, enrolled in Central Asian Scientific Research Institute for Irrigation (SANIIRI), Tashkent, Uzbekistan

2 Poplars [*Populus alba* L., *Populus Bachofene*], Ash [*Fraxinus pennsylvanica*], acacia [*Robinia pseudoacacia* L.], maple [*Acer semenovii*], Russian olive [*Elaeagnus angustifolia*], elm [*Ulmus pinnatoramosa* Dieck ex Koehne] and other trees planted in 1960s (area under different tree species is 6 ha) (later referred to as Arboretum)
3 Ash [*Fraxinus pennsylvanica*] trees planted in fall 2003 (area under Ash tree is 1 ha) (later referred to as AST03)
4 Ash [*Fraxinus pennsylvanica*] trees planted in fall 2004 (area under Ash tree is 1 ha) (later referred to as AST04)

2.3. SOIL AND WATER SAMPLING AND ANALYSIS

Composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m prior to the initiation of the study. The sampling was done before the implementation of the treatments (initial soil condition) and after harvest of cotton in each cropping year. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations such as Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions such as carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated using Equation 2.2.5.1 from the concentrations (*C*) of soluble cations Ca^{2+}, Mg^{2+}, and Na^+, expressed as $mmol_c\ L^{-1}$.

$$SAR = C_{Na} / [(C_{Ca} + C_{Mg}) / 2]^{1/2} \qquad [2.2.5.1]$$

The classification of the various forms of salinity is based on the Soviet system (Bazilevich and Pankova, 1986) that is commonly used throughout the region. The classification system is based on ratios of anions that effectively define the type of salinity (Table 2.2.5.1).

Table 2.2.5.1 Classification of salinity types commonly used in Central Asia as developed by Bazilevich and Pankova (1986)

Type of salinity	Anions	Ratio of anions		
		$Cl:SO_4$	$HCO_3:Cl$	$HCO_3:SO_4$
Chloride	Cl	≥ 2,5		
Chloride-sulphate	SO_4-Cl	1.0–2.5		
Chloride-sodic	HCO_3-Cl	>1	>1	
Sodic chloride	Cl-HCO_3		<1	
Sulfate-sodic	HCO_3-SO_4			>1
Sodic-sulphate	SO_4-HCO_3			<1
Sulfate-chloride	Cl-SO_4	0.3–1		
Sulfate	SO_4	≤0.3		
Hydrocarbonate sulfate or hydrocarbonate chloride	HCO_3-SO_4-Cl		>1	<1

Within these types of salinity forms, saline soils are further classified as slightly, moderately, heavily, and extremely saline (Table 2.2.5.2). Toxic salts include chloride, bicarbonate, carbonate and sulfate salts of Mg^{2+} and Na^+ and chloride salt of Ca^{2+}. Toxic salts are equated to the total soluble salts minus the non-toxic salts of Ca^{2+}.

Table 2.2.5.2 Saline soil classification depending on the presence of toxic levels of anionic species in the soil, expressed in mg L^{-1} (Bazilevich, and Pankova, 1986)

Degree of Salinity	**Cl**	**SO_4-Cl**	**HCO_3-Cl; Cl-HCO_3**	**HCO_3-SO_4; SO_4-HCO_3**	**Cl-SO_4**	**SO_4**	**HCO_3-SO_4-CL**
None saline	< 300	< 500	< 1000	< 1500	< 1000	< 1500	< 1500
Slightly	300-1000	500-1200	1000-5000	1500-2500	1000-2500	1500-3000	1500-3000
Moderate	1000-3000	1200-3500	1500 - 3000	2500-3500	2500-5000	3000-6000	3000 - 5000
Highly	3000-6000	3500-7000	3000-5000	3500-6000	5000-9000	6000-14000	
Extremely	>6000	>7000	>5000	>6000	>9000	>14000	

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was determined on a randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent. Field capacity was determined from one randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture in the following days up to the time (usually 3-5 days) when there was minimal change in moisture content at all the soil depths. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer diameter ring of 0.4 m and inner diameter ring of 0.3 m. Both rings were buried int the soil to a depth of 0.1-0.15 m. Soil bulk density was determined on undistributed soil samples collected from each soil depth using core method. Soil moisture content was determined by gravimetric method.

Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. The water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}).

In order to monitor growth and development of trees and cotton, 10 monitoring plants were selected in each treatment. The collection of phonological data consisted of shoot height, crown diameter, and diameter at breast height (DBH).

Changes of the groundwater storage were estimated using Equation 2.2.5.2 (Kats, 1967):

$$DW = M \times \Delta H \times 10000 \qquad [2.2.5.2]$$

Where:
M = Specific groundwater storage
ΔH = Difference between groundwater levels

Actual Evapotranspiration (ET) was calculated by using the simple water balance Equation 2.2.5.3:

$$ET = I + P + T + \Delta W + ET_{gw} \qquad [2.2.5.3]$$

Where:
I = Irrigation rate, net (mm)
P = Precipitation (mm)
T= transpiration rate (mm)

ΔW = Changes in soil moisture storage at the upper (1.2 m) soil profile (mm)
ET_{gw} = Contribution of groundwater to ET

2.4. EXPERIMENTAL PROCEDURE

The control field was plowed to a depth of 0.40 m on 22 November 2005. Harrowing was undertaken with a tractor just before cotton sowing. Cotton variety An-Bayut-2 was sowed on 21 April 2006 at a seed rate of 55-60 kg ha^{-1}. Cotton was harvested in September 2006 and yield from each plot was recorded. In the subsequent year (2007), all the agronomic and fertilizer management practices were the same except that winter wheat was sown into standing cotton in October 2006 at a seed rate of 180-200 kg ha^{-1}.

3. RESULTS AND DISCUSSION

3.1. PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the particle-size distribution of the USDA classification system, the field soil is classified as a loam in texture throughout the profile up to a depth of 0.90 m (Table 2.2.5.3). In 2006 the pre-experiment soil salinity levels in terms of total dissolved salts (TDS) at the different soil depths extending up to 0.90 m were in the range of 4662 mg L^{-1} to 6335 mg L^{-1} (6.78 to 9.32 dS m^{-1}) (Table 2.2.5.4). Among the anions, SO_4^{2-} was dominant having concentration of 82.97 $mmol_c$ L^{-1} in the upper 0.15 m depth. The concentration of SO_4^{2-} varied in the range of 62.43 to 90.95 $mmol_c$ L^{-1}. Chloride concentration was considerably lower when compared to that of SO_4^{2-} and had a decreasing trend from surface to deeper horizons and ranged from 2.16 to 5.90 $mmol_c$ L^{-1}. Among the cations, Ca^{2+} was dominant at the soil surface followed by Mg^{2+}, Na^{+}, and K^{+}. The concentration of Ca^{2+} in the upper 0.15 m depth was determined to be 48.90 $mmol_c$ L^{-1}. Its concentration varied in the range of 32.85 to 49.33 $mmol_c$ L^{-1}. Magnesium concentration was less compared to that of Ca^{2+} at the different soil depths. Its concentration varied little depth and ranged from 24.33 to 36.80 $mmol_c$ L^{-1}. Likewise, sodium concentration little with depth and was in the range of 8.35 to 10.87 $mmol_c$ L^{-1}. Potassium concentration exhibited a decreasing trend from surface to deeper horizons and varied in the range of 0.49 to 1.35 $mmol_c$ L^{-1}. The SAR levels were in the range of 1.36 to 1.90, indicating that the soil was not alkaline in its characteristics.

Table 2.2.5.3 Physical properties of soil at Galaba site

Soil properties	Unit	Soil depth (m)			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
Sand particles (0.05-2.0 mm)	%	34.20	34.10	36.20	39.20
Silt particles (0.002-0.05 mm)	%	47.20	47.60	45.00	41.80
Clay particles (<0.002 mm)	%	18.50	18.30	18.80	19.00
Soil Texture (method USDA)	—	Loam	loam	loam	loam

Table 2.2.5.4 Chemical properties of the field site before start of the experiment in April 2006

		Soil depth (m)			
Soil characteristic	**Unit**	**0.0-0.15**	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
EC_e	dS m^{-1}	9.32	8.51	9.60	6.78
Soluble Ca^{2+}	$mmol_c$ L^{-1}	48.90	46.95	49.33	32.85
Soluble Mg^{2+}	$mmol_c$ L^{-1}	32.04	28.78	36.80	24.33
Soluble Na^{+}	$mmol_c$ L^{-1}	10.87	8.35	9.25	10.15
Soluble K^{+}	$mmol_c$ L^{-1}	1.35	1.04	0.62	0.49
Soluble HCO_3^{2-}	$mmol_c$ L^{-1}	4.27	3.79	3.43	3.36
Soluble Cl^{-}	$mmol_c$ L^{-1}	5.90	3.29	2.52	2.16
Soluble SO_4^{2-}	$mmol_c$ L^{-1}	82.97	78.78	90.95	62.43
SAR	—	1.71	1.36	1.41	1.90

3.2. IRRIGATION AND GROUNDWATER QUALITY

The average salt concentration in the open horizontal canal drains ranged from 1530 to 1854 mg L^{-1} (2.33-2.80 dS m^{-1}) over the monitoring period (Table 2.2.5.5). The composition of irrigation water from June to October in terms of cationic concentration revealed small temporal variation. The dominant cations were, Ca^{2+} and Mg^{2+} during 2006, Mg^{2+} and Ca^{2+} during 2007. The concentrations of Ca^{2+} varied in the range of 8.07 to 13.01 $mmol_c$ L^{-1} with corresponding Mg^{2+} concentrations ranging from 9.95 to 11.02 $mmol_c$ L^{-1}. The concentrations of Na^+ were in the range of 3.74 to 5.22 $mmol_c$ L^{-1}. The concentrations of K^+ were the lowest, ranging from 0.11 to 0.12 $mmol_c$ L^{-1}

Although there was small temporal variation of cationic concentrations in water samples collected during June and October, there was no consistent pattern for the variation during the cropping season. The anionic concentration in the irrigation water sampled during June and October was dominated by SO_4^{2-} having concentrations in the range of 18.62 to 21.77 $mmol_c$ L^{-1}. The concentration of Cl^- was much less was found to be 2.55-3.58 $mmol_c$ L^{-1} during 2006-2007. The concentrations of HCO_3^- ranged from 2.29 to 2.73 $mmol_c$ L^{-1}. The levels of SAR and SAR_{adj} were in the range of 1.14 to 2.12, suggesting that irrigation water is non-sodic in its characteristics. Evidently, irrigation conducted by applying this quality water will not cause sodicity problems to plants development

Table 2.2.5.5 Composition of irrigation water at the experimental site in 2006 and 2007

Characteristic	Unit	2006	2007	Average
EC_{iw}	dS m^{-1}	2.80±0.46[a]	2.33±0.32	2.57±0.23
TSS	mg L^{-1}	1854±328	1530±216	1692±162
Ca^{2+}	$mmol_c$ L^{-1}	13.11±3.47	8.07±2.18	10.59±2.52
Mg^{2+}	$mmol_c$ L^{-1}	11.02±2.39	9.95±2.10	10.48±0.54
Na^+	$mmol_c$ L^{-1}	3.74±0.94	5.22±0.79	4.48±0.74
K^+	$mmol_c$ L^{-1}	0.12±0.03	0.11±0.02	0.11±0.01
HCO_3^{2-}	$mmol_c$ L^{-1}	2.73±0.92	2.29±0.73	2.51±0.22
Cl^-	$mmol_c$ L^{-1}	3.58±1.76	2.55±0.48	3.06±0.52
SO_4^{2-}	$mmol_c$ L^{-1}	21.77±5.23	18.62±3.37	20.19±1.58
$Cl^-:SO_4^{2-}$	—	0.25±0.18	0.16±0.06	0.20±0.05
$Mg^{2+}:Ca^{2+}$	—	0.95±0.24	1.36±0.40	1.16±0.20
SAR	—	1.14±0.36	1.83±0.39	1.49±0.34
SAR_{adj}	—	1.36±0.40	2.12±0.43	1.74±0.38

[a] Figures with ± represent standard error

In 2006-2007 groundwater from April to October was of moderate and to highly and ranged from 6488 to 6948 mg L^{-1} (9.90-10.24 dS m^{-1}) during 2006-2007 (Table 2.2.5.6). The composition of groundwater from April to October in terms of cationic concentration showed moderate temporal variation. The dominant cations were, Ca^{2+} and Mg^{2+} during 2006, Na^+ and Mg^{2+} during 2007. The concentration of Ca^{2+} ranged from 21.17 to 38.09 $mmol_c$ L^{-1} with corresponding Mg^{2+} concentrations ranging from 34.54 to 36.29 $mmol_c$ L^{-1}. The concentrations of Na^+ were in the range of 29.53 to 41.33 $mmol_c$ L^{-1}. The concentrations of K^+ were the lowest, ranging from 0.23 to 0.24 $mmol_c$ L^{-1}.

The anionic concentration in groundwater sampled during 2006-2007, revealed SO_4^{2-} as the dominant anion with concentrations ranging from 81.14 to 89.20 $mmol_c$ L^{-1}. The concentration of Cl^- ranged from 9.79 to 15.42 $mmol_c$ L^{-1}. The concentrations of HCO_3^- ranged from 3.32 to 5.01 $mmol_c$ L^{-1}. Ratio of Cl^- to SO_4^{2-} was less than 0.3. The levels of SAR and SAR_{adj} were in the range of 5.50 to 8.21, indicating that the use of such groundwater for irrigation without appropriate management practices may cause gradual increase of sodium in the soil profile.

Table 2.2.5.6 Composition of ground water at the experimental site in 2006&2007

Characteristic	Unit	2006	2007	Average
EC_{gw}	dS m^{-1}	10.24±0.85 [a]	9.90±1.00	10.07±0.17
TSS	mg L^{-1}	6948±576	6488±663	6718±230
Ca^{2+}	$mmol_c$ L^{-1}	38.09±4.91	21.17±1.29	29.63±8.46
Mg^{2+}	$mmol_c$ L^{-1}	34.54±3.21	36.29±3.93	35.42±0.88
Na^{+}	$mmol_c$ L^{-1}	29.53±5.91	41.33±6.70	35.43±5.90
K^{+}	$mmol_c$ L^{-1}	0.23±0.02	0.24±0.03	0.24±0.00
HCO_3^{2-}	$mmol_c$ L^{-1}	5.01±0.37	3.32±0.26	4.16±0.85
Cl^{-}	$mmol_c$ L^{-1}	9.79±1.20	15.42±2.11	12.61±2.81
SO_4^{2-}	$mmol_c$ L^{-1}	89.20±8.07	81.14±8.83	85.17±4.03
$Cl^{-}:SO_4^{2-}$	—	0.12±0.02	0.23±0.04	0.17±0.05
$Mg^{2+}:Ca^{2+}$	—	1.29±0.17	1.89±0.23	1.59±0.30
SAR	—	5.50±1.16	7.29±1.02	6.40±0.90
SAR_{adj}	—	6.21±1.29	8.21±1.14	7.21±1.00

[a] Figures with ± represent standard error

3.3. CHANGES IN THE SOIL SALINITY AS AFFECTED BY VEGETATIVE COVER

The soil salinity level expressed in dS m^{-1} in September 2006 and September 2007 had increasing trend throughout the soil profile up to 0.90 m in all treatments except AST04 treatment (Table 2.2.5.7). The maximum increase in soil salinity up to 40 % under control might be associated with higher groundwater salinity which was in the range of 4188 to 11951 mg L^{-1} (2006), 5687 to 14890 mg L^{-1} (2007) whilst the attribute under AST04 ranged from 2936 to 7650 mg L^{-1} (2006) mg L^{-1}, 3040-8456 (2007) during the crop season.

Table 2.2.5.7 Averaged soil salinity for 2006-2007 (dS m^{-1}) as affected by different vegetation covers

Treatment	Month	Soil depth (m)				
		0-0.15	0.15-0.30	0.30-0.60	0.60-0.90	0-0.90
AST04	April	12.26	12.21	11.81	7.64	10.56
	September	11.47 (-6)[a]	10.67 (-13)	9.75 (-17)	8.35 (+9)	9.72 (-6)
AST03	April	9.13	7.46	6.99	5.99	7.09
	September	12.25 (+34)	10.89 (+45)	8.80 (+26)	6.92 (+16)	9.09 (+27)
Arboretum	April	6.23	6.67	8.49	7.14	7.36
	September	8.88 (+43)	8.21 (+23)	8.08 (-5)	10.13 (+42)	8.92 (+23)
Control	April	9.11	7.48	9.2	10.6	9.36
	September	21.44 (+135)	10.45 (+40)	11.37 (+24)	11.67 (+10)	12.99 (+40)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over April

A further reason of the highest soil salinity under control might be explained by shallow groundwater level (2.27 m) in the last week of September 2006 which increased soil salinity throughout the soil profile.

The data in Table 2.2.5.7 indicate a 23.00-27.17% increase in soil salinity under tree plantation at the end of crop season. A further positive impact of the tree plantation lay in fact that the soil salinity class (non-saline) did not change whereas the soil salinity class of control field was transformed from non saline to medium and high at the end of crop season in 2006 and 2007.

The amount of total toxic salts determined in September 2006 and October 2007 had an increasing trend throughout the soil profile up to 0.90 m in all treatments except AST04 treatment in 2006 (Table 2.2.5.8).

Table 2.2.5.8 Total soluble salts (mg L^{-1}) in 0.90 m soil depth as affected by different vegetation covers

Year	Treatment							
	AST04		AST03		Arboretum		Control	
	April	September	April	September	April	September	April	September
2006	3320	2990 (-10%)[a]	2040	2210 (+8%)	2060	2590 (+26%)	2750	3630 (+32%)
2007	2060	3240(+57%)	1860	3050 (+64%)	1440	3820 (+165%)	1360	5246 (+286%)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over April

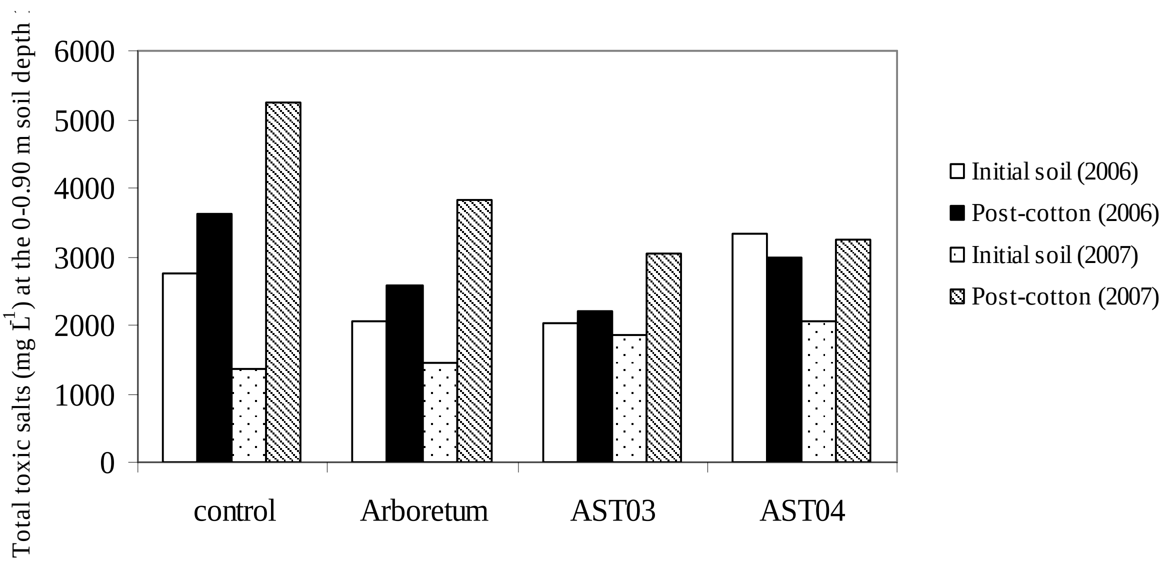

Figure 2.2.5.1 Total soluble salts as affected by different vegetation cover (2006-2007)

3.4. CHANGES IN GROUNDWATER LEVELS AS AFFECTED BY VEGETATION COVER

In 2006 the groundwater level was at 0.98-1.28 m in last week of April and gradually lowered to 2.92-3.17 m in September due to evaporation and transpiration, since subsurface outflow was assumed to negligible. The same trend of groundwater change was observed in 2007. Initial groundwater level in March 2007 (0.87-1.11 m) gradually lowered to 3.03-3.61 m in September 2007 due to evaporation and transpiration. In 2006 the maximum lowering of the groundwater level to 2.26 m was observed under Arboretum and minimum its value (1.76 m) was registered under AST03 treatment (Figure 2.2.5.2). In 2007 the maximum lowering of the groundwater level up to 3.16 m was observed under Arboretum and minimum value (2.34 m) was registered under control treatment (Figure 2.2.5.2). In 2007 the groundwater level under Arboretum was lower by 0.15-1.06 m over control. Groundwater levels under AST03 treatment were lower by 0.08-0.18 m over control in 2006 and by 0.04-0.56 m over control in 2007. The maximum lowering (0.18 m and 1.06 m) observed during the 29.04-10.08.06 and 10.06-11.07.2007 time periods, respectively. Groundwater level under AST04 treatment was lower by 0.13-0.16 m (2006) and by 0.07-0.26 m (2007) with maximum lowering during the 29.04-10.08 and 10.06-11.07.2007 time periods. In comparison to the control groundwater level under Arboretum treatment was higher by 0.12-0.20 m and 0.03-0.65 m during the 29 April 2006 -20 May 2006 and 20 September 2006-30 September 2007, respectively. It might be associated with two irrigations applied at the rates of 93.0 mm and 103.0 mm on 20 April 2006 and 25 September 2006, respectively. The groundwater level under AST03 treatment was higher by 0.03-0.50 m over control during the 29 August-30 September 2006 time period due to an irrigation applied on 27.08 (92.0 mm). The groundwater levels under AST04 were higher by 0.18-0.47 m

due to infiltration losses from the irrigation channels during the 20 September-30 September 2006. After 20 September 2006 and 10 September 2007 groundwater level in all treatments rose up to 1.62-2.23 m (2006) and 2.36-2.81 (2007) these differences might be associated with a higher subsurface inflow from the irrigation channels around the site (Figure 2.2.5.2).

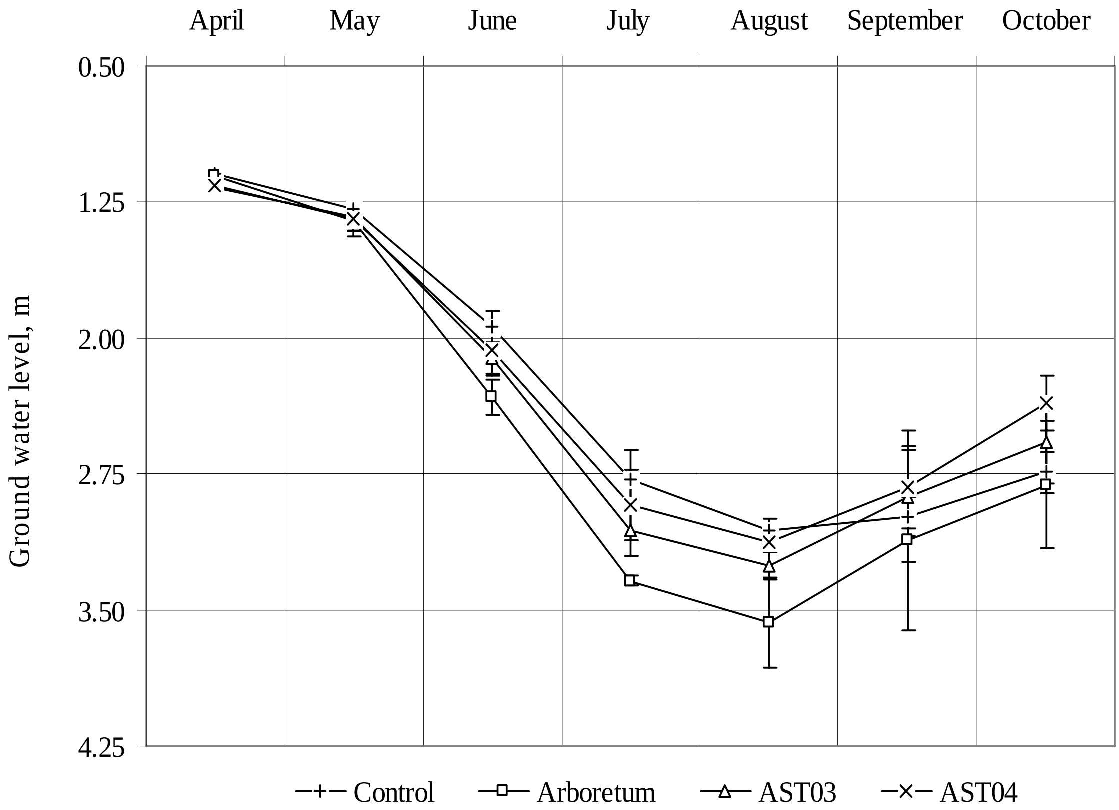

Figure 2.2.5.2 Changes in groundwater level under different treatments during 2006 and 2007

Since there is poor subsurface outflow from the experimental site, lowering of the groundwater level can be considered as a contribution of groundwater to ET. During irrigation events the groundwater storage changes could be used for estimating infiltration losses (Table 2.2.5.9).

Table 2.2.5.9 Groundwater contribution to ET at the experimental site (2006-2007)

Treatment	Changes of groundwater storage in 2006						ET_{gw}
	29.04-29.05	**29.05-29.06**	**29.06-29.07**	**29.07-10.08**	**10.08-29.08**	**29.08-10.09**	
Control	31	77	70	8	10	11	207
Arboretum	23	108	70	8	12	5	226
AST03	17	86	65	8	-21	9	185
AST04	29	80	55	6	12	10	192
	Changes of groundwater storage in 2007						
Treatment	10.03-10.04	10.04-10.05	10.05-10.06	10.06-10.07	10.07-11.08	11.08-10.09	ET_{gw}
Control	10	7	32	78	49	28	203
Arboretum	21	19	51	126	94	9	320
AST03	12	19	54	93	97	1	276
AST04	10	9	44	91	75	16	247

In 2006 the data cited in Table 2.2.5.9 revealed that maximum reductions of groundwater storages was observed during 29 May-29 June 2006 and its values were higher by 320 m^3 ha^{-1} (Arboretum), 100 m^3 ha^{-1} (AST03) and 40 m^3 ha^{-1} (AST04) over control. From 29 June to 29 August 2006 groundwater changes were not significant which may be explained by lowering transpiration rate of the trees. Since there was no irrigation at the site until late August, these differences might be associated with a higher transpiration rate by the trees in comparison with cotton field. In 2007 the maximum reductions of groundwater storages was observed during 10 May-10 June 2007 and its values were higher by 520 m^3 ha^{-1} (Arboretum), 150 m^3 ha^{-1} (AST03) and 130 m^3 ha^{-1} (AST04) over control. From 11 August to 10 September 2007 groundwater changes were not significant that may be explained by lowering transpiration rate of the trees. Since there was no irrigation at the site until late August, these differences might be associated with a higher transpiration rate by the trees in comparison with winter wheat field.

3.5. IRRIGATION

In 2006 first irrigation (90.0-96.0 mm) was applied to Arboretum treatment on 20 April 2006, which was followed by the 100-106 mm second irrigation on 25 September 2006. The total irrigation was estimated in the range of 190.0 to 202.0 mm. Only an irrigation of 93 mm in 2006 to AST03 treatment was applied in late August 2006 and an irrigation of 85.5 mm in early July 2007. No irrigation was applied under cotton field and AST04 during the crop season in 2006 and 2007.

3.6. PLANTS GROWTH AND DEVELOPMENT

In 2006 maximum relative height growth rate was observed under AST03 treatment and minimum relative height growth rate was under Arboretum. The growth rate declined from late May to late September from 0.052 mm d^{-1} to 0.0022 mm d^{-1} for AST03 and from 0.0122 mm to 0.0012 mm d^{-1} for Arboretum (Table 2.2.5.10). In 2007 maximum relative height growth rate was observed under AST04 treatment and minimum relative height growth rate was under Arboretum. The grow rate declined from mid June to late October from 0.0286 mm d^{-1} to 0.0072 mm d^{-1} for AST04 and from 0.0147 mm to 0.0094 mm d^{-1} for Arboretum.

Observation on groundwater level and water salinity and soil salinity suggest that soil salinity levels in te upper soil depths was declining, but the soil salinity at the whole aeration zone was not significantly changed. It is suggested that the open drains are not operating and salts are not being flushed out through the drain systems. Due to higher soil salinity in 2006 cotton yield was extremely low (up to 1.0 t ha^{-1}). In 2007 winter wheat was sown under this field and 90% of area occupied by undesirable plants. It is indicative of increasing soil salinity at the site.

Table 2.2.5.10 Crop data collected at Galaba tree plantation site in 2006 and 2007

		Treatments			Treatments		
Crop Characteristic	**Unit**	**AST04**	**AST03**	**Arboretum**	**AST04**	**AST03**	**Arboretum**
			29.04.2006			10.04.2007	
Plant height	cm	116	226	1041	149	323	1207
Crown height	cm	80	173	873	101	252	1023
DBH	cm	4	11	80	6	18	92
			29.05.2006			10.05.2007	
Plant height	cm	126	262	1072	160	331	1225
Crown height	cm	86	205	899	108	257	1032
DBH	cm	4	13	83	7	18	92
RHG	mm day^{-1}	0.0257	0.0516	0.0122	0.0241	0.0079	0.0058
RDG	mm day^{-1}	0.0761	0.0622	0.0157	0.0336	0.0084	0.0011
			29.06.2006			15.06.2007	
Plant height	cm	133	281	1103	177	366	1297
Crown height	cm	92	221	924	116	264	1094
DBH	cm	5	15	86	8	19	93
RHG	mm day^{-1}	0.0177	0.0243	0.0118	0.0286	0.0280	0.0147
RDG	mm day^{-1}	0.0333	0.0478	0.0168	0.0367	0.0169	0.0015
			29.07.2006			29.07.2007	
Plant height	cm	135	284	1138	200	389	1372
Crown height	cm	92	224	958	126	269	1160
DBH	cm	5	15	87	8	20	94
RHG	mm day^{-1}	0.0031	0.0040	0.0202	0.0272	0.0141	0.0139
RDG	mm day^{-1}	0.0206	0.0092	0.0022	0.0187	0.0099	0.0052
			29.08.2006			31.08.2007	
Plant height	cm	136	294	1158	216	413	1418
Crown height	cm	92	233	978	134	273	1194
DBH	cm	5	16	87	9	21	95
RHG	mm day^{-1}	0.0027	0.0119	0.0063	0.0244	0.0170	0.0107
RDG	mm day^{-1}	0.0038	0.0100	0.0024	0.0136	0.0124	0.0030
			29.09.2006			30.09.2007	
Plant height	cm	139	314	1199	231	433	1462
Crown height	cm	95	248	1018	144	287	1230
DBH	cm	6	17	91	9	22	96
RHG	mm day^{-1}	0.0086	0.0216	0.0118	0.0214	0.0159	0.0106
RDG	mm day^{-1}	0.0301	0.0195	0.0185	0.0126	0.0125	0.0029

3.7. EVAPOTRANSPIRATION AS AFFECTED BY VEGETATION COVER

The data cited in Table 2.2.5.11 indicate that maximum ET in 2006-2007 was observed (950-1042 mm) under Arboretum treatment while cotton treatment had a minimum value (280-378 mm).

Table 2.2.5.11 Changes in soil moisture storages, transpiration, irrigation rate, contribution of groundwater to ET during the crop season (mm)

Treatment	Parameter	2006				Total	2007				Total
		29.04-20.06	20.06-29.07	29.07-31.08	31.08-29.09		10.05-21.06	21.06-30.07	30.07-30.08	30.08-30.09	
Control	DW[a]	47.7	33.8	27.8	18.0	127.3	32.7	15.7	11.7	10	70.1
	T[b]	9.4	15.1	10.8	8.7	44.0	7.7	6.5	4.2	4.6	22.9
	I[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ET_{gw}[d]	108.0	70.0	18.0	11.0	207.0	58.0	86.3	34.3	8.4	187.0
	ET[e]	165.1	118.9	56.6	37.7	378.3	98.4	108.5	50.1	23.0	280.0
	T:ET, %	5.7	12.7	19.1	23.1	11.6	7.8	6.0	8.3	19.8	8.2
	ET_{gw}:ET,%	65.4	58.9	31.8	29.2	54.7	59.0	79.5	68.4	36.6	66.8
AST04	DW[a]	84.3	72.9	102.5	19.8	279.5	30.8	71.3	56.6	119.8	278.5
	T[b]	22.5	59.3	24.7	9.8	116.3	10.8	95.1	19.8	9.6	135.3
	I[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ET_{gw}[d]	109.0	55.0	18.0	10.0	192.0	74.0	149.8	34.5	2.7	261.0
	ET[e]	215.8	187.2	145.5	39.6	587.8	115.6	316.2	110.9	132.1	674.8
	T:ET, %	10.4	31.7	17.0	24.7	19.8	9.4	30.1	17.9	7.3	20.1
	ET_{gw}:ET,%	50.5	29.4	12.4	25.3	32.7	64.0	47.4	31.1	2.0	38.7
AST03	DW[a]	112.3	34.9	81.9	20.1	249.3	42.9	28.7	84.6	25.7	181.9
	T[b]	38.2	88.9	48.5	15.3	190.9	23.2	119.9	105.7	15.3	264.1
	I[c]	0.0	0.0	93.0	0.0	93.0	0.0	85.5	93.0	0.0	178.5
	ET_{gw}[d]	103.0	65.0	8.0	9.0	185.0	63.0	129.9	29.8	0.3	223.0
	ET[e]	253.5	188.8	231.4	44.4	718.2	129.1	364.1	313.1	41.3	847.5
	T:ET, %	15.1	47.1	20.9	34.5	26.6	17.9	33.0	33.8	37.0	31.2
	ET_{gw}:ET,%	40.6	34.4	3.5	20.3	25.8	48.8	35.7	9.5	0.7	26.3
Arboretum	DW[a]	92.9	32.5	68.9	19.0	213.4	71.9	95.7	0.9	20.9	189.4
	T[b]	107.5	166.4	101	42.3	417.2	110.5	287.6	187.6	44.9	630.6
	I[c]	93.0	0.0	0.0	103.0	196.0	0.0	0.0	0.0	0.0	0.0
	ET_{gw}[d]	131.0	70.0	20.0	5.0	226.0	62.3	129.9	29.8	0.3	222.3
	ET[e]	424.4	268.9	189.9	66.3	949.6	244.7	513.2	218.3	66.1	1042.3
	T:ET, %	25.3	61.9	53.2	63.8	43.9	45.2	56.0	85.9	67.9	60.5
	ET_{gw}:ET,%	30.9	26.0	10.5	7.5	23.8	25.5	25.3	13.7	0.5	21.3

[a]DW= Changes in soil moisture storage at the upper (1.2 m) soil profile (mm), [b]T= transpiration rate (mm), [c]I= Irrigation rate, net (mm), [d]ET_{gw}= Contribution of groundwater to ET, [e]ET= Actual Evapotranspiration

Evapotranspiration of AST03 and AST04 was estimated to be 718-848 mm and 588-685 mm, respectively. At the same time transpiration of Ash trees was in the range of 116-135 mm (AST04) to 191-264 mm (AST03) and had an increasing trend from the younger to older trees (Arboretum trees' transpiration was found to be 417-630 mm) whereas transpiration of cotton was 23-44 mm. Maximum contribution of transpiration in ET (T:ET) expressed as a % was observed under Arboretum 43.9-60.5%, while that under control was only 8.2-11.0%. This parameter under AST03 and AST04 was 26.6-31.2% and 19.8-20.1%. At the same time maximum groundwater contribution in ET (ET_{gw}:ET) expressed in % was observed under control 54.7-66.8%, while that under Arboretum was almost two times less and was in the range of 21.3-28.8%. This parameter under AST03 and AST04 was 25.8-26.3% and 32.7-38.7%. Tree plantations through reducing of evaporation from bare soil through their crown reduced capillary rise of saline groundwater to the upper soil depth thereby the salt accumulation was partially stopped, while higher evaporation rate from bare soil in control bring up soluble salts to the upper depth (0-0.30 m soil horizon) . The data presented in Table 2.2.5.11 reveal a positive relationship between an age of trees and transpiration. Maximum transpiration of different vegetation cover as in 2006 and 2007 was observed during the 20.06-30.07 time period when temperature was higher and the soil moisture had a minimum values at the different soil depths. It is more interesting that the old trees transpiration rate even higher than the changes in soil moisture storage (ΔW) of those trees during the crop season. It might be explained by higher water uptake by old trees' leaves which had maximum a sucking force due to higher LAI and number of leaves and deeper roots, which allow decreasing the groundwater level at the experimental site.

4. CONCLUSIONS

Efficacy of different age classes of tree plantations in regulating the water level was investigated in this study. Results would suggest that tree plantations are an effective land use option to control elevated groundwater tables. Initial groundwater levels in 2006 and 2007 had a gradually lowering trend from March to September due to evaporation and transpiration, since subsurface outflow has a low value for all the treatments. The same trend of groundwater change was observed in 2007. In tree plantation site, the average groundwater level in 2006-2007 was 0.11-0.49 m lower in comparison with no tree plantation site during summer months. Among different tree treatments the maximum reductions of groundwater levels in 2006-2007 was observed under Arboretum (0.18-0.56 m), followed by Ash-tree planted in fall 2003 (0.18-0.28 m) and Ash-tree planted in fall 2004 (0.07-0.14 m) in comparison with control (no tree plantation). In September 2006 and 2007 groundwater changes were not significant that may be explained by lowering transpiration rate of the trees.

The first-two year analyses reveal that tree plantation together with reducing groundwater level, created favorable microclimate and reduced bring up soluble salts from groundwater through the reduction of evaporation, higher leaf biomass and reduced the accumulation of salts by 18-42% at the end of cotton season in 2006-2007. A further positive effect of tree plantation is reducing of environmental impacts and it has direct benefits for farmers through the production of wood for construction and fuel.

2.3 AGRICULTURAL MANAGEMENT OF SALINE WATER RESOURCES

2.3.1 EVALUATING THE FERTILIZER USE AS A MANAGEMENT OPTION TO MITIGATE THE EFFECTS OF SALINE WATER IRRIGATION[10]

1. INTRODUCTION
2.

Supplies of good-quality water are falling short of demand for intensively irrigated agriculture in many arid and semi-arid countries due to increased pressures to produce more food for a growing population as well as competition from urban, industrial and environmental sectors. Therefore, available freshwater supplies need to be used more efficiently. In addition, reliance on marginal-quality water resources seems inevitable for irrigated agriculture (Minhas, 1996; Bouwer, 2002; Qadir *et al*., 2007).

As an important category of marginal-quality water resource, saline and/or sodic waters consist of drainage water generated by irrigated agriculture, and groundwater containing different types of salts. Drainage from irrigated lands is necessary for large scale irrigation to be sustainable (Oster and Grattan, 2002; Wichelns and Oster, 2006). Increases in cropping intensity, excessive use of fertilizers and pesticides, as well as inappropriate irrigation methods and use of salt-affected soils for crop production contribute to increased salt loads in drainage water (Van Schilfgaarde, 1994; Skaggs and Van Schilfgaarde, 1999). The exploitation of groundwater resources in different parts of the world reveals that areas characterized by water scarcity have most often naturally occurring saline aquifers. The concentration and composition of salts in groundwater largely dependent upon the geochemical environment that the infiltrating water encounters en route to the groundwater.

Changes in river runoff in Central Asia have direct implications for water quality such as salt concentration as salinity levels vary significantly along the rivers course from upstream to downstream. For example, long-term monitoring of water quality of the Amu-Darya and Syr-Darya rivers indicate that in the 1950s, the salinity of these rivers varied annually from 0.33 to 0.72 g L^{-1}. These values are considered as within the permissible limits of water to be used for irrigation. Other river water quality parameters such as major cations and anions, organic compounds, pH, and pesticide levels were also within safe limits during 1950s (UNDP, 2007). Since the 1970s, the levels of salts in river water have increased steadily as a result of a decrease in the flow of Amu-Darya and Syr-Darya and an increase in the discharge of return flow, particularly drainage water from irrigated schemes. Consequently, there has been a significant increase in river water salinity since 1980s. Although return flow of water to rivers is an additional reserve for use, it has become a source of additional salts to the river water (Altiyev, 2005). About 95% of total return water is collector-drainage water, which contains elevated levels of salts. Estimates reveal the average percentage of mobilized salts is 40% of the total salt discharged into the drainage water (Kijne, 2005). About 51% of the total return flow of water is disposed to rivers, about 33% to depressions, and 16% is reused in irrigation.

As the agricultural use of saline water resources increases, their sustainable use for food and feed production will become a significant challenge (Suarez, 2001; Wichelns and Oster, 2006). In the future, agricultural systems using these resources should be sustainable with minimized adverse environmental and ecological impacts (Qadir and Oster, 2004). This will require interventions in the existing approaches to soil and water management. This is in part related to the fact that the growth of crops irrigated with saline and/or sodic waters or grown on salt-affected soils is influenced by the osmotic and ion-specific effects, and ionic imbalances leading to deficiency and/or toxicity of some nutrients.

Studies have demonstrated that optimal use of fertilizers, particularly those supplying nitrogen (N), can assist in mitigating the adverse effects of soil or irrigation water salinity. The current field study in southern Kazakhstan in partnership with the Dostyk Water Users Association was undertaken to determine the effects of different rates of N and combinations of water quality on: (1) chemical changes in

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[10] This component was led by ICARDA. NARS partners include S. Magay, A. Paramonov, and S. Ibatullin Kazakh Research Institute of Water Management, Ministry of Agriculture, Taraz, Kazakhstan.

the soil characteristics: (2) growth response of cotton (*Gossypium hirsutum* L.), which is most commonly grown in the area; and (3) economics of the applied treatments.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND SITE CHARACTERIZATION

The study was undertaken out during the years 2005-2007 in southern Kazakhstan. Cotton is main crop grown covering about 95% of the cropped area in summer. The study site was in Makhamad private farm of the Dostyk Water Users Association in Makhtaaral district where irrigation was sourced from the Syr-Darya River. Site characterization was undertaken in May 2005. The area has a smooth landscape with slopes from 0.002 to 0.0035. Long-term annual precipitation ranges from 50 to 250 mm, with 90% occurring during October through May. The average precipitation during the study period (April-October) was in the range of 34.6-120.3 mm. The area has high summer temperatures (26-30°C during June, July and August). The temperature declines to as low as –10°C, with an average of 2°C, during the winter months. The air temperature during the study period ranged from 16°C to 28°C. The soils are medium loam with about 1% organic matter in the surface layer. Soil bulk density is 1.44±0.10 Mg m^{-3} and the pH varies narrowly from 7.8 to 7.9.

Meteorological data collected during the cotton growing season from the nearby weather station indicated that the average air temperature during the cropping season was consistent with minor variation (22.1±0.1°C) between the years. However, there were larger variations in rainfall with highest rainfall occurring in 2007 (120.3 mm), followed by 59.8 mm in 2005, and 34.6 mm in 2006 (Table 2.3.1.1). The highest relative humidity in April (75%) and May (59%) and above average precipitation (110.8 mm) during both the months in 2007 resulted in a delay in cotton sowing by approximately one month.

2.2. TREATMENTS

There were two factors that were considered in the design of the trial using cotton as the test crop. Firstly, soil fertility management, which included two rates of N application at 70 kg ha^{-1} (farmers' practice in the area) and 140 kg ha^{-1} (~ 20% above the recommended rate of N application for cotton in the region). The second factor was associated with water quality aspect relating to the use of different combinations of low-salinity water (~1100±100 mg L^{-1}) and high-salinity water (~7500±600 mg L^{-1}) pumped from a vertical well. The experimental layout was a completely randomized block design with three replications. The total number of experimental plots was 18 (2 nitrogen rates × 3 water quality levels × 3 replications). Each plot size was 400 m^2 with gross experimental area of approximately 1 ha including the water channels and non-experimental belts. The following six treatment combinations were implemented:

1 Irrigation throughout the crop season with low-salinity water (~1100±100 mg L^{-1}) + N applied at 70 kg ha^{-1}: Later referred to as LSW–N70
2 Irrigation same as in treatment 1 + N at 140 kg ha^{-1}: Later referred to as LSW–N140
3 Irrigation with a mix of low-salinity and high-salinity water (~7500±600 mg L^{-1}) in respective ratios of 4:1 + N applied at 70 kg ha^{-1}: Later referred to as LSW:HSW(4:1)–N70
4 Irrigation same as in treatment 3 + N at 140 kg ha^{-1}: Later referred to as LSW:HSW(4:1)–N140
5 Irrigation with a mix of low-salinity and high-salinity water in respective ratios of 2:1 + N applied at 70 kg ha^{-1}: Later referred to as LSW:HSW(2:1)–N70
6 Irrigation same as in treatment 5 + N at 140 kg ha^{-1}: Later referred to as LSW:HSW(2:1)–N140

Table 2.3.1.1 Meteorological parameters measured during the cotton growing season at the experimental site

Month	Air Temperature (°C)			Mean relative humidity (%)	Precipitations (mm)	Reference evapotranspiration, ETo (mm)
	Minimum	Maximum	Mean			
2005						
April	0.5	32.1	16.0	65	32.4	118
May	9.5	36.0	21.1	54	21.8	162
June	15.1	42.3	27.7	40	1.3	221
July	15.9	44.0	28.4	43	0.0	223
August	9.4	38.6	25.1	52	2.7	182
September	5.8	36.4	21.6	50	0.0	132
October	1.2	31.0	15.2	55	1.6	57
April-October	8.2	37.2	22.2	51	59.8	1095
2006						
April	1.5	38.9	17.2	60	20.4	123
May	9.2	39.4	23.8	45	3.9	177
June	13.9	40.6	26.7	40	1.4	202
July	11.9	39.5	26.7	45	3.3	209
August	10.2	39.1	24.3	43	0.0	185
September	3.8	34.4	19.2	51	0.6	122
October	5.5	32.1	17.0	60	5.0	78
April-October	8.0	37.7	22.1	49	34.6	1096
2007						
April	6.1	33.0	18.2	75	68.2	106
May	7.5	37.9	21.6	59	42.6	165
June	12.9	43.1	27.1	36	2.4	216
July	13.7	41.4	28.4	42	0.0	216
August	12.6	40.0	25.9	47	2.8	182
September	3.6	37.1	20.1	50	0.0	125
October	0.2	28.5	12.5	52	4.3	76
April-October	8.1	37.3	22.0	51.6	120.3	1086

During first year of the experiment (2005), all treatments received N at the rate of 70 kg ha^{-1}. In the subsequent years (2006 and 2007), N was applied at 70 kg ha^{-1} to the treatments with odd numbers (1, 3, and 5) while increased rate of N (140 kg ha^{-1}) was applied to those treatments with even numbers (2, 4, and 6).

2.3. SOIL AND WATER SAMPLING AND ANALYSIS

Composite soil samples were collected from each plot at the following depths prior to the implementation of treatments: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Further sampling was undertaken after the harvest of cotton in each cropping year. The methodologies used in tha nalaysis of samples has been described previously (See section 2.2.) and for brevity will not be repeated here.

2.4. EXPERIMENTAL PROCEDURE

The field was plowed with a tractor during last week of February 2006. This was followed by land leveling in mid March 2006. In order to facilitate the leaching of salts from the root zone, a leaching irrigation (1500-2000 m^3 ha^{-1}) was applied in late March 2006. Harrowing was achieved with a tractor just before cotton sowing. Cotton variety Makhtaaral-3044 was sown with a seeder (Model: SPC-3.6) in late April 2006 at the seed rate of 24 kg ha^{-1}. Chiseling was undertaken to a depth of 0.10-0.12 m before sowing to breakup stubble (Stubble Breaker CHKU-3.6). Cultural practices for cotton cultivation in the control and

conjunctive water used plots were the same and in accordance with the prevalent system of agriculture used in the region (Umbetaev and Batkaev, 2000). Nitrogen in the form of ammonium nitrate (NH_4NO_3) was applied at the rate of 70 and 140 kg ha^{-1} in early June 2006. Cotton was harvested in late September 2006 and yield from each plot was recorded. In the subsequent year (2007), all the agronomic and fertilizer management practices were the same except early soil leaching with a greater volume of water (2000-2200 m^3 ha^{-1}) in late February 2007 and late sowing of cotton (late May 2007), late application of nitrogen fertilizers (mid July 2007) and late harvesting of cotton (mid October 2007).

3. RESULTS AND DISCUSSIONS

3.1. PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

The soil was classified as a silt loam throughout the profile up to the depth of 0.90 m. Field capacity in the upper 0.15 m depth was 20.47%; for the 0.15-0.30 m depth, its value was 21.00%. At the 0.30-0.60 m and 0.60-0.90 m depths, field capacity was estimated to be 21.28% and 23.71%, respectively. Soil bulk density had an increasing trend from surface to deeper horizons and ranged from 1.34 to 1.37 Mg m^{-3} at the upper 0.15 m layer, and from 1.52-1.54 Mg m^{-3} at the 0.30-0.60 m depth. This trend of soil bulk density is commonly observed in old irrigated soils. The organic matter content was low throughout the soil profile, i.e. 0.65% at 0-0.15 m soil depth, 0.54% at 0.15-0.30 m, 0.33% at 0.30-0.60 m, and 0.22% at 0.60-0.90 m. In terms of nutrient availability status in the 0.9 m soil profile, available nitrogen was 46 mg kg^{-1}, phosphorous 35 mg kg^{-1}, and potassium 226 mg kg^{-1}. The pre-experiment soil salinity levels in terms of total dissolved salts (TDS) at different soil depths extending down to 0.9 m were in the range of 4982 mg L^{-1} to 6449 mg L^{-1} with the highest value observed in the 0.60-0.90 m soil depth (Table 2.3.1.2). The corresponding EC_e values were in the range 7.46-9.85 dS m^{-1}. Among the anions, SO_4^{2-} was dominant with a maximum concentration of 85.34 mmol$_c$ L^{-1} at the 0.30-0.60 m depth and varied from 61.69 to 85.34 mmol$_c$ L^{-1}. Small variations in SO_4^{2-} were observed at the 0.0-0.15 m (61.69 mmol$_c$ L^{-1}) and 0.15-0.30 m soil depths (61.74 mmol$_c$ L^{-1}). Its concentration increased in the 0.30-0.60 and 0.60-0.90 m soil depths (71.30-85.34 mmol$_c$ L^{-1}). The Cl^- concentrations were less than that of SO_4^{2-} and showed a slightly increasing trend from surface to deeper horizons and varied in the range 8.53 to 11.76 mmol$_c$ L^{-1}. With small variations at different soil depths, the concentrations of HCO_3^{2-} were much less than that of Cl^- and ranged from 3.61 to 4.29 mmol$_c$ L^{-1}.

Among the cations, Ca^{2+} concentration was higher at the soil surface than other cations, Na^+ and Mg^{2+} (Table 2.3.1.2). Sodium concentrations did not differ much (13.39-19.68 mmol$_c$ L^{-1}) over soil depths. Mg^{2+} concentration ranged from 22.56 to 28.89 mmol$_c$ L^{-1}. The K^+ concentration was ≤ 1 mmol$_c$ L^{-1}. The SAR levels were in the range of 2.48 to 3.44, indicating that the soil was saline in its characteristics.

Table 2.3.1.2 Chemical properties of the field site before start of the experiment

Soil characteristic	Unit	Soil depth (m)			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
pH	—	7.70	7.72	7.65	7.68
EC_e	dS m^{-1}	7.64	7.46	9.85	8.67
Soluble Ca^{2+}	mmol$_c$ L^{-1}	37.78	36.81	53.19	38.89
Soluble Mg^{2+}	mmol$_c$ L^{-1}	22.56	23.47	28.89	27.78
Soluble Na^+	mmol$_c$ L^{-1}	15.11	13.39	15.91	19.68
Soluble K^+	mmol$_c$ L^{-1}	0.97	0.90	0.52	0.32
Soluble HCO_3^{2-}	mmol$_c$ L^{-1}	4.20	4.29	3.79	3.61
Soluble Cl^-	mmol$_c$ L^{-1}	10.53	8.53	9.38	11.76
Soluble SO_4^{2-}	mmol$_c$ L^{-1}	61.69	61.74	85.34	71.30
SAR	—	2.77	2.51	2.48	3.44

3.2. IRRIGATION AND GROUNDWATER QUALITY

The salt concentration expressed as total soluble salts (TSS) in low-saline irrigation water ranged from 1050 to 1156 mg L^{-1} (1.58-1.76 dS m^{-1}) during 2006, and from 1029 to 1149 (1.55-1.75 dS m^{-1}) during 2007 (Table 2.3.1.3). pH levels were alkaline in reaction with values in the range of 8.12 to 8.24 during

2006-2007. The composition of irrigation water from June to October in terms of cationic concentration indicated small temporal variation. The dominant cations were Ca^{2+} and Mg^{2+} with limited differences in their concentrations. The levels of SAR and SAR_{adj} did not differ over the monitoring period. The salt concentrations in drainage water were in the range of 6935-8107 mg L^{-1} (11.01-13.03 dS m^{-1}) during 2006 and 6956 mg L^{-1} (11.02 dS m^{-1}) in September 2007 (Table 2.3.1.3). The pH of drainage water (7.85-8.36) was alkaline in reaction. The ratio Cl^{-}:SO_4^{2-} was almost one, while the concentration of HCO_3^{2-} was much less, indicating sulfate-chloride type of salinity in drainage water. The levels of SAR and SAR_{adj} were in the range of 14.45 to 18.57 (2006-2007), suggesting that the use of such drainage water for irrigation without appropriate management practices would cause gradual increase in Na^{+} levels in the irrigated soils.

Table 2.3.1.3 Composition of irrigation, drainage and groundwater at the experimental site

Charac-teristic	Unit	Irrigation water 2006	Irrigation water 2007	Drainage water 2006	Drainage water 2007	Groundwater 2006	Groundwater 2007
pH	—	8.20±0.04 [a]	8.15±0.03	8.28±0.08	7.85 [b]	8.02±0.05	8.00±0.06
EC	dS m^{-1}	1.67±0.09	1.65±0.10	12.02±1.01	11.02	8.56±0.48	8.72±0.44
TSS	mg L^{-1}	1103±53	1089±60	7521±586	6956	5434±301	5531±297
Ca^{2+}	$mmol_cL^{-1}$	6.53±0.29	6.40±0.31	16.75±0.25	16.00	27.15±1.17	25.89±0.59
Mg^{2+}	$mmol_cL^{-1}$	5.65±0.43	5.47±0.27	29.00±3.00	25.00	35.94±2.74	37.19±2.91
Na^{+}	$mmol_cL^{-1}$	4.46±0.30	4.57±0.38	74.34±7.33	69.12	22.41±2.80	24.02±2.32
K^{+}	$mmol_cL^{-1}$	0.07±0.00	0.07±0.00	0.07±0.00	0.05	0.05±0.00	0.06±0.00
HCO_3^{-}	$mmol_cL^{-1}$	2.61±0.15	2.51±0.05	2.16±0.08	2.16	5.11±0.35	3.08±0.20
Cl^{-}	$mmol_cL^{-1}$	2.97±0.20	2.93±0.19	54.00±8.00	46.00	18.81±3.54	19.44±2.34
SO_4^{2-}	$mmol_cL^{-1}$	11.13±0.83	11.07±0.83	64.00±2.00	62.00	61.61±4.30	64.71±2.65
Cl^{-}:SO_4^{2-}	$mmol_cL^{-1}$	0.27±0.01	0.27±0.01	0.84±0.10	0.74	0.39±0.09	0.29±0.03
Mg^{2+}:Ca^{2+}	—	0.86±0.04	0.85±0.01	1.73±0.20	1.56	1.47±0.16	1.47±0.12
SAR	—	1.81±0.10	1.87±0.11	15.52±1.07	15.26	3.84±0.45	3.89±0.50
SAR_{adj}	—	2.10±0.12	2.17±0.12	17.38±1.19	17.10	4.36±0.50	4.42±0.56

[a] Figures with ± represent standard error of the mean

[b] Drainage water samples were collected once in mid September 2007

The groundwater salinity levels ranged from 5133 to 5735 mg L^{-1} (8.08-9.04 dS m^{-1}) during 2006 and from 5234 to 5828 mg L^{-1} (8.28-9.16 dS m^{-1}) during 2007 (Table 2.3.1.3). The pH levels ranged from 7.94 to 8.07 (2006-2007). The levels of SAR and SAR_{adj} were in the range of 3.39 to 4.98 during 2006-2007. Groundwater had a low alkaline reaction and was highly saline. Upward flow from ground water level could cause the develop of sodic characteristics in the soil profile.

3.3. SOIL SALINITY AND SODICITY

At the end of the cropping season in 2006, soil salinity and sodicity increased in comparison with initial level under all the treatments where irrigations were applied through blending of irrigation and drainage water in ratio 4:1 and 2:1 (Table 2.3.1.4). The maximum increase in soil salinity was in the 0-0.15 m soil depth was observed under LSW:SW (2:1)-N70 treatment where there was 36 % increase over the initial soil salinity level in 2006 (Table 2.3.1.4). Soil salinity levels at the same depth increased by 24-36% and 13-32% under treatments where single and increased rates of nitrogen fertilizers were applied

Table 2.3.1.4 Soil salinity levels expressed as EC_e (dS m^{-1}) and soil sodicity as expressed by sodium absorption ratio (SAR) in the soil profile as affected by treatments in 2006 and 2007

Soil depth (m)	EC_e			SAR		
	Initial soil (2006)	Post-cotton (2006)	Post-cotton (2007)	Initial soil (2006)	Post-cotton (2006)	Post-cotton (2007)
LSW–N70						
0-0.15	7.08	7.55 (+7) [a]	6.67 (-6)	3.40	3.33 (-2) [b]	2.07 (-39)
0.15-0.30	5.64	7.67 (+36)	5.02 (-11)	2.64	3.79 (+44)	2.04 (-23)
0.30-0.60	8.85	12.8 (+45)	11.45 (+29)	1.98	1.98 (0)	1.83 (-8)
0.60-0.90	9.36	11.39 (+22)	11.22 (+20)	2.83	1.77 (-37)	2.58 (-9)
LSW:HSW(4:1)–N70						
0-0.15	8.37	10.35 (+24)	6.99 (-16)	2.49	2.12 (-15)	1.66 (-33)
0.15-0.30	8.40	10.34 (+23)	5.05 (-40)	1.93	2.68 (+39)	1.74 (-10)
0.30-0.60	11.50	16.77 (+46)	14.3 (+24)	2.57	2.99 (+16)	2.78 (+8)
0.60-0.90	9.83	14.68 (+49)	12.49 (+27)	2.71	4.13 (+52)	2.44 (-10)
LSW:HSW(2:1)–N70						
0-0.15	9.57	12.98 (+36)	8.38 (-12)	2.69	4.04 (+50)	2.32 (-14)
0.15-0.30	10.75	11.65 (+8)	7.69 (-28)	2.59	2.85 (+10)	2.54 (-2)
0.30-0.60	10.87	16.25 (+49)	14.12 (+30)	2.85	2.93(+3)	3.02 (+6)
0.60-0.90	8.69	16 (+84)	12.89 (+48)	4.50	3.31 (-26)	2.86 (-36)
LSW–N140						
0-0.15	6.13	8.10 (+32)	7.64 (+25)	2.84	3.32 (+17)	4.48 (+58)
0.15-0.30	5.98	8.43 (+41)	7.12 (+19)	4.01	4.47 (+11)	2.92 (-27)
0.30-0.60	8.59	10.53 (+23)	10.12 (+18)	2.74	3.17 (+16)	3.56 (+30)
0.60-0.90	8.03	11.9 (+48)	9.71 (+21)	3.65	3.02 (-17)	3.68 (+1)
LSW:HSW(4:1)–N140						
0-0.15	7.28	7.11 (-2)	9.12 (+25)	2.33	2.87 (+23)	2.78 (+19)
0.15-0.30	6.92	7.46 (+8)	8.25 (+19)	1.80	3.35 (+86)	1.80 (0)
0.30-0.60	8.91	10.04 (+13)	10.77 (+21)	2.08	2.66 (+28)	2.51(+21)
0.60-0.90	7.22	13.81 (+91)	8.92 (+24)	3.22	2.40 (-25)	2.55 (-21)
LSW:HSW(2:1)–N140						
0-0.15	7.42	8.42 (+13)	9.92 (+34)	2.89	4.98 (+72)	3.16 (+9)
0.15-0.30	7.05	8.26 (+17)	8.45 (+20)	2.10	5.72 (+172)	2.77 (+32)
0.30-0.60	10.39	13.4 (+29)	12.39 (+19)	2.66	3.40 (+28)	3.28 (+23)
0.60-0.90	8.86	14.39 (+62)	10.83 (+22)	3.75	3.63 (-3)	3.96 (+6)

[a]Figures in parenthesis indicate percentage increase (+) or decrease (–) over pre-experiment soil salinity level

[b]Figures in parenthesis indicate percentage increase (+) or decrease (–) over pre-experiment soil sodicity level

The maximum increase in soil sodicity was observed under LSW:SW (2:1)-N140 at the 0.15-0.30 m soil depth (172%). There was no clear pattern in 2007, which was probably due to: (1) spatial variability in the soil in terms of salt distribution in the soil profile, (2) dissolution of ammonium nitrate that increased soil salinity, particularly in the upper 0.15 m soil depth, and (3) higher amount of precipitation observe in spring 2007.

3.4. IRRIGATION PARAMETERS

The first irrigation (1083-1202 m^3 ha^{-1}) in 2006 was applied on 2 August, which was followed by the 1015-1225 m^3 ha^{-1} second irrigation on 27 August. The total irrigation was estimated to be between 2098 to 2427 m^3 ha^{-1} (Table 2.3.1.5). In 2007 first irrigation (1160-1230 m^3 ha^{-1}) was applied on 8 August 2007, which was followed by the 1100-1180 m^3 ha^{-1} second irrigation on 16-19 September 2007. The total irrigation was estimated in the range of 2260 to 2410 m^3 ha^{-1}.

Table 2.3.1.5 Irrigation rates of cotton (m^3 ha^{-1}) during 2006 and 2007

Treatment	Irrigation dates (2006)		Irrigation dates (2007)	
	02.08.2006	27.08.2006	08.08.2007	16-19.09.2007
LSW–N70	1083	1105	1160	1140
LSW–N140	1202	1195	1230	1180
LSW:HSW(4:1)–N70	1083	1015	1160	1110
LSW:HSW(4:1)–N140	1202	1030	1230	1150
LSW:HSW(2:1)–N70	1083	1060	1160	1100
LSW:HSW(2:1)–N140	1202	1225	1230	1130

3.5. CHANGES IN GROUNDWATER LEVEL

Ground water level fluctuated from 1.48 to 2.63 m during June-October 2006-2007 (Figure 2.3.1.1). Since the canal water was in short supply in 2006 and 2007, the first irrigation was applied in early August in both the years. The second irrigation was applied at about the same rate in late August 2006 and mid September 2007. Irrigation rates were increased by 10% as compared to control when 140 kg ha^{-1} rate of nitrogen was applied. In the initial stages until mid July, plants were supplied from the shallow ground water level. Even to the end of July, soil moisture content in the 0-0.90 m soil layer was more than 60-65% field capacity, which indicates upward flow from the groundwater level.

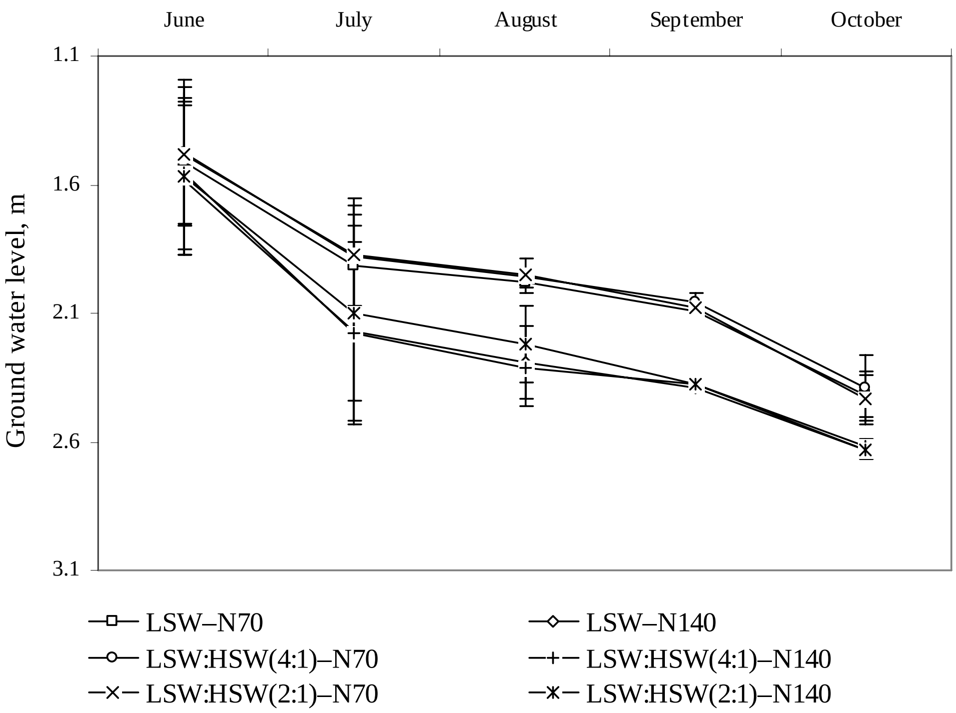

Figure 2.3.1.1 Averaged ground water levels at the experimental site (2006-2007)

During the vegetative growth stage percolation losses from the irrigated fields resulted in the groundwater becoming moderately saline. Under treatments with increased rates of the nitrogen fertilizer, ground water level was deeper by 0.20-0.36 m when compared to treatments receiving the normal farmer rates (Figure 2.3.1.1).

3.6. COTTON GROWTH AND YIELD

In 2006 cotton yields from the different treatments ranged from 2.12-2.84 t ha^{-1} (Table 2.3.1.6). Conjunctive use of irrigation and drainage water (2500 mg L^{-1}) reduced cotton yield by only 7-9%, while the salinity of irrigation water of 3100 mg L^{-1} reduced the cotton yield by 13-16% in comparison with irrigation using fresh water. In 2006, the yields of raw cotton were increased by 16.4, 14.3, and 12.6% under the nitrogen fertilizer application at 140 kg N ha^{-1} as compared to the 70 kg N ha^{-1} (Table 2.3.1.6).

Table 2.3.1.6 Cotton yield (t ha^{-1}) as affected by various treatments

Fertilizers (factor A)	Quality of water (factor B)			Average on factor A[a]
	LSW	LSW:HSW (4:1)	LSW:HSW (2:1)	
2006				
N70	2.44	2.26	2.12	2.28
N140	2.84	2.58	2.39	2.61
Average on factor B[b]	2.64	2.42	2.26	2.44
2007				
N70	2.26	2.15	2.01	2.14
N140	2.53	2.35	2.17	2.35
Average on factor B[b]	2.40	2.25	2.09	2.24

[a] Least significance difference at $p = 0.05$ for factor A was 0.11 t ha^{-1} in 2006 and 2007
[b] Least significance difference at $p = 0.05$ for factor B was 0.13 t ha^{-1} in 2006 and 2007

3.7. CROP WATER PRODUCTIVITY

In 2006, the maximum water productivity (WP) of cotton (1.04 kg m^{-3}) was recorded in LSW–N140 treatment, followed by LSW:HSW(4:1)–N140 (1.00 kg m^{-3}), LSW–N70 (0.96 kg m^{-3}), LSW:HSW(4:1)–N70 (0.92 kg m^{-3}), LSW:HSW(2:1)–N140 (0.86 kg m^{-3}), and LSW:HSW(2:1)–N70 (0.85 kg m^{-3}) (Figure 2.3.1.3). In the subsequent year (2007), the water productivity was in the order: LSW–N140 treatment (0.70 kg m^{-3}) > LSW–N70 (0.65 kg m^{-3}) ≈ LSW:HSW(4:1)–N140 (0.65 kg m^{-3}) > LSW:HSW(4:1)–N70 (0.62 kg m^{-3}) ≈ LSW:HSW(2:1)–N140 (0.61 kg m^{-3}) > LSW:HSW(2:1)–N70 (0.58 kg m^{-3}) (Figure 2.3.1.3).

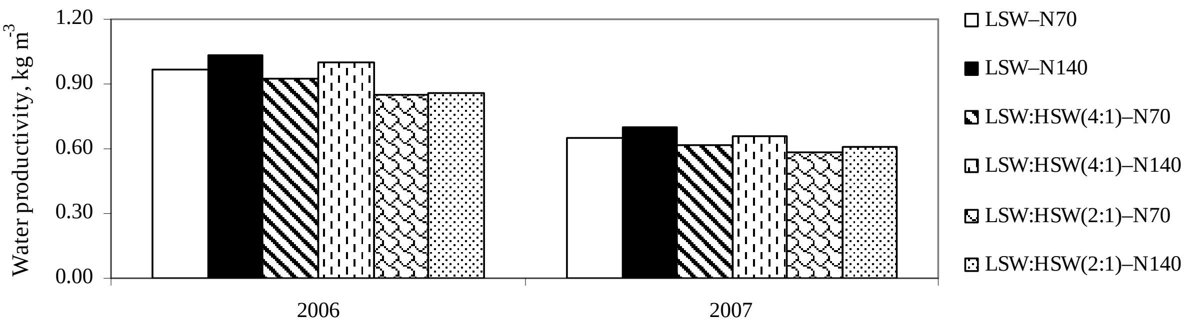

Figure 2.3.1.3 Average values of water productivity (kg m^{-3}) of cotton as affected by different treatments during cotton growing season (May-October) in 2006 and 2007

In the present study, WP in 2007 was lower by 20-35% when compared to 2006, since there were larger variations in rainfall amount with highest rainfall occurring during May-October 2007 (120.3 mm), followed by 34.6 mm in the same period in 2006.

3.8. ECONOMICS OF THE TREATMENTS

Economic efficiency of saline water use for irrigation with increasing rates of nitrogen application are presented in Table 2.3.1.7. The data suggest that the prime cost of cotton production was increased in the treatments with the doubling rate of nitrogen application (140 kg ha^{-1}). The maximum prime cost (US$ 476 in 2006 and US$ 568 in 2007) was received under the LSW-N140 treatment; the minimum (US$ 420 in 2006 and US$ 494 in 2007) under the LSW:SW(2:1)-N70 treatment.

In terms of net income, the treatments where low-saline water was used for irrigation throughout the cropping season at both rates of N application (LSW–N70 and LSW–N140) performed better than other treatments. The net income in these treatments was almost US$ 100 more than other treatments. The net

profit under double rate of N fertilizers was almost same in the treatments when saline and canal waters were mixed in the ratio of 4:1 (438 $US in 2006 and 591US$ in 2007) and where only canal water was applied for irrigation (429 $US and 607 $US in 2007). Farmers can address deficit periods in canal water supply by applying saline water in conjunction with canal water in the ratio of 4:1 but at the same time they should increase the rate of nitrogen fertilizer application.

Table 2.3.1.7 Economic efficiency of saline water use for irrigation and increasing the rate of nitrogen application (expressed in US$) [a]

Expenditure/income	LSW–N70	LSW:HSW(4:1)–N70	LSW:HSW (2:1)–N70	LSW–N140	LSW:HSW(4:1)–N140	LSW:HSW(2:1)–N140
Year 2006						
Cultivation [b]	324	316	309	338	329	320
Fertilizer	49	49	49	81	81	81
Water and irrigation	57	62	61	57	62	61
Prime cost of cotton	430	427	420	476	472	462
Gross income [c]	859	796	747	999	910	843
Net income	429	369	327	523	438	381
Year 2007						
Cultivation [b]	363	357	350	378	368	358
Fertilizer	78	78	78	128	128	128
Water and irrigation	62	67	66	62	67	66
Prime cost of cotton	504	503	494	568	564	553
Gross income [c]	1111	1057	988	1244	1155	1067
Net income	607	554	494	676	591	514

[a] The expenditures and income determined in local currency (Kazakh tenge) were converted to US$ with the currency exchange rate in the respective year

[b] Includes costs on plowing, making furrows, land leveling, harrowing, grinding, chiseling, sowing, weeding, spraying and crop harvesting

[c] Derived from the product of cotton yield and market price of cotton in the region in the respective year

4. CONCLUSIONS

In order to evaluate the interactive effects of two rates of nitrogen fertilizer application and three levels of water quality, a study was undertaken to evaluate different treatment combinations on the growth and yield of cotton, which is a common summer crop under irrigated agriculture in Kazakhstan. The results reveal that the increase in salinity of irrigation water caused a decrease in cotton yield. Application of saline water in conjunction with canal water in the ratio of 4:1 with a doubling of the rate of nitrogen fertilizer application (140 kg ha^{-1}) could be appropriate recommendation for the area where experiment was conducted under water scarcity conditions. An increase in the nitrogen application rate result in the significant increase in cotton yield over current farmer practices where 70 kg N ha^{-1} are commonly applied. These results suggest that suitable combinations of nutrient application to the soil and irrigation water quality can offset in part the effects of elevated salinity in irrigation water. These finding are particularly important in areas where freshwater resources are limited or will be limited in the foreseeable future. Farmers can cover deficits in high-quality freshwater by using saline water in conjunction with canal water and appropriate levels of nitrogen fertilizer application.

2.3.2 PRODUCTIVITY ENHANCEMENT OF FODDER-BASED CROPPING SYSTEMS THROUGH THE USE OF SALINE DRAINAGE WATER[11]

1. INTRODUCTION

The supplies of freshwater are declining for agriculture in several parts of Central Asia. As an alternative, farmers are using low saline water having salinity levels around 1200 mg L^{-1} (≈1.8 dS m^{-1}) in most of the irrigated lands of Turkmenistan. This situation is further complicated as low-saline water is not available in sufficient quantities to fulfill the crop water needs. Cyclic use of saline and freshwater, also known as rotational use, facilitates the conjunctive use of freshwater and saline drainage effluent. In this mode, saline drainage water replaces canal water in a predetermined sequence or cycle. Cyclic use is an option for where the salinity of the drainage water exceeds the salinity threshold value of the desired crop. A condition for cyclic use is that two different water sources can be applied to the field separately. Therefore, it is not normally applied at irrigation-scheme level but at a tertiary or farm level. In areas where irrigation water is delivered on a rotational basis to the watercourses (tertiary canal) and individual farms, this approach offers considerable potential for optimal use of water resources. Modeling and field studies have demonstrated the feasibility of the cyclic reuse strategy (Rhoades, 1987; Rhoades *et al.*, 1988a and b; Rhoades 1989; and Rhoades *et al.*, 1989).

A field study was undertaken in Turkmenistan to evaluate the response of some fodder crops — sorghum [*Sorghum bicolor* (L.) Moench], maize [*Zea mays* L.], and an indigenous variety of sorghum [*Sorghum sernuum* Host] — to multi-quality waters used conjunctively.

2. MATERIALS AND METHODS

This experiment was undertaken at Akdepe farm in Dashauz Province of Turkmenistan. The experimental layout consisted of a completely randomized block design with three replications with plot size of 30 m × 60 m. The total number of experimental plots was 9 (3 treatments × 3 replications = 9). The crops used in the study were sorghum [*Sorghum bicolor* (L.) Moench], maize [*Zea mays* L.], and an indigenous variety of sorghum [*Sorghum sernuum* Host]. With each irrigation treatment consisting of four irrigations during the cropping season, the following conjunctive use options were established:

1. Control (all fours irrigations during the cropping season with low saline water with salinity level (~1000±200 mg L^{-1}): Later referred to as LSW
2. Cyclic use of low saline water (first irrigation) and a highly saline drainage water (~4000 mg L^{-1}; remaining three irrigations): Later referred to as LSW_1:SW_3
3. Cyclic use of low saline water (first two irrigations) and a highly saline drainage water (~4000 mg L^{-1}; remaining two irrigations): Later referred to as LSW_2:SW_2

2.1. SOIL AND WATER SAMPLING AND ANALYSIS

Composite soil samples were collected from each plot prior to the implementation of treatments at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. Further samples were collected after the crop was harvested. The methodologies used in the analysis of soil and water samples were described previously in this report.

[11] This component was led by ICARDA. NARS partners include D. Nurmedov, K. Redjepbaev, and S. Ruziev Turkmen Research Institute of Agriculture, Ministry of Agriculture, Ashgabat, Turkmenistan

2.2. EXPERIMENTAL PROCEDURE

The field was plowed to a depth of 0.35-0.40 m on 27 May 2005, 8 March 2006 and 29 March 2007. Land leveling was undertaken on the 28 May 2005, 24 March 2006 and 29 March 2007. In 2005-2007, sorghum, maize, and an indigenous genotype of sorghum were cultivated as test crops. Sorghum and maize were sown by manual broadcasting on 17 June 2005, 9 July 2006, 23 May 2007 at the seeding rates of 30-40 kg ha^{-1}. Sorghum indigenous variety *Sorghum sernuum* was sown on the same dates at a rate of 25 kg ha^{-1}. Chiseling was done at 0.10-0.12 m depth before sowing to break stubble (Stubble Breaker CHKU-3.6). Just before sowing, a harrowing operation was undertaken (Harrow ZBS-1 on Tractor MTZ 80). Nitrogen in form of ammonium nitrate was applied in two splits at a rate of 146 and 50 kg ha^{-1} on 16 June 2005 and 6 July 2005, respectively. Just before sowing, in 2006-2007 Nitrogen fertilizer in the form of Carbamide was applied by manual broadcasting at the rate of 200 kg ha^{-1} in early June 2006 and at the rate of 100 kg ha^{-1} in late May 2007. At maturity (10-17 October 2005-2007), the crops were harvested from each plot to determine the fodder yields on plot basis, which was subsequently calculated and reported on per hectare basis.

3. RESULTS AND DISCUSSIONS

3.1. PRE-EXPERIMENT SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

The soil is silt loam in texture throughout the profile to a depth of 0.90 m (Table 2.3.2.1). Field Capacity in the upper 0.15 m depth was 23.79%; for the 0.15-0.30 m depth, its value was 24.08%. Infiltration rate was found to be 5.48 mm h^{-1}. Soil bulk density varied in the range of 1.36 to 1.41 Mg m^{-3}.

Table 2.3.2.1 Physical properties of the experimental field at the Akdepe farm in Dashauz

Soil properties	Unit	Soil depth (m)			
		0.0-0.15	0.15-0.30	0.30-0.60	0.60-0.90
Sand particles (0.05-2.0 mm)	%	27.62	27.15	29.57	24.84
Silt particles (0.002-0.05 mm)	%	55.70	56.46	54.10	57.13
Clay particles (<0.002 mm)	%	16.68	16.39	16.33	18.04
Soil texture (method USDA)	—	silt loam	silt loam	silt loam	silt loam
Field capacity	%	23.79	24.08	25.48	25.22
Infiltration rate	mm h^{-1}	5.48	—	—	—
Soil bulk density	Mg m^{-3}	1.36	1.40	1.39	1.41

In 2005 the pre-experiment soil salinity levels in terms of TDS at different soil depths extending to 0.9 m ranged from 8269 mg L^{-1} to 9161 mg L^{-1} (12.77 to 14.15 dS m^{-1}) (Table 2.3.2.2). Among the anions, SO_4^{2-} was dominant having maximum concentration of 93.67 me L^{-1} at the upper 0.15 m depth. The concentration of SO_4^{2-} declined from surface to deeper horizons and varied in the range of 74.83 to 93.67 $mmol_c$ L^{-1}. Chloride (Cl^-) concentration was the lower compared to that of SO_4^{2-} and had an increasing trend from top to deeper horizons and ranged from 43.48 to 49.29 me L^{-1} at different soils depths. However, there were minor concentrations of HCO_3^{2-}, ranging from 3.60 to 4.36 me L^{-1}. Among the cations, Na^+ was dominant in the soil surface horizon followed by Ca^{2+}, Mg^{2+}, and K^+ (Table 2.3.2.2). The concentration of Na^+ in the upper 0.15 m depth was determined to be 56.61 me L^{-1}. It also followed a different pattern compared to SO_4^{2-} as its concentration had an increasing trend from surface to deeper horizons and varied in the range 56.61 to 70.39 me L^{-1}. The concentration of Ca^{2+} in the upper 0.15 m soil depth was determined to be 52.44 me L^{-1}. It also followed a pattern similar to the dominant anion (SO_4^{2-}) as its concentration had a decreasing trend from surface to deeper horizons and varied in the range of 32.94 to 52.44 me L^{-1}. The concentration of Mg^{2+} was less than Ca^{2+} concentration at the different soil depths. It ranged from 23.28 to 30.61 me L^{-1} and followed a pattern similar to Ca^{2+} concentration with respect to soil depth. The K^+ concentration had a decreasing trend from surface to deeper horizons and varied in the range 1.11 to 1.83 me L^{-1}. The SAR levels had an increasing trend from

top to deeper horizons and were in the range of 8.78 to 13.28. As we can see SAR values at the 0.30-0.90 cm closer to threshold value (SAR ~ 13) and these soils could cause sodicity problems to plants development.

Table 2.3.2.2 Chemical properties of the field site before start of the experiment

		Soil depth (m)			
Soil Characteristic	**Unit**	**0.0-0.15**	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
pH	—	8.61	8.67	8.73	8.69
EC_e	dS m^{-1}	14.15	13.03	12.77	12.92
TDS	mg L^{-1}	9161	8391	8269	8367
Soluble Ca^{2+}	$mmol_c$ L	52.44	36.89	32.94	34.83
Soluble Mg^{2+}	$mmol_c$ L	30.61	27.72	23.28	24.67
Soluble Na^{+}	$mmol_c$ L	56.61	64.32	70.39	68.51
Soluble K^{+}	$mmol_c$ L	1.83	1.40	1.11	1.16
Soluble CO_3^{2-}	$mmol_c$ L	abs	abs	abs	abs
Soluble HCO_3^{2-}	$mmol_c$ L	4.36	4.13	3.60	3.73
Soluble Cl^{-}	$mmol_c$ L	43.48	45.67	49.29	48.57
Soluble SO_4^{2-}	$mmol_c$ L	93.67	80.53	74.83	76.87
SAR	—	8.78	11.32	13.28	12.56

3.2. IRRIGATION, DRAINAGE, AND GROUNDWATER QUALITY

The salt concentrations in irrigation, drainage and in ground waters are presented in Table 2.3.2.3-2.3.3.5. The salt concentration in low-saline irrigation had a slightly increasing trend and ranged from 652 to 968 mg L^{-1} (0.89-1.48 dS m^{-1}) during 2005, from 742 to 2159 mg L^{-1} (1.12-3.27 dS m^{-1}) during 2006, and from 945 to 1331 mg L^{-1} (1.41-2.03 dS m^{-1}) during 2007. The composition of irrigation water from June to October in terms of cationic concentration indicated small temporal variation. The dominant cations were Na^{+} and Ca^{2+} in 2005-2006 and Na^{+} and Mg^{2+} in 2007. The levels of SAR and SAR_{adj} ranged from 2.52 to 3.57 (2005-2007). The irrigation water was alkaline in reaction, and is saline. Evidently, irrigation conducted by applying this quality water will not cause sodicity problems to plants development

The salt concentrations in moderate-saline drainage had an increasing trend and were in the range of 861-3795 mg L^{-1} (1.19-5.96 dS m^{-1}) during 2005, 2361-10391 mg L^{-1} (3.68-16.93 dS m^{-1}) during 2006 and 3539-8761 mg L^{1} (3.54-8.76 dS m^{-1}) during 2007. The ratio Cl^{-}:SO_4^{2-} was in the range of 0.53-1.39 (2005-2007). The levels of SAR and SAR_{adj} were in the range of 1.72 to 15.64 (2005-2007), suggesting that the use of such drainage water for irrigation without appropriate management practices may cause gradual increase in Na^{+} levels in the irrigated soils.

Table 2.3.2.3 Composition of irrigation water at the experimental site in 2005-2007

Indices	Unit	Mean				Range (Minimum-Maximum)		
		2005	2006	2007	2005-07	2005	2006	2007
pH	—	7.44	7.38	7.95	7.59(±0.18)[a]	6.75-8.65	6.82-8.30	7.35-8.50
EC_e	dS m^{-1}	1.20	1.84	1.70	1.58 (±0.20)	0.89-1.48	1.12-3.27	1.41-2.06
TDS	mg L^{-1}	808	1210	1111	1043 (±121)	652-968	742-2159	945-1331
Ca^{2+}	$mmol_c$ L^{-1}	4.20	6.80	4.64	5.21 (±0.80)	3.60-4.60	4.00-15.80	3.75-5.60
Mg^{2+}	$mmol_c$ L^{-1}	2.93	3.83	5.18	3.98 (±0.65)	2.20-4.00	2.40-5.80	3.75-6.80
Na^+	$mmol_c$ L^{-1}	4.82	7.33	6.93	6.36 (±0.78)	3.05-6.41	3.80-10.80	5.60-8.00
K^+	$mmol_c$ L^{-1}	abs	0.45	0.22	0.33 (±0.12)	abs	0.17-1.25	0.16-0.28
HCO_3^{2-}	$mmol_c$ L^{-1}	2.03	2.61	2.43	2.36 (±0.17)	1.76-2.40	2.16-3.04	2.08-2.72
Cl^-	$mmol_c$ L^{-1}	3.96	6.13	5.27	5.12 (±0.63)	1.79-5.90	3.54-9.40	4.40-6.40
SO_4^{2-}	$mmol_c$ L^{-1}	6.13	9.67	9.42	8.41 (±1.14)	5.74-6.51	5.23-20.29	7.61-11.49
Cl^-:SO_4^{2-}	—	0.63	0.68	0.56	0.62 (±0.03)	0.31-0.91	0.46-0.80	0.55-0.58
Ca^{2+}:Mg^{2+}	—	1.50	1.77	0.93	1.40 (±0.25)	1.10-1.77	1.07-3.29	0.75-1.22
SAR	—	2.52	3.16	3.13	2.94 (±0.21)	1.79-3.13	2.00-4.50	2.74-3.44
SAR_{adj}	—	2.89	3.61	3.57	3.36(±0.24)	2.08-3.57	2.31-5.10	3.14-3.92

[a] Figures in parenthesis indicate the standard error of the mean.

Table 2.3.2.4 Composition of drainage water at the experimental site in 2005-2007

Indices	Unit	Mean				Range (Min-Max)		
		2005	2006	2007	2005-07	2005	2006	2007
pH	—	8.22	7.76	7.95	7.98 (±0.13)[a]	8.05-8.40	7.35-8.25	7.08-8.48
EC	dS m^{-1}	3.17	11.78	6.99	7.31 (±2.49)	1.19-5.96	3.68-16.93	3.54-8.76
TDS	mg L^{-1}	2073	7258	6966	5432 (±1682)	861-3795	2361-10391	3539-8761
Ca^{2+}	$mmol_c$ L^{-1}	8.47	19.30	20.93	16.23 (±3.9)	5.40-12.50	9.20-25.00	18.00-22.91
Mg^{2+}	$mmol_c$ L^{-1}	9.17	33.35	30.06	24.19 (±7.6)	3.00-18.50	9.40-50.00	11.00-40.63
Na^+	$mmol_c$ L^{-1}	14.05	64.78	59.33	46.05 (±16.1)	3.52-28.62	18.00-94.00	25.00-78.00
K^+	$mmol_c$ L^{-1}	abs	0.40	0.42	0.41 (±0.01)	abs	0.20-0.59	0.23-0.55
HCO_3^{2-}	$mmol_c$ L^{-1}	abs	abs	abs	abs	3.84-6.40	3.12-6.80	5.28-6.88
Cl^-	$mmol_c$ L^{-1}	4.69	5.64	6.32	5.55 (±0.47)	4.53-22.80	13.31-88.19	16.80-67.20
SO_4^{2-}	$mmol_c$ L^{-1}	11.38	61.48	47.73	40.20 (±14.9)	4.35-30.42	20.37-74.83	32.15-71.00
Cl^-:SO_4^{2-}	—	15.86	50.71	56.68	41.08 (±12.7)	0.53-1.04	0.65-1.39	0.52-1.00
Ca^{2+}:Mg^{2+}	—	0.77	1.13	0.79	0.90 (±0.12)	0.68-1.80	0.48-0.98	0.54-1.64
SAR	—	1.24	0.67	0.92	0.95 (±0.16)	1.72-7.27	5.90-15.35	6.57-13.95
SAR_{adj}	—	4.28	12.07	11.35	9.23 (±2.49)	2.00-8.19	6.66-17.20	7.40-15.64

[a] Figures in parenthesis indicate the standard error of the mean.

In 2005-2007 the pH levels in groundwater were in the range of 7.68 to 8.13. The composition of groundwater from May to September in terms of cationic concentration revealed moderate temporal variation. The dominant cations were Na^+ and Mg^{2+}. The concentration of Na^+ ranged from 99.10 to 130.75 $mmol_c$ L^-1 with corresponding Mg^{2+} concentrations ranging from 47.04 to 56.22 $mmol_c$ L^{-1}. The concentrations of Ca^{2+} were in the range of 22.70 to 26.50 $mmol_c$ L^{-1}. The concentrations of K^+ were the lowest, ranging from 0.73 to 1.64 $mmol_c$ L^{-1}.The salt concentrations in high-saline groundwater ranged from 6950 to 21448 mg L^1 (10.87-33.96 dS m^{-1}) during 2005, from 7669 to 25667 mg L^1 (11.92-40.38 dS m^{-1}) during 2006 and from 1322 to 28024 mg L^{-1} (2.00-45.14 dS m^{-1}) during 2007. The data presented in Table 2.3.2.5 revealed that ground water has poor ratio of Cl^-:SO_4^{2-} (0.67±0.02). The ratio of Ca^{2+}: Mg^{2+} in groundwater (0.62±0.03) suggesting that ground water is an additional source of magnesium in the soil. Indicative values of SAR during 2005-2007 for ground waters (18.06±1.38) revealed that use of these ground waters for irrigation without appropriate management practices may cause gradual increase in Na^+ levels in the irrigated soils (Table 2.3.2.5).

Table 2.3.2.5 Composition of groundwater at the experimental site in 2005-2007

Indices	Unit	Mean				Range (Min-Max)		
		2005	2006	2007	2005-07	2005	2006	2007
pH	—	7.68	7.86	8.13	7.89 (±0.13) [a]	6.72-8.65	6.90-8.67	7.45-8.55
EC	dS m^{-1}	20.02	21.51	16.96	19.50 (±1.34)	10.87-33.96	11.92-40.38	2.00-45.14
TDS	mg L^{-1}	12771	13732	10794	12432 (±865)	6950-21448	7669-25667	1322-28024
Ca^{2+}	$mmol_c$ L^{-1}	23.71	26.50	22.70	24.30 (±1.14)	15.50-34.00	22.00-34.00	3.80-35.42
Mg^{2+}	$mmol_c$ L^{-1}	50.00	56.22	47.04	51.09 (±2.71)	25.50-76.00	24.00-120.0	4.00-118.74
Na^{+}	$mmol_c$ L^{-1}	125.5	130.75	99.10	118.45 (±9.8)	54.18-233.2	58.45-259.8	8.00-296.00
K^{+}	$mmol_c$ L^{-1}	1.12	1.64	0.73	1.16 (±0.26)	0.71-1.45	0.66-12.0	0.21-2.20
HCO_3^{2-}	$mmol_c$ L^{-1}	9.69	8.93	8.63	9.08 (±0.32)	30.19-154.7	31.20-152.0	7.00-226.00
Cl^{-}	$mmol_c$ L^{-1}	76.94	79.53	63.77	73.41 (±4.88)	57.93-177.3	71.16-241.9	5.23-221.74
SO_4^{2-}	$mmol_c$ L^{-1}	113.1	126.65	97.17	112.29 (±8.5)	0.42-1.20	0.38-0.83	0.39-2.49
Cl^{-}:SO_4^{2-}	—	0.70	0.63	0.69	0.67 (±0.02)	0.29-0.88	0.18-1.17	0.21-2.40
Ca:Mg	—	0.57	0.64	0.66	0.62 (±0.03)	10.48-32.18	10.52-31.12	3.35-33.71
SAR	—	19.67	19.22	15.31	18.06 (±1.38)	11.76-35.96	11.82-34.77	3.82-37.67
SAR_{adj}	—	22.01	21.50	17.15	20.22 (±1.54)	11.76	11.82	3.82

[a] Figures in parenthesis indicate the standard error of the mean.

3.3. SOIL SALINITY

The soil salinity levels (July 2005-October 2007) in terms of TDS over the 0-0.90 m soil depth ranged from 5455 mg L^{-1} to 8547 mg L^{-1} (Table 2.3.2.6). The corresponding EC_e values were in the range of 8.10 dS m^{-1} to 13.22 dS m^{-1}. Among the anions, SO_4^{2-} was dominant having concentrations in the range of 53.91 to 81.47 $mmol_c$ L^{-1}. Among the cations, Ca^{2+} was dominant at the soil surface followed by Mg^{2+}, Na^{+}, and K^{+}. The SAR levels suggest that the soil was saline in character with values ranging from 4.09 to 11.27. Ratio of chloride to sulfate was in range of 0.21 to 0.58, indicating sulfate-chloride soil salinity type (Table 2.3.2.6). Overall, the concentration of soluble ions had a decreasing trend at the end of crop season during 2005-2007. However, the concentration of HCO_3^{2-} in 0-0.90 m soil depth increased by 11-17% in late September 2005 and early October 2006, while concentration of Cl^{-} declined in the same layer by 51-55%. The concentration of Ca^{2+} increased by 12-18% in April and in October 2007 over initial level (July 2005).

Table 2.3.2.6 Soil chemical properties at the 0-0.90 m soil depth during crop season of 2005-2007

Soil Characteristic	Unit	Date				
		2.07.05	23.09.05	05.10.06	27.04.07	20.10.07
pH	—	8.67	8.72 (+1) [a]	8.41 (-3)	8.46 (-2)	8.40 (-3)
EC_e	dS m^{-1}	13.22	8.10 (-39)	8.27 (-37)	10.88 (-18)	8.63 (-35)
TDS	mg L^{-1}	8547	5460 (-36)	5455 (-36)	7230 (-15)	7464 (-13)
Soluble Ca^{2+}	$mmol_c$ L^{-1}	39.28	30.10 (-23)	29.83 (-24)	44.26 (+12)	46.32 (+18)
Soluble Mg^{2+}	$mmol_c$ L^{-1}	26.57	18.42 (-31)	15.78 (-41)	22.85 (-14)	14.26 (-46)
Soluble Na^{+}	$mmol_c$ L^{-1}	64.96	31.28 (-52)	36.01 (-45)	39.41 (-39)	24.49 (-62)
Soluble K^{+}	$mmol_c$ L^{-1}	1.37	1.23 (-10)	1.05 (-23)	2.22 (+62)	1.19 (-13)
Soluble CO_3^{2-}	$mmol_c$ L^{-1}	abs	abs	abs	abs	abs
Soluble HCO_3^{2-}	$mmol_c$ L^{-1}	3.96	4.4 (+11)	4.64 (+17)	4.17 (+5)	3.54 (-11)
Soluble Cl^{-}	$mmol_c$ L^{-1}	46.75	22.72 (-51)	20.99 (-55)	23.49 (-50)	13.03 (-72)
Soluble SO_4^{2-}	$mmol_c$ L^{-1}	81.47	53.91 (-34)	55.15 (-32)	81.09 (0)	69.96 (-14)
Cl^{-}:SO_4^{2-}	—	0.58	0.45 (-22)	0.41 (-29)	0.30 (-48)	0.21 (-64)
SAR	—	11.27	6.41 (-43)	7.80 (-31)	6.97 (-38)	4.09 (-64)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over initial level (2 July 2005)

At the end of the cropping season in 2005-2007, the soil salinity level expressed in dS m^{-1} declined over the initial soil salinity levels by 53-68% in the surface 0.15 m soil layer under the control (Table 2.3.2.7). Treatments associated with the cyclic use of low saline water (under first irrigation) and highly saline drainage water for the remaining 3 irrigations (LSW_1:SW_3) increased the soil salinity by 11-98% whereas the soil salinity level under LSW_2:SW_2 declined by 22-69% with respect to initial soil salinity level at the end of crop season in 2005-2007 (Table 2.3.2.7, Figure 2.3.2.1).

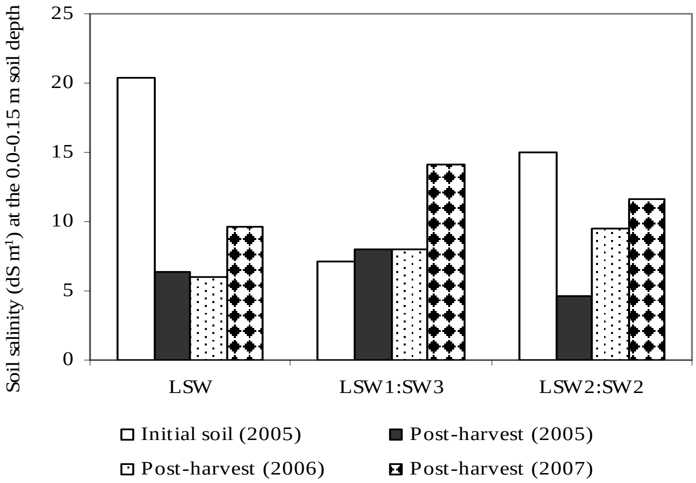

Figure 2.3.2.1 Soil salinity (dS m^{-1}) at the upper 0.15 m soil depth as affected by different treatments in 2005-2007

Table 2.3.2.7 Soil salinity levels expressed as EC_e (dS m^{-1}) in the soil profile as affected by treatments during 2005-2007

Soil depths, m	Initial soil [a] (2005)	Post-harvest [b] (2005)	Post-harvest (2006)	Post-harvest (2007)
LSW				
0-0.15	20.34	6.43 (-68) [c]	5.95 (-71)	9.60 (-53)
0.15-0.30	20.95	7.23 (-65)	4.55 (-78)	13.97 (-33)
0.30-0.60	15.93	6.39 (-60)	5.19 (-67)	13.24 (-17)
0.60-0.90	15.66	8.02 (-49)	7.08 (-55)	12.33 (-21)
LSW_1:SW_3				
0-0.15	7.15	8.02 (+12)	7.97 (+11)	14.16 (+98)
0.15-0.30	6.00	12.57 (+110)	10.30 (+72)	9.91 (+65)
0.30-0.60	7.31	12.16 (+66)	8.69 (+19)	8.48 (+16)
0.60-0.90	9.24	11.61(+26)	11.99 (+30)	8.27 (-10)
LSW_2:SW_2				
0-0.15	14.96	4.63 (-69)	9.52 (-36)	11.68 (-22)
0.15-0.30	12.15	5.57 (-54)	7.36 (-39)	14.89 (+23)
0.30-0.60	15.08	6.15 (-59)	9.02 (-40)	12.24 (-19)
0.60-0.90	13.85	8.46 (-39)	11.61 (-16)	13.95 (+1)

[a] Initial soil salinity level was determined in 2 July 2005

[b] Post-harvest soil salinity level was determined in 23 September 2005, 5 October 2006 and 11 October 2007

[c] Figures in parenthesis indicate percentage increase (+) or decrease (–) over pre-experiment soil salinity level

At the end of the cropping season in 2005-2007, the soil salinity sodicity expressed by sodium absorption ratio reduced over the initial level by 50-69% in the top 0.15 m soil layer under the control treatment (Table 2.3.2.8). Treatment associated with cyclic use of low saline water (under first irrigation) and highly saline drainage water for the remaining 3 irrigations (LSW_1:SW_3) increased the soil sodicity level by 20-105% at the end of crop season in 2005 and 2007 and reduced the soil sodicity by 27% in post-harvest season in 2006 whereas the soil sodicity level under LSW_2:SW_2 reduced by 9-44% with respect to initial soil sodicity level at the end of crop season in 2005-2006. The soil sodicity under LSW_2:SW_2 in post-harvest season in 2007 increased by 15% over initial level in 2005 (Table 2.3.2.8, Figure 2.3.2.2).

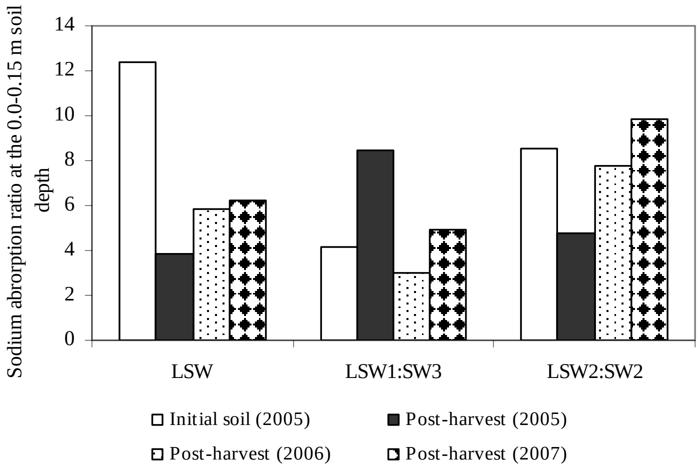

Figure 2.3.2.2 Sodium absorption ratio at the upper 0.15 m soil depth as affected by different treatments in 2005-2007

Table 2.3.2.8 Soil sodicity as expressed by sodium absorption ratio (SAR) in the soil profile as affected by treatments during 2005-2007

Soil depths, m	Initial soil (2005)	Post-harvest (2005)	Post-harvest (2006)	Post-harvest (2007)
LSW				
0-0.15	12.42	3.84 (-69)	5.83 (-53)	6.22 (-50)
0.15-0.30	12.89	4.62 (-64)	7.92 (-39)	11.27 (-13)
0.30-0.60	15.11	6.26 (-59)	7.55 (-50)	8.56 (-43)
0.60-0.90	13.14	8.47 (-36)	6.92 (-47)	7.72 (-41)
LSW_1:SW_3				
0-0.15	4.13	8.47 (+105)	2.99 (-27)	4.94 (+20)
0.15-0.30	6.44	5.21 (-19)	5.17 (-20)	4.88 (-24)
0.30-0.60	8.56	7.73 (-10)	12.43 (+45)	6.01 (-30)
0.60-0.90	8.02	8.03 (0)	14.22 (+77)	6.53 (-19)
LSW_2:SW_{21}				
0-0.15	8.55	4.75 (-44)	7.75 (-9)	9.83 (+15)
0.15-0.30	14.20	5.50 (-61)	7.66 (-46)	9.91 (-30)
0.30-0.60	15.26	6.81 (-55)	7.89 (-48)	7.77 (-49)
0.60-0.90	16.49	7.25 (-56)	7.31 (-56)	7.54 (-54)

3.4. CHANGES IN GROUNDWATER LEVEL

Monitoring fluctuations in groundwater level during 2005-2007 indicated that the water level ranged from 0.81-1.66 m in March-June and subsequently declined mid July to mid September which would suggest that it contributed to the water requirements of the crop as well as to physical evaporation (Figure 2.3.2.3). The main reason of shallow ground water level in March-June was the lack of drainage at the experimental

site. The groundwater level was in the range of 0.79-3.20 m, 0.64-2.18 m and 0.47-2.65 m during the March-September 2005, 2006 and 2007, respectively. The statistical analyses indicated that there was no significant difference in the average depth of ground water level among treatments during the crop season of 2005-2007.

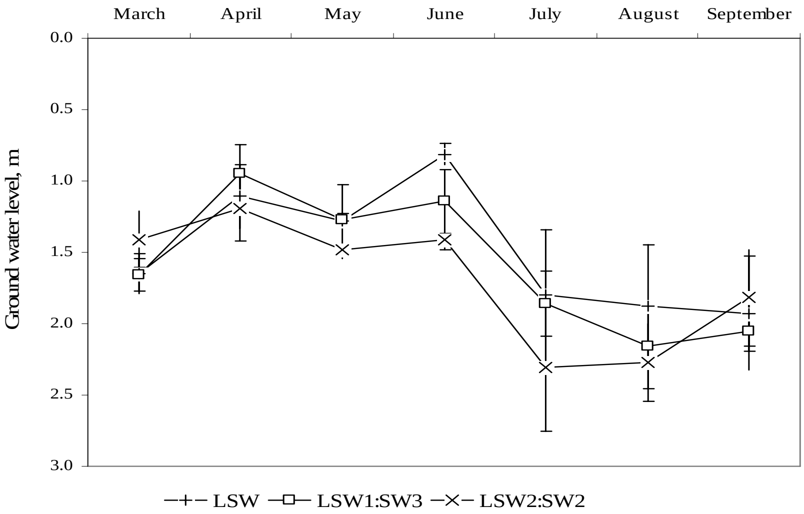

Figure 2.3.2.3 Changes of ground water level at Akdepe site during the cropping season

3.5. IRRIGATION PARAMETERS

The soil was leached by applying 2400 m^3 ha^{-1} of canal water on 15 May 2005. First irrigation (780 m^3 ha^{-1}) was applied on 4 June 2005, which was followed by the 450 m^3 ha^{-1} second irrigation on 27 July 2005. A third irrigation (600 m^3 ha^{-1}) was applied on 14 August 2005, which was followed by the 600 m^3 ha^{-1} fourth irrigation on 1 September 2005. Irrigation water salinity was 800±100 mg L^{-1}. The total amount of irrigation during crop growing season was estimated to be 2430 m^3 ha^{-1}. The total amount of water applied and soil leaching was 4830 m^3 ha^{-1} in 2005 (Table 2.3.2.9).

Since drainage water was not available at the experimental site in 2005, irrigations in all treatments were applied using canal water. The main source of drainage water is drainage water from irrigated neighboring crop fields. As these lands were abandoned during last 10 years, the drainage effluent was not available at the experimental site.

Table 2.3.2.9 Total amount of irrigation at the Akdepe experimental station in 2005-2007

Year	**Irrigation rates, m^3 ha^{-1}**		
	LSW	**LSW_1:SW_3**	**LSW_2:SW_2**
2005	4830	4830	4830
2006	4790	4790	4790
2007	1750	1750	1750

In 2006 sorghum and maize were irrigated four times. The first irrigation (800 m^3 ha^{-1}) was applied as a basin irrigation on 4 September 2006, which was followed by the 1330 m^3 ha^{-1} second irrigation on 16 September 2006. The same irrigation depth (1330 m^3 ha^{-}) was applied during third (27 September 2006) and fourth irrigation (14 October 2006). Irrigation water salinity was 1200±200 mg L^{-1}. Drainage water applied for irrigation had salinity at 4000 mg L^{-1}. The total amount of irrigation applied was estimated at 4790 m^3 ha^{-1} (Table 2.3.2.9).

In 2006 all irrigations in the LSW treatment were applied using canal water. In the $LSW_1:SW_3$ treatment canal water was used only in the first irrigation. Drainage water was applied for the following irrigation events. In the $LSW_2:SW_2$ treatment canal water was applied for 1st and 2nd irrigation and drainage water for 3rd and 4th. Since there was dyke breach at the canal delivering water to the site, there was no water at the site during July. During this period, fodder crops utalized subsoil water supply from highly saline ground waters. Later irrigation water to the site was transported by a truck.

In 2007 sorghum and maize were irrigated three times. First irrigation (550 m^3 ha^{-1}) was applied as a basin application on 13 July 2007, which was followed by the 600 m^3 ha^{-1} second irrigation on 12 August 2007. The same irrigation depth (600 m^3 ha^{-1}) was applied at the third irrigation event on September 22, 2007. Drainage water applied for irrigation had salinity at 4000 mg L^{-1}. The total amount of irrigation water applied during the crop growing season was estimated at 1750 m^3 ha^{-1} (Table 2.3.2.9).

In 2007 all irrigations in the LSW treatment were applied using canal water. Irrigation water salinity was 1100±200 mg L^{-1}. In the treatment $LSW_1:SW_3$ canal water was used only in the second irrigation. Drainage water was applied for the first and third irrigation. In the treatment $LSW_2:SW_2$ drainage water was applied for all irrigations.

3.6. CROP GROWTH AND YIELD

Averaged fodder crop yield data from 2005 to 2007 suggest that the maximum maize yield (53.44 t ha^{-1}) was obtained from the $LSW_1:SW_3$ treatment (Table 2.3.2.10) (Figure 2.3.2.4). Maize fodder yield from other treatments was in the order: 52.56 t ha^{-1} (LSW) and 52.20 t ha^{-1} ($LSW_2:SW_2$).

The maximum *Sorghum bicolor* yield (55.33 t ha^{-1}) was obtained from $LSW_1:SW_3$ treatment where irrigation was undertaken with low saline water (as first irrigation) and drainage water (as remaining irrigations). *Sorghum bicolor* yield from other treatments was in the order: 47.44 t ha^{-1} ($LSW_2:SW_2$) and 44.22 t ha^{-1} ($LSW_2:SW_2$).

The maximum *Sorghum sernuum* yield (34.61 t ha^{-1}) was obtained from the treatment where cyclic use of low-saline water and drainage water ($LSW_2:SW_2$). *Sorghum sernuum* yield from other treatments was in the order: 34.44 t ha^{-1} ($LSW_1:SW_3$) and 32.56 t ha^{-1} (LSW)

Table 2.3.2.10 Effect of treatments on fodder crop yield at Akdepe experimental station

Treatment	Crop	Green biomass (t ha^{-1})			
		2005[a]	**2006**[b]	**2007**[c]	**Average**
	Maize	42.00±8.02[d]	46.00±1.00	69.67±9.87	52.56±8.63
LSW	*Sorghum bicolor*	28.00±5.00	40.67±1.20	64.00±10.02	44.22±10.54
	Sorghum sernuum	30.33±2.67	42.67±0.33	24.67±0.33	32.56±5.31
	Maize	40.33±1.45	44.67±0.88	75.33±8.97	53.44±11.01
$LSW_1:SW_3$	*Sorghum bicolor*	57.33±8.69	31.33±0.58	77.33±13.68	55.33±13.32
	Sorghum sernuum	47.00±6.66	35.00±0.58	21.33±6.39	34.44±7.42
	Maize	36.61±13.91	40.00±1.15	80.00±10.41	52.20±13.93
$LSW_2:SW_2$	*Sorghum bicolor*	52.00±13.08	30.00±0.58	60.33±10.33	47.44±9.05
	Sorghum sernuum	43.83±6.51	29.33±1.86	30.67±8.76	34.61±4.63

[a] In 2005 Least significance difference (LSD) at p = 0.05 was estimated as 12.67 t ha^{-1} (factor A and factor B)
[b] In 2006 Least significance difference (LSD) at p = 0.05 was estimated as 1.60 t ha^{-1} (factor A and factor B)
[c] In 2007 Least significance difference (LSD) at p = 0.05 was estimated as 17.08 t ha^{-1} (factor A and factor B)
Factor A associated with irrigation water quality and factor B associated with crop response to crop yields
[d] Figures with ± refer to standard error

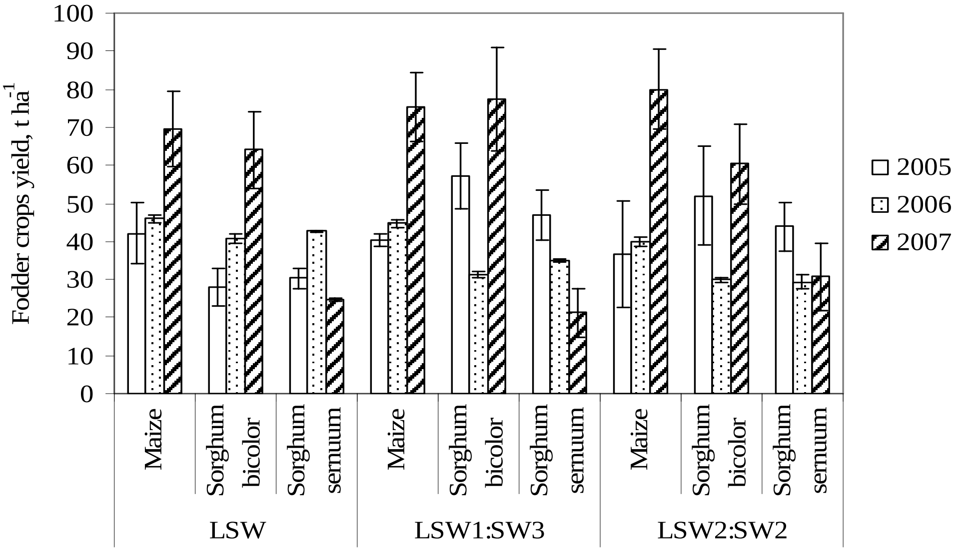

Figure 2.3.2.4 Effect of irrigation water quality on fodder crop yields

The average fodder crops yields during 2005-2007 revealed that *Zea mays* L. yields were higher by 10-19 % in comparison with that of Sorghum *bicolor* (L.) Moench under LSW and LSW_2:SW_2 treatments whereas there were negligible differences in those crops yields under LSW_1:SW_3 treatment. At the same time the Maize yields were higher by 51-61% in comparison with that of *Sorghum sernuum* Host under all treatments as shown in Figure 2.3.2.5.

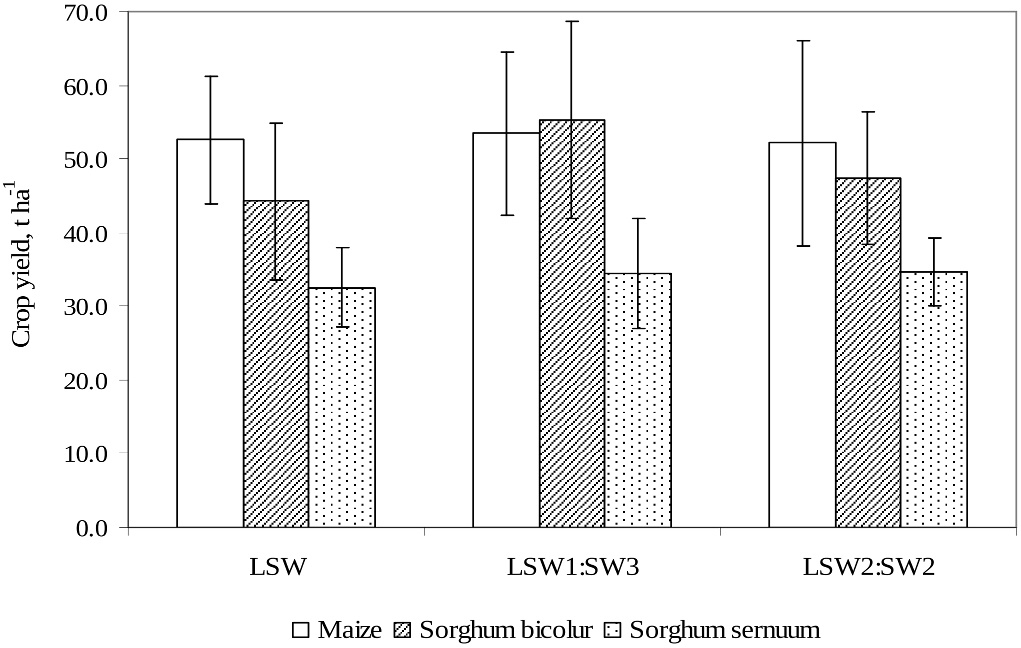

Figure 2.3.2.5 Effect of crop species and irrigation water quality on yield of fodder crops

4. DISSEMINATION

The results of the experiment were disseminated in 2007 at Navoi and Magtimguly farms both in Niyazov province of Turkmenistan. The fields were located on different soil and hydro-geological conditions. The treatments tested at these farms were the same as already used for the experimental site.

4.1. Dissemination at Navoi Farm

Plowing to a 35-40 cm depth was undertaken with a tractor (Model: MTZ-80) followed by land leveling on 7 April 2007. Soil leaching (1200 m^3 ha^{-1}) was applied through the basin method in mid April 2007. Chiseling and soil dicing opertions were performed before sowing to breakup stubble (Stubble Breaker CHKU-3.6). Just before sowing, phosphorous fertilizer was applied by manual broadcasting at the rate of 150 kg ha^{-1}. Preparation of the checks and dividing plots were completed on 25 May 2007. On 26 May 2007, *Sorghum bicolor* (L)*, Sorghum sernuum* (*Sorghum sernuum* H.) and *Maize* (*Zea mays* L.) were sowed by a manual broadcasting at the seed rates of 30 kg ha^{-1}, 25 kg ha^{-1} and 40 kg ha^{-1}, respectively. Maize and Sorghum Bicolor germinated on 30 May 2007 and *Sorghum sernuum* on 31 May 2007.

In 2007 the pre-experiment soil salinity levels in terms of TDS at different soil depths extending to 0.9 m were in the range of 4800 mg L^{-1} to 9750 mg L^{-1} (7.19 to 14.62 dS m^{-1}). Among the anions, SO_4^{2-} was dominant having maximum concentration of 123.30 me L^{-1} at the upper 0.15 m depth. The concentration of SO_4^{2-} had a decreasing trend from top to deeper horizons and varied in the range of 54.05 to 123.30 $mmol_c$ L^{-1}. Among the cations, Ca^{2+} was dominant at the soil surface followed by Na^+, Mg^{2+}, and K^+. The concentration of Ca^{2+} in the upper 0.15 m depth was determined to be 84.00 me L^{-1}. It also followed a pattern similar to the dominant anion (SO_4^{2-}) with respect to soil depth as its concentrations had a decreasing trend from top to deeper horizons and varied in the range of 39.00 to 84.00 me L^{-1}. The concentration of Ca^{2+} in the upper 0.15 m soil depth was determined to be 84.00 me L^{-1}. The SAR levels had an increasing trend from top to deeper horizons and were in the range of 3.73 to 5.24.

From April to September 2007 the salt concentration in slightly and moderate saline canal water ranged from 945 to 1331 mg L^{-1} (1.33-2.07 dSm^{-1}). The pH levels were found to be in the range of 7.35 to 8.50. The dominant cations from April to September were Na^+ and Mg^{2+} with little differences in their concentrations. Sulfate ions were dominating anion with chloride ion to sulfate ratios varied from 0.56 to 0.58, revealing sulfate-chloride salinity type. The salt concentration in high-saline drainage water ranged from 2088 to 6282 mg L^{-1} (2.35-9.99 dSm^{-1}) during April – September 2007; the pH level ranged from 7.75 to 8.60 and was moderate alkaline in a reaction. The levels of SAR were in the range of 4.54 and 13.49 during April – September 2007 revealed that use such ground waters for irrigation without appropriate management practices may cause gradual increase in Na^+ levels in the irrigated soils.

The groundwater has high salinity ranging from 1352 to 9416 mg L^{-1} (2.06-14.60 dS m^{-1}). The pH with a value of 7.85 to 8.50 was moderate alkaline in reaction. The dominant cations were Na^+ and Mg^{2+} with wide differences in their concentrations. The levels of SAR were in the range from 4.38 to 11.43 suggesting that groundwater is marginal in its characteristics. Groundwater level fluctuated between 0.85 and 1.50 m during the growing season in 2007. The high salinity levels in the ground water indicated the need to apply a basin irrigation (flooding) in the initial stages of the plant establishment to suppress an upward flow from the saline groundwater.

Sorghum and maize were irrigated five times. First (600 m^3 ha^{-1}) and second irrigation (600 m^3 ha^{-1}) were applied as a basin method on 3 and 24 June 2007 with low saline irrigation water in all treatments, which was followed by the 600 m^3 ha^{-1} third irrigation using low saline irrigation water (LSW and LSW_1:SW_3 treatments) and saline drainage water (LSW_2:SW_2 treatment) on 30 July 2007. Irrigation water salinity was 1100 mg L^{-1}. The same irrigation depth (600 m^3 ha^{-1}) was applied at the forth irrigation with saline drainage water (LSW_1:SW_3, LSW_2:SW_2) and with low saline irrigation water (LSW), on 22 August 2007. Fifth irrigation (600 m^3 ha^{-1}) was applied with drainage water (LSW_2:SW_2 treatment), and with low saline irrigation water (LSW and LSW_1:SW_3 treatments) on 9 September 2007. Drainage water applied for irrigation had salinity at 4000 mg L^{-1}. The total amount of irrigation water applied during crop growing season was estimated at 3000 m^3 ha^{-1} .

All irrigations in the first treatment were applied using canal water. In the LSW_1:SW_3 treatment drainage water was used only in the forth irrigation. Irrigation water was used for the 1st, 2nd, 3rd and 5th irrigation.

In the LSW_2:SW_2 treatment canal water was applied for 1st and 2nd irrigation. Fodder crops' yields data are given in the Table 2 3.2.11

Table 2.3.2.11 Yield of fodder crops at the Navoi farm (t ha^{-1})

Treatment	Crop	Green biomass yield [a] (t ha^{-1})
LSW	Maize	64.06±6.57[b]
	Sorghum bicolor	79.61±8.18
	Sorghum sernuum	68.39±8.99
LSW_1:SW_3	Maize	69.61±8.35
	Sorghum bicolor	73.11±2.79
	Sorghum sernuum	68.39±3.10
LSW_2:SW_2	Maize	58.83±3.13
	Sorghum bicolor	65.61±12.59
	Sorghum sernuum	77.22±7.14

[a] Least significance difference (LSD) at $p = 0.05$ was estimated as 12.63 t ha^{-1} (factor A and factor B) Factor A associated with irrigation water quality and factor B associated with crop response to crop yields
[b] Figures with ± represent standard error

The data obtained shows that maximum yield of fodder crops was obtained from the treatment where low-saline water was applied for 1st, 2nd, 3rd and 5th irrigation (LSW_1:SW_3). Averaged fodder crops yield data in 2007 revealed that the maximum maize yield (69.6 t ha^{-1}) was obtained from the LSW_1:SW_3 treatment (Table 2.3.2.11). Maize yield from other treatments was in the order: 64.00 t ha^{-1} (LSW) and 58.80 t ha^{-1} (LSW_2:SW_2). The maximum *Sorghum bicolor* yield (79.60 t ha^{-1}) was obtained from LSW treatment where irrigation was done with low saline water. *Sorghum bicolor* yield from other treatments was in the order: 73.10 t ha^{-1} (LSW_1:SW_3) and 64.50 t ha^{-1} (LSW_2:SW_2). The maximum *Sorghum sernuum* yield (77.20 t ha^{-1}) was obtained from the LSW_2:SW_2treatment. *Sorghum sernuum* yield from other treatments was in the order: 68.40 t ha^{-1} (LSW_1:SW_3) and 32.56 t ha^{-1} (LSW).

4.2. Dissemination at Magtimguly Farm

Plowing to the 35-40 cm depth was implemented by tractor MTZ-80 followed by land leveling on 10 April 2007. The soil leaching (1200 m^3 ha^{-1}) was applied through the basin method in early April 2007. Chiseling and soil grinding was done before sowing to break stubbles (Stubble Breaker CHKU-3.6) on the field. Just before sowing, phosphorous fertilizer was applied by manual broadcasting at the rate of 150 kg ha^{-1}. Preparation of the checks and dividing plots were completed on 10 April 2007. On 10 April 2007 the same fodder crops were sown by a manual broadcasting at the seed rates of 30 kg ha^{-1}, 25 kg ha^{-1} and 40 kg ha^{-1}, respectively.

From April to September 2007 the salt concentration in slightly and moderate saline canal water ranged from 945 to 1331 mg L^{-1} (1.33-2.07 dS m^{-1}). The pH levels were found to be in the range of 7.35 to 8.50. The dominant cations from April to September were Na^+ and Mg^{2+} with a little difference in their concentrations. The salt concentration in high-saline drainage water ranged from 8568 to 13408 mg L^{-1} (12.31-23.02 dS m^{-1}) during April – September 2007; the pH level ranged from 7.75 to 8.45 and was moderate alkaline in a reaction. The levels of SAR were in the range of 15.52 and 27.73 during April – September 2007 revealed that use such ground waters for irrigation without appropriate management practices may cause gradual increase in Na^+ levels in the irrigated soils. The groundwater has high salinity fluctuating from 2758 to 4988 mg L^{-1} (3.96-7.80 dSm^{-1}). The pH with a value of 8.25 to 8.50 was moderate alkaline in a reaction. The dominant cations were Na^+ and Ca^{2+} with wide differences in their concentrations. The levels of SAR were in the range from 6.03 to 8.68 suggesting that groundwater is marginal in its characteristics.

During April-October, 2007 the groundwater level was monitored in the field. Groundwater level fluctuated between 1.10 and 2.10 m on crop season of 2007.

Sorghum and maize were irrigated four times. First irrigation (600 m^3 ha^{-1}) was applied as a basin method on 15 May with low saline water in all treatments, which was followed by second irrigation (600 m^3 ha^{-1}) with low saline irrigation water (LSW and LSW_1:SW_3 treatments) and high saline water (LSW_2:SW_2 treatment) on 29 June 2007. Irrigation water salinity was 1100 mg L^{-1}. The same irrigation depth (600 m^3 ha^{-1}) was applied at the third irrigation with saline drainage water (LSW_1:SW_3 and LSW_2:SW_2 treatments) and with low saline irrigation water (LSW_2:SW_2), on 14 July 2007. Forth irrigation (600 m^3 ha^{-1}) was applied with drainage water (LSW_2:SW_2 treatment), and with low saline irrigation water (LSW and LSW_1:SW_3 treatments) on 4 August 2007. Drainage water applied for irrigation had salinity at 4000 mg L^{-1}. The total amount of irrigation water applied during crop growing season was estimated at 2400 m^3 ha^{-1}.

Fodder crops' yields data are given in the Table 2 3.2.12. Averaged fodder crops yield data in 2007 revealed that the maximum maize yield (75.50 t ha^{-1}) was obtained from the LSW_2:SW_2 treatment (Table 2.3.2.12). Maize yield from other treatments was in the order: 75.00 t ha^{-1} (LSW_1:SW_3) and 74.50 t ha^{-1} (LSW). The maximum *Sorghum bicolor* yield (93.30 t ha^{-1}) was obtained from (LSW treatment where irrigation was done with low saline water. *Sorghum bicolor* yield from other treatments was in the order: 91.70 t ha^{-1} LSW_1:SW_3 and 86.70 t ha^{-1} (LSW_2:SW_2). The maximum *Sorghum sernuum* yield (91.70 t ha^{-1}) was obtained from (LSW treatment where irrigation was done with low saline water. *Sorghum sernuum* yield from other treatments was in the order: 86.70 t ha^{-1} (LSW_1:SW_3) and 83.30 t ha^{-1} (LSW_2:SW_2).

Table 2.3.2.12 Yield of fodder crops at the Magtimguly farm (t ha^{-1})

Treatments	**Crops**	**Green biomass yield (t ha^{-1})[a]**
LSW	Maize	75.56±4.34[b]
	Sorghum bicolor	93.33±7.26
	Sorghum sernuum	91.67±8.33
LSW_1:SW_3	Maize	75.00±1.67
	Sorghum bicolor	91.67±4.41
	Sorghum sernuum	86.67±4.41
LSW_2:SW_2	Maize	75.56±2.94
	Sorghum bicolor	86.67±10.14
	Sorghum sernuum	83.33±12.02

[a] In 2007 Least significance difference (LSD) at $p = 0.05$ was estimated as 12.04 t ha^{-1} (factor A and factor B)
Factor A associated with irrigation water quality and factor B associated with crop response to crop yields
[b] Figures with ± represent standard error

The data obtained shows that maximum yield of fodder crops was obtained from the treatment where low-saline water was applied for irrigation during the whole crop vegetation season. The results obtained show that applying canal water is important especially for first irrigation, when the young plants are most sensitive to salinity of water available. In spite of high soil salinity level sorghum bicolor showed relatively good results as compared to *Sorghum sernuum* and maize.

5. CONCLUSIONS

The 3 years field research (2005-2007) carried out at Akdepe experimental site in Turkmenistan has demonstrated that applying canal water is important especially for first irrigation, when the young plants are most sensitive to salt-affected conditions. In spite of high salinity soil level, *Zea mays* L. showed relatively promising results in comparison to *Sorghum bicolor* (L.) Moench *and Sorghum sernuum* Host.

In first year of cultivation of fodder crops, heavy soil leaching (2000-2400 m^3/ha) should be applied at the site in order to dissolve harmful salts from the root zone and it will create favorable conditions for crops growth and development. Only after this farming practice the cyclic use of drainage and irrigation water could be implemented.

The same crops species were tested in 2007 at two other sites with different soil salinity and hydro-geological conditions at Navoi and Magtimguly farms both in Niyazov Province of Turkmenistan. Preliminary results of the dissemination reveal *Sorghum bicolor* producing relatively higher yields than *Sorghum sernuum* and maize. Further research and developments are needed to ensure higher yield and water productivity of fodder crops for sustainable productivity and management of natural resources in saline environments. The farmers are much interested in adoption of such low-cost technology and this technology is ready to be disseminated in other provinces of Turkmenistan with similar soil-climatic conditions.

2.3.3 USE OF WATERS OF DIFFERENT QUALITIES AND MULCHING OF FURROWS TO IMPROVE CROP PRODUCTIVITY AND REDUCE EVAPORATION LOSSES [12]

INTRODUCTION

The supplies of freshwater are falling short of agricultural requirements in several arid and semi-arid regions (Rhoades, 1999; Bouwer, 2002; Qadir et al., 2007), including Central Asia where saline water is used for irrigation as an alternate of freshwater. For example, farmers in some areas of Uzbekistan use water having salinity levels around 2600 mg L^{-1} (≈ 4.0 dS m^{-1}) for irrigation. This situation is further complicated as water of this salinity is not available in sufficient quantities to fulfill the crop water needs. As a next step, highly saline drainage or groundwater could be used conjunctively with this water to increase the volume of irrigation water to be used in agriculture. However, the use of saline water for irrigation without suitable management may result in increased levels of salts in the root zone, thereby affecting crop growth and yield (Rhoades, 1989; Sharma and Minhas, 2005).

When using saline water where the concentration of soluble salts in the soil is expected to be high in the surface, mulching can considerably help leach salts through reduced evaporation and thus facilitate crop production. Mulching is widely used to control erosion, weed and soil evaporation in water-limited environments. Therefore, in order to reduce the upward flux of soluble salts mulching should be encouraged, whenever feasible (Rhoades *et al*., 1992).

Research in southern Italy on mulching suggests that durum wheat straw could be used as mulch, left on the soil after harvest in June, to increase soil water storage for the horticultural crops sown later during August-September (Rinaldi *et al*., 2000). An experiment was carried out at Foggia during 1998 summer to evaluate the effect of mulching on soil water evaporation by comparing soil evaporation rate in bare (B) and mulched (M) conditions using weighing lysimeters. The results indicate the highest evaporation rate of "B" treatment in the first hour after the irrigation or rainfall. Evaporation values of 0.53 mm were found in the "B" treatment as compared to 0.1 mm in the "M" treatment. In the following hours, the evaporation rate became similar and after 18 hours the aggregated soil evaporation was 2.4 and 1.9 mm for "B" and "M" treatments, respectively. The water evaporated in "B" treatment was 73% of the water input as compared to 60% in the mulched treatment, revealing a positive effect of straw mulch on soil water conservation particularly in the upper soil layer.

Other studies carried out on different aspects of mulching reveal beneficial effects of this intervention. For example, the research conducted in Heilonggang low-lying plain of China where Yan-min *et al.* (2006) compared the effects of different mulch materials on winter wheat production. Four treatments used were: (1) no mulch, (2) mulch with plastic film, (3) mulch with corn straw, (4) mulch with concrete slab between the rows. The result indicated that concrete mulch and straw mulch were effective in conserving soil water compared to plastic film mulch which increased soil temperature. Concrete mulch decreases surface soil salinity better in comparison with other mulches used. Straw mulch conserved more soil water but decreased wheat grain yield. The authors attributed the decrease in yield to low temperature.

The growth and yield of cotton (*Gossypium hirsutum* L.), commonly grown in Central Asia, is affected by the limited supply of freshwater, which is offset by using saline water for irrigation in some cotton growing areas. We carried out a field study in Syrdarya district of Uzbekistan in partnership with the Uzbek Cotton Growing Research Institute (UCGRI) to evaluate the effects of hey mulching and combinations of water quality on: (1) chemical changes in the soil characteristics: (2) growth response of cotton; and (3) economics of the applied treatments.

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[12] This component was led by ICARDA and IWMI. NARS partners include R. Mirhashimov and G. Bezborodov Uzbek Cotton Growing Research Institute, Ministry of Agriculture, Uzbekistan

MATERIALS AND METHODS

STUDY AREA AND SITE CHARACTERIZATION

This on-farm study was carried out during the years 2005-2007 in Uzbekistan. Cotton is main crop grown covering about 90% of the cropped area in summer. The study site was in Syrdarya district where irrigation is done with Syr-Darya River water, which is becoming limited considering the growing needs to produce more. Site characterization was done in May 2005. The area has a smooth landscape with slopes from 0.002 to 0.0035. Long-term annual precipitation ranges from 100 to 300 mm, with 90% occurring during October through May. The average precipitation during the study period (April-September) was in the range of 43-106 mm. The area has high summer temperatures (26-30°C during June, July and August). The temperature decreases to as low as –6°C, with an average of 2°C, during the winter months. The air temperature during the study period ranged from 16°C to 28°C. The soils are medium loam with about 1% organic matter in the surface layer. Soil bulk density remains 1.33±0.15 Mg m^{-3} and the pH varies narrowly from 8.2 to 8.4.

TREATMENTS

This study consisted of two major factors based on which the experimental treatments were designed using cotton as the test crop. One factor consisted of water quality with moderately saline (~2600±200 mg L^{-1}) and saline (~5300±400 mg L^{-1}) waters used in different combinations for irrigation. Other factor was based on mulching of the furrows to reduce evaporation losses from the field and to improve water productivity.

The experimental layout was based on a randomized complete block design. The total number of experimental plots was 18 (2 mulching levels × 3 water quality levels × 3 replications). Each plot size was 360 m^2 with gross experimental area around 0.8 ha including the water channels and non-experimental belts. There were six treatment combinations as given below:

1. Irrigation throughout the cropping season with moderately-saline water (~2600±200 mg L^{-1}): Later referred to as MSW
2. Irrigation throughout the cropping season with highly-saline water pumped from a vertical well (~5300±400 mg L^{-1}): Later referred to as SW
3. Irrigation with a mix of moderately-saline and high saline water in the respective ratio of 1:1: Later referred to as $MSW{:}SW_{1:1}$
4. Irrigation same as in the treatment 1 + mulching of furrows: Later referred to as MSW+M
5. Irrigation same as in the treatment 2 + mulching of furrows: Later referred to as SW+M
6. Irrigation same as in the treatment 3 + mulching of furrows: Later referred to as $MSW{:}SW_{1:1}$+M

SOIL AND WATER SAMPLING AND ANALYSIS

After experimental layout, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. The sampling was done before the implementation of the treatments (initial soil condition) and after harvest of cotton in each cropping year. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations such as Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions such as carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by

precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated using Equation 2.3.1.1 from the concentrations (*C*) of soluble cations Ca^{2+}, Mg^{2+}, and Na^{+}, expressed as $mmol_c\ L^{-1}$.

$$SAR = C_{Na} / [(C_{Ca} + C_{Mg}) / 2]^{1/2} \qquad [2.3.1.1]$$

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was done using one randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent. Field capacity was determined from one randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture in the following days up to the time (usually 3-5 days) when there was minimal change in moisture content at all the soil depths. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer ring of 0.4 m and inner ring of 0.3 m. The both rings were put into soil up to 0.1-0.15 m. Soil bulk density was determined on undistributed soil samples collected from each soil depth using core method. Soil moisture content was determined by gravimetric method.

Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. The water samples were analyzed for the following parameters: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}).

EXPERIMENTAL PROCEDURE

The field was plowed with a tractor in February 2005 to a depth of 0.3 m. Cotton variety Bayaut-2 was sown with a seeder (Romanian Seeder SPC-3.6) on 20 April 2005 using seed rate of 25 kg ha^{-1}. Chiseling was done on 14 April 2005 at 0.10-0.12 m depth before sowing to break stubbles (Stubble Breaker CHKU-4). Just before cotton sowing, harrowing (Harrow ZBS-1 on Tractor MTZ 80) was also done. The cultural practices for cotton cultivation in the control and conjunctive water used plots were the same and in accordance with the prevalent system of agriculture used in the region (Umbetaev and Batkaev, 2000). Nitrogen in the form of ammonium nitrate (NH_4NO_3) was applied in two splits at the rate of 34 and 68 kg ha^{-1} on 6 May and 28 May 2005, respectively. In late September, crop was harvested from each plot to determine the cotton yield on plot basis, which was subsequently calculated and reported on per hectare basis.

In the subsequent years (2006 and 2007), all the agronomic and fertilizer management practices were the same except that plowing was done in late November 2005 and early December 2006, land leveling in mid April, sowing of cotton in late April, application of nitrogen fertilizers in mid July 2007, and harvesting of cotton in mid October. In addition, in order to facilitate the leaching of salts, soil leaching was applied in late December 2006 through the basin method.

RESULTS AND DISCUSSION

SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

According to the classification system of the USDA for particle-size distribution, the field soil is silt loam in texture throughout the profile up to the depth of 0.90 m (Table 2.3.3.1). Field capacity in the upper 0.15 m depth was 23.64%; for the 0.15-0.30 m depth, its value was 23.80%. At the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were estimated at 31.54% and 34.07%, respectively. Infiltration rate was 24.2 mm h^{-1}. Soil bulk density varied from 1.41 to 1.52 Mg m^{-3}.

Table 2.3.3.1 Physical properties of the experimental field at the experimental site

Soil properties	Unit	Soil depth (m)			
		0.0-0.15	0.15-0.30	0.30-0.60	0.60-0.90
Sand particles (0.05-2.0 mm)	%	24.89	22.48	26.15	34.18
Silt particles (0.002-0.05 mm)	%	61.68	64.84	64.29	58.89
Clay particles (<0.002 mm)	%	13.43	12.68	9.56	6.93
Soil texture (method USDA)	—	silt loam	silt loam	silt loam	silt loam
Field capacity	%	23.64	23.80	31.54	34.07
Infiltration rate	mm h^{-1}	24.42	—	—	—
Soil bulk Density	Mg m^{-3}	1.18	1.31	1.48	1.38

The pre-experiment soil salinity levels in terms of TDS at different soil depths extending up to 0.90 m were in the range of 9746 to 13862 mg L^{-1} (Table 2.3.3.2). Among the anions, SO_4^{2-} was dominant having concentration of 115.71 me L^{-1} at the upper 0.15 m depth. The concentration of SO_4^{2-} ranged from 115.71 to 179.46 $mmol_c$ L^{-1}at different soils depths. Chloride (Cl^-) concentration was much less compared to that of SO_4^{2-} and ranged from 17.01 to 18.22 $mmol_c$ L^{-1}at different soils depths. The HCO_3^{2-} concentrations ranged from 3.47 to 5.05 $mmol_c$ L^{-1}. Among the cations, Ca^{2+} was dominant at the soil surface followed by Mg^{2+}, Na^+, and K^+ (Table 2.3.3.2). The concentration of Ca^{2+} in the upper 0.15 m depth was 88.30 $mmol_c$ L^{-1} and ranged from 88.30 to 139.03 $mmol_c$ L^{-1}. The concentration of Mg^{2+} was less than Ca^{2+} concentration at all the soil depths. The Mg^{2+}concentration ranged from 28.81 to 35.59 $mmol_c$ L^{-1}. The Na^+ concentration ranged from 23.65 to 25.89 $mmol_c$ L^{-1} at different soils depths. The K^+ concentration ranged from 0.57 to 1.14 $mmol_c$ L^{-1}. The SAR levels were in the range of 2.63 to 3.13 indicating that the soil was saline in its characteristics.

Table 2.3.3.2 Chemical properties of the field site before start of the experiment (spring 2005)

Soil characteristic	Unit	Soil depth (m)			
		0.0-0.15	0.15-0.30	0.30-0.60	0.60-0.90
EC_e	dS m^{-1}	13.89	15.99	18.09	20.11
TDS	mg L^{-1}	9746	11144	12583	13862
Soluble Ca^{2+}	$mmol_c$ L^{-1}	88.30	104.43	124.20	139.03
Soluble Mg^{2+}	$mmol_c$ L^{-1}	25.81	29.06	32.76	35.59
Soluble Na^+	$mmol_c$ L^{-1}	23.65	25.58	23.26	25.89
Soluble K^+	$mmol_c$ L^{-1}	1.14	0.87	0.65	0.57
Soluble HCO_3^{2-}	$mmol_c$ L^{-1}	5.05	4.45	3.88	3.47
Soluble Cl^-	$mmol_c$ L^{-1}	18.22	17.27	17.01	17.75
Soluble SO_4^{2-}	$mmol_c$ L^{-1}	115.71	138.99	161.50	179.46
Cl^-:SO_4^{2-}	—	0.16	0.12	0.11	0.10
SAR	—	3.13	3.14	2.63	2.77

IRRIGATION, DRAINAGE AND GROUNDWATER QUALITY

The chemical composition of water from open canal used for irrigation at the experimental site during the years 2005-2007 is presented in Table 2.3.3.3. The salt concentration in irrigation water had a slightly increasing trend and ranged from 2257 to 2499 mg L^{-1} (3.35-3.71 dS m^{-1}) during 2005, from 2338 to 2672 mg L^{-1} (3.47-3.91 dS m^{-1}) during 2006, and from 2777 to 2933 mg L^{-1} (4.24-4.46 dS m^{-1}) during 2007. The composition of irrigation water from June to October in terms of cationic concentration revealed small temporal variation. The dominant cations were Mg^{2+} and Ca^{2+} with little differences in their concentrations. The levels of SAR and SAR_{adj} were almost the same and ranged from 2.08-4.18 (2007).

Table 2.3.3.3 Composition of irrigation water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{iw}	dS m^{-1}	3.53±0.18	3.69±0.22	4.35±0.11	3.86(±0.25)[a]
TDS	mg L^{-1}	2378±121	2505±167	2855±78	2579 (±143)
Ca^{2+}	$mmol_c$ L^{-1}	12.89±1.95	12.79±1.94	14.00±0.53	13.23 (±0.39)
Mg^{2+}	$mmol_c$ L^{-1}	12.24±2.84	14.74±1.97	15.84±0.69	14.27 (±1.06)
Na^{+}	$mmol_c$ L^{-1}	10.03±2.01	9.24±1.68	13.30±0.83	10.86 (±1.24)
K^{+}	$mmol_c$ L^{-1}	0.17±0.04	0.17±0.02	0.31±0.06	0.22 (±0.05)
HCO_3^{2-}	$mmol_c$ L^{-1}	2.94±0.64	3.25±0.16	1.50±0.28	2.57 (±0.54)
Cl^{-}	$mmol_c$ L^{-1}	9.92±2.03	8.09±2.70	8.54±0.44	8.85 (±0.55)
SO_4^{2-}	$mmol_c$ L^{-1}	22.83±3.19	26.42±3.81	33.61±1.02	27.62 (±3.17)
Cl^{-}:SO_4^{2-}	—	0.54±0.22	0.47±0.24	0.25±0.01	0.42 (±0.09)
Mg^{2+}:Ca^{2+}	—	1.29±0.63	1.33±0.27	1.14±0.07	1.25(±0.06)
SAR	—	2.91±0.65	2.58±0.50	3.45±0.23	2.98 (±0.25)
SAR_{adj}	—	3.32±0.72	2.95±0.56	3.93±0.25	3.40 (±0.28)

[a] Figures with ± indicate standard error

The salt concentrations in moderate-saline drainage were in the range of 4757-6059 mg L^{-1} (8.00-9.80 dS m^{-1}) during 2005, 4213-4925 mg L^{-1} (6.60-7.52 dS m^{-1}) during 2006 and 5602-6224 mg L^{-1}(8.98-10.04 dS m^{-1}) during 2007. The ratio Cl^{-}:SO_4^{2-} was in the range of 0.80-2.06 (2005-2007). The levels of SAR and SAR_{adj} were in the range of 7.58 to 14.57 (2005-2007), suggesting that the use of such drainage water for irrigation without appropriate management practices may cause gradual increase in Na^{+} levels in the irrigated soils. There is also poor ratio of Mg^{2+}:Ca^{2+} in the irrigation water from vertical drainage well (1.68±0.18), which indicating treat of accumulation of Mg in the soil (Table 2.3.3.4).

Table 2.3.3.4 Composition of drainage water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{dw}	dS m^{-1}	8.90±0.90	7.06±0.46	9.51±0.53	8.49±0.74[a]
TDS	mg L^{-1}	5408±651	4569±356	5913±311	5297±392
Ca^{2+}	$mmol_c$ L^{-1}	14.70±1.95	18.23±4.55	13.96±0.22	15.63±1.32
Mg^{2+}	$mmol_c$ L^{-1}	24.40±1.80	21.30±1.71	24.14±0.52	23.28±0.99
Na^{+}	$mmol_c$ L^{-1}	49.73±8.29	30.87±5.40	56.80±4.86	45.80±7.74
K^{+}	$mmol_c$ L^{-1}	0.13±0.05	0.22±0.07	0.22±0.03	0.19±0.03
HCO_3^{2-}	$mmol_c$ L^{-1}	2.08±0.46	2.60±0.13	1.29±0.08	1.99±0.38
Cl^{-}	$mmol_c$ L^{-1}	50.43±3.46	29.57±5.67	47.06±0.80	42.35±6.47
SO_4^{2-}	$mmol_c$ L^{-1}	34.51±8.21	40.48±8.94	45.79±4.12	40.26±3.26
Cl^{-}:SO_4^{2-}	—	1.74±0.32	1.13±0.33	1.07±0.13	1.31±0.21
Mg^{2+}:Ca^{2+}	—	1.96±0.57	1.36±0.15	1.73±0.03	1.68±0.18
SAR	—	11.20±1.79	7.58±1.63	12.99±1.04	10.59±1.59
SAR_{adj}	—	12.57±1.99	8.53±1.82	14.57±1.16	11.89±1.78

[a] Figures with ± indicate standard error

The salt concentration in groundwater ranged from 8048 to 9068 mg L^{-1} (12.72-14.66 dS m^{-1}) during 2005, from 10029 to 12049 mg L^{-1} (15.73-18.61 dS m^{-1}) during 2006, and from 11447 to 12021 mg L^{-1} (18.00-19.08 dS m^{-1}) during 2007. The data presented in Table 2.3.3.5 revealed that groundwater pumped from the vertical well had an overall Cl^{-}:SO_4^{2-} of 0.87 during the three years of the study. The ratio of Mg^{2+}:Ca^{2+} in groundwater (1.95) revealed the dominance of Mg^{2+} over Ca^{2+}. The values of SAR (11.61) during 2005-2007 for groundwater suggest that capillary raise from groundwater can cause sodicity problem in the topsoil.

Table 2.3.3.5 Composition of ground water at the experimental site in 2005-2007

Characteristic	Unit	2005	2006	2007	Average
EC_{gw}	dS m^{-1}	13.69±0.97	17.17±1.44	18.54±0.54	16.46±1.44[a]
TDS	mg L^{-1}	8558±510	11039±1010	11734±287	10443±964
Ca^{2+}	$mmol_c$ L^{-1}	27.71±1.97	37.96±8.91	28.43±1.86	31.37±3.30
Mg^{2+}	$mmol_c$ L^{-1}	51.59±1.96	57.61±2.05	59.60±1.93	56.27±2.41
Na^{+}	$mmol_c$ L^{-1}	56.92±9.32	75.66±11.60	96.63±2.19	76.41±11.47
K^{+}	$mmol_c$ L^{-1}	0.64±0.10	0.43±0.06	0.69±0.05	0.59±0.08
HCO_3^{2-}	$mmol_c$ L^{-1}	4.55±1.11	5.04±0.63	2.40±0.36	4.00±0.81
Cl^{-}	$mmol_c$ L^{-1}	67.36±1.89	63.62±5.91	81.38±6.81	70.79±5.40
SO_4^{2-}	$mmol_c$ L^{-1}	63.56±10.09	104.64±13.58	102.63±1.41	90.28±13.37
$Cl^{-}:SO_4^{2-}$	—	1.12±0.19	0.69±0.14	0.80±0.08	0.87±0.13
$Mg^{2+}:Ca^{2+}$	—	1.89±0.22	1.83±0.25	2.12±0.12	1.95±0.09
SAR	—	9.05±1.47	11.26±1.98	14.52±0.15	11.61±1.59
SAR_{adj}	—	12.49±2.91	12.64±2.21	16.27±0.16	13.80±1.23

[a] Figures with ± indicate standard error

SOIL SALINITY AND SODICITY

Salinity determinations made on soil samples collected after harvest of cotton in different years reveal increase in EC_e with respective to the pre-experiment levels (Table 2.3.3.6). The increases in EC_e levels in different treatments were 2-106% (2005), 6-66% (2006) and 5-47% (2007) over the respective initial levels at the 0-0.15 m soil depth. Maximum increase in the soil salinity (106%) at the 0-0.15 m soil depth over the initial soil salinity level was observed under SW+M treatment in 2005, 66% increase in SW treatment in 2006, and 47% increase in SW+M treatment in 2007.

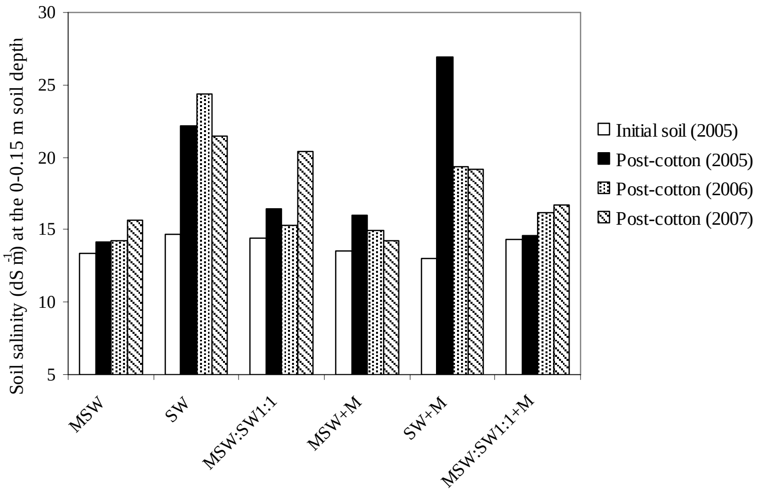


Figure 2.3.3.1 Soil salinity level as affected by different treatments in 2005-2007

Table 2.3.3.6 Soil salinity levels expressed as EC_e (dS m^{-1}) in the soil profile as affected by treatments during 2005-2007

Soil depth (m)	Initial soil (2005)	Post-cotton (2005)	Post-cotton (2006)	Post-cotton (2007)
MSW				
0-0.15	13.35	14.16 (+6)[a]	14.27 (+7)	15.64 (+17)
0.15-0.30	18.20	16.15 (-11)	16.79 (-8)	14.10 (-22)
0.30-0.60	17.64	20.49 (+16)	18.65 (+6)	18.60 (+5)
0.60-0.90	19.69	19.92 (+1)	21.45 (+9)	18.03 (-8)
SW				
0-0.15	14.65	22.14 (+51)	24.39 (+66)	21.47 (+46)
0.15-0.30	14.93	14.37 (-4)	23.33 (+56)	19.43 (+30)
0.30-0.60	19.39	19.32 (0)	18.51 (-4)	23.98 (+24)
0.60-0.90	19.41	20.34 (+5)	22.09 (+14)	20.85 (+7)
MSW:$SW_{1:1}$				
0-0.15	14.43	16.45 (+14)	15.27 (+6)	20.38 (+41)
0.15-0.30	15.02	16.14 (+7)	12.87 (-14)	17.23 (+15)
0.30-0.60	18.90	21.04 (+11)	18.34 (-3)	21.63 (+14)
0.60-0.90	21.02	21.35 (+2)	20.50 (-2)	20.52 (-2)
MSW+M				
0-0.15	13.58	16.01 (+18)	14.96 (+10)	14.22 (+5)
0.15-0.30	16.86	17.26 (+2)	15.40 (-9)	12.85 (-24)
0.30-0.60	17.09	20.87 (+22)	19.70 (+15)	18.68 (+9)
0.60-0.90	19.35	20.59 (+6)	18.99 (-2)	17.88 (-8)
SW+M				
0-0.15	13.03	26.89 (+106)	19.37 (+49)	19.19 (+47)
0.15-0.30	14.42	16.80 (+16)	19.94 (+38)	17.53 (+22)
0.30-0.60	17.14	19.57 (+14)	25.47 (+49)	23.30 (+36)
0.60-0.90	21.10	20.84 (-1)	20.83 (-1)	21.67 (+3)
MSW:$SW_{1:1}$+M				
0-0.15	14.29	14.57 (+2)	16.15 (+13)	16.68 (+17)
0.15-0.30	16.53	17.03 (+3)	14.82 (-10)	15.50 (-6)
0.30-0.60	18.36	20.74 (+13)	20.11 (+10)	19.85 (+8)
0.60-0.90	20.08	18.49 (-8)	18.53 (-8)	17.94 (-11)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over initial level

At the same time, the average EC values of the mulching plots at the 0-0.15 m soil depth at the end of crop season during 2006 and 2007 were lower in comparison with that of the plots where mulching was not done. The maximum reduction in soil salinity (13%) was observed in 2007, followed by 6% in 2006, whereas this parameter did not change significantly in 2005. These results suggest that hey mulching application could reduce or maintain the salt concentration at the upper soil depth (0-0.15 m).

Data from soil samples collected from different soil depths after harvesting the first cotton crop revealed an overall increase in SAR levels in all treatments (Table 2.3.3.7). Maximum increase in the soil sodicity at the 0-0.15 m soil depth over the initial soil salinity level was observed in the treatment where saline water was used throughout the cropping season without mulching or other management practice (Figure 2.3.3.2). These results are in line with those of Sharma and Minhas (2005) suggesting that irrigation with saline water without a suitable salinity management intervention leads to salinity and sodicity build-up in the irrigated soil, particularly in the root zone.

Table 2.3.3.7 Sodium absorption ratio (SAR) in the soil profile as affected by various treatments

Soil depth (m)	Initial soil (2005)	Post-cotton (2005)	Post-cotton (2006)	Post-cotton (2007)
MSW				
0-0.15	2.60	3.25(+25)[a]	5.24 (+101)	5.26 (+102)
0.15-0.30	3.80	2.95 (-22)	5.76 (+52)	4.80 (+26)
0.30-0.60	2.53	2.80 (+11)	5.66 (+124)	3.64 (+44)
0.60-0.90	2.49	2.31 (-7)	3.26 (+31)	3.34 (+34)
SW				
0-0.15	2.90	8.05 (+177)	10.03 (+245)	6.30 (+117)
0.15-0.30	3.05	3.36 (+10)	8.90 (+192)	6.33 (+108)
0.30-0.60	2.72	2.90 (+7)	4.59 (+69)	5.71 (+110)
0.60-0.90	2.45	2.66 (+9)	3.87 (+58)	5.08 (+108)
MSW:SW$_{1:1}$				
0-0.15	4.36	3.39 (-22)	5.80 (+33)	5.45 (+25)
0.15-0.30	3.90	3.27 (-16)	4.61 (+18)	5.03 (+29)
0.30-0.60	2.47	3.02 (+22)	4.15 (+68)	4.43 (+80)
0.60-0.90	3.22	2.89 (-10)	2.77 (-14)	4.05 (+26)
MSW+M				
0-0.15	2.98	2.95 (-1)	4.61 (+55)	3.98 (+34)
0.15-0.30	2.53	3.19 (+26)	4.74 (+88)	2.88 (+14)
0.30-0.60	2.72	3.10 (+14)	4.14 (+52)	3.27 (+20)
0.60-0.90	2.27	2.64 (+17)	3.33 (+47)	3.09 (+36)
SW+M				
0-0.15	2.94	7.13 (+142)	7.13 (+142)	5.66 (+93)
0.15-0.30	2.75	3.27 (+19)	7.10 (+158)	5.82 (+112)
0.30-0.60	2.68	3.07 (+14)	6.89 (+157)	5.33 (+99)
0.60-0.90	3.68	2.90 (-21)	4.27 (+16)	5.14 (+40)
MSW:SW$_{1:1}$+M				
0-0.15	3.01	3.32 (+10)	5.47 (+82)	4.51 (+50)
0.15-0.30	2.80	3.89 (+39)	4.76 (+70)	4.19 (+50)
0.30-0.60	2.65	3.57 (+35)	4.95 (+87)	3.77 (+42)
0.60-0.90	2.51	2.88 (+15)	4.12 (+64)	3.17 (+26)

[a] Figures in parenthesis indicate percentage increase (+) or decrease (–) over initial level (2005)

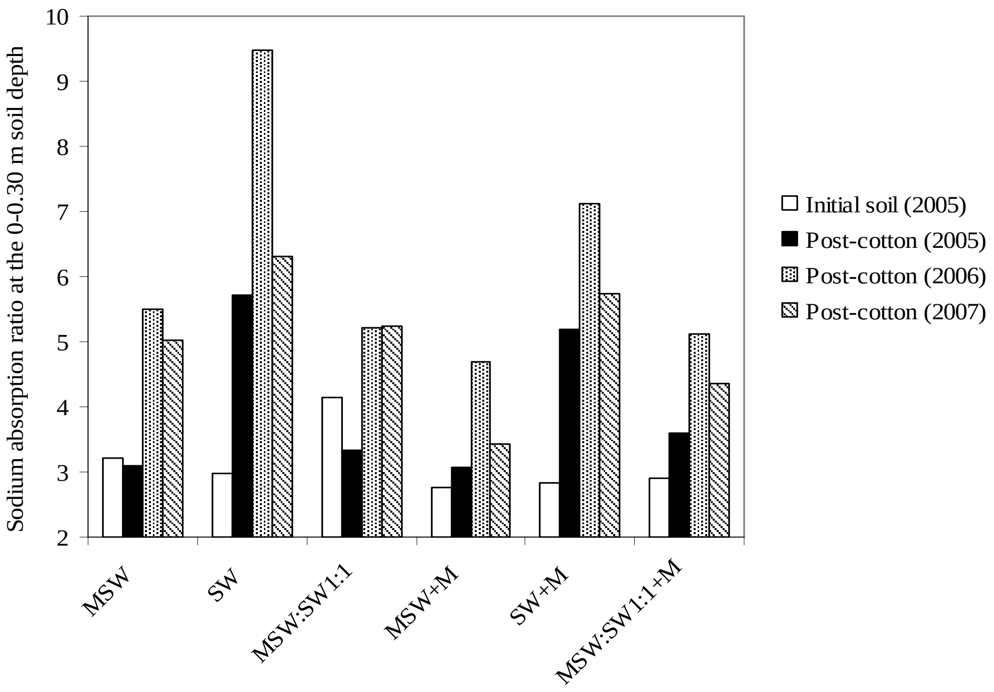


Figure 2.3.3.2 Sodium absorption ratio as affected by different treatments in 2005-2007

Soil sodicity expressed in terms of SAR at the 0.30 m soil depth under mulching treatments was lower by 2-18% in comparison with that under no mulch treatments (Figure 2.3.3.3). These results indicate that mulching could reduce the soil sodicity at the upper soil depth (0-0.30 m). These results are in line with those of Sharma and Minhas (2005) suggesting that irrigation with saline water without a suitable salinity management intervention leads to salinity and sodicity build-up in the irrigated soil, particularly in the root zone.

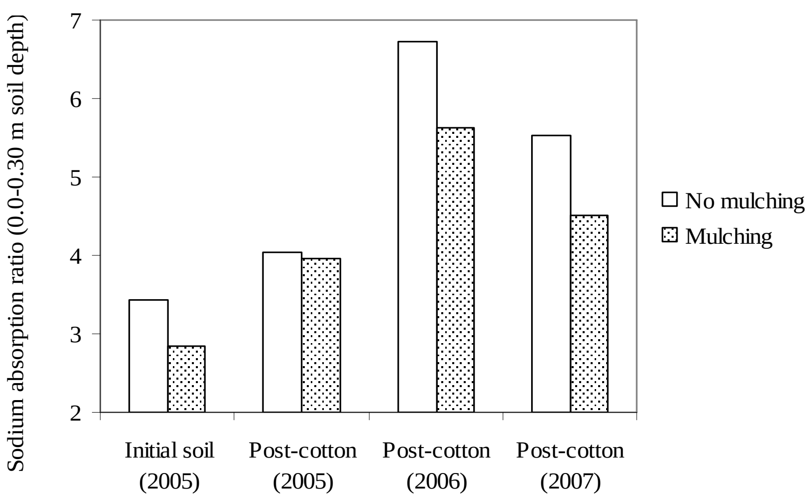


Figure 2.3.3.3 Effect of mulching and non-mulching treatments on sodicity level after harvest of cotton in different years

IRRIGATION PARAMETERS AND IRRIGATION EFFICIENCY

The first irrigation (873-927 m^3 ha^{-1}) in 2005 was applied on 7 July, which was followed by the 690-820 m^3 ha^{-1} second irrigation on 9 August. The total amount of irrigation was estimated in the range of 1597 to 1740 m^3 ha^{-1} (Table 2.3.3.8). In 2006 first irrigation (684-714 m^3 ha^{-1}) was applied on 13-14 May, which was followed by the 570-580 m^3 ha^{-1} second irrigation on 6 June. The third irrigation (1050-1108 m^3 ha^{-1}) was applied on 6-7 July, which was followed by the 854-950 m^3 ha^{-1} fourth irrigation on 1-3 August. The total irrigation was estimated in the range of 3188 to 3299 m^3 ha^{-1}. In 2007, first irrigation (1128-1156 m^3 ha^{-1}) was applied on 8 July 2007, which was followed by the 1046-1185 m^3 ha^{-1} second irrigation on 12 August 2007. The total irrigation was estimated in the range of 2190 to 2330 m^3 ha^{-1}.

Table 2.3.3.8 Irrigation parameters at the experimental station (2005-2007)

Irrigation date	Gross irrigation rate [a]	Irrigation efficiency [b]					
		MSW	SW	MSW:SW$_{1:1}$	MSW+M	SW+M	MSW:SW$_{1:1}$+M
7.07.2005	873-927	79 (728)[c]	79 (728)	80 (728)	83 (728)	83 (728)	83 (728)
9.08.2005	690-820	80 (644)	79 (644)	93 (644)	89 (644)	89 (644)	82 (644)
13-14.05.06	684-714	83 (594)	87 (594)	84 (594)	84 (594)	84(594)	87 (594)
06.06.2006	570-580	72 (410)	71 (410)	72 (410)	71 (410)	71 (410)	72 (410)
06-07.07.2006	1050-1108	74 (780)	74 (828)	74 (803)	72 (763)	74 (810)	74 (805)
1-3.08.2006	854-950	96 (824)	91 (805)	90 (849)	89 (815)	88 (805)	87 (830)
6-8.07.2007	1128-1156	58 (664)	64 (726)	57 (656)	60 (678)	63 (716)	57 (655)
7-12.08.2007	1046-1185	71 (845)	70 (753)	72 (771)	71 (819)	69 (743)	67 (696)

[a] Gross irrigation rate (GIR) expressed as m^3 ha^{-1}

[b] Irrigation efficiency (IE) estimated by using the equation: $IE = (NIR/GIR)\ 100$

[c] Figures in parenthesis indicate net irrigation rate (NIR) expressed as m^3 ha^{-1}

CHANGES IN GROUNDWATER LEVEL

Monitoring the fluctuation of groundwater level during 2005-2007 revealed that the water level lowered from mid July to mid September, suggesting the contribution of groundwater to cotton and possible physical evaporation. The groundwater level was in the range of 0.74-1.88 m, 1.04-2.05 m, and 0.84-2.09 m during the May-October (cotton growing season) of 2005, 2006 and 2007, respectively. The statistical data analyses revealed that there were non-significant differences in terms of groundwater level among the treatments.

CROP GROWTH AND YIELD

Averaged cotton crop yield data from 2005 to 2007 revealed that the maximum cotton yield (2.27 t ha^{-1}) was observed in the treatment where moderately-saline water was used for irrigation throughout the cropping season in combination with mulching (Table 2.3.3.9). The cotton yields from other mulching treatments were 2.02 t ha^{-1} in the MSW:SW$_{1:1}$+M treatment and 1.84 t ha^{-1} in the SW+M treatment. The yield from the treatments without mulching was in the order: 2.04 t ha^{-1}(MSW), 1.92 t ha^{-1} (MSW:SW$_{1:1}$), and 1.76 t ha^{-1} (SW).

Table 2.3.3.9 Effect of mulching and non-mulching treatments on yield of cotton variety Bayut-2

Treatment	Cotton yield			
	2005[a]	**2006**[b]	**2007**[c]	**Average**
MSW	2.13	1.47	2.52	2.04±0.31[d]
SW	1.93	1.24	2.12	1.76±0.27
$MSW:SW_{1:1}$	1.97	1.37	2.41	1.92±0.30
MSW+M	2.21	1.78	2.83	2.27±0.30
SW+M	1.94	1.33	2.24	1.84±0.27
$MSW:SW_{1:1}$+M	1.99	1.47	2.60	2.02±0.33
No mulching treatments	2.01	1.36	2.35	1.91±0.29
Mulching treatments	2.05	1.53	2.56	2.04±0.30

[a] In 2005 LSD at $p = 0.05$ was 0.05 t ha^{-1} (factor A; mulching) and 0.06 t ha^{-1} (factor B; water quality)
[b] In 2006 LSD at $p = 0.05$ was estimated as 0.06 t ha^{-1} (factor A) and 0.07 t ha^{-1} (factor B)
[c] In 2007 LSD at $p = 0.05$ was estimated as 0.14 t ha^{-1} (factor A) and 0.17 t ha^{-1} (factor B)
[d] Figures with ± indicate standard error

Comparison between the effect of the mulching and irrigation water salinity (Table 2.3.3.9) reveals that the mulching resulted in a better crop response. In the mulching treatments, the average cotton yields in 2005-2007 were higher by 2-12% than no mulching treatments. In addition, the yields were adversely affected by the increase in the level of irrigation water salinity.

CONCLUSIONS

In order to evaluate the interactive effects of mulching and water quality, this 3-year field study was carried out to evaluate different treatment combinations on the growth and yield of cotton, which is commonly grown in Central Asia. The results reveal the beneficial effects of mulching in the form of a better crop response as well as management of salinity and sodicity in the root zone. In the mulching treatments, the average cotton yields during the three years were higher by 2-12% than respective no mulching treatments in combination with irrigation water salinity. Mulching reduced the soil salinity by 6-13% at the end of cropping seasons. Long-term use of mulching would further improve the soil conditions vis-à-vis yield.

Based on the quality and availability of drainage water and groundwater for irrigation, there is a need to consider that groundwater at the site has inappropriate ratios of $Cl^-:SO_4^{2-}$ and $Ca^{2+}:Mg^{2+}$, suggesting that groundwater level is to be maintained at a low level as much as possible to minimize its movement to the root zone to avoid salt accumulation there. Since adequate amounts of canal water are not available at the site, water from the open drain can be applied for irrigation. In addition, water pumped from the vertical well can be applied for irrigation in conjunction with the open drain water during the second half of the cotton growing season, when plants are more tolerant to ambient levels of salinity.

2.3.4 USE OF SWAP (SOIL-WATER-ATMOSPHERE-PLANT) MODEL FOR IMPROVED MANAGEMENT OF SALT PRONE ENVIRONMENTS. [13]

1. INTRODUCTION

Increasing demand and decreasing water quality has placed enormous pressure on the agriculture sector to use available water resources more efficiently and to improve the productivity of water. These pressures are a result of increasing demand for food within the context of declining lateral expansion of the irrigated area due to scarcity of land and water resources and significant costs of development (Shanan, 1992). The growing scarcity of water has also increased inter-sectoral competition for water, particularly from the municipal and industrial sectors. Consequently, in future, irrigation's contribution to food security will in part have to come from the use of marginal quality water resources (Minhas, 1996; Bouwer, 2002; Qadir *et al.*, 2007).

In arid and semi-arid regions of the world, freshwater resources are becoming increasingly scarce to meet agricultural water requirements. This situation is inclusive of significant areas in Central Asia where saline water is used for irrigation to supplement deficits in freshwater (Rhoades, 1999; Bouwer, 2003; Qadir et al., 2007). For example, farmers in some areas of Uzbekistan use water having salinity levels around 2600 mg L^{-1} ($\approx$ 4.0 dS m^{-1}) for irrigation. This situation is further exacerbated as water of this salinity is not available in sufficient quantities to fulfill crop water requirements. As a possible alternative, highly saline drainage or groundwater could be used conjunctively with this water to increase the volume of irrigation water to be used in agriculture. However, the use of saline water for irrigation without suitable management may result in increased levels of salts in the root zone, thereby affecting crop growth and yield (Rhoades, 1989; Sharma and Minhas, 2005).

In saline environments mulching can assist in reducing salt accumulation in the soil profile through a combination of providing excess water for leaching and reducing soil evaporation. Mulching is widely practiced to control erosion, weed infestations and soil evaporation in water-limited environments. In order to reduce the upward flux of soluble salts mulching should be encouraged, whenever feasible (Rhoades *et al.*, 1992). Research in southern Italy on mulching suggests that durum wheat straw could be used as mulch, left on the soil after harvest in June, to increase soil water storage for horticultural crops sown later during August-September (Rinaldi *et al.*, 2000). Other studies undertaken on different aspects of mulching also reveal beneficial effects of this intervention. Yan-min *et al.* (2006) indicated that a concrete mulch and straw mulch were effective in conserving soil water compared to plastic film mulch which increased soil temperature. Concrete mulch decreases surface soil salinity more effectively in comparison with other mulches used. Straw mulches conserved more soil water but decreased wheat grain yield.

The growth and yield of cotton (*Gossypium hirsutum* L.), commonly grown in Central Asia, is affected by the limited supply of freshwater, which is offset by using saline water for irrigation in some cotton growing areas. Irrigation with poor water quality may cause salinity, specific ion toxicity or soil infiltration problems. These factors may effect crop production as well as physical properties of the soil. Crop production and associated deep percolation losses are largely dependent upon irrigation and agronomic practices, depth to groundwater table and soil characteristics such as infiltration rate and water holding capacity. The complex interaction between these parameters can be better defined by transient simulations models that are able to simulate soil water fluxes under a variety of climatic and physical conditions. Models are also useful tools for estimating the effects of various irrigation management practices on crop production and other water balance parameters. In this study, Soil-Water-Atmosphere-Plant (SWAP) relationship model is used as a means of understanding the processes in the saturated zone that are difficult to measure *in situ*. The objectives of this study were as follows:

- To calibrate soil water transport model SWAP for soil, climate and crop conditions prevailing in Sardarya Province of Uzbekistan;

[13] This component was led by IWMI. NARS partners include Dr. German Bezborodov and Ruslan Kalandarov (Uzbekistan).

- To evaluate the impact of current irrigation practices with saline water on crop production, soil salinity and depth to groundwater table.
- To evaluate the impact of mulching on soil salinity and crop production;
- To estimate suitable groundwater table depth and irrigation requirements to optimize cotton production.

2. DESCRIPTION OF SWAP MODEL

Feddes *et al.* (1978) developed the one-dimensional model SWATR to describe transient water flow in a heterogeneous soil-root system that is influenced by groundwater depth. This model was further refined by Belmans *et al.* (1983), Wesseling *et al.* (1991), Van den Broek *et al.* (1994) and Van Dam *et al.* (1997) and is now referred to as SWAP. The model attempts to simulate unsaturated flow, solute transport, heat flow and crop growth in the atmosphere-plant-soil environment at field scale. The model offers a wide range of possibilities to address practical questions in the field of agriculture, water management and environmental protection. Previous versions of this model have successfully been applied in many hydrological studies for a variety of climatic and agricultural conditions (Bastiaanssen *et al.*, 1996; Sarwar, 2000; Singh, 2005). Options exist for irrigation scheduling, drainage design, prediction of depth to groundwater table, soil salinity and leaching of nitrogen and pesticides.

SWAP employs Richards' equation for soil water flow in the soil matrix. Richards' equation is a combination of Darcy's law and the classical continuity equation (conservation of mass). For vertical flow, the equation

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + 1\right) \right] - S(h)$$

reads:

where *h* (cm) is soil water pressure head, *K* (cm d^{-1}) is hydraulic conductivity, *C* ($d\theta/dh$) (cm^{-1}) is the differential soil water capacity, *S* ($cm^3\ cm^{-3}\ d^{-1}$) is soil water extraction rate by plant roots, *z* (cm) is the vertical coordinate positive in the upward direction and *t* (d) is time. Richards' equation is solved through an implicit finite difference scheme as described by Van Dam and Feddes (2000).

Richards' equation has a clear physical basis at a scale where the soil can be considered as a continuum of soil, air and water. SWAP solves Richards' equation numerically for both the unsaturated and saturated zone, subject to specified initial and boundary conditions and with known relations between soil water content (θ), soil water pressure head (*h*) and unsaturated hydraulic conductivity (*K*). These relationships, which are generally called the soil hydraulic functions, can be measured directly in the soil, or might be obtained from basic soil data. The soil hydraulic functions are described by the Van Genuchten (1980) and Mualem (1976) model or by tabular values. Hysteresis of the water retention function can be taken into account with the scaling model of Scott *et al.* (1983).

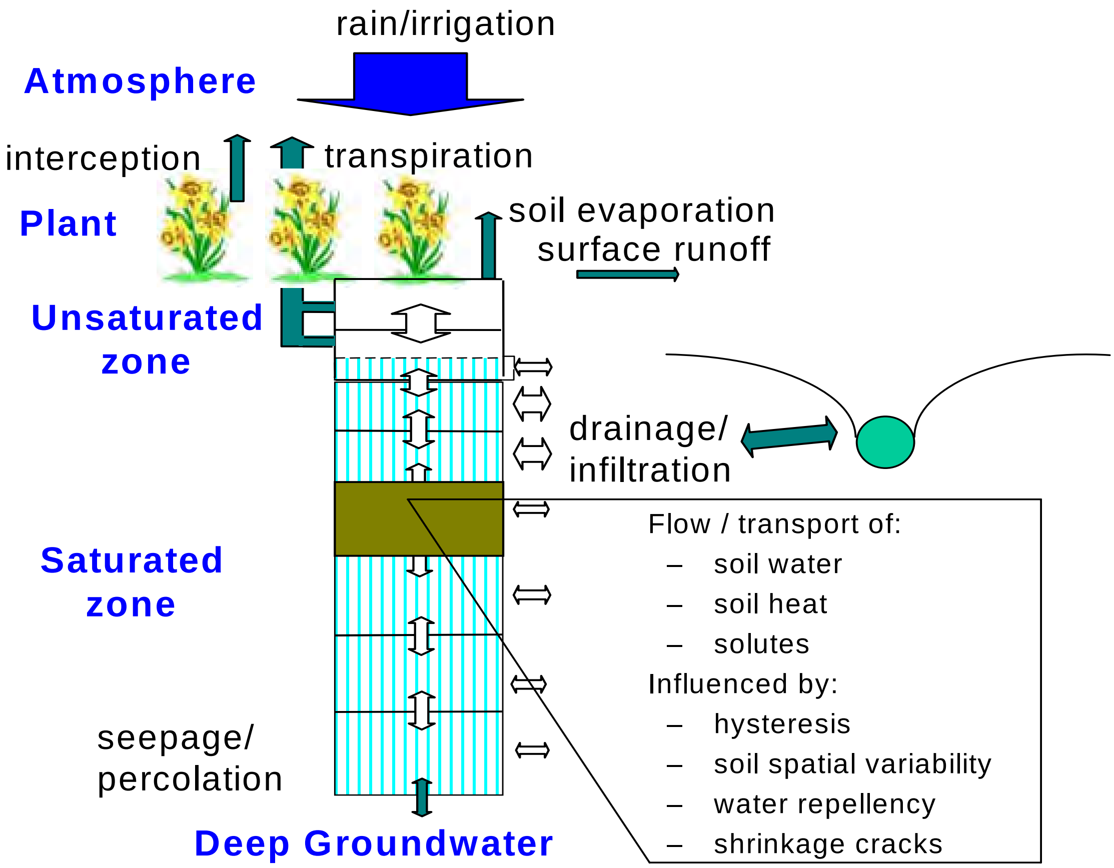


Figure 2.3.4.1. Processes incorporated in the SWAP model.

The potential root water extraction rate (S_{pot}), integrated over the rooting depth (D_{root}) is equal to the potential transpiration rate, T_{pot}, which is governed by atmospheric conditions. The potential root water extraction rate at a certain depth, S_{pot} (z) (d^{-1}), may be determined by the root length density, l_{root} (z) (cm cm^{-3}), at this depth as a fraction of the integrated root length density (e.g. Bouten, 1992). Figure 1 presents a schematic of the processes incorporated in SWAP model.

Stresses due to dry or wet conditions and/or high salinity concentrations may reduce S_{pot} (z). Water stress in SWAP is described by the function proposed by Feddes *et al.* (1978).

$$S(h,z) = \alpha_{rw}(h) S_{pot}(z)$$

where $\alpha_{rw}(h)$ is a dimensionless function of soil water pressure head (h) (see Figure 2.3.4.2). The value of α_{rw} varies between 0 and 1. When α_{rw} is 1, water extraction by roots is equal to potential. If $0 < \alpha_{rw} < 1$, the soil water status in the root zone becomes important. Above h_1 no water uptake takes place due to oxygen deficiency, while below the wilting point, h_4, the plant is not able to extract water due to 'too dry' conditions. Between h_2 and h_3, water uptake remains optimal. Critical pressure head values of this sink term function for a variety of crops can be obtained from Taylor and Ashcroft (1972), Wesseling *et al.* (1991) and can also be derived from the soil and crop data given in FAO Publications (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979; Smith, 1995).

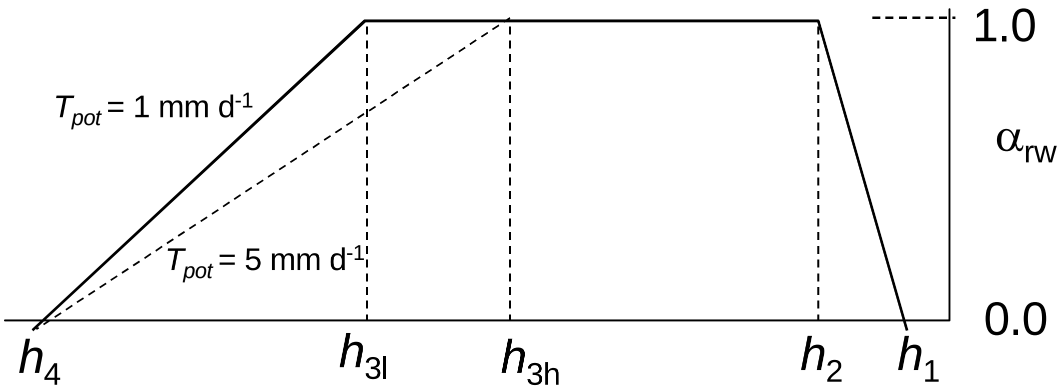


Figure 2.3.4.2. Dimensionless sink term variable, α_{rw}, as function of soil water pressure head h and potential transpiration rate T_{pot} (after Feddes et al., 1978).

The wide range of upper and lower boundary conditions being offered in SWAP is one of the key advantages of the model. The upper boundary conditions of the system are described by potential evapotranspiration rate, ET_{pot} (cm d^{-1}), irrigation and precipitation. SWAP uses daily meteorological data to calculate daily ET_{pot} according to Penman-Monteith (Smith, 1995). If meteorological data are not available, SWAP opts for alternative procedures and ET_{pot} or reference evapotranspiration rate, ET_o (cm d^{-1}) can directly be used as input. Precipitation may be provided either on a daily basis or as actual intensities. Short-term rainfall data allow the calculation of runoff and preferential flow.

ET_{pot} is divided into potential transpiration rate, T_{pot} (cm d^{-1}) and potential soil evaporation rate, E_{pot} (cm d^{-1}) based either on the leaf area index, *LAI* (m^2 m^{-2}) or the soil cover fraction, *SC* (-), both as a function of crop development. Reduction of the potential soil evaporation rate into actual soil evaporation rate, E_{act} (cm d^{-1}) depends on the maximum soil water flux in the top soil according to Darcy's law or is calculated by an empirical function following either Black *et al.* (1969) or Boesten and Stroosnijder (1986). For this study, reference evapotranspiration rate calculated by the Penman-Monteith method was directly used as input. Soil cover fraction was used to partition ET_{pot} into E_{pot} and T_{pot}, while the empirical function of Boesten and Stroosnijder (1986) was used for the reduction of E_{pot} into E_{act}.

At the bottom of the system, the boundary conditions can be described with various options. These include groundwater level as a function of time, flux to/from semi-confined aquifers, flux to/from open surface drains, an exponential relationship between bottom flux and groundwater table or zero flux, free drainage and free outflow (Van Dam *et al.*, 1997). In the current study, for the calibration of the model daily measured groundwater levels were used as the bottom boundary condition. For model simulations, zero flux at the bottom of the soil profile was applied.

Irrigations in SWAP may be prescribed at fixed times or scheduled according to a number of criteria. The scheduling options allow the evaluation of alternative application strategies. Two irrigation depth criteria can be specified: a constant application depth, a volume of water needed to fill the root zone back to field capacity. Five different timing criteria can be selected to generate an irrigation schedule. These include allowable daily stress, allowable depletion of readily available water in the root zone, allowable depletion of totally available water in the root zone, allowable depletion of an amount of water in the root zone and critical pressure head or water content at a certain depth.

Effects of water on crop production in irrigation design and management are paramount. Plants consume water essentially for the process of photosynthesis and transpiration. Water is transported to the roots of a plant and then removed from the leaf surface via transpiration. Transpiration is controlled by the stomatal aperture and by the vapor pressure gradient from the leaf to the atmosphere. Since stomata acts as regulators for CO_2 exchange and water loss, water stress sufficient to close stomata depresses photosynthesis and ultimately crop yield.

Under water limiting conditions, it is important to know the minimum amount of irrigation water needed to ensure the maximum production of a certain crop. Doorenbos and Kassam (1979) suggested that when the full crop water requirements are not met, the effect of water stress on crop production can be quantified by deriving a relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically-derived yield response factor (K_y):

$$1-\frac{Y_{act}}{Y_{pot}}=K_y\left(1-\frac{ET_{act}}{ET_{pot}}\right)$$

where Y_{act} (kg ha^{-1}) is the actual crop yield, Y_{pot} (kg ha^{-1}) is the potential crop yield, ET_{act} (cm d^{-1}) is the actual evapotranspiration rate and ET_{pot} (cm d^{-1}) is the potential evapotranspiration rate. The value of K_y is based on a wide range of growing conditions.

Since photosynthesis/dry matter production and transpiration are directly related through the processes of diffusion of carbon dioxide and water vapor through the stomata of leaves (Feddes, 1985; Feddes and Koopmans, 1997), loss of water to the atmosphere through the plant surface should be considered for determining water use efficiency. De Wit (1958) pointed out that under high radiation conditions not restricting transpiration, the water requirements of plants are more or less proportional to the level of radiation expressed as evaporation from a free water surface, E_o. Therefore, for a given crop and year for which E_o is constant, a simplified relationship between relative yield Y_{act}/Y_{pot} and relative transpiration T_{act}/T_{pot} applies:

$$\frac{Y_{act}}{Y_{pot}}=\frac{T_{act}}{T_{pot}}$$

The validity of De Wit's linear relationship in field experiments was confirmed by several researchers in different climates (Hanks, 1974, 1983; Stewart *et al.*, 1977; Feddes, 1985). Further details of SWAP are described by Van Dam *et al.* (1997) and the program use is documented by Kroes *et al.* (1999).

3. MATERIALS AND METHODS

3.1 CHARACTERIZATION OF THE STUDY AREA

The study area is located in the Syrdarya district at the longitude of 68.05^{o}E and latitude of 40.38^{o}N (Figure 2.4.3.3). The area has a smooth landscape with slopes from 0.002 to 0.0035. The area is arid continental, with seasonal fluctuations of air temperature and rainfall. The absolute summer maximum temperature exceeds 42^{o}C. The absolute winter minimum temperature drops -32^{o}C. The temperature decreases to as low as –6°C, with an average of 2°C, during the winter months. The air temperature during the summer ranges from 16°C to 28°C.

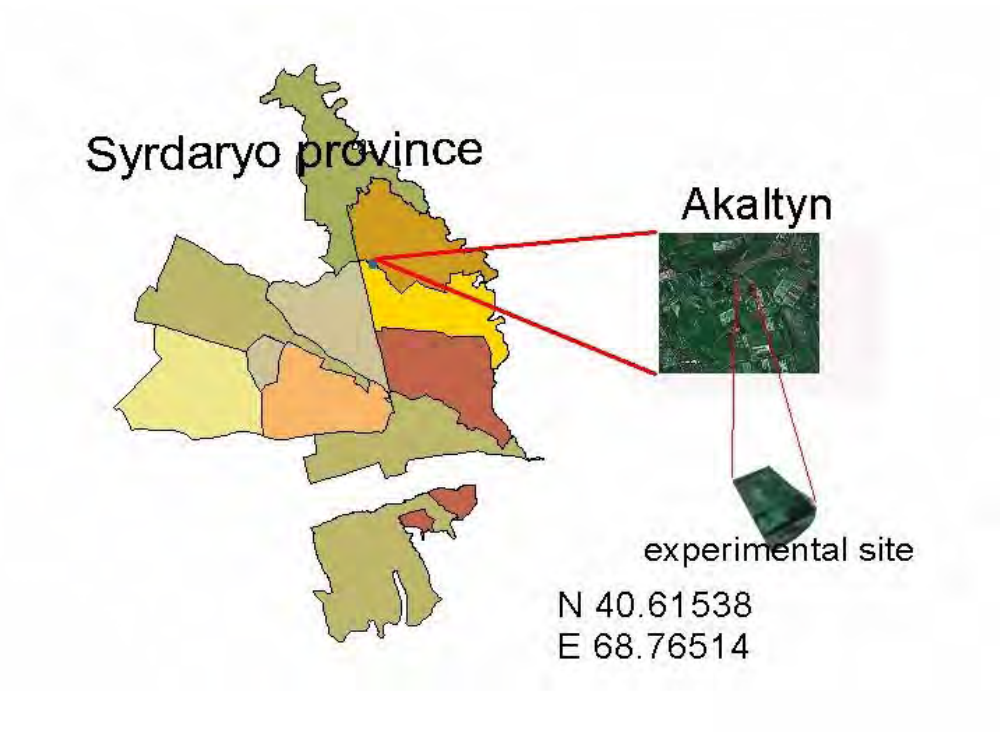


Figure 2.3.4.3. Location of the study area in Uzbekistan.

Precipitation primarily occurs during the winter-spring period. Long-term annual precipitation ranges from 100 to 300 mm, with 90% occurring during October through May. The average precipitation during the cotton growing period (April-September) is in the range of 43-106 mm. The soils are medium loam with about 1% organic matter in the surface layer. The average daily reference evapotranspiration estimated using measured climatic data of 2005-07 and the Penman-Monteith equation (Allen *et al.*, 1998) is presented in Table 2.3.4.1.

Table 2.3.4.1. Average monthly reference evapotranspiration for the study area.

Month	Air Temperature, °C			Mean relative humidity %	Precipitations, mm	Sunshine, hours	Reference daily evapotranspiration (ETo) mm
	Minimum	Maximum	Mean				
January	-3.55	4.14	-0.35	89	47.5	2.55	0.57
February	-0.57	9.00	3.37	85	40.7	3.39	1.13
March	5.59	17.25	10.76	80	57.0	4.75	2.06
April	10.75	24.33	17.12	77	42.6	8.18	3.64
May	14.58	29.83	22.11	68	21.7	10.09	5.09
June	18.36	35.86	27.51	61	0.6	12.43	6.68
July	18.69	36.97	28.01	61	2.3	13.11	6.86
August	16.53	35.09	25.76	61	0.1	12.09	5.83
September	11.19	30.28	20.58	61	1.0	10.54	4.15
October	6.73	23.21	14.19	68	8.7	8.17	2.39
November	3.46	14.62	8.14	81	37.2	4.43	1.14
December	-1.89	5.32	0.88	90	34.3	3.08	0.51
January-December	8.32	22.16	14.84	73	29.4	7.73	3.34

Mono-cropping system is followed in the region. Cotton is the main crop grown covering about 90% of the cropped area in summer. The cotton vegetative phase passes from April to October. Fields are usually kept fallow between the two cotton growing seasons to retain natural fertility levels. Another reason which restricts the sowing of second crop is shortage of water and other input parameters such as fertilizer.

Therefore double cropping in a year is officially restricted in the area. Due to high soil salinity and scarcity of good quality irrigation water, cropping yields are generally low. The average cotton yields in the area are from 2-2.5 tons/has as compared to the production potential of up to 5-6 tons/ha.

In the study area, irrigation waters are sourced from the Syr-Darya River, which is becoming limited considering the growing needs to produce more food. The area has a severe shortage of surface water therefore use of saline water for irrigation is a common practice. Drainage water from open drains and groundwater pumped through deep tubewells is widely used to irrigate cotton crop. Drainage water pumped from open drain is usually relatively low in salinity levels as compared to groundwater extracted from deep tubewells. Total dissolved solids (TDS) in drainage water varied from 2156 to 3130 mg L^{-1}. The corresponding EC values were in the range of 3.37- 4.76 dS m^{-1}. The composition of irrigation water during the cotton growing season (June to October) in terms of cationic concentration revealed small temporal variation. The dominant cations were Mg^{2+} and Ca^{2+} with little differences in their concentrations. The levels of SAR and SAR_{adj} in irrigation water ranged from 2.58 to 3.93. The irrigation water was low alkaline in reaction, and is moderately saline. The salt concentrations in high-saline groundwater ranged from 7557 to 12862 mg L^{-1}. The corresponding EC values were in the range of 11.78 to 20.69 dS m^{-1}.

The study area consists of a vast stretch of alluvial deposits, mainly saline sierozems. According to the particle-size distribution of the USDA classification system, these soils are silt loam in texture. Volumetric Field Capacity in the upper 0.15 m depth was 33.3%; for the 0.15-0.30 m depth, its value was 36.2%. At the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were at 45.1% and 46.3%, respectively. Infiltration rate of the soil was estimated to be 24.2 mm h^{-1}. Soil bulk density had an increasing trend from top to deeper horizons and varied in the range of 1.41 to 1.52 Mg m^{-3}.
The soil samples collected before the start of the cotton season in 2007 at different soil depths extending down to 0.90 m shows salinity levels (TDS) in the range of 9343 mg L^{-1} to 14291 mg L^{-1}. At the end of the crop season in 2007, the soil salinity did not change much as compared with spring 2007. This could be explained by unusually heavy precipitations that occurred at the site in spring 2007.

The study area has a network of surface drains, which are poorly maintained and therefore do not control the groundwater table effectively. As a result, groundwater table in the area is shallow causing wide spread soil salinization and a reduction in crop yields. The groundwater table varies from 80 to 200 cm during the cotton season. The salt concentration in groundwater ranged from 8048 to 12021 mg L^{-1} (18.00-19.08 dS m^{-1}) during 2007. Groundwater had an overall Cl^-:SO_4^{2-} of 0.87. The ratio of Mg^{2+}:Ca^{2+} in groundwater (1.95) revealed the dominance of Mg^{2+} over Ca^{2+}. The SAR values for the groundwater ranged from 10 to 12, which suggests that capillary rise from groundwater can cause serious sodicity problem in the soil profile.

3.2 EXPERIMENTAL PROCEDURE

The field experiment was conducted at the Akaltyn experimental site, Syrdarya province, Uzbekistan. A 2 ha farmer field was selected for conducing this experiment. The field was plowed with a tractor to a depth of 0.3 m. Chiseling was done on 14 April at 0.10-0.12 m depth before sowing to break stubble (Stubble Breaker CHKU-4). Cotton variety Bayaut-2 was sown with a seeder (Romanian Seeder SPC-3.6) on 20 April using a seeding rate of 25 kg ha^{-1}. Just before cotton sowing, harrowing (Harrow ZBS-1 on Tractor MTZ 80) was undertaken. The cultural practices for cotton cultivation in the control and conjunctive water used plots were the same and in accordance with the prevalent system of agriculture used in the region (Umbetaev and Batkaev, 2000). Nitrogen in the form of ammonium nitrate (NH_4NO_3) was applied in two splits at the rate of 34 and 68 kg ha^{-1}. All the agronomic and fertilizer management practices were kept the same in all plots. In late September, the crop was harvested from each plot to determine the cotton yield on a plot basis, which was subsequently calculated and reported on per hectare basis.

3.3 TREATMENTS

This study consisted of two major factors based on which the experimental treatments were designed using cotton as the test crop. One factor consisted of water quality with moderately saline (~2600±200

mg L^{-1}) and saline (~5300±400 mg L^{-1}) waters used in different combinations for irrigation. The other factor was based on mulching of the furrows to reduce evaporation losses from the field and to improve water productivity.

The experimental layout was a randomized complete block design. The total number of experimental plots was 18 (2 mulching levels × 3 water quality levels × 3 replications). Each plot size was 360 m^2 with gross experimental area of approximately 0.8 ha including the water channels and non-experimental belts. There were six treatment combinations as given below:

1 Irrigation throughout the cropping season with moderately-saline water (~2600±200 mg L^{-1}): Later referred to as MSW

2 Irrigation throughout the cropping season with highly-saline water pumped from a vertical well (~5300±400 mg L^{-1}): Later referred to as SW

3 Irrigation with a mix of moderately-saline and high saline water in the respective ratio of 1:1: Later referred to as $MSW{:}SW_{1:1}$

4 Irrigation same as in the treatment 1 + mulching of furrows: Later referred to as MSW+M

5 Irrigation same as in the treatment 2 + mulching of furrows: Later referred to as SW+M

6 Irrigation same as in the treatment 3 + mulching of furrows: Later referred to as $MSW{:}SW_{1:1}$+M

3.4 FIELD DATA COLLECTION

For water productivity analysis, quantification of agro-hydrological parameters that include transpiration, evapotranspiration, and percolation is required. Measurements of these parameters in the field are difficult, expensive and complicated. The soil-water-flow models such as SWAP, once calibrated using measured data from field experiments, can be used to obtain reliable estimates of these parameters under field conditions. However, the accuracy of these predictive models depends very much on the input parameters used for the calibration. For this study, comprehensive field data on hydrological and agronomic aspects needed for the SWAP model was collected from farmer fields located in the Akaltyn experimental farm.

Daily values of maximum and minimum temperatures, wind speed, humidity etc was collected from a nearest meteorological station. Figure 2.3.4.4 shows the variation in daily maximum and minimum temperatures and precipitation during the cotton growing season of 2007. The total rainfall during the growing period was 52 mm and almost all was received during the months of April and May.

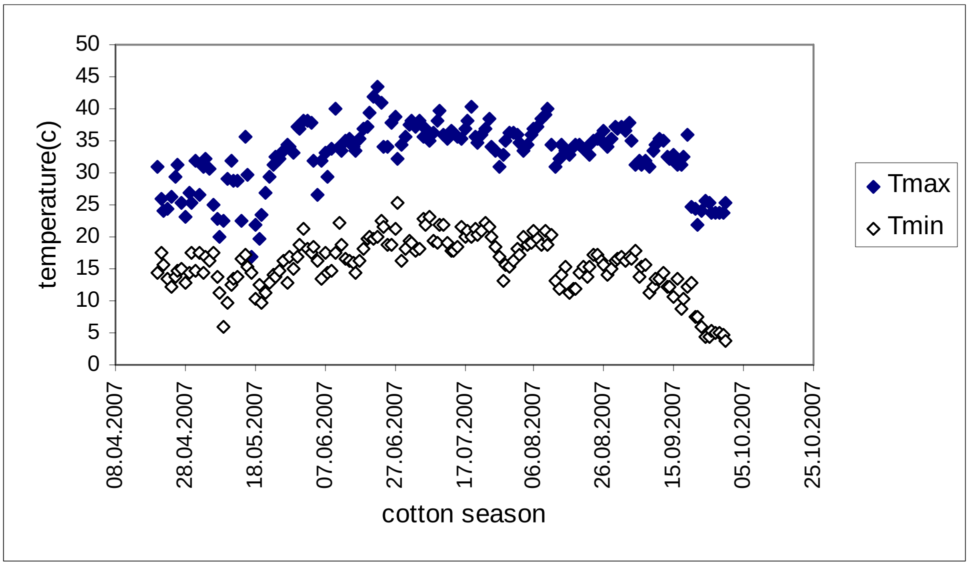
Soil and water sampling and analysis

After laying out the experiment plots, composite soil samples were collected from each plot at the following depths: 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m. The sampling was undertaken before the implementation of the treatments (initial soil condition) and after harvest of cotton in each cropping year. The collected samples were air-dried and processed for the following parameters: pH by colorimetric method; electrical conductivity (EC) by electrical conductivity meter (expressed in terms of decisiemens per meter, dS m^{-1}); soluble cations such as Ca^{2+} and Mg^{2+} by titration with ethylenediaminetetracetate, and Na^+ and potassium (K^+) by flame photometry; and soluble anions such as carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) by titration with sulfuric acid, chloride (Cl^-) by titration with silver nitrate, and sulfate (SO_4^{2-}) by precipitation as barium sulfate (U.S. Salinity Laboratory Staff, 1954). Sodium adsorption ratio (SAR) was calculated using the equation given below from the concentrations (C) of soluble cations Ca^{2+}, Mg^{2+}, and Na^+, expressed as $mmol_c\ L^{-1}$.

$$SAR = C_{Na} / [(C_{Ca} + C_{Mg}) / 2]^{1/2}$$

The soil physical attributes consisted of particle-size analysis, field capacity, infiltration rate, saturated hydraulic conductivity, bulk density, and moisture content. Particle-size analysis was performed using one

randomly selected sample from 0-0.15, 0.15-0.30, 0.30-0.60, and 0.60-0.90 m depths in each treatment by sedimentation method using sodium hexametaphosphate as a dispersing agent. Field capacity was determined from one randomly selected location (2 m × 2 m) in each treatment by flooding, covering of flooded area with polyethylene sheet, and determining soil moisture content for between 3-5 days following flooding until there was minimal change in moisture content over all the soil depth intervals. Infiltration rate and saturated hydraulic conductivity were determined using standard double ring metallic infiltrometers with an outer ring diameter of 0.4 m and inner ring diameter of 0.3 m. Both rings were inserted into the soil to a depth of between 0.1-0.15 m. Soil bulk density was determined on undistributed soil samples collected from each soil depth using the core method. Soil moisture content was determined by the gravimetric method.



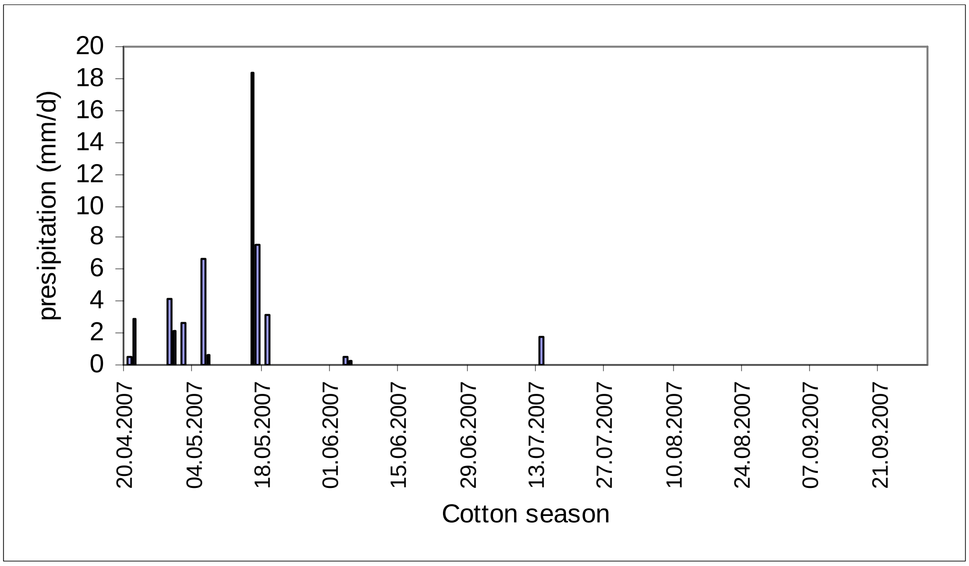


Figure 2.3.4.4. Daily variations in maximum and minimum temperatures and precipitation during the growing season 2007.

Irrigation and groundwater samples were collected on a monthly basis. In addition, groundwater level was monitored each month. Water samples were analyzed for the following chemical attributes: pH, EC, soluble cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (CO_3^{2-}, HCO_3^-, Cl^-, and SO_4^{2-}).

Soil samples from depths of 0-30, 30-60, and 60-90 cm were collected for textural analysis. Soils of this area are mainly saline sierozems. According to the classification system of the USDA for particle-size distribution, the soil is silt loam in texture throughout the profile up to the depth of 0.90 m (Table 2.3.4.2). Field capacity in the upper 0.15 m depth was 23.64%; for the 0.15-0.30 m depth, its value was 23.80%. At

the 0.30-0.60 m and 0.60-0.90 m depths, the values of field capacity were estimated to be 31.54% and 34.07%, respectively. Infiltration rate was 24.2 mm h^{-1}. Soil bulk density varied from 1.41 to 1.52 Mg m^{-3}.

Table 2.3.4.2. Physical properties of the soils at the experimental field site.

Soil properties	**Unit**	**Soil depth (m)**			
		0.0-0.15	**0.15-0.30**	**0.30-0.60**	**0.60-0.90**
Sand particles (0.05-2.0 mm)	%	24.89	22.48	26.15	34.18
Silt particles (0.002-0.05 mm)	%	61.68	64.84	64.29	58.89
Clay particles (<0.002 mm)	%	13.43	12.68	9.56	6.93
Soil texture (method USDA)	—	silt loam	silt loam	silt loam	silt loam
Field capacity	%	23.64	23.80	31.54	34.07
Infiltration rate	mm h^{-1}	24.42	—	—	—
Soil bulk Density	Mg m^{-3}	1.18	1.31	1.48	1.38

Physical and chemical analysis of soil samples were conducted collected from all 6 treatments. These measurements were carried out before sowing of cotton crop, before and after each irrigation application and after the harvest of cotton. The pre-experiment soil salinity levels in terms of TDS at different soil depths extending to a depth of 0.90 m were in the range of 9746 to 13862 mg L^{-1}. Among the anions, SO_4^{2-} was dominant having concentration of 115.71 $cmol_c$ L^{-1} at the upper 0.15 m depth. The concentration of SO_4^{2-} ranged from 115.71 to 179.46 $mmol_c$ L^{-1}at different soils depths. Chloride (Cl^-) concentration was much less compared to that of SO_4^{2-} and ranged from 17.01 to 18.22 $mmol_c$ L^{-1}at different soils depths. The HCO_3^{2-} concentrations ranged from 3.47 to 5.05 $mmol_c$ L^{-1}.

Among the cations, Ca^{2+} was dominant at the soil surface followed by Mg^{2+}, Na^+, and K^+ (Table 2.3.3.2). The concentration of Ca^{2+} in the upper 0.15 m depth was 88.30 $mmol_c$ L^{-1} and ranged from 88.30 to 139.03 $mmol_c$ L^{-1}. The concentration of Mg^{2+} was less than Ca^{2+} concentration at all soil depths. The Mg^{2+}concentration ranged from 28.81 to 35.59 $mmol_c$ L^{-1}. The Na^+ concentration ranged from 23.65 to 25.89 $mmol_c$ L^{-1} at different soils depths. The K^+ concentration ranged from 0.57 to 1.14 $mmol_c$ L^{-1}. The SAR levels were in the range of 2.63 to 3.13 indicating that the soil was saline in its characteristics.

4. MODEL CALIBRATION

4.1 INPUT DATA FOR MODEL CALIBRATION

The model calibration was performed for the cotton growing season of 2007, which extended from April to October. The upper boundary condition of the soil profile was described on a daily basis by potential evapotranspiration rate (PET), actual rainfall and irrigation. Daily climatic data (rainfall, sunshine hours, and wind speed, maximum and minimum temperatures) were obtained from the meteorological station situated at the study site. These data were used to calculate reference evapotranspiration (RET) by Penman-Monteith (PM) method. Potential evapotranspiration (PET) was obtained by multiplying reference evapotranspiration (RET) by the crop factor (Kc). The depths of all irrigations were used as input for model. Surface runoff from the obtuse furrows was considered equal to zero. During the calibration period, only two irrigations were applied to cotton crop. First irrigation of 86 mm was applied on 6 July 2007, which was followed by 89 mm of the second irrigation on 7 August 2007. The total irrigation was recorded as 175 mm. The bottom boundary condition of the soil profile was described by daily ground water levels measured with the help of piezometers. The groundwater level was in the range of 0.84-2.09 m during the cotton growing seasons.

Agronomic parameters including sowing and harvesting dates, fertilizer application rates, crop development stages and crop height estimates were recorded during the field surveys. Data on rooting depth, Leaf Areas Index (LAI) and soil cover values as a function of crop development stage were obtained from local available literature. LAI, crop height and rooting depth are used by SWAP to simulate crop growth. Crop height needs to be specified for the calculation of the crops' aerodynamic resistance. LAI is also necessary for the calculation of potential transpiration from crop reference evapotranspiration.

The root depth determines from which depth water is withdrawn by the plant. The maximum rooting depth for cotton was taken as 100 cm (Bespalov, 1992). Root length density distribution was considered to decline linearly with depth. Root water uptake is described semi-empirically by a sink term, which is a function of the maximum root water uptake and the soil water pressure head (Feddes *et al.* 1978). The maximum root water uptake at a particular depth is proportional to the root length, which is prescribed as function of the relative rooting depth (Feddes *et al.* 1988; Prasad, 1988). The Boesten model (Boesten and Stroosnijder, 1986) was used for the reduction of the potential soil evaporation rate into actual soil evaporation rate. The values of limiting pressure heads for regulating root water uptake for cotton crop were taken from Sarwar *et al.* (2001) as no local data was available. The *h1* to *h4* values refer to the sink term theory of Feddes *et al.* (1978). The different input parameters used in the SWAP model are given in Table 2.3.4.3.

Table 2.3.4.3. Input parameters used in the SWAP model.

Input parameters	**Cotton**
Boesten parameter, β ($cm^{1/2}$)	0.63
Kc value for full crop cover	1.00
Maximum rooting depth (cm)	100
Limiting pressure heads (cm)	*h1=-0.1; h2=-30.0; h3=-300; h3'= -1500; h4=-16000*

Source: Sarwar, 2000

On the basis of a change in physical properties, soil profile at 400 cm was divided into three layers. The first layer is from 0-30 cm, second from 30-60 cm and third beyond 60-400 cm. The soil domain for fields was further divided into a total of 25 numerical compartments. As most of the soil evaporation under field conditions occurs in the top few centimeters of the soil, nodal distance for the first 25 cm of the profile was taken as 2 cm. The soil hydraulic properties of all three layers were described by the six Van-Genuchten-Mualem (VGM) parameters (Van-Genuchten 1980; Mualem 1976). These parameters are saturated soil moisture content (Θs), residual soil moisture content (Θr), empirical shape parameters (α, n, λ) and saturated hydraulic conductivity (Ks). As no measured data on VGM parameters was available for this area, soil hydraulic parameters described by the Starring Series (Wösten *et al.*, 1998) corresponding to three layers of each field were initial chosen. These parameters were adjusted to match the field measured soil moisture contents with the model simulated values at different depths. Finally selected calibrated VGM parameters are given in Table 2.3.4.4.

Initial soil moisture conditions could not be determined in the field therefore model was run for one year in advance using same parameters to achieve zero annual change in the water storage. Last day moisture contents of this simulation were used as initial condition for the model.

Salinity parameters

The salinity parameters in the classical convection-dispersion equation that describe salt transport are the dispersivity, D_{dis} (cm)*)*, and the diffusion, D_{dif} ($cm^2\ d^{-1}$). The model is more sensitive for dispersion than to diffusion. The value of D_{dis} typically ranges from 0.5 cm, or less, for laboratory scale experiments involving disturbed soils, to about 10 cm or more for field scale experiments (Nielsen *et al.*, 1986). The values for D_{dis} and D_{dif} that gave best results of simulated profiles $EC_e(z)$, were 0.48 cm and 15 $cm^2\ d^{-1}$ respectively. For salinity stress the response function of Maas and Hoffman (1977) was used

Table2.3.4. 4: Calibrated Van Genuchten-Mualem (VGM) parameters used in the SWAP model

Parameters	**Field**		
	Layer 1	**Layer 2**	**Layer 3**
Depth of Layer (cm)	0-30	30-60	>60
Soil texture	Silty loam	Silty loam	Silty loam
Residual moisture content θ_{res}	0.01	0.01	0.01
Sat. water content θ_{sat}	0.30	0.34	0.38
Sat. hyd. cond. K_{sat} (cm d^{-1})	10.06	30	35
Shape parameter a (cm)	0.016	0.018	0.018
Shape parameter λ (-)	1.42	1.42	1.42
Shape parameter n (-)	1.37	1.23	1.20

4.2 RESULTS OF MODEL CALIBRATION

Soil moisture contents

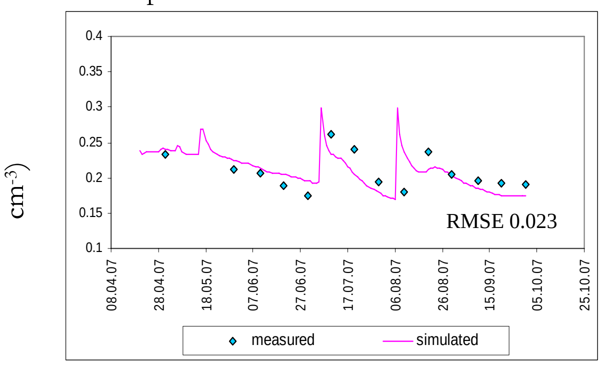
The measured soil moisture content values were compared with the simulated results for model calibration. Soil moisture content was determined 8 times during the vegetation season using the gravimetric method. The Root Mean Square Error (RMSE) was calculated to quantify agreement between simulated and measured values. The RMSE represents how much the simulation overestimated or underestimated the actual field measurements.

Figure 2.3.4.5 shows a comparison of simulated and measured soil moisture contents at 30, 60 and 90 cm depths for all 6 treatments. It is pertinent to note that irrigation has a significant effect on the moisture contents of the soil profile. The effect of irrigation was more pronounced in the top 30 cm layer and gradually reduced with the depth. The graphs show that the soil moisture trends simulated by the model for field conditions are in good agreement with the measured data. RMSE values for all depths and for all treatments are well within acceptable limits of 5% (Table 2.3.4.5). The close agreement between measured and simulated values of moisture content and small RMSE values reveal that estimated soil and crop parameters are good enough to simulate soil water flow with reasonable accuracy.

Figure 2.3.4.5. Measured and simulated soil moisture for 6 treatments.

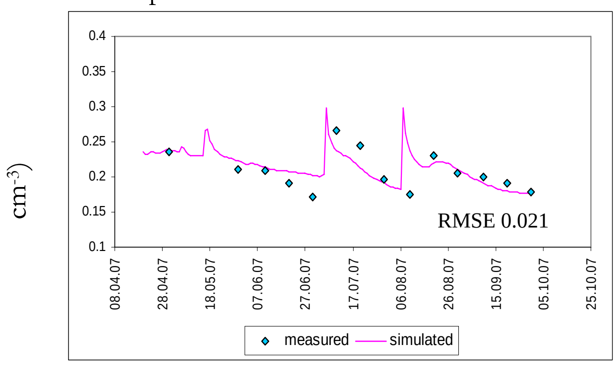
Treatment 1

Depth 30 cm



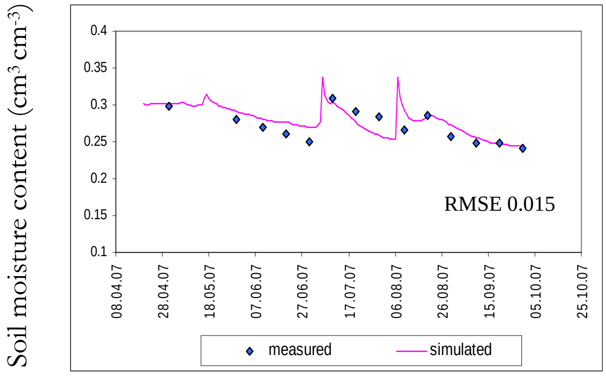
Treatment 2

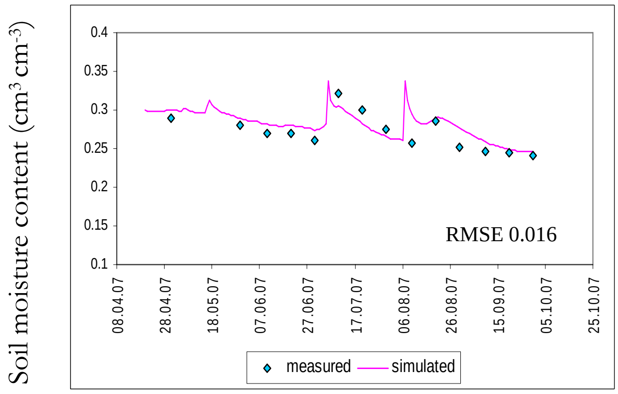
Depth 30 cm



Depth 60 cm

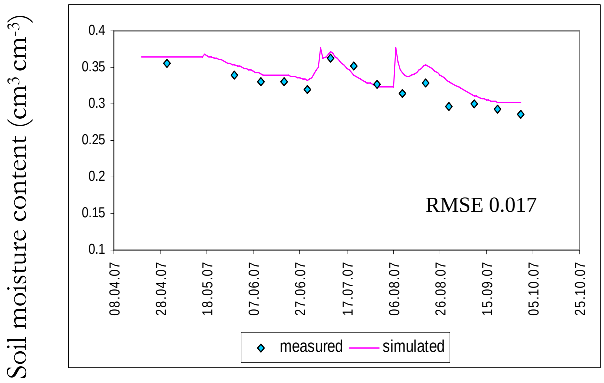
Depth 60 cm

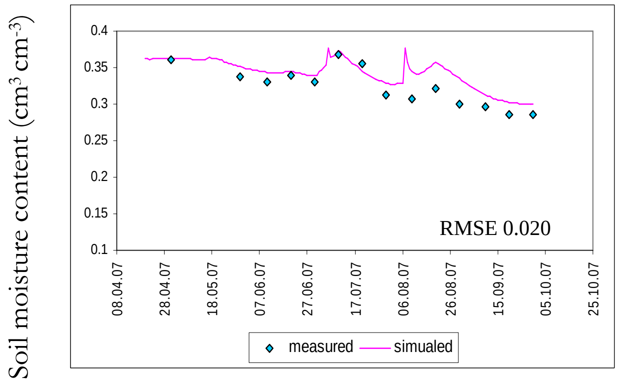




Depth 90 cm

Depth 90 cm



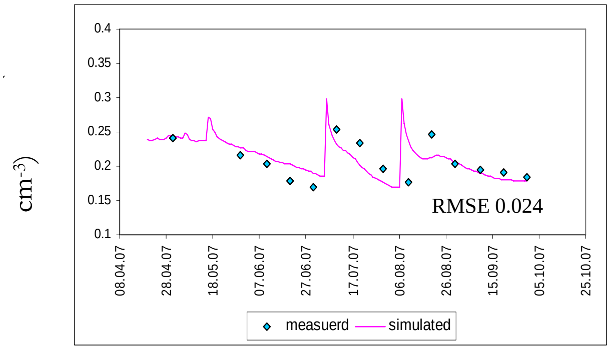


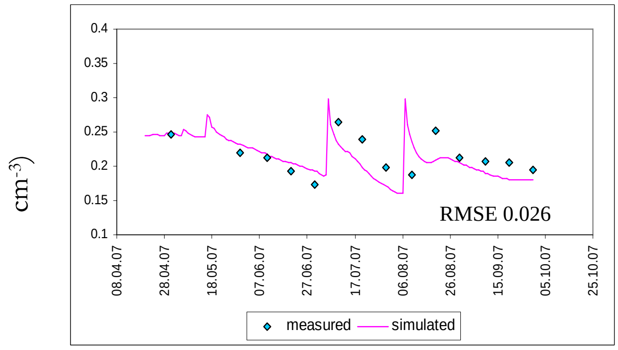
Treatment 3

Treatment 4

Depth 30 cm

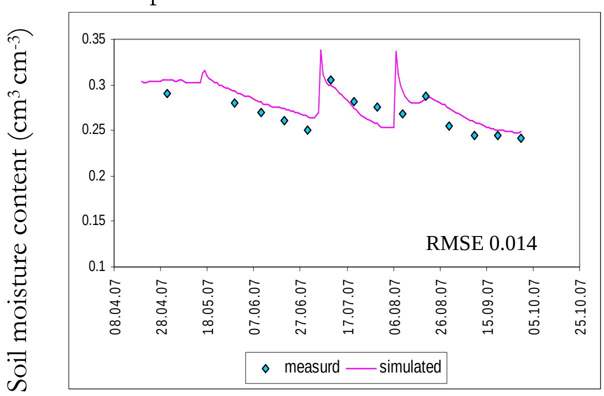
Depth 30 cm

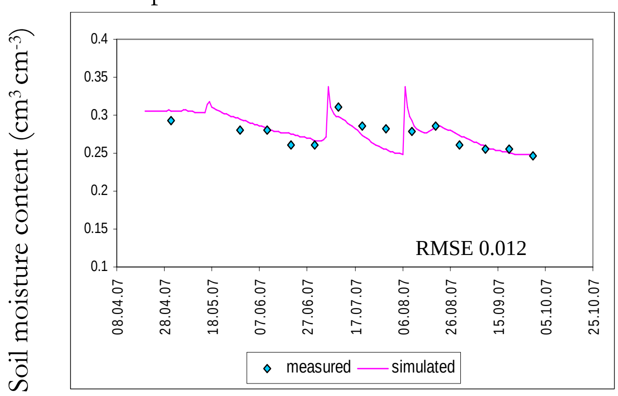




Depth 60 cm

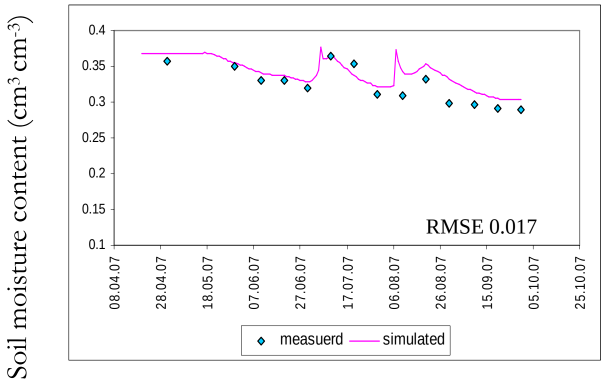
Depth 60 cm

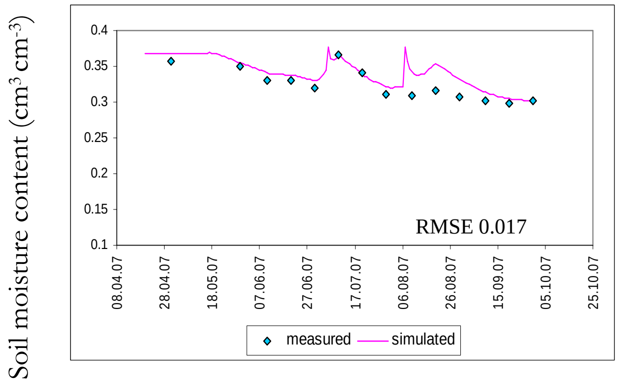




Depth 90 cm

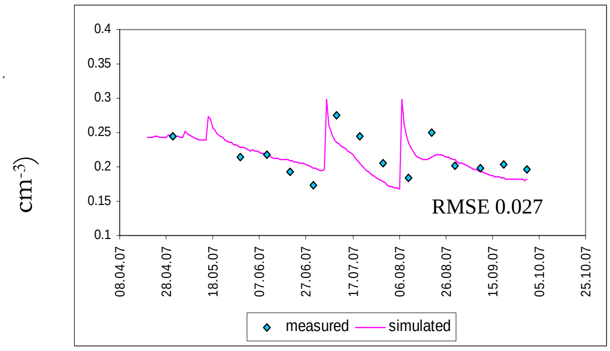
Depth 90 cm





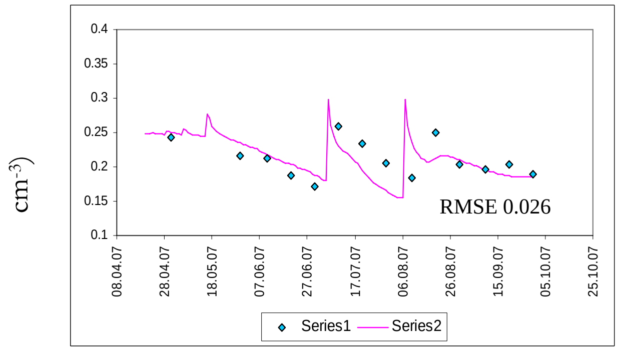
Treatment 5

Depth 30 cm

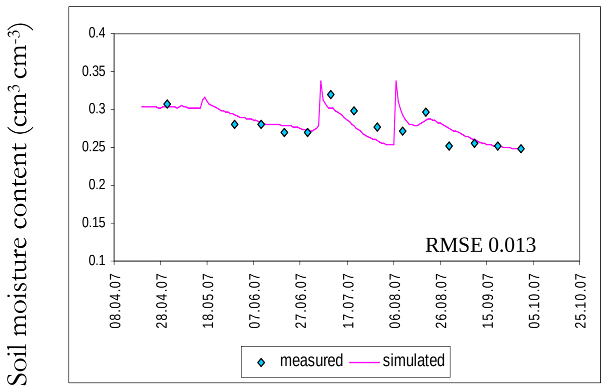


Treatment 6

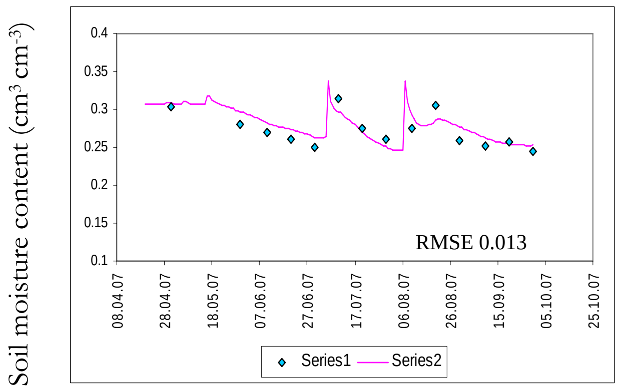
Depth 30 cm



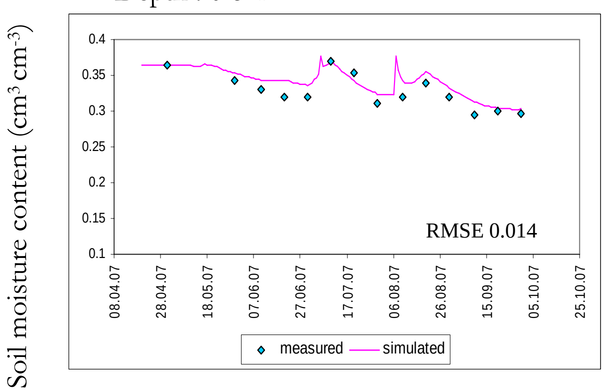
Depth 60 cm



Depth 60 cm



Depth 90 cm



Depth 90 cm

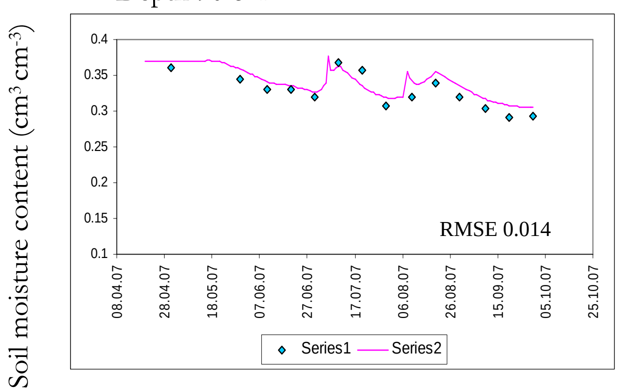


Table 2.3.4.5. Root Mean Square Errors (RMSE) for soil water contents for all depths and treatments.

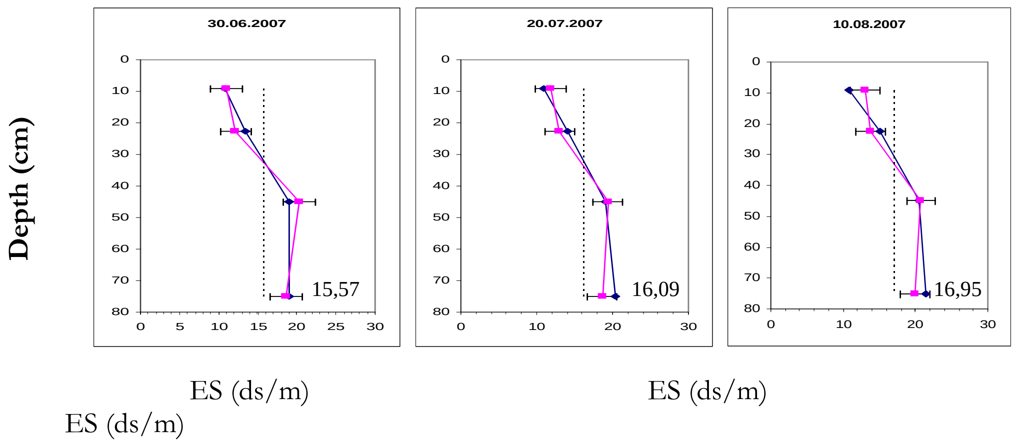
Treatments	**Soil depths (cm)**			**Average all depths**
	30	**60**	**90**	
Treatment 1	0.023	0.015	0.017	**0.018**
Treatment 2	0.021	0.016	0.020	**0.019**
Treatment 3	0.024	0.014	0.017	**0.018**
Treatment 4	0.026	0.012	0.017	**0.018**
Treatment 5	0.027	0.013	0.014	**0.018**
Treatment 6	0.026	0.013	0.014	**0.018**
Average 1-6	**0.024**	**0.013**	**0.017**	**0.018**

Soil salinity

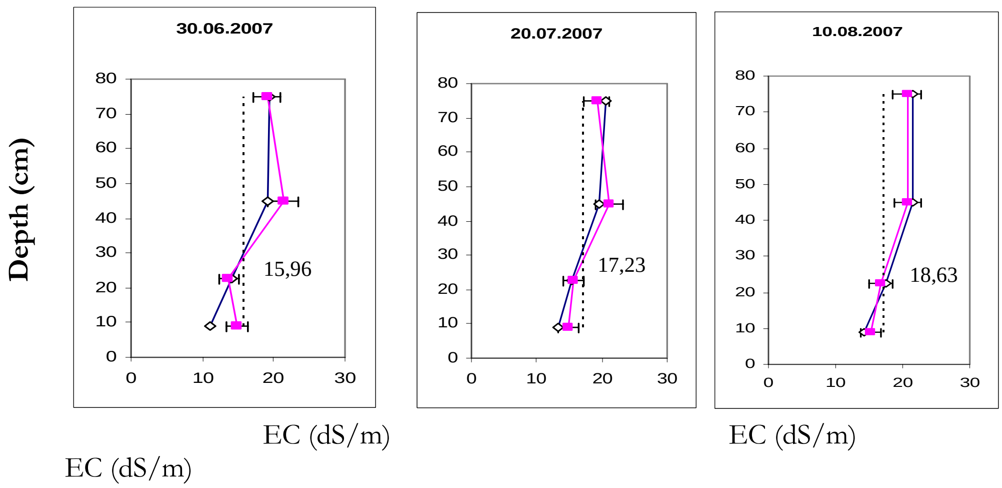
The measured EC_e values from the experimental field were available for three days during the cotton growing season. Therefore a comparison could only be accomplished for these three days. Figure 2.3.4.6 presents a comparison of measured and simulated salinity profiles for all treatments. The simulated salinity values at all depths are within the standard deviation of the measured values. The close proximity between measured and simulated values demonstrates that SWAP model gives an acceptable representation of salinity at the field scale.

Figure 2.3.4.6. Measured and simulated soil salinity profiles for all treatments.

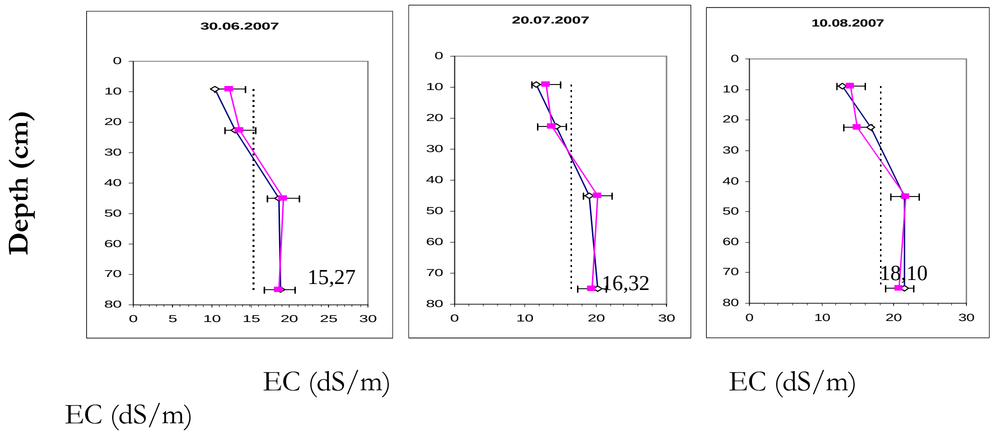
Treatment 1



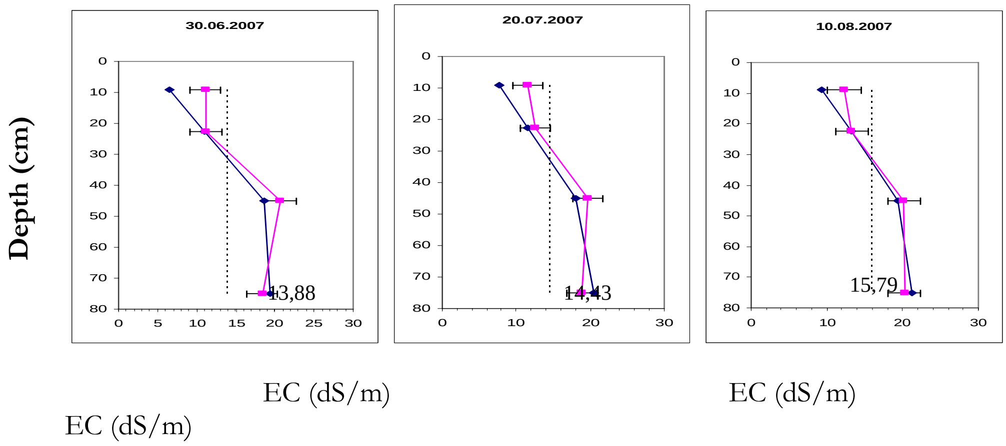
Treatment 2



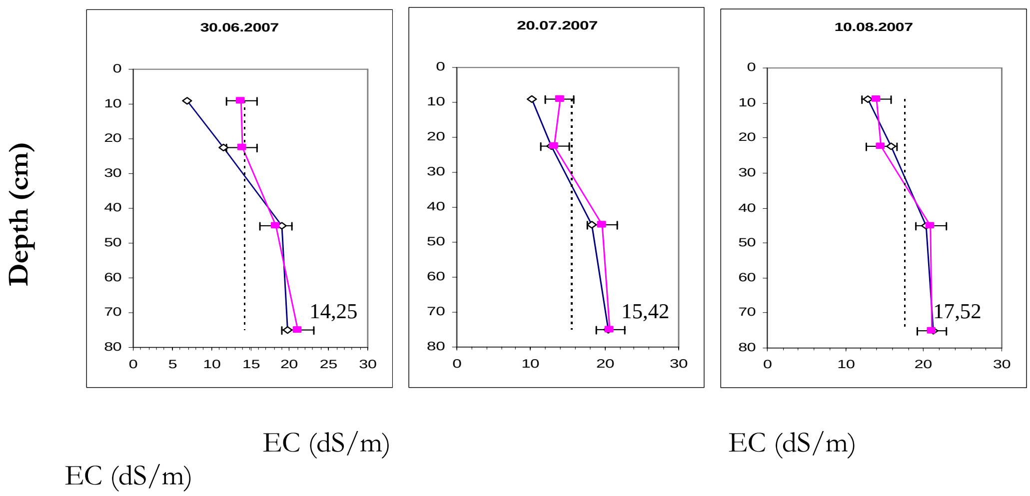
Treatment 3



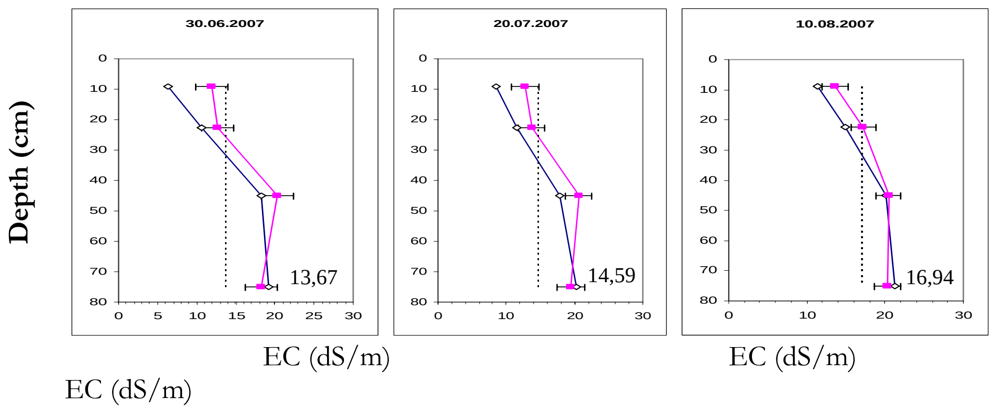
Treatment 4



Treatment 5



Treatment 6



4.3 SEASONAL WATER BALANCE

The water balance parameters simulated by SWAP model include actual evapotranspiration, actual transpiration, soil evaporation, changes in soil moisture and soil water fluxes within and at the bottom of the soil profile. Positive value of Q_{bot} represents addition of water to the soil profile from groundwater. Simulated water balance terms for all treatments during the cotton growing season (April to October, 2007) are given in Table 2.3.4.6. Treatments 1-3 represent plots without any mulching cover whereas treatments 4-6 represent mulching cover.

Table 2.3.4.6: Simulated water balance components for cotton grown in 2007.

Water balance components	**Non-mulching**			**Mulching**		
	T1-MSW	T2-SW	T3-M/SW	T1-MSW	T2-SW	T3-M/SW
Irrigation (mm)*	175	175	175	175	175	175
Rainfall (mm)*	51.4	51.4	51.4	51.4	51.4	51.4
ET_a (mm)	420.7	374.4	393	362	340.4	354
T_a (mm)	320.6	292.3	310.9	349.3	327.7	341.3
E_a (mm)	82.1	82.1	82.1	12.7	12.7	12.7
Tp (mm)	532.4	532.4	532.4	532.4	532.4	532.4
T_a/T_p	0.60	0.55	0.58	0.66	0.62	0.64
$Y_{measured}$ (t ha^{-1})*	2.52	2.12	2.40	2.83	2.24	2.60
$Ys_{imulated}$ (t ha^{-1})	2.40	2.20	2.30	2.60	2.50	2.60
Q_{bot} (mm)	82.2	60.9	81	45.9	31.5	50
Water storage, ΔW, mm	-96.9	-97.7	-95.7	-95.7	-93.2	-90.5
WP_T (kg m^{-3})	0.75	0.75	0.74	0.74	0.76	0.76
WP_{ET} (kg m^{-3})	0.57	0.59	0.58	0.72	0.73	0.73

** Measured values*

The data presented in Table 2.3.4.5 shows that increasing profile salinity affected the actual evapotranspiration of the crop. The cotton yield under T1-MSW treatment was 19 percent higher than T2-SW treatment and this was mainly attributed to increased salinity in the soil profile which restricted the plant roots ability to extract water for transpiration. As a result, downward flux increased causing the groundwater table to rise. After each irrigation application, groundwater table rises sharply resulting in more addition of salt in the root zone. This is evident from the high negative values of change in storage (ΔW). This would suggest that the amount of water applied for at each irrigation application were in excess of what should have been applied to keep the groundwater table below the root zone.

Increase in profile salinity was caused by the application of saline irrigation water but was exacerbated by the contribution of highly saline groundwater through sub-irrigation. Table 2.3.4.6 shows that the total inflow (irrigation + rainfall) to the field was 226.4 as compared to actual evapotranspiration of 420.7 for T!-MSW and 374.4 for T2-SW. The difference in these two amounts was met by the contribution of groundwater, which is evident from the positive value of Q_{bot}.

Figure 2.3.4.6 presents that average profile salinity over the growing season under T1-MSW was around 15.5 dS m^{-1} as compared to about 17.5 dS m^{-1} for T2-SW. Mass (1977) advocates that cotton yields can be reduced to 50% at salinity levels exceeding18 dS m^{-1}. Considering soil fertility conditions of the study area, the potential attainable yields are estimated at 4.0 t ha^{-1}. Therefore achieved cotton yields of 2.12 t ha^{-1} for an average profile salinity of around 18 dS m^{-1} are justified. To simulate the effects of mulching, model parameters were adjusted to reduce the bare soil evaporation to minimum. As the mulching provided in the field was not very comprehensive, some soil evaporation can still be expected. Model adjustments reduced the soil evaporation of mulching plots by 85% as compared to non-mulching plots (Table 2.3.4.6). The results presented in Table 2.3.4.6 indicate that on average cotton yields under mulching were 9 percent higher for all treatments, ranging from 12.5 percent for T1-MSW to 5.5 percent for T2-SW. This yield increase can be explained by the considerable reduction in soil evaporation which restricted the upward movement of saline groundwater and addition of salts in the soil profile. Figure 2.3.4.6 shows that under treatment T5 (with-mulching), soil salinity in the upper 60 cm of the soil profile was lower than T2 (without-mulching). This explains higher transpiration and crop yield under T5 as compared to T2. Lower

positive Q_{bot} values for mulching plots (treatments 4-6) also confirm less groundwater contribution and salts in the root zone. This shows that mulching can be a useful intervention in managing salinity and crop yields under saline environment.

Water productivity

To evaluate the performance of agricultural production systems, the concept of water productivity is used. The term water productivity is defined as "crop production per unit of water used" (Molden, 1997; Molden et al., 2001). The water productivity is usually expressed in kg m^{-3}. The actual transpiration is a direct measure of the physiological performance of a certain crop. Therefore, water productivity is usually expressed in terms of actual crop yield per unit amount of actual transpiration ($WP_T=Y_a/T_a$). The inevitable loss of water due to soil evaporation negatively affects the water productivity from WP_T to WP_{ET}, which is expressed in terms of actual yield per unit of actual evapotranspiration ($WP_{ET} = Y_a/ET_a$). WP_{ET} represents the total amount of water used in crop production. Relatively lower WP_{ET} values would indicate the need to reduce soil evaporation by agronomic measures such soil mulching or conservation tillage.

WP_T and WP_{ET} values for all treatments are given in Table 2..3.4.6. These terms were calculated using the simulated water balance components T_a, ET_a and simulated yields. WP_T values for all treatments are comparable because there was very little variation in actual transpiration values between different treatments. However there is a clear difference between W_{ET} values for mulching and non-mulching plots. Average WP_{ET} values for mulching plots are 23.7 percent higher than non-mulching plots. This clearly shows the effect of mulching on actual water use by crop. On average, mulching plots used 12.5 percent less water and produced 11.5 percent higher yields as compared to non-mulching plots. The significant increase in yields was attributed to increased crop transpiration as a result of reduced salinity in the soil profile.

Analysis of the data presented in Table 2.3.4.6 would suggest that farmers in this area should better plan their irrigation amounts very carefully to keep water table deep enough to avoid unnecessary additions of salts in the root zone. Furthermore, mulching could yield beneficial results if properly practiced. This necessitates precise calculations of crop water demands and irrigation schedules to reduce unnecessary percolation loses, stop groundwater table rise and improve crop production.

5. EVALUATING ALTERNATIVE WATER MANAGEMENT SCENARIOS

5.1 ADJUSTING IRRIGATION SCHEDULES

As discussed above the amount of water applied per irrigation by farmers were found to be responsible for raising groundwater table to undesirable levels, which causes addition of salts to the root zone and affected the crop transpiration and consequently crop yields. The calibrated model was used to simulate the effect of reduced irrigation amounts on groundwater table depth and crop yields. For these simulations, total amount of applied irrigation water was kept constant (175 mm). However, this amount was applied in four irrigation events instead of two as was being practiced by farmers. The simulations were performed for moderately saline water (MSW) with an EC of 3.05 dS m^{-1}. To evaluate the effect of water quality on soil salinity and crop yields, additional simulations were also performed with fresh water (EC = 0.5 dS m^{-1}). The results of these simulations are shown in Table 2.3.4.7.

Table 2.3.4.7. Results of model simulations to evaluate the effect of adjusted irrigation schedule.

Scenarios	T_a/T_p	$Y_{simulated}$ (t ha^{-1})	% increase in yield as per scenario 1	Average salinity over 1 m profile
2IRR-MSW	0.60	2.40	-	16.20
4IRR-MSW	0.62	2.48	3.5	15.80
2IRR-FW	0.64	2.50	4.2	15.80
4IRR-FW	0.66	2.64	10	14.70

2IRR-MSW represents 2 irrigations with moderately saline water. 4IRR-MSW represents 4 irrigations with moderately saline water. 2IRR-FW represents 2 irrigations with fresh water. 4IRR-FW represents 4 irrigations with fresh water.

Table 2.3.4.7 indicates that by applying 175 mm of irrigation water in four equal irrigation amounts will increase the yield by 3.5 percent. Improving irrigation water quality with two irrigation schedule will not have any significant effect on crop yield because the rising saline water table will offset any benefits of good quality irrigation water. The combined effect of improved irrigation schedule and irrigation water quality will be large as it will increase cotton yields up to 10 percent. These results show that under the prevailing conditions in the study area, slight adjustments in irrigation amounts can assist farmers get gaining additional benefits by changing their current management practices. Provision of good quality irrigation water can have a significant impact on the cotton yields even if the drainage conditions are not improved in the short term.

5.2 ADJUSTING GROUNDWATER TABLE DEPTH

Realizing the fact that depth to groundwater table is more crucial for controlling salinity in the soil profile than irrigation water quality, model simulations were performed to determine the optimal groundwater table depth for the area to control soil salinity and improve crop yields. The model simulations were performed to evaluate the effect of five different groundwater table depths (i.e. 100 cm, 150 cm, 200 cm, 250 cm 300 cm) and five different irrigation water qualities (0.5 dS m^{-1}, 1.5 dS m^{-1}, 3.0 dS m^{-1}, 6.0 dS m^{-1}, 9.0 dS m^{-1}) on root zone salinity and crop yields. The results of these simulations are presented in Table 2.3.4.8.

Table 2.3.4.8. Simulated water and salt balance components for different groundwater table and irrigation water quality combinations.

Scenarios	T_a (mm)	T_p (mm)	T_a/T_p	Yield (t ha^{-1})	Bottom Flux (mm)	Avg. salinity over 1m depth (dS m^{-1})
100cmEC0.5	302.9	532.4	0.57	2.28	171.5	15.20
150cmEC0.5	358.9	532.4	0.67	2.70	220.9	13.55
200cmEC0.5	372.9	532.4	0.70	2.80	195	10.38
250cmEC0.5	351.8	532.4	0.66	2.64	143	8.62
300cmEC0.5	332	532.4	0.62	2.49	96.9	7.63
100cmEC1.5	298.9	532.4	0.56	2.25	167.6	15.43
150cmEC1.5	355.8	532.4	0.67	2.67	218.1	13.80
200cmEC1.5	372.2	532.4	0.70	2.80	194.6	10.58
250cmEC1.5	351.5	532.4	0.66	2.64	142.9	8.78
300cmEC1.5	331.9	532.4	0.62	2.49	96.9	7.77
100cmEC3.0	292.7	532.4	0.55	2.20	161.4	15.76
150cmEC3.0	350.8	532.4	0.66	2.64	213.4	14.18
200cmEC3.0	371	532.4	0.70	2.79	193.9	10.89
250cmEC3.0	351.1	532.4	0.66	2.64	142.7	9.01
300cmEC3.0	331.7	532.4	0.62	2.49	96.8	7.97
100cmEC6.0	279.6	532.4	0.53	2.10	148.4	15.48
150cmEC6.0	339.8	532.4	0.64	2.55	203.1	14.94
200cmEC6.0	367.9	532.4	0.69	2.76	192	11.53
250cmEC6.0	350.1	532.4	0.66	2.63	142.1	9.49
300cmEC6.0	331.2	532.4	0.62	2.49	96.6	8.40
100cmEC9.0	266.1	532.4	0.50	2.00	135	17.05
150cmEC9.0	326.6	532.4	0.61	2.45	190.6	15.66
200cmEC9.0	363.8	532.4	0.68	2.73	189.4	12.24
250cmEC9.0	348.7	532.4	0.66	2.62	141.3	10.00
300cmEC9.0	330.6	532.4	0.62	2.48	96.3	8.86

The data presented in Table 2.3.4.8 indicates that for all scenarios, maximum yields are obtained at groundwater table depth of 200 cm. Figure 2.3.4.7 illustrates that if drainage could maintain the

groundwater table at an average depth of 200 cm or more, a considerable yield benefit would result. This depth would be an appropriate agricultural drainage criterion for the study area. At this depth, average root zone salinity reduced as a result of less contribution from groundwater resulting in an increase in crop transpiration. Below this groundwater table depth, although root zone salinity further decreased, but yields started reducing probably as a result of moisture stress due to reduced upward flux from groundwater table and limited irrigation supplies. The trend in Figure 2.3.4.7 suggests that maintaining an average groundwater table deeper than 200 cm would be excessive as the costs would be higher and there will be no additional crop response. It should, however, be noted that crop production is not exclusively determined by the depth of groundwater table but by many other agricultural conditions.

Figure 2.3.4.7 also shows that differences in cotton yields for different quality irrigation water at any given groundwater table depth are minimal. However, these differences are more significant between different groundwater table depths. This suggests that in order to maintain a favorable salt balance in the root zone, groundwater depth is more important than the quality of irrigation water. Therefore for sustaining crop production in these areas, drainage systems need to be rehabilitated to control groundwater table depths at the desired depths. This further strengthens the argument that for the conditions of the study area, a drainage system capable of maintaining groundwater table around 200 cm would be adequate to ensure long term sustainability of cotton production.

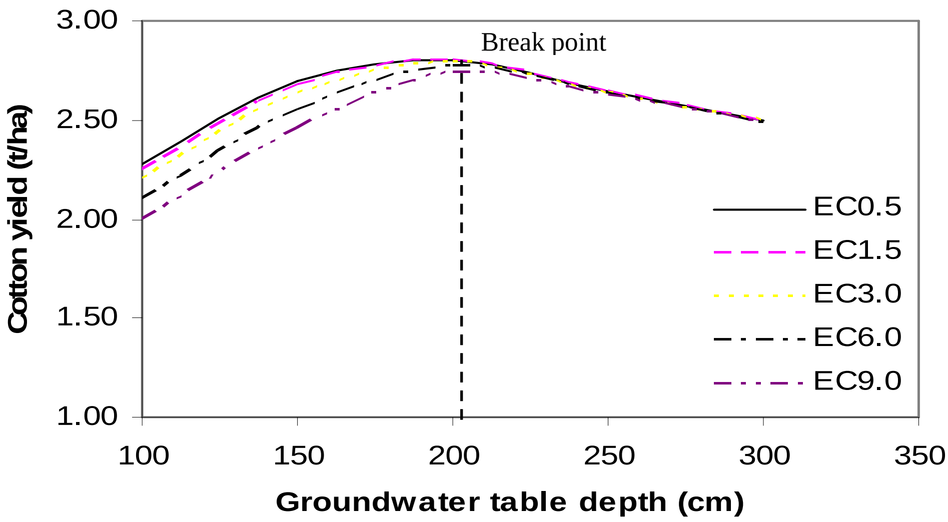


Figure 2.3.4.7. Cotton yields as affected by different groundwater table depths and quality.

5.3 ADJUSTING IRRIGATION AMOUNTS

Figure 2.3.4.8 presents the relationship between groundwater table depth and the rate of capillary rise for the study area. Capillary rise from a groundwater table depth of 300 cm is almost half the capillary rise at 150 cm depth. As a result of a drop in groundwater table, the length of the soil profile is increased, which requires more water through irrigation to keep the favorable moisture conditions for crop growth in the root zone. Therefore at deeper groundwater table depths, irrigation supplies will have to be adjusted for optimal crop production.

For this study, we performed additional model simulations to determine the optimum irrigation amounts needed to retain sufficient moisture in the soil profile for critical depth of groundwater table (200 cm). Simulations were performed for 5 irrigation water quality and 5 irrigation regimes i.e. 175, 250, 300, 350 and 400 mm. Average cotton yield as affected by different irrigation regimes is presented in Figure 2.3.4.9. Cotton yields have an increasing trend up to an irrigation amount of 250 mm, however above this increases in yield are almost nominal (3-5%). This clearly shows that for the saline conditions of the study area, maximum attainable cotton yields will be around 3 t ha^{-1} if proper drainage conditions and irrigations are provided. In order to get maximum yields of up to 5-6 t/ha, extra leaching of salts from the soil profile would be imperative.

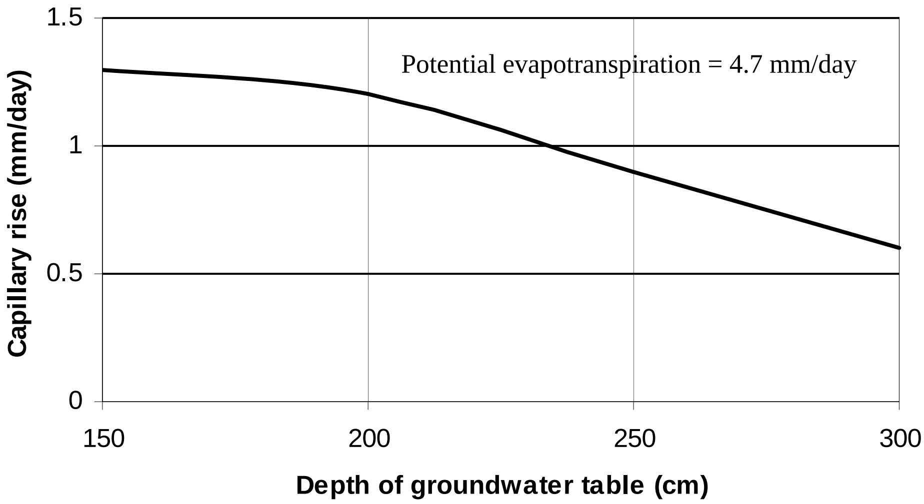


Figure 2.3.4.8. The relationship between groundwater table depth and rate of capillary rise.

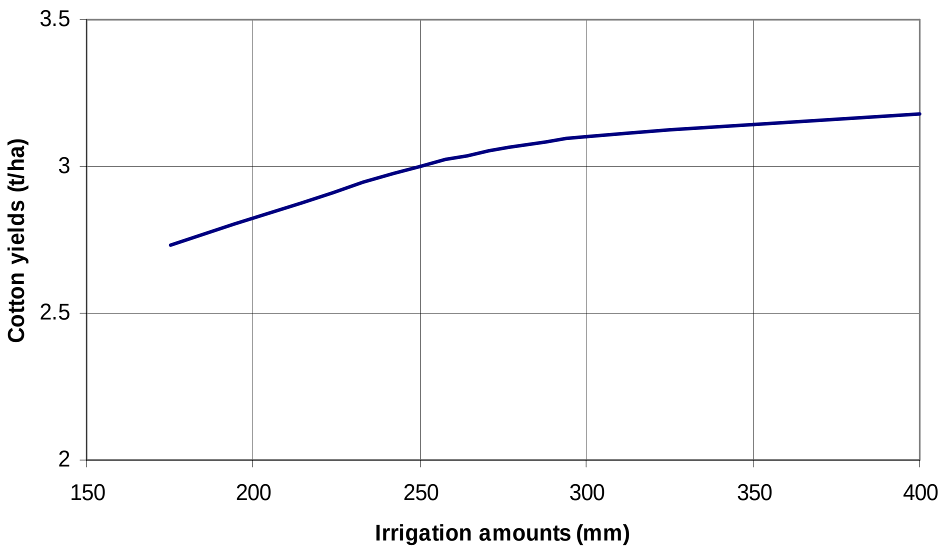


Figure 2.3.4.9. Cotton yields as affected by different irrigation regimes under groundwater table depth of 200 cm.

6. CONCLUSIONS

The premise of this study was to calibrate SWAP model using field data from the cotton fields to evaluate the impact of mulching on reducing soil salinity and improving crop production. The close agreement between measured and simulated soil moisture contents and profile salinity shows that parameters used in the model are effective in providing realistic estimates of water and salt balances at field level. The model simulations supported by field data shows that on average cotton yields under mulching were 9% higher as compared to non-mulching conditions. This was mainly attributed to reduced salinity levels in the root zone. Mulching helps in minimizing soil evaporation, which in turn reduces upward flux and inflow of salts in the root zone from groundwater. Decreased soil evaporation also significantly reduced the water used by crop. Actual evapotranspiration values under mulching were 12% lower than non-mulching treatments. Mulching also produced 11% higher yields and increased the productivity of water (WP_{ET}) by 24%.

The model simulations also reveal that the amounts of water per irrigation event applied by farmers are excessive, which is a major reason for groundwater rise and inflow of salts into the root zone. Therefore, for conditions prevailing in the study area, farmers should apply irrigations more frequently and in lower quantities to avoid an unnecessary rise of groundwater table and build up of salts in the root zone.

Modeling results further show that a groundwater table depth of 200 cm will be optimal to achieve maximum cotton yields regardless of irrigation water quality. However at this groundwater table depth irrigation quantities will have to be increased to 250 mm to keep the root zone free of excessive salts. Therefore, for this area, drainage systems capable of maintaining groundwater table depths at 200 cm would be adequate for long-term sustainability of irrigated agriculture. Drains deeper than this would not be suitable as costs will increase and crop responses will be negligible.

These findings are representative of the current soil salinity situation in the area. Presently average root zone salinity in the study area is ranging between 12-18 dS m^{-1}, which is very high for any type of cropping. Therefore to boost the cotton production to its maximum potential of 5-6 t ha^{-1}, excessive leaching of salts from the soil profile should be accomplished. For this purpose, surface drainage systems present in the area need to be rehabilitated to improve their efficiency.

2.3.5. SPATIAL AND TEMPORAL ASSESSMENT OF SOIL SALINITY USING RS TECHNIQUES IN THE SYRDARYA BASIN.[14]

1. INTRODUCTION

The temporal and spatial assessment of soil salinity is imperative in developing appropriate land and water management strategies. In Central Asia, during Former Soviet Union (FSU), salinity monitoring and control was undertaken by the Amelioration Departments of the Amelioration and Water Management Ministry. Information pertaining to salinity was predominantly based on routine soil survey exercises that sampled key cotton and wheat growing regions. The basic information for preparing the soil salinity maps were received from the "monitoring points", located inside the irrigated areas. These samples were analyzed in the laboratory and the results were presented through annual salinity maps at a 1:25000 and 1:50000 scales. For effective monitoring of soil salinity, samples were collected (usually one point being representative of 100 - 150 ha) and their chemical content was analyzed. Relatively dense "monitoring points" helped to successfully monitor and manage soil salinity until 1990's. However, shrinking budgets and the irregular collection of data from these monitoring points, has resulted in a decline in the quality of maps and hence has restricted the ability of key stakeholders to assess the scale and scope of soil salinity in irrigated areas of Central Asia.

Using Remote Sensing (RS) and GIS platforms in addition to conventional method of soil salinity assessment can assist in reducing the costs associated with monitoring as well as increase the accuracy of soil salinity monitoring. Generally two approaches are used for soil salinity mapping using remote sensing. These include

- Direct approach - through analysis of spectral reflectance from bare soil;
- Indirect approach - through analysis of vegetation condition.

Both approaches of soil salinity mapping were evaluated.

2. METHODOLOGY AND DATA COLLECTION

Data collected during 2005-from two test farms i.e. "Gafur Gulyam" and "Galaba", located in Syrdarya Province of Uzbekistan were used for the validation of results obtained from RS studies. The location of the two test farms is shown in Figure 2.3.5.1.

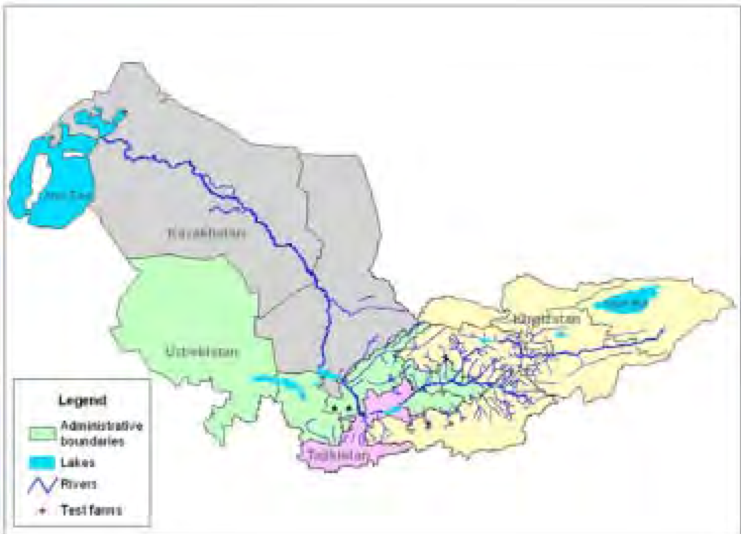


Figure 2.3.5.1. The location of test farms in Syrdarya river basin

2.1. PRE-PROCESSING OF SOURCE SATELLITE IMAGES

[14] This component was led by IWMI. NARS partners include Shovkat Khodjaboev (Uzbekistan)

The Landsat-5 TM and Landsat-7 ETM+ satellite images (Table 2.3.5.1) on the dates of maximum vegetation condition of two main crops (winter wheat in April and cotton in August-September) were used in this study.

Table 2.3.5.1. Details of Landsat satellite images used for this study.

Images Type	Acquisition Date	Sun Elevation	Sun Azimuth
Landsat-5_TM	1998_0410	50.000	137.000
Landsat-5_TM	1998_0816	55.000	131.000
Landsat-5_TM	1999_0429	56.000	133.000
Landsat-7_ETM+	1999_0827	54.100	140.800
Landsat-7_ETM+	2000_0407	51.100	143.000
Landsat-7_ETM+	2000_0829	53.047	141.115
Landsat-7_ETM+	2001_0426	57.044	138.140
Landsat-7_ETM+	2001_0731	59.578	129.419

The following steps were undertaken in the processing of the Landsat images.

1. The conversion of pixel's digital number (the raw solar energy collected by the sensor) to absolute units of radiance is the first step of multi-sensor and multi-date image normalization. This was was achieved using the following equation:

$$L_\lambda = ((LMax_\lambda - LMin_\lambda)/(DN\_Max - DN\_Min)) * (DN - DN\_Min) + LMin_\lambda \quad \text{[Eq. 2.3.5.1]}$$

Where L_λ – Spectral Radiance at the sensors aperture in watts/(m^2 * ster * µm).
DN – Digital Number of pixel.
DN_Min – the minimum value (corresponding to $LMin_\lambda$) of DN.
DN_Max – the maximum value (corresponding to $LMax_\lambda$) of DN.
$LMin_\lambda$ and $LMax_\lambda$ – the spectral radiances for each band that is scaled to DN_Min and DN_Max, respectively, in watts/(m^2 * ster * µm).

The $LMin_\lambda$ / $LMax_\lambda$ values for Landsat-5 TM (Table 2.3.5.2), Landsat-7 ETM+ images for dates before 1 July, 2000 (Table 2.3.5.3) and after 1 July, 2000 (Table 2.3.5.4), are presented below.

Table 2..3.5.2. The Min/Max spectral radiances for Landsat-5 TM bands

	Band1	Band2	Band3	Band4	Band5	Band6	Band7
LMin	-2.568	-5.098	-3.914	-4.629	-0.763	1.238	-0.338
LMax	160.527	318.527	244.726	230.455	31.516	15.243	16.853

Table 2.3.5.3. Min/Max spectral radiances for Landsat-7 ETM+ bands before 1 July, 2000

Gain		Band1	Band2	Band3	Band4	Band5	Band6	Band7
Low	LMin	-6.2	-6.0	-4.5	-4.5	-1.0	0.0	-0.35
Low	LMax	297.5	303.4	235.5	235.0	47.70	17.04	16.60
High	LMin	-6.2	-6.0	-4.5	-4.5	-1.0	3.2	-0.35
High	LMax	194.3	202.4	158.6	157.5	31.76	12.65	10.932

Table 2.3.5.4. The Min/Max spectral radiances for Landsat-7 ETM+ bands after 1 July, 2000

Gain		Band1	Band2	Band3	Band4	Band5	Band6	Band7
Low	LMin	-6.2	-6.4	-5.0	-5.1	-1.0	0.0	-0.35
Low	LMax	293.7	300.9	234.4	241.1	47.57	17.04	16.54
High	LMin	-6.2	-6.4	-5.0	-5.1	-1.0	3.2	-0.35
High	LMax	191.6	196.5	152.9	157.4	31.06	12.65	10.80

The Landsat-7 ETM+ sensor has the ability to change the gain state (low or high), depending upon the brightness of the scene, so there are different values of **LMin**$_\lambda$ / **LMax**$_\lambda$ for each gain state. These values are changing slowly over time as the ETM+ detectors are degraded.

2. The calculation of effective at-satellite reflectance (or albedo) values reduces the within-image variability through normalization for solar irradiance:

$$\rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos\theta_s}$$

where:

ρ_p - The unitless planetary reflectance;
L_λ - The spectral radiance at the sensor's aperture in watts/(m² * ster * µm);
d – The Earth-Sun distance in astronomical units, interpolated from tabular values based on Julian Day of the image date;
$ESUN_\lambda$ - The mean solar exoatmospheric irradiances in watts/(m² * µm) for Landsat images are shown in Table 2.3.5.5.
θ_s – The solar zenith angle in degrees (from the header file of each image).

Table 2.3.5.5. The mean solar exoatmospheric irradiances for bands of Landsat images.

	Band1	Band2	Band3	Band4	Band5	Band6	Band7
Landsat-5 TM	1957	1829	1557	1047	219.3		74.52
Landsat-7 ETM+	1969	1843	1555	1047	227.1		80.53

3. Within the images scenes of points representing bare soil and high vegetation were selected. The reflectance values at these points were used for the calculation of Ratios (Band_i/Band_j) and Normalized Indexes (Band_i – Band_j)/(Band_i + Band_j) for all possible combinations of Landsat band's (1 – 5, 7), and it's range (Minimum and Maximum) values.

The highest range of differences for bare soil and high vegetation of Landsat band's Ratios and Normalized Indexes was found for Band_4/Band_3 and Band_4/Band_7, and there is very high correlation between these combinations of bands (Figure 2.3.5.2).

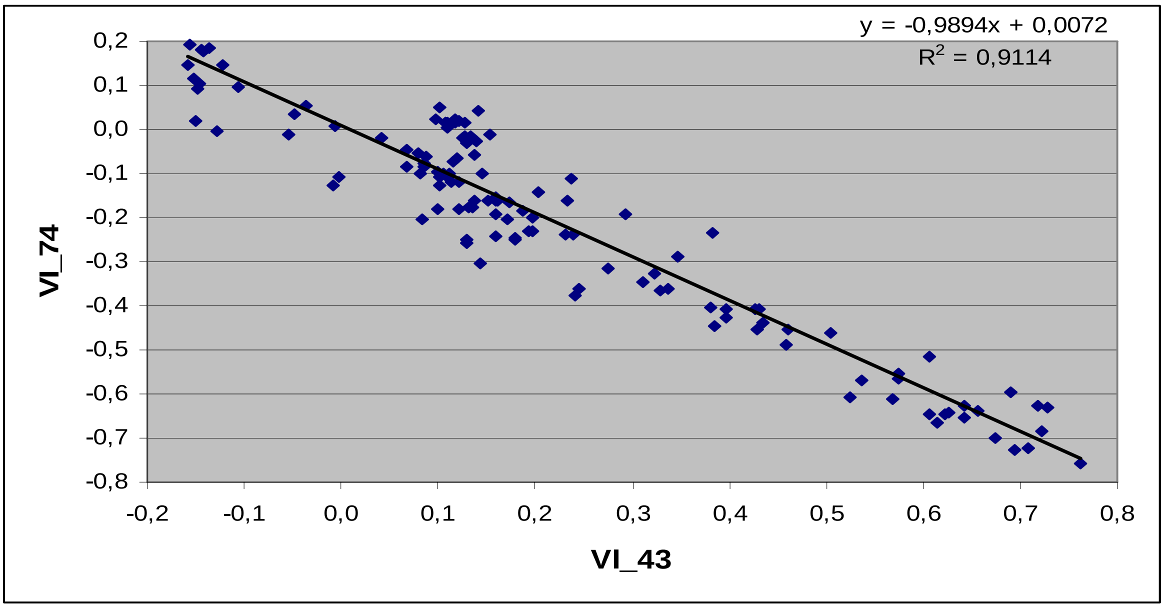


Figure 2.3.5.2. The correlation between Band_4/Band_3 and Band_4/Band_7 Normalized Indexes

For the analysis of vegetation condition, NDVI (Normalized Difference Vegetation Index) was calculated from Landsat satellite images using the below formula:

$$NDVI = (Band\_4 – Band\_3) / (Band\_4 + Band\_3)$$

where: Band_3 – the reflectance in Red spectra; Band_4 – the reflectance in Near-InfraRed (NIR) spectra;

3. RESULTS AND DISCUSSION

3.1 MAPPING SOIL SALINITY FROM MULTI-TEMPORAL SATELLITE IMAGES

Analysis of multi-annual vegetation conditions obtained from NDVI values of seasonal Landsat images were used to map soil salinity for 1998 – 2001. For this purpose, the following procedure was adopted:

- Calculation of NDVI raster layers from all images;
- Calculation of the annual maximum NDVI raster layers from the seasonal (April and August) NDVI layers for each year;
- Calculation of the absolute maximum NDVI raster layer from the annual maximum NDVI layers of 1998-2001.
- To reclassify the range of absolute maximum NDVI values to soil salinity gradation;

Comparison of the soil salinity maps obtained by traditional and remote sensing analysis methods are shown in Figures 2.3.5.3 and 2.3.5.4. Figure 2.3.5.3 shows the soil salinity map of “Gafur Gulyam” experimental farm of SANIIRI, which was developed in 1989 using chemical analysis data of soil samples collected during the field surveys.

The soil salinity map from multi-temporal analysis of vegetation (Figure 2.3.5.4) shows greater detailed variation in salinity when compared to traditional map (Figure 2.3.5.3). In this respect the traditional map shows a much coarser picture of salinity because salinity gradation boundaries were manually interpolated from not-representative points of soil sampling, which can be a considerable source of error. The map developed by RS analysis would appear to be more representative of reality as it shows patches of high and very high salinity within the fields, which are normally visible during the field visits.

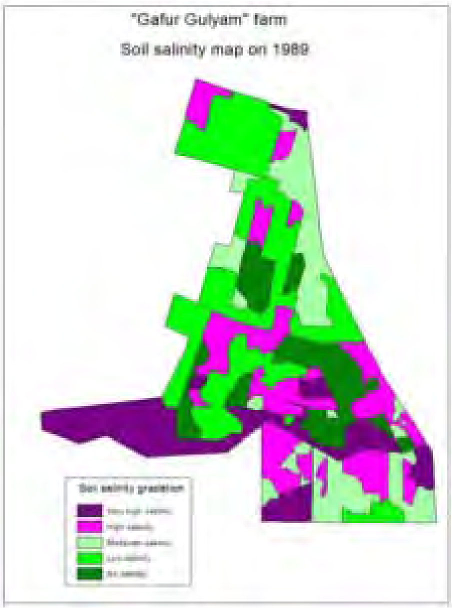


Figure 2.3.5.3. Traditional soil salinity map

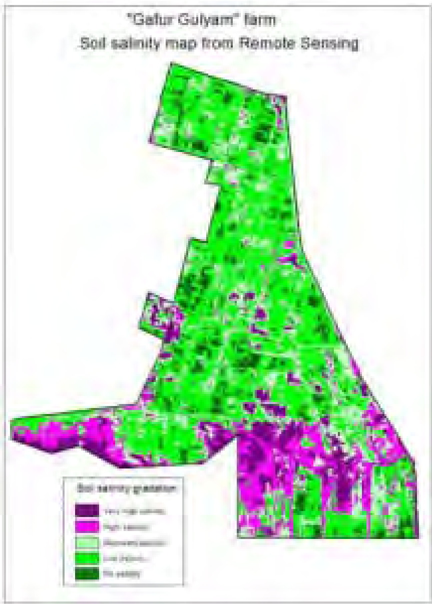


Figure 2.3.5.4. Map produced by RS analysis

As the traditional map was out dated when to compare with the RS map derived for the period 1998-2001, it was decided to undertake salinity measurements using EM-38 equipment for verification of the results. The EM-38 measures the bulk electrical conductivity in the field in two modes: vertical (EM_v), the average for 0-150 cm depth and horizontal (EM_h), the average for 0-75 cm soil in the horizon. The measurements were made during 2005-07 at 532 points within 38 fields of Galaba farm. At each point of

EM-38 readings, coordinates were determined using a Garmin-12 GPS meter. A very high correlation between EM_v and EM_h measurements was found (Figure 2.3.5.5).

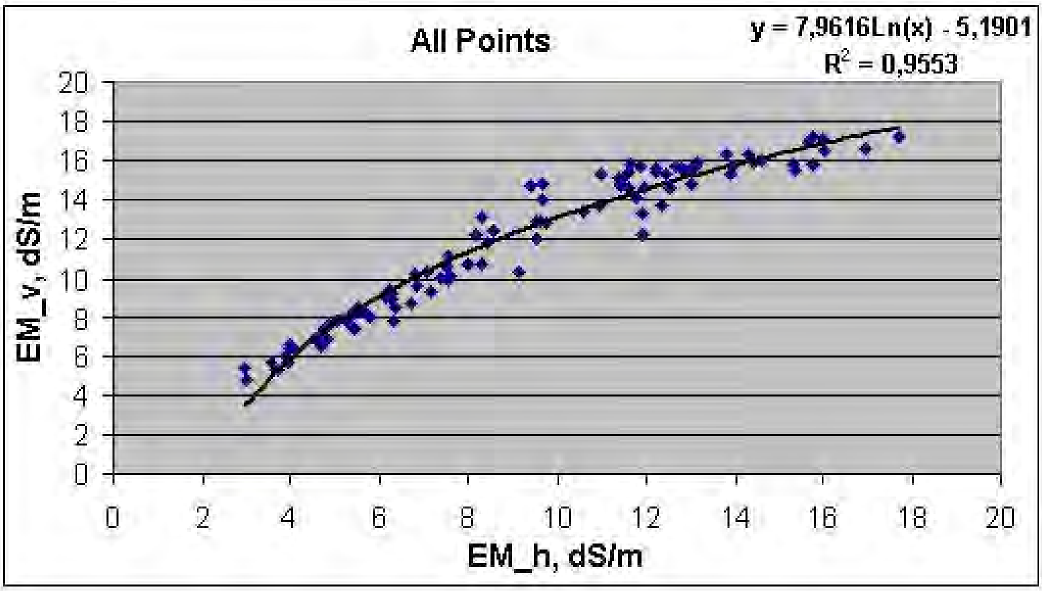


Figure 2.3.5.5. The correlation between EM_v and EM_h measurements of EM-38 meter.

However, the correlation between EM-38 “point” measurements and maximum multi-annual NDVI values was found to be very low (Figure 2.3.5.6).

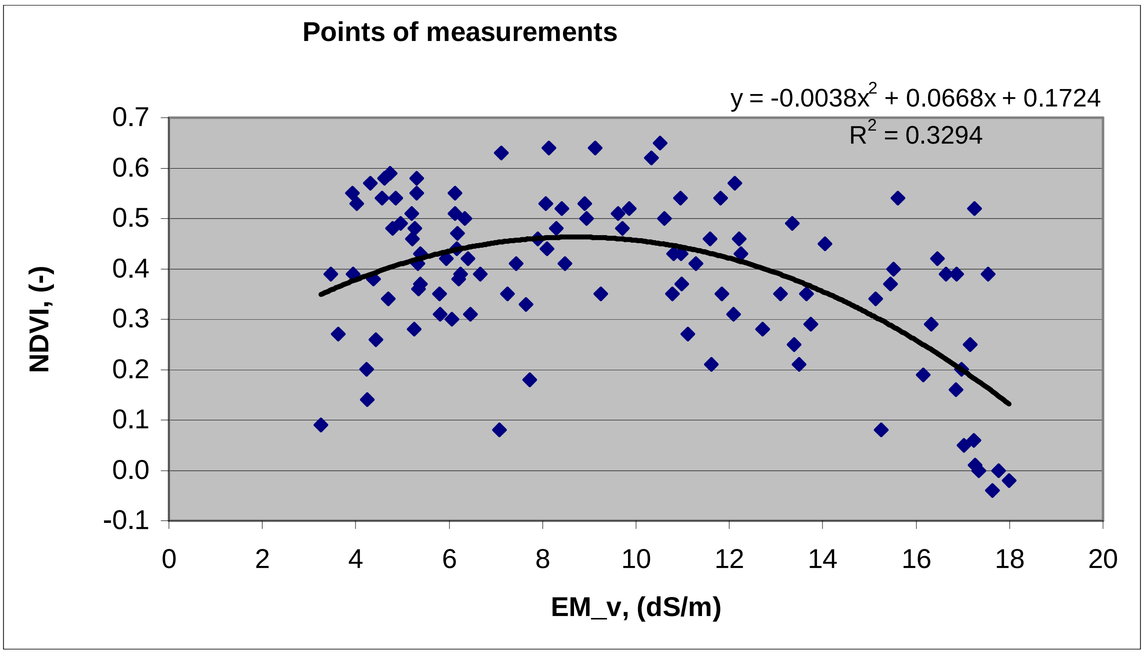


Figure 2.3.5.6. The correlation between EM_v and maximum multi-annual NDVI values.

To analyze the spatial variability of soil salinity, measurements by EM-38 were made more densely (the distance between points of measurement was reduced to 10 m in comparisons to the previous 30 m) within the areas of very low and high vegetation patches obtained through maximum multi-annual NDVI. It was found that point measured values can not be representative of the surrounding area as salinity varies continuously spatially (Figure 2.3.5.7).

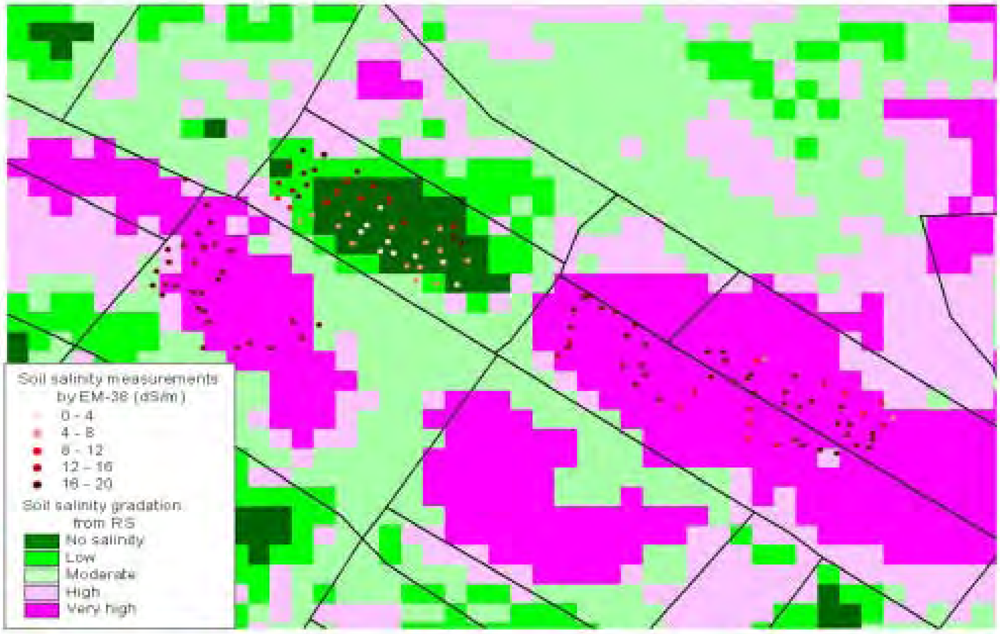


Figure 2.3.5.7.. The spatial variability of soil salinity measurements by EM-38 meter.

The results were considerably improved when mean value of maximum multi-annual NDVI was calculated for each field polygon. These values were then compared with the mean values of EM-38 taken at 532 points from 38 fields of Galaba farm (Figure 2.3.5.8). Considering other factors such as changes in soil and vegetation types, this correlation is reasonable.

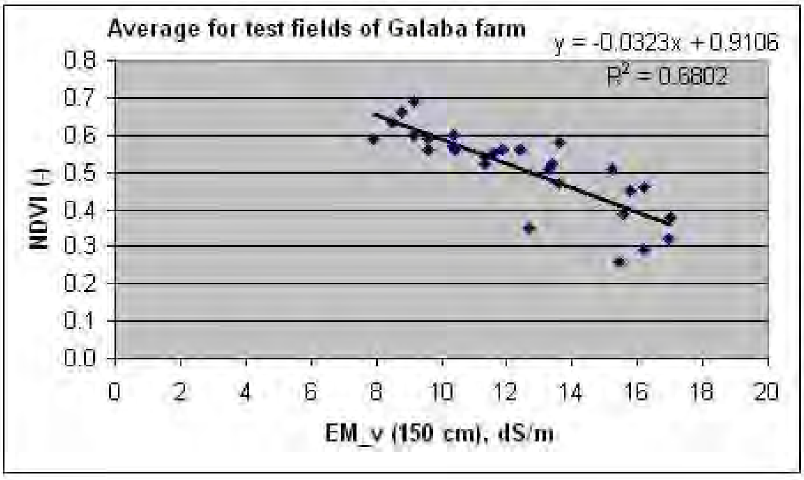
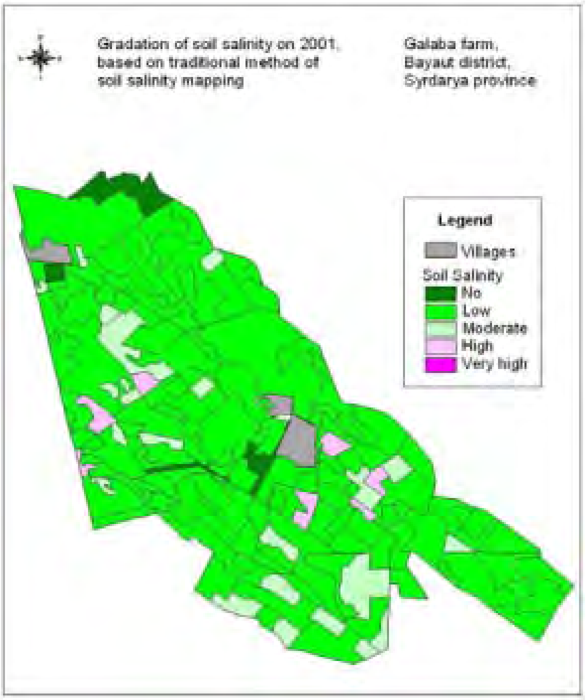


Figure 2.3.5.8. The correlation between EM_v and NDVI values measured for field polygons.

3.2 MAPPING SOIL SALINITY BY USING MULTI-TEMPORAL SATELLITE IMAGES AND GIS

Multi-annual analysis of vegetation condition (NDVI) was used to calculate mean NDVI values for each field polygon (GIS layer), which, in turn, was used to create soil salinity maps for Galaba farm, Bayaut district, Syrdarya province (Figure 2.3.5.10). This map was then compared with the soil salinity map created by traditional method (Figure 2.3.5.9) at Hydro-Melioration Expedition of Syrdarya province for 2001 data.



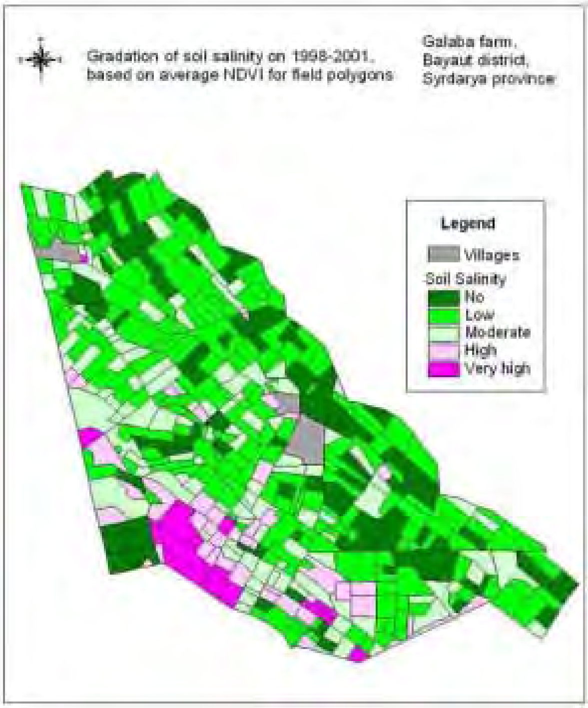


Figure 2.3.5.9. Traditional salinity map **Figure2.3..5.10.** Salinity map created using RS

This procedure was further used to prepare soil salinity map for the whole Syrdarya basin. For this purpose, additional work was undertaken to map out urban and water areas in the NDVI raster layers to improve the comparison with official statistic data. These steps included:

- Creation of GIS layers of urban areas (cities and villages) and water bodies (river bed and fishery farms) using on-screen digitizing from the satellite image;
- Map out urban areas and water areas in the grids of soil salinity.

The soil salinity map for Syrdarya province created from multi-annual satellite images of 1998-2001 is shown in Figure 2.3.5.11. This map was then used to quantify the area degraded by salinity and the results are presented in Table 2.3.5.6.

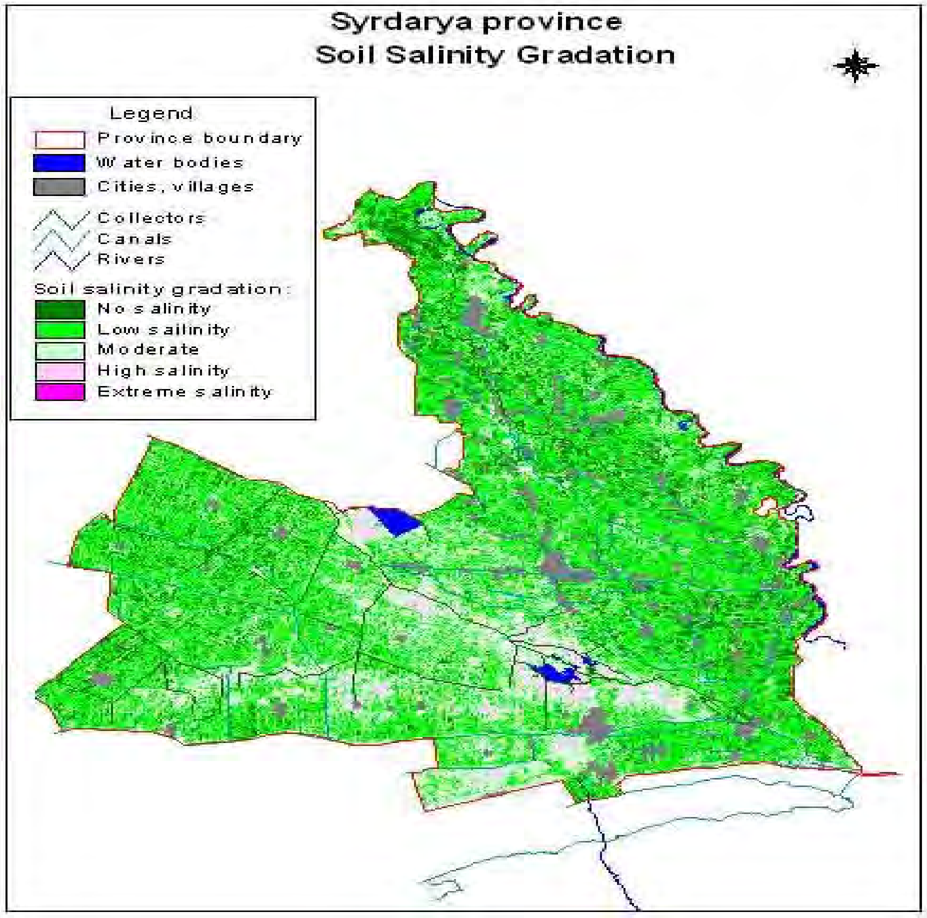


Figure 2.3.5.11: Soil salinity map of Syrdarya province.

Table 2.3.5.6: Comparison of area under different classes of salinity (ha).

Classes	**Government Statistics**						**RS Determination**	
	1989	% of total	1995	% of total	2005	% of total	RS	% of total
	34620	14.52	12900	4.35	7334	2.52	48771	12.50
	126370	52.99	220980	74.53	211894	72.90	212616	54.48
	62130	26.05	48710	16.43	61615	21.20	109974	28.18
High Salinity	15360	6.44	13910	4.69	9840	3.39	18800	4.82
Extreme Salinity							138	0.04
tal (to be rechecked)	**2384800**		**2965000**		**290683**		**3902999**	

The official data obtained from the statistical department reflects the area currently being monitored (the net irrigated areas) whereas the remotely sensed data as determined in this study represents the total gross area. Table 2.3.5.6 shows that the percentage of saline area calculated using remote sensing technique matches well with percentage of soil salinity area of 1989 when actual field measurements were undertaken in order to estimate the area affected by salinity. The reasons for relatively lower values in 1995 are clear and need to be carefully assessed. This may reflect a decline in the level of support associated with monitoring salinity in the region as a whole due to budgetary constraints.

In general soil salinization in the region is often associated with shallow groundwater table depths. In order to verify this hypothesis, data on 10-day groundwater measurements from all observation wells located in the Bayaut district (from Hydro-Melioration Expedition of Syrdarya province) for 2006 was collected and processed. Figure 2.3.5.12 presents the decadal changes of groundwater depth for a large number of observation wells. A comparison of Figures 2.3.5.12 and 2.3.5.13 clearly shows the influence of shallow groundwater table on soil salinity. It is of not that the western area of Bayaut district has the

highest salinity values, which are linked to groundwater table depths of less than 1 m. The low density of observation wells does not allow more detailed investigation however, there seems to be a high probability that linkage between soil salinity and groundwater table depth are evident and that the approach being taken in this study could yield significant positive benefits in delineating these two attributes.

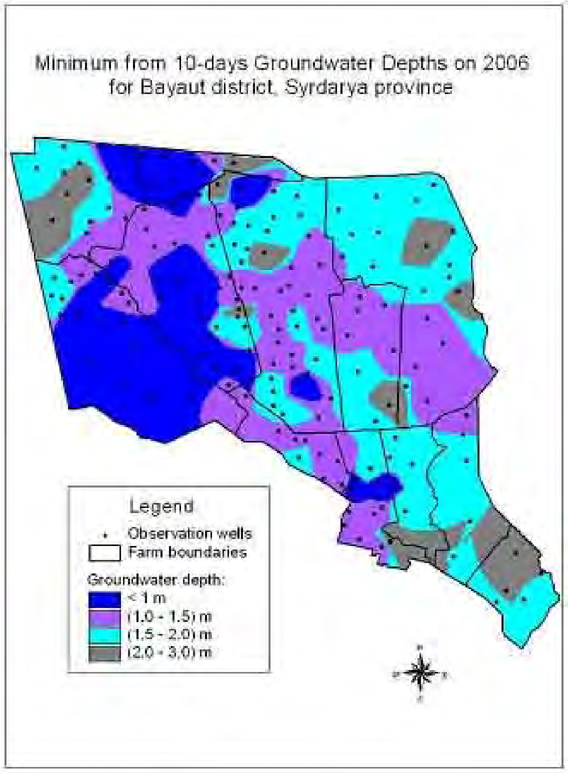


Figure 2.3..5.12: Groundwater table depth

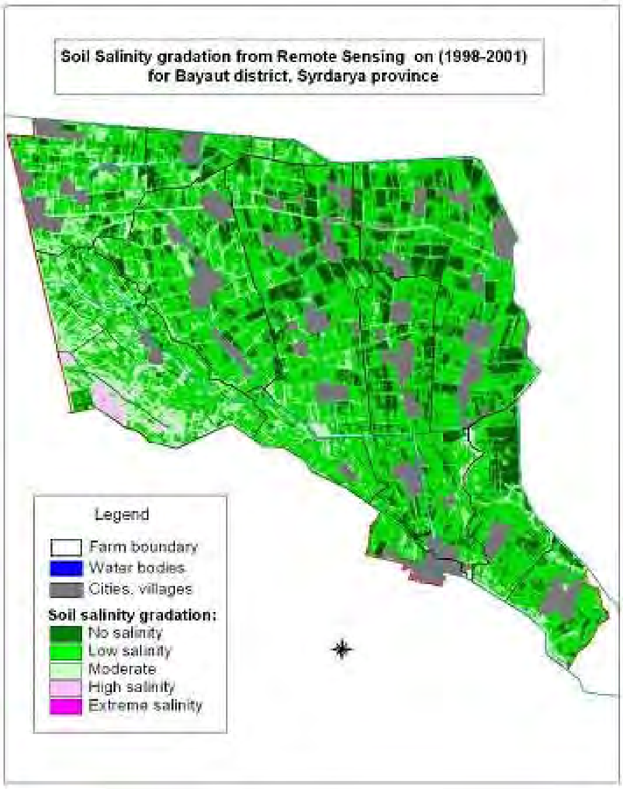


Figure 2.3.5.13 Soil salinity map of Bayaut district:

3.3 TEMPORAL ANALYSIS OF SOIL DEGRADATION USING REMOTE SENSING

To determine temporal trends in changes in soil salinity, additional Landsat-7 ETM+ satellite images for 2002 and 2006 were purchased and processed (Table 2.3.5.7).

Table 2.3.5.7. Parameters of additional Landsat-7 ETM+ satellite images

Images Type	Acquisition Date	Sun Elevation	Sun Azimuth
Landsat-7_ETM+	2002_0429	57.676	136.955
Landsat-7_ETM+	2002_0920	46.243	148.079
Landsat-7_ETM+	2006_0424	56.388	138.573
Landsat-7_ETM+	2006_0814	56.740	134.465

These seasonal images together with Landsat-5 TM images were analyzed to determine soil degradation between 1998-2002-2006. The procedure was based on the calculation of maximum annual NDVI raster layers for 1998, 2002 and 2006. The maximum annual NDVI values for each year were classified into 6 land use classes (LUC):

1. (NDVI < 0) – water;
2. (0<= NDVI < 0.2) – bare soil;
3. (0.2<= NDVI < 0.4) – low vegetation;
4. (0.4<= NDVI < 0.6) – moderate vegetation;
5. (0.6<= NDVI < 0.8) – high vegetation;
6. (0.8<= NDVI < 1) – very high vegetation.

The raster layer of land use changes (maximum 216 classes) was created by applying the following formula:

LUC_1998*100 + LUC_2002*10 + LUC_2006

These classes were then reclassified to 8 classes:

1. water (if presence in any year);
2. bare soil (regularly in all years);
3. low vegetation (regularly in all years);
4. moderate vegetation (regularly in all years);
5. high and very high vegetation (regularly in all years);
6. unstable condition;
7. improved condition;
8. Degraded condition.

For simplification, land use classes of high and very high vegetation were combined because there were very few pixels with regularly very high vegetation during all years. After filtering out the pixels, located outside the area of selected districts, the number of pixels inside each class was converted to an Excel file for analysis and chart creation. Trends in soil salinity changes over time for Bayaut and Mirzabad districts are presented in Figures 2.3.5.14 and 2.3.5.15. The saline area in Bayaut district in 2006 had increased by 26.9% over that determined in 1998. Furthermore, about 6% of the area is constantly under limited vegetation. The situation in Mirzabad district is similar with a 27.2% increase in saline area between 1998 and 2006 and a considerably higher percentage (14.2%) of the area under regularly limited vegetation. These results clearly indicate that over the last 10 years, soil salinity in Syrdarya province has increased which should be a concern. If proper remedial measures are not implemented, it is plausible that this situation will continue to deteriorate.

4. CONCLUSIONS

This limited study was undertaken to evaluate a methodology for the identification of saline lands using remote sensing and GIS techniques. The results indicate that processing of multi-annual remote sensing images can assist to a reasonable extent in estimating temporal changes in the area affected by salinity. This method is particularly important when an objective assessment is required of the extent of the problem over larger areas. The approach cost effective when compared to traditional land survey practices and less time consuming. Despite its effectiveness, there are limitations with respect to the identification of differences in low vegetation that may not be attributed to salinity but to other factors such as water stress. It is recommended that for large scale applications and to facilitate improved accuracy, a concerted is needed to refine this methodology. The analyses presented here clearly demonstrate that urgent actions are needed to address the increasing problem of salinity in Sardarya Province to sustain irrigated agriculture, improve food security and enhance livelihood of rural poor.

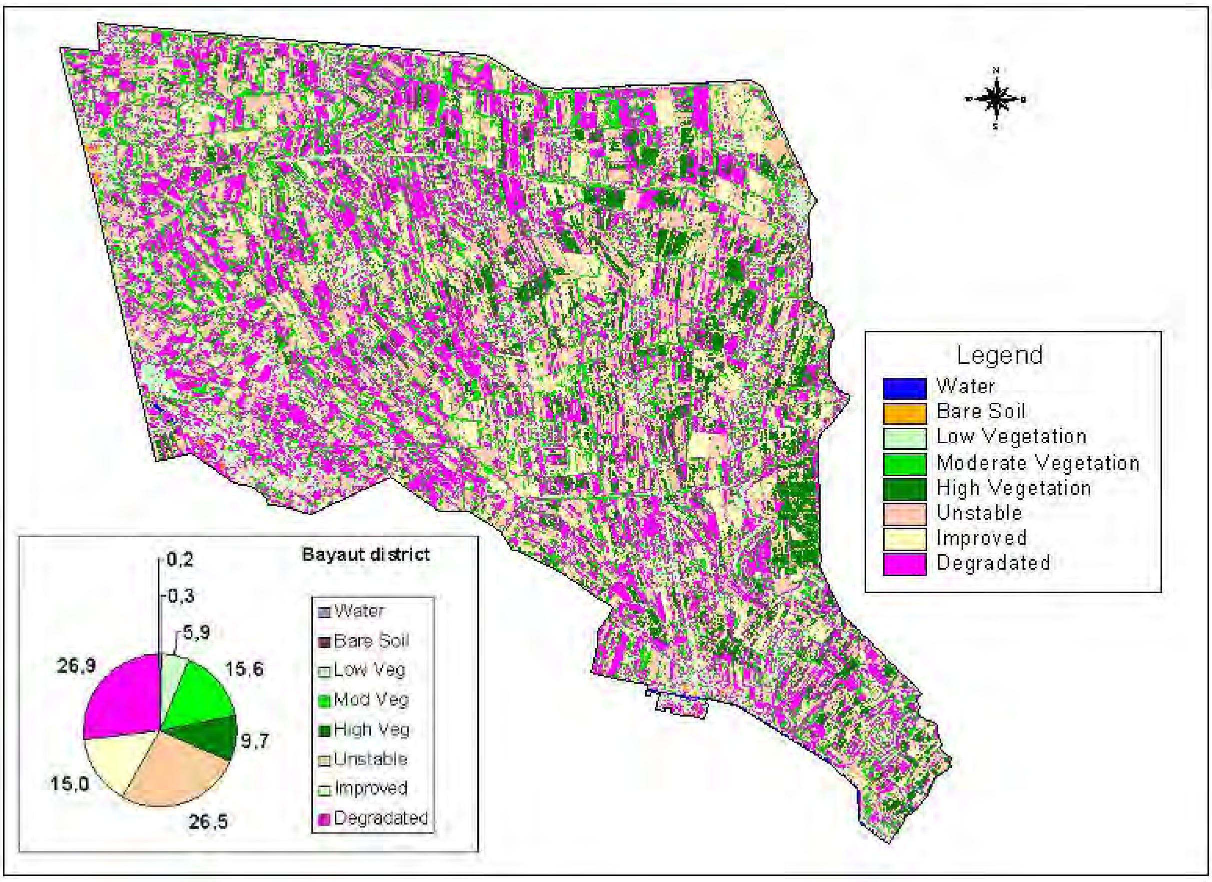


Figure 2.3.5.14: Temporal changes in soil salinity in the Bayaut district.

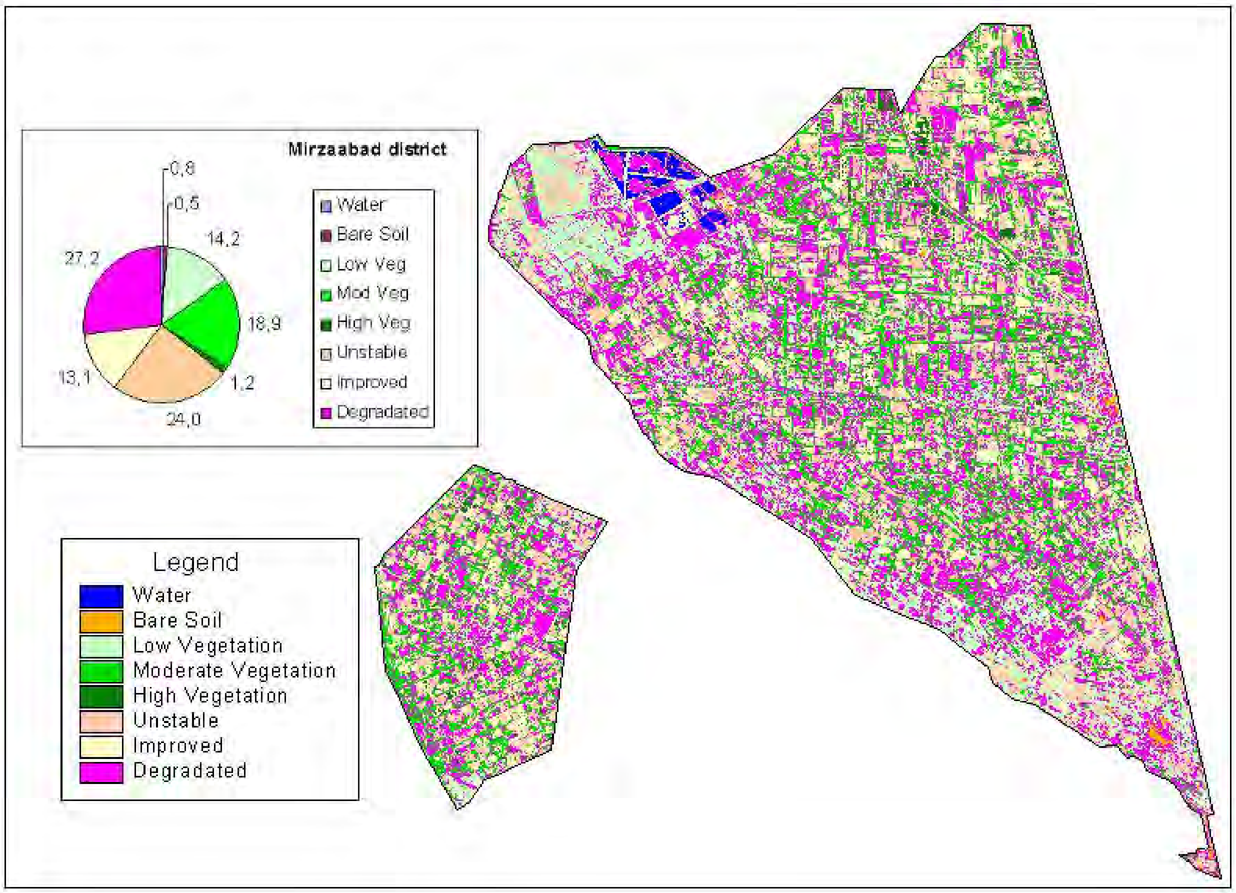


Figure 2.3.5.15. Temporal changes in soil salinity in the Mirzabad district

2.4 SOCIO-ECONOMIC ASPECTS OF SALINE ENVIRONMENTS

2.4.1 ASSESSMENT OF THE SOCIO-ECONOMIC ASPECTS OF FARMING COMMUNITIES CONFRONTED WITH SALINE ENVIRONMENTS (KAZAKHSTAN, TURKMENISTAN, AND UZBEKISTAN)

2.4.1.1 ECONOMIC ASSESSMENT OF HAY MULCHING UNDER DIFFERENT SALINITY LEVEL IRRIGATION WATERS IN SYRDARYA PROVINCE OF UZBEKISTAN[15]

1. INTRODUCTION

Syrdarya province is one of the regions of Uzbekistan most affected by land degradation (ADB, 2004). Land degradation in the province is mainly manifested by secondary salinization. Among the dominant anthropologic reasons for the rise of salinity are the inefficient operation of drainage and irrigation systems, uneven field leveling, non-observance of agronomic practices in terms of their timing and prescribed techniques, low efficiency of on-farm water use, all of which contribute to a rise in groundwater levels and the subsequent mobilization of salts. Syrdarya is also known for the strong natural risk of land degradation due to its climatic and agroecological conditions specified by hot summers and low precipitation, leading to rapid evaporation from soil surfaces and induced salinity. FAO's Land Degradation Assessment in Drylands (LADA) project estimates in its technical report for Uzbekistan in 2003 that out of the total 505,653 ha area in Syrdarya, 121,139 ha are moderately susceptible to natural risk of land degradation, 239,680 ha are highly susceptible, with the remainder not being predisposed to natural degradation risk.. The same report indicates that out of the total 505,653 ha area in Syrdarya, 135,810 ha are moderately degraded and 281,370 ha are highly degraded as a result of human land and water mismanagement, with the inefficient use of irrigation waters at on-farm level being one of the leading causes of growing salinity and land abandonment.

The province has a total population of 1.9 million people, of whom 68.5% reside in rural areas. The GDP per capita in the region is estimated to be equal to 2,080 USD when calculated at purchasing power parity, which is 73.4% of the national average (UNDP, 2006). In view of the large share of rural population in the total population of the province, agricultural development is a key factor for overall economic development. However, accelerated land degradation and growth of salinity is impacting negatively on the livelihoods of rural communities in the province.

Insufficiency of fresh water resources is the main constraint for agricultural development in the province, even though it is believed that considerable amounts of underground saline and drainage waters do exist. In this regard, two-factorial on-farm experiments on the use of mulching and waters with different salinity level (high, medium, low) were conducted at Ak-Altin experimental station in Syrdarya province under the present project between 2005 and 2007. The agronomic results of these experiments are described in detail in the earlier sections of this report. This study presents the results of the socioeconomic feasibility analysis of these experiments.

1.1. PROPOSED TECHNOLOGY

Mulching is a well known soil improvement measure. It is effective in improving soil physical properties by reducing water runoff and increasing water infiltration. It also protects the soil against raindrop impact, preventing soil crusting and contributing to soil organic matter and nutrients. Application of hay mulch to soils can reduce tail water generation at the field level, and thus increase water use efficiency.

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[15] This component was led by ICARDA. NARS partners include Abdulla Avezbaev, Abdugani Mukumov Tashkent Irrigation Institute, Uzbekistan.

The advantages of hay mulching are numerous. *Firstly*, hay mulching allows for greater moisture retention in the soil by preventing rapid evaporation from the soil surface under high summer temperatures, thus reducing the need for increased irrigation. *Secondly*, the decomposition of hay increases the fertility of soils adding much needed organic matter and nutrients to the soil. *Thirdly*, mulching reduces cost associated with weeding and inter-row cultivation. *Fourthly*, the yields under mulching are higher than without mulching as the moisture is kept in the soil uniformly for a longer period, the upper layer of soil does not become hard. *Finally*, hay mulching is conducive to the development of different microorganisms and insects communities that ensures the soil remains friable without additional costly cultivation. Hay mulching is also a low cost alternative to polyethylene mulching. The hay is widely available in the region. Farmers can access it either from their own production fields or they can buy it in the market. Hay costs about 10 USD/t which is significantly lower than the cost of polyethylene film (1,700 USD/t). Under the studies within the ADB-funded RETA 6136 project on "Soil and Water Management" in neighboring Djizzak province, mulching of 50% of furrows with polyethylene film required 30 kg/ha of polyethylene film, i.e. 51 USD/ha, while under hay mulching of about 2 t/ha of hay under the current experiment, the cost is about 20 USD/t. Besides, hay decomposes into organic matter, while polyethylene does not. Contrasting this, irrigating cotton with drainage or mixed waters could contribute to the efficient use of water resources, especially in view of growing shortage of fresh water resources. However, it should be stressed that the main requirement for the sustainability of this practice is the efficient operation of the drainage system.

Hay mulching technology has also constraints for large scale adoption in the province, as well as in Uzbekistan in general. It should be emphasized that the biggest difficulty for promoting this technology is the hay's competitive use as animal feed. During informal interviews with farmers it was found out that farmers prefer to give it to animals as feed rather than use it as mulch in growing cotton, mainly because they have more direct and tangible benefits from livestock production than from cotton cultivation. In addition, their awareness of the benefits of hay mulching is also quite limited. Finally, hay for mulching is applied manually, necessitating labor costs, though, we have to also consider that hay mulching saves on labor costs related to inter-row cultivation.

2. METHODS AND MATERIALS

The methodology used for economic evaluation is based on cost benefit analysis of on-farm enterprise budgets for each treatment under the experiment. The cost benefit analysis is a technique for evaluating the total costs of one or more technologies with their total benefits. The data, regarding the total costs including the costs of inputs, as variable costs, and fixed costs such as taxes and depreciation, represent the actually incurred costs during the on-farm trials for the treatments under the project. The total benefits represent the income from all farm outputs sold at given prices. The difference between the total benefits and total costs is the net benefit from the given technology. The following are the definitions of the main indicators applied in the economic evaluation using cost- benefit method:

a. **Marginal Rate of Return (MRR):** is the ratio between the change in net benefit or net gross margin (Gross Margin "With" - Gross Margin "Without") – (Total cost "With" – Total Cost "Without") and the change in total cost. It shows the returns to the additional investment due to technology adoption.
b. **Benefit Cost Ratio (B/C):** this is the ratio between gross margins and total costs, it is a profitability indicator, values > 1 indicate that the technology is profitable, values < 1 suggest the technology is not profitable.

3. RESULTS AND DISCUSSION

As presented in Table 2.4.1.1, the cotton yields under hay mulching were higher than without mulching, on average, by 7% during the period of 2005-2007. During the experiments, cotton yields were adversely affected by the increase in the level of irrigation water salinity.

Table 2.4.1.1 Benefit cost analysis of mulching and no-mulching technologies for growing cotton under irrigation water of different levels of salinity (expressed in USD)

Sales and Costs	**No mulching**			**Mulching**		
	Low salinity water	**Medium salinity water**	**High salinity water**	**Low salinity water**	**Medium salinity water**	**High salinity water**
2005						
Total yield, t/ha	2.13	1.97	1.93	2.21	1.99	1.94
Total sales	435	402	394	451	406	396
Total costs	367	355	352	413	395	404
Net benefits	68	47	42	38	11	-8
BCR	1.18	1.13	1.12	1.09	1.03	0.98
2006						
Total yield, t/ha	1.47	1.37	1.24	1.78	1.47	1.33
Total sales	403	376	341	484	403	364
Total costs	371	349	326	409	378	354
Net benefits	32	27	16	75	25	10
BCR	1.09	1.08	1.05	1.18	1.07	1.03
2007						
Total yield, t/ha	2.52	2.41	2.12	2.83	2.60	2.24
Total sales	727	695	612	816	750	646
Total costs	595	556	518	603	559	516
Net benefits	132	139	93	214	191	130
BCR	1.22	1.25	1.18	1.35	1.34	1.25
Average BCR	**1.16**	**1.15**	**1.12**	**1.21**	**1.15**	**1.09**

The average marginal rate of return of mulching treatments against those without mulching was 37%. This low level of marginal rate of return of mulching treatments against no-mulching treatments is explained by the low profitability levels under mulching with high salinity waters. In fact, mulching and the use of high salinity waters yielded less net benefits than its no-mulching equivalent. However, the treatment involving mulching and the use of low saline waters was significantly more profitable than the treatment without mulching and the use of low saline waters, with the marginal rate of return of the first against the latter being equal to 110%. Similarly, mulching and use of medium saline waters had the marginal rate of return of 19% against use of medium saline waters without mulching. Finally, use of high saline waters without mulching generated more marginal returns than with mulching. In this regard, mulching can be feasibly used only in combination with the use of low saline waters. In the other two cases, the level of additional returns from mulching are either not sufficient (mulching/no mulching along with the use of medium saline waters), or even negative (mulching/no mulching and use of high saline waters).

4. CONCLUSIONS

1. The analysis demonstrated that hay mulching can be applied with sufficiently high profitability only in combination with low saline waters. Mulching in combination with medium saline waters is slightly more profitable than the use of medium saline waters without mulching, but the level of returns is not sufficiently high to encourage farmers to rapidly adopt this management approach. It is not recommended to use mulching in combination with high saline waters because of negative profitability as compared to use of high saline waters without mulching.

2. Hay mulching contributes to the improvement of soil fertility and leads to increased cotton yields. However, hay's alternative use as animal feed would be the highest constraint for the adoption of this technology by farmers.

2.4.1.2. THE POTENTIAL IMPACT OF LICORICE FOR REMEDIATION OF SALINE SOILS: THE CASE OF MIRZACHUL AREA IN UZBEKISTAN[16]

1. INTRODUCTION

Globally, the total acreage of lands affected by salinity has earlier been reported to be 351.5 mln ha. Further the largest area affected by salinity is in North and Central Asia - 91.6 mln ha (Szabolcs, 1989). Inefficient irrigation water management in the absence of appropriate surface or subsurface drainage systems often leads to a rise in groundwater table leading to an accumulation of secondary salts in the root zone. When soluble salts accumulate in amounts above the threshold salt tolerance limits of crops, the process of secondary salinization begins to adversely affect agricultural production, environmental health, and the economic welfare of the people (Rengasamy, 2006). As a result of salinity build-up, productivity of irrigated agriculture in Central Asia has been undergoing rapid degradation over the last two decades. This problem has led to declining farm incomes in rural areas in Uzbekistan. Failing irrigation infrastructure, unclear property rights, misguided agricultural polices, and lack of support for agricultural research and technology transfer have been found to be largely responsible for this problem (Babu and Tashmatov, 2000; UNDP, 2003; CACILM, 2006; Orlovsky and Orlovsky, 2002; Kushiev *et al.*, 2005; Paroda, 2007).

In Syrdarya province of Uzbekistan, soil salinity build-up is resulting in the abandonment of once fertile lands due to significant yield losses. Leaching is a common practice of reducing salinity build-up in Central Asia (Vyshposky *et al.*, 2008). Generally, in spring and before the cropping season, soils are flooded with irrigation water which is expected to flush the salts out to deeper soil layers and away into the drainage system. However, leaching has become more and more excessive in recent years, now sometimes being carried out three or four times before the cropping season. Given the present inefficient operation of drainage systems, leaching often actually worsens soil salinity, as salts are only moved vertically in the soil layer but not removed from the land (Ibrakhimov and Awan, in prep.). Moreover, excessive leaching may also lead to removal of essential nutrients from the soil (Vyshposky *et al.*, 2008). Importantly, in view of the expected growing shortage of water resources in the region as a consequence of climate change and ever increasing water demands (Martius *et al.*, 2008), the leaching practice which involves up to 6,000 m^3 of water per hectare is not sustainable in the long run. Three types of leaching are practiced now by farmers in Syrdarya province: 1) deep flooding on highly saline areas, 2) shallow flooding on medium saline areas and 3) furrow leaching (or pre-tillage irrigation) on low saline areas. However, majority of on-farm drainage systems need significant rehabilitation for normal functioning. The problem becomes even more complicated because of the present nature of dividing responsibilities for irrigation system maintenance. The State is responsible for inter-farm level and farmers for on-farm level. However, most of the farmers don't have the necessary financial resources to maintain the function of on-farm drainage systems in their fields; moreover, given the current land tenure system, with farmers having only usufructuary rights through a long-term lease without full ownership, there is no incentive for significant long term investment in rehabilitation.

The salinity problem is exacerbated by raising ground water level (Ibrakhimov, 2005), uneven field leveling, monocropping of cotton which is a national strategic crop (Wehrheim and Martius, 2008) and lack of agricultural machinery for appropriate cultivation and tillage (Tursunov, in prep.), and vast water losses at the farm level as a result of wasteful irrigation methods involving furrow irrigation (Conrad *et al.*, 2007). The choice of crop rotations is fixed by the State; consequently, cotton and wheat are planted on the majority of arable lands. Alternative crops are planted only on a limited area. As a result, about 99.1% of the agricultural lands in Syrdarya are affected by different degrees of salinity (FAO, 2003). The salinization of agricultural land is spreading with alarming speed, leading to the abandonment of up to 3% of irrigated area in Syrdarya annually (Kushiev *et al.*, 2005). This is endangering the livelihoods of already impoverished rural communities.

In the absence of appropriate open drainage systems which are very expensive to maintain, it is only prudent that other measures with the potential for rehabilitation of saline soils be adopted. In this regard,

[16] This component was led by ICARDA. NARS partners include Sadulla Avezbaev, Abdugani Mukumov - Tashkent Irrigation Institute, Uzbekistan; Habib Kushiev, Gulistan State University.

the phyto-remediation experiences acquired in Uzbekistan for reducing deep percolation losses of water leading to rising water tables using licorice could prove very useful elsewhere in reclamation and management of the saline soils having high water table conditions.

In this study, we intend to investigate the economic potential for addressing the salinity problem through the planting of a native, salinity-tolerant value crop, licorice.

Licorice grows naturally in many regions of the world, especially in West Asia and North Africa, the Caucasus and Central Asia (Lange, 1998). It grows best in the fertile soils of the river valleys (Houseman and Lacey, 1929). In 1970s the area under licorice industrial cultivation in Uzbekistan stretched to some 16,000 ha in Karakalpakastan region of Uzbekistan. In addition, licorice was growing naturally on considerable areas in the deltas of Amudarya, Syrdarya and Zaravshan rivers of Uzbekistan (Ashurmetov *et al.*, 2005). However, presently licorice grows only on a very limited area in the deltas of the above-mentioned rivers, and on the banks of small rivers in Fergana valley, Tashkent, Bukhara, Khorezm and Samarkand provinces. This is mainly because of the over-exploitation of natural areas of licorice growth and virtual disappearance of its industrial cultivation. However, currently there are no comprehensive data or maps on licorice growing areas in Uzbekistan.

The aboveground height of licorice can reach 1.5 m. The licorice plant has a strong root system, reaching up to 17 meters in length. With such a root system licorice is able to access ground water thereby effectively reducing the risk of upward movement and secondary salinization of the profile. Due to its morphological attributes, the plant is persistent and may become a weedy species in cultivated lands where it is indigenous and is difficult to control without appropriate management. It is quite robust, highly competitive and successfully expands by out-competing other plants. Licorice can also grow well in low fertility lands thanks to its ability to fix nitrogen.

Although licorice is considered an easy plant to grow (Whitten, 1997; Olukoga and Donaldson, 1998) there is little published information defining the agronomic requirements to optimize root production (Douglas *et al.*, 2004). Licorice is normally grown from rhizome cuttings or harvested crowns taken from mature crops and laid out in shallow furrows (Molyneux, 1975; Anon., 1982; Singh *et al.*, 1984). Normally, the roots are harvested from only the top 1 m, but where complete root harvests have been made, fresh root yields of 50 t/ha have been reported (Molyneux, 1975; Duke, 1981; Anon., 1982). Licorice root for use as a medicinal herb is required to contain at least 4% glycyrrhizin (glycyrrhizic acid) (American Botanical Council, 1998; WHO, 1999); this is generally achieved after four to five years of cultivation. The cultivation of inter-row crops to generate income until the pharmaceutical glycyrrhizin levels are attained, is possible, however, it is not recommended (Singh *et al.*, 1984), as it may decrease licorice root yields (De Mastro *et al.*, 1993; Marzi *et al.*, 1993; Bezzi and Aiello, 1996).

In addition to its effects in lowering ground water levels and hence, salinity, the yields of crops planted after licorice can be higher by as much as 3-6 times, as compared when no licorice has been used for soil remediation (Kushiev *et al.*, 2005). Licorice roots as well as biomass could serve as a valuable livestock fodder. In addition, licorice has important uses in numerous industries (Nieman, 1957; Chandler, 1985; Fenwick *et al.*, 1990; Olukoga and Donaldson, 1998), such as: i) pharmaceutics, ii) food and beverages, iii) fertilizers, iv) chemical and paints, v) metallurgy, vi) ceramics, vii) paper production, viii) textiles, ix) perfumery, x) tobacco, etc.; thus, licorice roots have a significant export potential.

2. METHODS AND MATERIALS

2.1. RESEARCH SITE

The Syrdarya province of Uzbekistan covers some 428 thousand hectares, of which 84% are considered to be potentially suitable for irrigated agriculture. Currently, total irrigated area is about 293 thousand hectares (WEMP Sc-A1, 2001). Out of the total irrigated area, 54% is considered to be affected with low salinity, 25% with moderate salinity and 7% with high salinity (FAO, 2003). The province has a total population of 1.9 million people, of whom 68.5% reside in the rural area. The GDP per capita in the

region is estimated to be equal at about USD 2,080 calculated at purchasing power parity, which is 73.4% of the national average (UNDP, 2006).

The region is located in Mirzachul (Hungry Steppe) zone, which is a vast plain, bordering with Turkestan mountain chains in the south, the Syrdarya River in the north and east, and Kyzylkum desert in the west. It was incorporated into agricultural production following a massive land reclamation effort in the 1970s (FAO, 2001; Khasankhanova, 2003). The area is now one of the major cotton producing belts in Uzbekistan and Central Asia. In the hot dry summers evaporation losses of water are extremely high in Mirzachul facilitating the upward movement of the salts leading to peak salinization rates in absence of any appreciable rainfall event. Present lack of investment in rehabilitation, repair and cleaning of drainage systems has become a major factor significantly diminishing the positive effects of conventional salinity management practices such as leaching which is in turn leading to infrastructure deterioration and land degradation.

Main crops cultivated in the area are cotton and wheat. In addition, the livestock represents an important source of household livelihoods in the rural areas. Average yields of cotton and wheat in Mirzachul area are low, making up 1.5 t/ha and 1.75 t/ha, respectively (Kushiev *et al.*, 2005).

2.2. METHODS

Cultivation of licorice for the remediation of salinity-affected areas was studied by the Gulistan State University at Navbahor collective farm of Syrdarya province from 1999-2003 under a partial funding from the Asian Development Bank (ADB) as reported by Kushiev *et al.*, 2005. Starting from 2005, the output of this research has been further expanded through a research for development program of out-scaling to farmer demonstration plots under the present project.

Under the research at Navbahor farm, the experimental site was located in the highly saline abandoned area. There were two treatments laid out in autumn 1999 in adjacent fields: i) control without licorice (10 ha), ii) licorice cultivation (13 ha). These fields were typical of abandoned farmer fields in Mirzachul area due to high salinity. The average yield of licorice biomass at the experimental plot made up 3.66 t/ha in 2001 and over the next two years reached the maximum of 5.11 t/ha in 2003. The licorice root yield attained 5.63 t/ha and 8.55 t/ha in 2002 and 2003, respectively. Winter wheat and cotton were planted in three replications in the total area of 1 ha for each crop in autumn 2003 and spring 2004, respectively. The size of the control fields both for winter wheat and cotton were equal to 1 ha each. The average yields of winter wheat were equal 0.87 t/ha and 2.42 t/ha for control and licorice treatments, respectively. The average yields of cotton were 0.31 t/ha and 1.89 t/ha for control and licorice treatments, respectively.

The ex-ante analysis of licorice cultivation presented below is based on general agronomic attributes of licorice as well as the on-farm results of the above mentioned research activities. The purpose of economic evaluation is to analyze the profitability of licorice cultivation under different prices, inflation, capital cost and yield scenarios.

The data and assumptions used in the economic evaluation are based on cost benefit analysis using enterprise budgets. The production cost data, including variable (inputs) and fixed costs (taxes and depreciation), were collected through interviews with 10 farmers participating in the licorice out-scaling activities under the Bright Spots Project. As the licorice cultivation is undertaken in cycles corresponding to the maturing of licorice roots with required pharmaceutical properties, a long-term cost-benefit analysis was applied and indictors such as net present value (NPV) and internal rate of returns (IRR) were computed.

Taking into account the cyclical nature of licorice roots development, the agronomic results of the experiments (Kushiev *et al.*, 2005) and on-farm data collected through farmer interviews, the cost-benefit analysis model used the following five scenarios:

1. Licorice is cultivated for 5 years (*Scenario LC5yrs*),
2. Licorice is cultivated during 10 years (*Scenario LC10yrs*)
3. Licorice is cultivated for 5 years, then the farmer switches to cotton-wheat rotation for the following 5 years (*Scenario LC5yrsCW5yrs*)

4. Cotton-wheat rotation is practiced in the high saline area, without rehabilitation of land using licorice (*Scenario No LC*)
5. Current average profitability of cotton cultivation in Mirzachul, all levels of salinity combined. (*Scenario No LC, Only Cotton*).

Taking into account that it is quite difficult to remove licorice roots before planting cotton and wheat after land rehabilitation with licorice, costs of cleaning the fields from licorice roots before planting cotton or wheat are incorporated into the costs of the Scenario *LC5yrsCW5yrs.*

Main assumptions:

1. Annual discount rate is equal 10% .
2. The yields of crops and irrigation water use are taken from the on-farm data provided by farmers during the informal interviews and the earlier research by the Gulistan State University as described in H.Kushiev et al, 2005.
3. For simplicity of comparison and better understanding, the data is converted on per hectare basis.
4. The prices and costs are kept unchanged over the years, their current levels are used, and they are expressed in US Dollars (USD). The conversion rate from UZS to Dollar used in this study is equal to 1250 UZS per 1 USD.
5. Licorice roots reach marketable quality at the fifth year of cultivation, and once harvested, the roots take another five years to regenerate to the appropriate quality requirements..
6. In addition to the roots, licorice provides biomass as livestock feed. Therefore, analysis takes into account both the economic benefits from the licorice roots, as well as benefits from its biomass as fodder.

3. RESULTS AND DISCUSSION

The analysis demonstrated that under *Scenario LC5yrs* the Net Present Value (NPV) of the net benefit is 112 USD per hectare, or 22 USD/ha annually over 5 years. The cost benefit ratio is equal 1.2 at the end of the fifth year. Similarly, under *Scenario LC10yrs* the NPV of the net benefit is 252 USD per hectare, or 25 USD/ha annually over 10 years. The cost benefit ratio is equal 1.3 at the end of the tenth year. To analyze the profitability of switching to cotton-wheat rotation after 5 years of licorice cultivation under *Scenario LC5yrsCW5yrs,* we combine the data on the licorice profitably from the Scenario LC5yrs with average costs and benefits of the cotton-wheat cultivation. The NPV of this scenarios is 222 USD per hectare, or 22 USD/ha annually over 10 years. The cost benefit ratio is equal 1.1. Under *Scenario NO LC,* the net profitability is negative and loses USD 258 per hectare for the 10-year period, i.e. USD 25.8 USD/ha annually. Thus, the analysis clearly demonstrates that these highly saline lands, which are now abandoned, cannot be cultivated profitably under cotton or wheat at this level of salinity. Under *Scenario No LC, Only Cotton,* we analyzed the average profitability of growing cotton in Mirzachul, all levels of salinity combined. The NPV of the net benefit makes up 169 USD/ha for the 10-year period, i.e. 16.9 USD/ha annually. Table 2.4.2.1 summarizes the results of the analysis. The detailed on-farm budgets under each scenario are given in the Annexes.

Table 2.4.2.1 Profitability of licorice cultivation under different scenarios in Mirzachul area of Uzbekistan

Indicators	LC5yrs	LC10yrs	LC5yrsCW5yrs	NO LC	No LC Only Cotton
Revenues	689	1,132	1,829	1,217	3,380
Costs	587	880	1,607	3,800	3,548
Net benefit	112	252	222	-2,583	169
BCR	1.2	1.3	1.1	negative	
Annual Net benefit	22	25	22	negative	17

The *scenario LC10yrs* comes out slightly more profitable than *scenario LC5yrs*, *scenario No LC*, *scenario Only Cotton Model* (all salinity levels) and *scenario LC5yrsCW5yrs*, and much more profitable than cultivating either cotton or wheat in highly saline areas.

3.1. SENSITIVITY ANALYSIS

3.1. FACTORS INFLUENCING THE CHOICE OF OPTIONS

Several factors, such as licorice root price, licorice biomass price, cotton price, wheat price and discount rate can influence the option between the different models described above. Tables 2.4.2.2-6 present the simulation results of these factors on the profitability of each option[17].

As the price of licorice root increases, other factors remaining equal, the LC5yrs scenario becomes the most profitable. The breakeven licorice root price for the scenario LC5yrs is USD/t 77, while it is 67 for the scenario LC10yrs, and 54 for the scenario LC5yrsCW5yrs. Hence, as the licorice root prices go lower the scenario LC5yrsCW5yrs becomes more profitable for farmers (Table 2.4.2.2).

Table 2.4.2.2 Simulated effects of licorice root prices on the annual net benefits (USD/ha) of licorice cultivation options as saline amendment practice

	Licorice root prices			
	100 USD/t	150 USD/t	200 USD/t	250 USD/t
LC5yrs	22	70	118	166
LC10yrs	25	64	103	141
LC5yrsCW5yrs	22	46	70	94
No LC	-258	-258	-258	-258
No LC, Only Cotton	-25	-25	-25	-25

As the price of licorice biomass increases, all other factors remaining equal, the LC5yrs scenario again is the most profitable. As the licorice biomass prices go lower the scenario LC5yrsCW5yrs becomes more profitable for farmers (Table 2.4.2.3).

The rise in the cotton price increases the average profitability of growing cotton in Mirzachul as a whole (scenario No LC, Only Cotton), but it does not improve much the performance of growing cotton in the highly saline areas. Even at the price of cotton at 500 USD/t, the scenarios including some licorice cultivation remain more profitable than growing cotton without licorice rehabilitation in the highly saline areas (Table 2.4.2.4). The most profitable of the options including licorice is the scenario LC5yrsCW5yrs.

Table 2.4.2.3 Simulatied effects of licorice biomass prices on the annual net benefits (USD/ha) of licorice cultivation options as saline amendment practice

Licorice biomass price	15	20	25	30
LC5yrs	22	37	52	66
LC10yrs	25	37	49	61
LC5yrsCW5yrs	22	30	37	44
No LC	-258	-258	-258	-258
No LC, Only Cotton	-25	-25	-25	-25

Table 2.4.2.4 Simulating the effects of cotton prices on the annual net benefits (USD/ha) of licorice cultivation options as saline amendment practice

Cotton price	350	400	450	500
LC5yrs	22	22	22	22
LC10yrs	25	25	25	25
LC5yrsCW5yrs	22	31	40	49
No LC	-258	-252	-246	-240
No LC, Only Cotton	17	68	118	169

[17] The most profitable options under each scenario are highlighted in orange background color

At the current rate of 150 USD/t of wheat, the LC10yrs model is the most profitable. However, as the prices for wheat increase, the LC5yrsCW5yrs model becomes more profitable (Table 2.4.2.5).

Table 2.4.2.5 Simulating the effects of wheat prices on the annual net benefits (USD/ha) of licorice cultivation options as saline amendment practice

Wheat price	**150**	**200**	**300**	**350**
LC5yrs	22	22	22	22
LC10yrs	25	25	25	25
LC5yrsCW5yrs	22	39	72	88
No LC	-258	-232	-180	-154
No LC, Only Cotton	17	17	17	17

A rise in discount rates makes all options of cultivating crops on highly saline soils less profitable. However, the interest rate sensitivity analysis demonstrates that even at 40% interest rate, cotton cultivation in Syrdarya province as a whole, all salinity soils combined, still remains profitable, while the other scenarios have negative profitability. However, even with higher interest rates, licorice cultivation scenarios are found to be more economic than cultivating only cotton in the highly saline areas (Table 2.4.2.6).

Table 2.4.2.6 Simulated effects of discount rate on the annual net benefits (USD/ha) of licorice cultivation options as saline amendment practice

Discount rate	**0.1**	**0.2**	**0.3**	**0.4**
LC5yrs	22	6	-4	-11
LC10yrs	25	9	0	-5
LC5yrsCW5yrs	22	10	2	-3
No LC	-258	-258	-258	-258
No LC, Only Cotton	17	13	10	8

As a general conclusion, the sensitivity analysis points out that at the current price levels for licorice root and the expected upward trends of these prices, since the current licorice root prices in Uzbekistan are under-valued as compared to the world prices, the most profitable option is cultivating licorice only on the highly saline areas. However, the scenario LC5yrsCW5yrs is found to be the optimal for the highly saline areas of Mirzachul since it is less exposed to various risks associated with price and interest rate volatilities than other scenarios. Moreover, considering current food security policy which gives prominence to strategic food and cash crops, it would be possible for farmers to switch to cotton and winter wheat cultivation, once the land is rehabilitated and cleaned from licorice roots, increasing the economic and environmental sustainability of these otherwise abandoned lands.

3.2. MARKET POTENTIAL

Licorice root is marketed in two main forms: peeled or unpeeled dried roots, or chipped and shredded root. The roots are dried either by slow air drying or in low temperature ovens. Licorice root has to meet defined quality specifications for sale. Tests are carried out to assess *glycyrrhizin* content as well as levels of soil and microbial contamination, pesticide residues, etc. Hot water is used to extract licorice from the green or dried roots. The licorice extract then passes through several evaporators to be concentrated before it is machine molded. The extract is sold in either a solid or powder form after being granulated or spray dried. It is sometimes mixed with wheat flour to produce licorice paste.

During 1992, the average import price at North European ports was 500 USD/t (ITC, 1992a). Most of the supply comes from the former USSR, Spain, Turkey, Syria, Iraq and Afghanistan. A major portion of the commercial supply comes from wild sources and there is only limited area under cultivation.

During the Soviet period in Uzbekistan, the marketing of licorice was carried out by a centralized body Soyuzlakritsa based in Charjou, Turkmenistan. Since the independence, the licorice exports are regulated by the Government of Uzbekistan through licensing procedures. In recent years, there has been an expansion in the internal licorice processing capacities. Currently, two licorice processing factories operate in Uzbekistan, one in Tashkent, the other in Nukus, Karakalpakastan. However, there are several dozens

of firms dealing, among other activities, in the export of dried licorice roots. The market structure for licorice roots operates in a quite chaotic way, extending from officially registered companies dealing in licorice roots to private un-regulated entrepreneurs. The exact figures on export of licorice roots are not available, but expert estimates indicate that Uzbekistan exports some 15,000 tons of dried licorice roots annually.

Licorice roots in Uzbekistan now come from exploitation of naturally growing licorice areas. In this regard, over-collection might lead to the reduction of plant cover and biomass, as is already occurring in some other countries and Central Asia itself (Le Houeârou, 2002), and exacerbate the on-going land degradation and desertification in Uzbekistan. Therefore, cultivation of licorice as part of the cropping system offers two important opportunities: 1) opportunity to take advantage of growing global market demand, and 2) opportunity to rehabilitate abandoned and highly saline lands and return profitable cropping again. This analysis suggests that industrial cultivation of licorice in highly saline lands of Uzbekistan can enhance the economic and environmental sustainability of these lands, and will improve rural livelihoods and reverse land degradation.

4. CONCLUSIONS

Cultivation of licorice, a highly salt and drought tolerant crop known for its capacity to lower ground water levels, presents a feasible alternative in the remediation of highly saline abandoned soils. Cost benefit analysis indicates that growing licorice on saline soils does not only have highly effective attributes of land reclamation and land quality remediation, but also is quite profitable for farmers after the roots start being collected in the fifth year. These results and the potential impacts they suggest are important given the vast irrigated areas (192 thousand hectares) of Uzbekistan considered to be highly saline, or abandoned (FAO, 2003). In other words, the total impact of licorice cultivation on these highly saline soils could reach as high as 4.2-4.8 million USD of annualized net benefits (at current prices), from these otherwise abandoned lands. The analysis also shows that cultivation of food (wheat) and commercial (cotton) crops after soil remediation with licorice, leads to increased yields and profitability of these crops, as compared to the option without land rehabilitation using licorice. At the same time, certain constraints of licorice cultivation, such as initial investment costs and negative cash flow during the first 4 years, underdeveloped access to international markets, difficulty of eradicating licorice roots from the field once planted should be given due consideration. The analysis showed that switching to cotton-wheat rotation after the fifth year of licorice cultivation was the optimal option in the current policy, economic and social environment.

Annex 2.4.2.1 Profitability of licorice cultivation, 2005-2009, (Scenario LC5yrs)

Items	2005	2006	2007	2008	2009	NPV	Annual NPV
Yield licorice raw root, t/ha	0	0	0	0	10		
Yield licorice root, t/ha (dried)	0	0	0	0	7		
Price root, USD/t	100	100	100	100	100		
Licorice biomass yield, t/ha	2.2	2.9	3.7	4.4	5.1		
Licorice biomass price, USD/t	15	15	15	15	15		
Total sales	**33**	**44**	**55**	**66**	**777**	**698**	**140**
Weeding	32	0	0	0	0		
Tillage	28	0	0	0	0		
Harrowing	12	0	0	0	0		
Leveling	12	0	0	0	0		
Chiseling	12	12	12	0	0		
Making beds	12	0	0	0	0		
Planting roots	20	10	0	0	0		
Making furrows	2	2	2	0	0		
Irrigation	8	8	8	0	0		
Harvesting biomass	30	40	50	60	69		
Harvesting roots	0	0	0	0	120		
Drying/cleaning roots - 10 t	0	0	0	0	100		
Roots classification	0	0	0	0	71		
Total costs	**170**	**73**	**72**	**60**	**360**	**587**	**117**
Net profit	**-137**	**-29**	**-17**	**6**	**416**	**112**	**22**
BCR						**1.2**	**1.2**

Annex 2.4.2.1 Profitability of licorice cultivation, 2005-2014, *(Scenario LC10yrs)*

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	NPV	Annual NPV
Yield licorice raw root, t/ha	0	0	0	0	10	0	0	0	0	10		
Yield licorice root, t/ha (dried)	0	0	0	0	7	0	0	0	0	7		
Price root, USD/t	100	100	100	100	100	100	100	100	100	100		
Licorice biomass yield, t/ha	2.2	2.9	3.7	4.4	5.1	2.2	2.9	3.7	4.4	5.1		
Licorice biomass price, USD/t	15	15	15	15	15	15	15	15	15	15		
Total sales	**33**	**44**	**55**	**66**	**777**	**33**	**44**	**55**	**66**	**777**	**1,132**	**113**
Weeding	32	0	0	0	0		0	0	0	0		
Tillage	28	0	0	0	0	0	0	0	0	0		
Harrowing	12	0	0	0	0	0	0	0	0	0		
Leveling	12	0	0	0	0	0	0	0	0	0		
Chiseling	12	12	12	0	0	12	12	12	0	0		
Making beds	12	0	0	0	0	12	0	0	0	0		
Planting roots	20	10	0	0	0	0	0	0	0	0		
Making furrows	2	2	2	0	0	2	2	2	0	0		
Irrigation	8	8	8	0	0	8	8	8	0	0		
Harvesting biomass	30	40	50	60	69	30	40	50	60	69		
Harvesting roots	0	0	0	0	120	0	0	0	0	120		
Drying/cleaning roots - 10 t	0	0	0	0	100	0	0	0	0	100		
Roots classification	0	0	0	0	71	0	0	0	0	71		
Total costs	**170**	**73**	**72**	**60**	**360**	**65**	**63**	**72**	**60**	**360**	**880**	**88**
Net profit	**-137**	**-29**	**-17**	**6**	**416**	**-32**	**-18**	**-17**	**6**	**416**	**252**	**25**
BCR											**1.3**	**1.3**

Annex 2.4.2.3 Average projected profitability of the cotton-wheat rotation

Year	Price		Yield		Cost		Net benefit		Cotton-Wheat rotation		
	Cotton	Wheat	Cotton	Wheat	Cotton	Wheat	Cotton	Wheat	Total sales	Total costs	Net benefits
2010	350	150	0	2.4	0	300	0	63	363.0	300	63.0
2011	350	150	1.9	0	500	0	161.5	0	661.5	500	161.5
2012	350	150	0	2.1	0	300	0	8.6	308.6	300	8.6
2013	350	150	1.6	0	500	0	62.3	0	562.3	500	62.3
2014	350	150	0	1.7	0	300	0	-37.7	262.3	300	-37.7

Annex 2.4.2.4 Profitability of switching to cotton-wheat rotation after 5 years of licorice (Scenario LC5yrsCW5yrs)

Years	Total sales	Total costs	Net benefits	BCR
2005	33	170	-137	
2006	44	73	-29	
2007	55	72	-17	
2008	66	60	6	
2009	777	360	416	
2010	363	360	3	
2011	662	500	162	
2012	309	300	9	
2013	562	500	62	
2014	262	300	-38	
NPV	**1,829**	**1,607**	**222**	
NPV ann	**183**	**161**	**22**	**1.1**

Annex 2.4.2.5 The profitability of cotton-wheat rotation in the highly saline areas of Mirzachul (Scenario NO LC)

Year	Price		Yield		Cost		Net benefit		Cotton-Wheat rotation		
	Cotton	Wheat	Cotton	Wheat	Cotton	Wheat	Cotton	Wheat	Total sales	Total costs	Net benefits
2005	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
2006	350	150	0.3	0	500	0	-391.5	0	108.5	500	-391.5
2007	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
2008	350	150	0.3	0	500	0	-391.5	0	108.5	500	-391.5
2009	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
2010	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
2011	350	150	0.3	0	500	0	-391.5	0	108.5	500	-391.5
2012	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
2013	350	150	0.3	0	500	0	-391.5	0	108.5	500	-391.5
2014	350	150	0	0.9	0	300	0	-169.5	130.5	300	-169.5
NPV									**1,217**	**3,800**	**-2,583**
NPV Ann									**121.7**	**380**	**-258.3**

Annex 2.4.2.6 The profitability of cotton cultivation in Mirzachul, all salinity levels combined (No LC, Only Cotton Scenario)

Year	Price	Yield	Total cost	Total sales	Net benefit
2005	350	1.5	500	525	25
2006	350	1.5	500	525	25
2007	350	1.5	500	525	25
2008	350	1.5	500	525	25
2009	350	1.5	500	525	25
2010	350	1.5	500	525	25
2011	350	1.5	500	525	25
2012	350	1.5	500	525	25
2013	350	1.5	500	525	25
2014	350	1.5	500	525	25
NPV			**$3,380**	**$3,548**	**$169**
NPV annual			**$337.95**	**$354.85**	**$16.9**

2.4.2 THE IMPACT OF SOIL SALINITY ON THE LIVELIHOODS OF FARMERS IN SYRDARYA PROVINCE IN UZBEKISTAN[18]

1. INTRODUCTION

In Uzbekistan's Syrdarya province soil salinity build-up is leading to growing abandonment of once fertile lands due to significant yield losses. Excessive leaching, a common practice of reducing salinity build-up in Central Asia (Vyshposky *et al.*, 2008) is not providing a viable solution to this problem, as it actually worsens soil salinity given the present inefficient operation of the drainage system. Moreover, excessive leaching also leads to the removal of essential nutrients from the soil (Vyshposky *et al.*, 2008). Three types of leaching are practiced by farmers in Syrdarya province: 1) deep flooding for highly saline areas, 2) shallow flooding for medium saline areas and 3) furrow leaching (or pre-tillage irrigation) for low saline areas. However, majority of on-farm drainage systems need massive rehabilitation for normal functioning which they are not at the moment. The problem becomes even more complicated because of the present nature of dividing responsibilities for the maintenance of the irrigation system. The State is responsible for inter-farm level and farmers for on-farm level. However, most of the farmers don't have the necessary financial resources for the upkeep of the on-farm drainage systems in their fields; moreover, given current land tenure rights with land rented out to farmers and not owned by them, there is no incentive for significant long term investment in rehabilitation. Furthermore, in view of the growing shortage of water resources in the region, leaching practices which involve up to 6,000 m^3 of water per hectare is not sustainable.

The rise in salinity is also caused by increases in ground water level, uneven field leveling, cotton and wheat monocropping and lack of agricultural machinery for appropriate cultivation and tillage, vast water losses at on-farm level as a result of wasteful irrigation methods involving furrow irrigation, etc. The choice of crop rotations is fixed by the State; consequently, cotton and wheat are planted in almost all arable lands. Alternative crops are planted on a limited areas. As a result, about 99.1% of the agricultural lands in Syrdarya are affected by different degrees of salinity (FAO, 2003). The salinization of agricultural land is spreading with dangerous speed, leading to the abandonment of up to 3% of irrigated area in Syrdarya annually (Kushiev *et al.*, 2005). This is endangering the livelihoods of already impoverished rural communities.

1.1. THE PROBLEM, HYPOTHESIS AND OBJECTIVES

The basic hypothesis for the study is that soil salinity in Mirzachul area of Uzbekistan is leading to increased vulnerability of farmers' livelihoods. All other factors being equal, there could be strong relationship between the level of soil salinity at the farm and the livelihood levels of farmers. However, in reality, farmers have various coping strategies which may affect the livelihoods outcomes in a manner that reduces the vulnerability caused by rising salinity levels. Thus, the study objective is to analyze the relationship between soil salinity and rural poverty and to identify the existing coping strategies, both agronomic and socioeconomic that farmers adopt to reduce the negative impact of soil salinity on their livelihoods.

The following research questions are posed:

1. *How salinity impacts the livelihoods of farmers in the target area?*
2. *What coping strategies farmers are adopting against salinity? How successful are they? How and who can facilitate the success of these coping strategies?*
3. *What actions and alternative policy and institutional options should be adopted to improve the livelihoods of farmers in saline areas and to ensure the sustainability of the resource base?*

[18] This component was led by ICARDA. NARS partners include Sadulla Avezbaev, Abdugani Mukumov Tashkent Irrigation Institute, Uzbekistan

2. MATERIALS AND METHODS

The methodology used for the livelihoods analysis in this study (Figure 2.4.3.1) is a simplified adoption from the Sustainable Livelihoods Approach Framework developed by DFID (2001) with a focus on assessing the impact of soil salinity on the livelihoods of farmers, as well as farmers' coping strategies under various soil salinity levels in Syrdarya province of Uzbekistan.

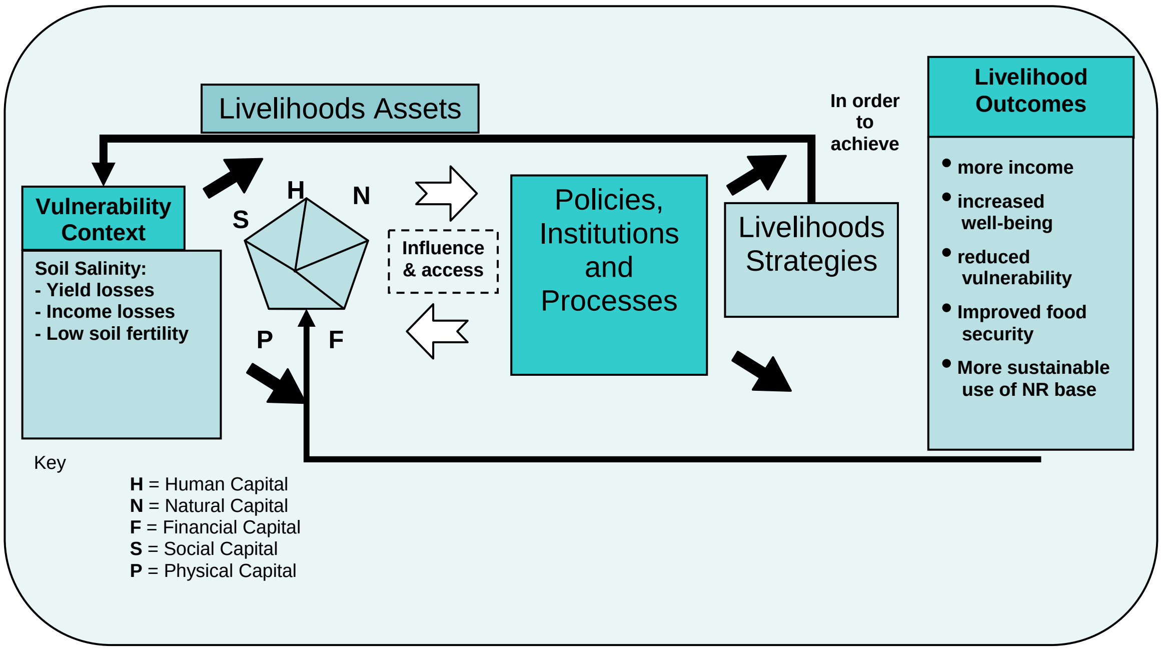

Figure 2.4.3.1 Framework for Sustainable Livelihoods, DFID (2001)

2.1. DATA COLLECTION

A sample of_150 farming households has been randomly selected from a total of 843 farming households in the Mirzaabad district of Syrdarya province. The farmers were selected from three salinity zones. Fifty farmers were selected from a high salinity zone, 50 from a medium salinity zone and 50 from a low salinity zone. The salinity levels were determined on the basis of existing local salinity maps produced by the provincial specialized bodies with the scale of 1:1000. The list of farming households and farm plot numbers, obtained from the local administration, was used to segregate the farmers into zones of different salinity levels based on the salinity maps.

Enumerators were selected from students at the Tashkent Irrigation Institute, Uzbekistan; they were trained on farm level survey techniques covering both theoretical and practical aspects for conducting the survey and data management. Field visits were undertaken as part of the training to give enumerators practical field experience of conducting the survey, and fine-tuning the survey instrument. Enumerators worked in pairs: one person interviewed farmers, while the second one was recording farmers' replies and whenever it was needed, provided assistance in accomplishing the interview. All data generated were entered into computer and e-database was developed in MS Excel. Then the data were transferred to SPSS software which was used in the analysis.

2.2. DATA ANALYSIS

Both qualitative and quantitative methods were used. The survey respondents were clustered into three salinity groups. In addition, the farmers in the target area were also classified into five clusters based on the area of their land plots, using hierarchal clusters. This was done in parallel to the salinity level clustering in order to capture the relationship between the farm size and various elements related to asset ownership, land quality and livelihoods strategies. The influence of salinity on ownership of various assets and farm profitability, as well as farmers' coping strategies were analyzed through descriptive statistics and comparing the means of selected indicators between salinity groups.

3. RESULTS AND DISCUSSION

3.1. HOUSEHOLD CHARACTERISTICS

3.1.1. HUMAN CAPITAL

The analysis showed that the majority of farming households in the target area are headed by males, i.e. 96%, while only 4% of farming households are headed by females. In those few households headed by females, 50% are married and living with their husbands, 33% widows, and 17% divorced. The female household heads were found to have, on average, slightly less saline lands than their male counterparts (Table 2.4.3.1), though it should be noted that the low number of female household heads in the total number does not allow making definite conclusions in this regard.

Table 2.4.3.1 Gender and distribution of saline soils

Household Head Gender	Salinity Zone Mean	Number of Households	Std. Deviation
Male	1.99	144	0.824
Female	2.17	6	0.753

The mean age of household heads is equal to 45.95 with standard deviation of 10.03, meaning that, on average, majority of farmers are between 35-55 years old (Figure 2.4.3.2). In addition, the analysis shows that the mean age slightly increases from high salinity to medium and to low salinity groups, meaning that the elder (and more experienced) farmers are slightly more likely to have better quality lands (Figure 2.4.3.3). Almost all farmers are married (94.7%). The households with lower salinity have on average more family members than those with higher soil salinity (Table 2.4.3.2.). Of the total number of farmers, only 36.7% have had previous jobs related to agriculture, and the rest have had varying professional backgrounds such as accounting, teaching, medicine, painting, etc (Table 2.4.3.3). In terms of education level, all farmers have at least the secondary level of education.

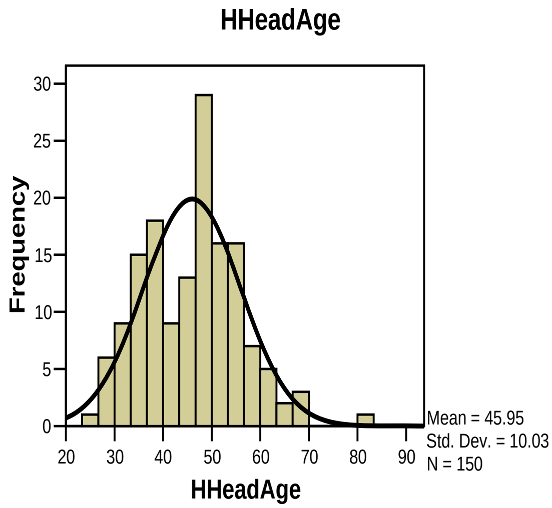

Figure 2.4.3.2. Age of farming household head

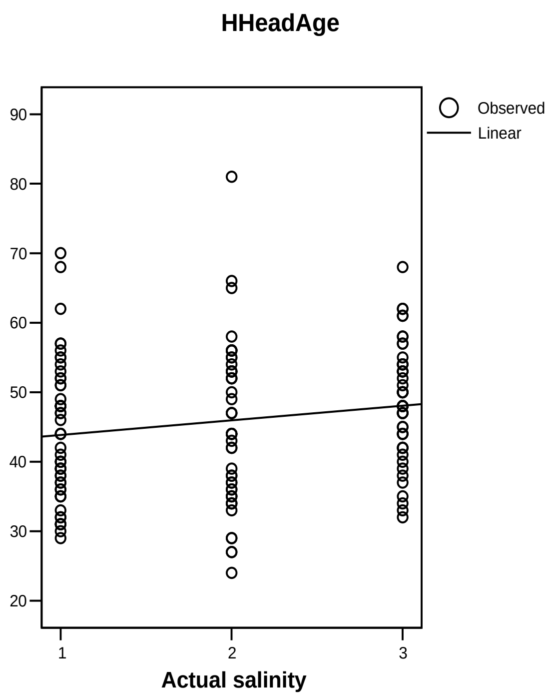

Figure 2.4.3.3 Age of farming household head by salinity group

Table 2.4.3.2 Salinity and number of household members

Actual salinity	Indicators	Number of family members
High	Mean	4.42
	Std. Deviation	1.05
Medium	Mean	4.60
	Std. Deviation	1.09
Low	Mean	5.36
	Std. Deviation	1.44

Table 2.4.3.3 Salinity and professional background of the farm head

Salinity Group	Previous Job in Agriculture (1-yes, 2-no) Mean
High	1.62
Medium	1.68
Low	1.60
Total	1.63

3.1.2. LAND ASSETS

Out of a total of 150 farmers, 146 have annually cropped lands, while the remaining four farmers have tree plantations and other types of lands. Almost all farming plots, except for two cases, were irrigated. The only method of irrigation applied by farmers is furrow irrigation. All farmers have their lands on a long-term lease following the dismantling of former collective farms. In general, the farmers in the target area could be classified into five clusters based on the area of their land plots, as shown in Table 2.4.3.4.

Table 2.4.3.4 Classification of farmers by land area

Clusters	Land Area	Number of farmers in the total (%)	Share of Land Area in the total (%)
Cluster 1	1-23 ha	50.0%	29.0%
Cluster 2	24-34 ha	28.7%	31.8%
Cluster 3	35-42 ha	12.0%	18.0%
Cluster 4	42-55 ha	5.3%	10.5%
Cluster 5	55-75 ha	4.0%	10.7%

Overall, the average landholding of the total sample was 25 ha. Out of total 150 farmers, 50% are in the first cluster with the land area between 1-23 ha, while 28.7 farmers (Cluster 2) have the land area of 24-34 ha, 4% have a land area of 35-42 ha (Cluster 3), 5.3% have the land area of 42-55 ha (Cluster 4), and 12% have the land area of 55-75 ha (Cluster 5). In terms of land distribution, 50% of farmers, which are smallholders with the land area between 1-23 ha, have only 29% of the total land area, while the 21.3% of farmers, with the land area of 35-75 ha, have almost 40% of the total land.

Out of the total land area of 3,816 ha cultivated by the survey respondents, 35% of the land has high salinity, 31% medium salinity, and 33% low salinity. Table 2.4.3.5 presents the data on distribution of lands with varying degrees of salinity across the five clusters based on farm size. The table demonstrates that smallholder farmers (Cluster 1) are actually better off than larger farmers in other clusters in terms of lower soil salinity. It should be also mentioned that those most affected by salinity are farmers who have the land area between 35-55 ha, while the situation is more complicated with the farmers having more than 55 hectares, who though have the highest percentage of high saline lands as a group, but at the same time there are significant variances at individual levels since the share of low saline lands in their total land area is also significant.

Table 2.4.3.5 Salinity and farm size

Salinity	Total Land Area, ha	Percentage (%)	Cluster 1	Cluster 2	Cluster 5	Cluster 4	Cluster 3
High	1,346	35%	28%	34%	39%	37%	49%
Medium	1,202	31%	36%	32%	28%	39%	16%
Low	1,269	33%	36%	33%	33%	25%	36%
Total	3,816	100%	1,105	1,214	687	402	410

3.2. FARMERS' PERCEPTIONS
3.2.1. SALINITY LEVELS

In terms of farmers' perceptions on the extent of salinity, on average, they seemed to be quite complacent indicating that major parts of their lands were not saline, across all the salinity levels (Table 2.4.3.6).

Table 2.4.3.6 Farmers' perceptions of the soil salinity in their plots

Salinity level	no salinity	low salinity	medium salinity	high salinity	abandoned
High	61.40%	11.28%	24.42%	0.90%	2.00%
Medium	68.65%	11.85%	18.46%	0.46%	0.00%
Low	64.64%	14.74%	15.66%	0.48%	0.72%

In addition, farmers reported that 15 hectares of land were abandoned because of salinity in the high salinity group, 2 hectares in the medium salinity group and 7 hectares in the low salinity group. The farmers in the low salinity group indicated that 64.64% of their lands were not saline, 14.74% - low saline, 15.66% - medium saline, and 0.48% highly saline, whereas farmers in the medium salinity group indicated that 68.65% of their lands were not saline, 11.85% - low saline, 18.46% - medium saline, and 0.46% highly saline. Similarly, the farmers in the high salinity group indicated that 61.40% of their lands were not saline, 11.28% - low saline, 24.42% - medium saline, and 0.90% highly saline. In this regard, even though in absolute terms, all farmers were not fully aware of the true extent of salinity in their lands, in relative terms between the salinity groups, the farmers' perceptions have shown a growing share of more saline areas from low salinity to medium and further to high salinity groups. The analysis also demonstrated that, even within each salinity group, there was no visible link between the farmers' perceptions on the extent of salinity in their lands and the actual crop yields.

3.3. STATE OF DRAINAGE SYSTEMS

In terms of their perception of the reasons for salinity farmers were unanimous in naming: 1) improper operation of the drainage systems, and 2) rise in ground water levels.

In the target area, 40% of the drainage system was found to be vertical drainage, 56% open horizontal drainage, and only 4% closed horizontal drainage. According to the farmers' perceptions, the quality of on-farm drainage networks is at medium level. It should also be noted that the farmers in the high salinity group are more optimistic on the quality of their on-farm drainage networks than those in the other groups, while the farmers in the medium group were the most pessimistic in this regard. As for the quality of inter-farm drainage system, 44.7% of all farmers indicated that it functions very bad, and 55.3% said that it functions at medium level, while none of the farmers said that the inter-farm drainage network functions well. The farmers in the high salinity group were more optimistic than in other groups about the functioning of the inter-farm drainage network, while those in the medium salinity group were the most pessimistic. When asked about the quality of land leveling in their fields, 80% of farmers in the high salinity group said that the quality of land leveling in their fields was medium and only 20% that it was bad. Similarly, 60% and 76% of the farmers in the medium and low salinity groups said that the quality of their lands was at medium level, respectively, and 40% and 24%, respectively, said that it was bad (Table 2.4.3.7).

Table 2.4.3.7 The quality of on-farm and inter-farm drainage network, and the quality of land leveling, (%)

Salinity level	On-farm drainage			Inter-farm drainage			Quality of land leveling		
	Excellent	Medium	Bad	Excellent	Medium	Bad	Excellent	Medium	Bad
High	10.92	75.14	13.84	0	70%	30%	0	80%	20%
Medium	4.7	66.74	25.16	0	42%	58%	0	60%	40%
Low	3.48	77.02	15.48	0	54%	46%	0	76%	24%

Probably, one of the reasons for the high salinity group farmers being complacent about the quality of land leveling in their plots was that they invested on average 31 USD over the last two years on land leveling, while the farmers in the medium group invested 19 USD, and those in the low salinity group invested only 15 USD, during the same period. This is consistent with the general view that uneven field leveling is one of the causes of rising salinity, whereby farmers in the high salinity have more uneven plots and have to spend more on leveling operations than those on the lower salinity groups.

The yield dynamics in these three salinity group clearly show the negative link between the level of salinity and cotton and wheat yields (as shown later in Table 2.3.3.10), however, the farmers' perceptions on the level of on-farm drainage indicate that those in the high salinity group, which are worst affected by salinity, are least concerned by the state of their on-farm drainage networks.

The level of ground waters, on average, was found to be at 1.8 meters in the high salinity group, at 1.9 meters in the medium salinity group, and at 2.0 meters at the low salinity group (Figure 2.4.3.4).

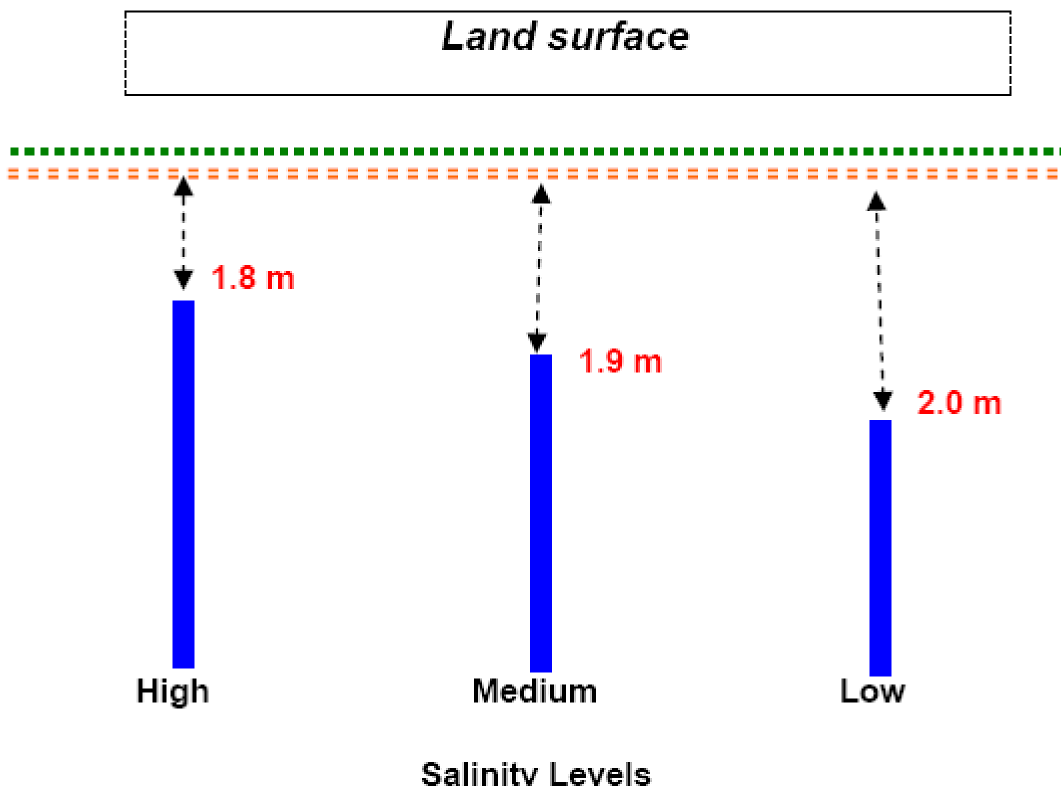

Figure 2.4.3.4. The depth of ground waters by salinity group

3.4. IMPACT OF SALINITY ON PRODUCTIVITY AND FARM INCOME

As reported by farmers, the yields of cotton have declined by almost 1 t/ha after the rise of salinity. In addition, the area under cotton was reduced, in total, by 9% after salinity as compared to the cotton area before salinity. However, it should be noted that cotton production has also been re-located from high and medium salinity zones to low salinity zones (Table 2.4.3.8). This was done by the State through its cotton quota planning, and not individually by farmers who, as leaseholders, are obliged to cultivate the crops mandated by the landowner – the State.

Table 2.4.3.8 Area and yield of cotton before and after salinity

Salinity Level	Cotton Area (ha)		Cotton Yield (t/ha)	
	Before*	**After****	**Before**	**After**
High	10.84	8.74	1.42	0.97
Medium	12.74	11.68	1.58	1.36
Low	12.72	13.29	1.79	1.50
Difference	**-2.59**		**-0.96**	

* Before: average yields before the occurrence of salinity, as reported by farmers
** After: average yields after the occurrence of salinity, as reported by farmers

For most of the farmers salinity occurred on 2003-2005. The farmers reported that salinity negative impact became most obvious starting from these years. The yields reports under 'before' were from the year of the salinity occurrence and 'after' is after the year when salinity occurred. We should note that these data represent farmer's perception only.

As for wheat, the yields have actually increased by more than 1 t/ha, and the area was increased by about 80%, across all salinity levels after the rise in salinity (Table 2.4.3.9), which is, in fact, more influenced by other factors rather then salinity, since wheat is known to be less salt tolerant that cotton. These factors could be the policies that have been giving priority to grain self-sufficiency, as well as the higher farmer incentive to grow wheat, which provides with hay as feed for livestock, and secondly, the grain produced above the State quota can be sold by the farmer in the market for cash, whereas in the case of cotton farmer will sell all the amount produced to the public ginneries.

Table 2.4.3.9 Area and yield of wheat before and after salinity

Salinity Level	Wheat Area (ha)		Wheat Yield (t/ha)	
	Before	**After**	**Before**	**After**
High	8.26	14.28	0.77	1.08
Medium	10.86	19.86	1.27	1.56
Low	12.18	22.32	1.21	1.69
Difference		**25.16**		**1.09**

When asked about the crops they cultivated during the last two seasons, for 2005, 38.0% answered that they cultivated only cotton as the first crop in their plots, while 47.4% cultivated both cotton and wheat as the first crops, and only 6.7% of farmers cultivated only wheat as the first crop. The remaining 2.7% cultivated maize as the first crop, and 5.2% of land was fallow during the same year. As for the double crops in 2005, 96% of land was left fallow after the first cropping, and the remaining 4% was planted with maize. However, in 2006, 34.7% have answered that they cultivated only cotton as the first crop in their plots, while 41.3 % cultivated both cotton and wheat as the first crops, and 19.3 % of farmers cultivated only wheat as the first crop in their land. In addition, 2% of land was left fallow, 2.7% was under maize as the first crop. As for the double crops, 97.3% of land was left fallow after the first crops, and only 2.7% was planted with maize as the double crop. The data show that over the two years of 2005 and 2006, there was a move to cultivating more wheat instead of cotton in the target area. However, double cropping remained very limited, and even declined in 2006 as compared to 2005. Besides, the only double crop that farmers said they were growing was maize (Figure 2.4.3.5). In terms of crop choice, there are not many differences across the salinity levels due to strict land use and cropping rules that farmers have to abide.

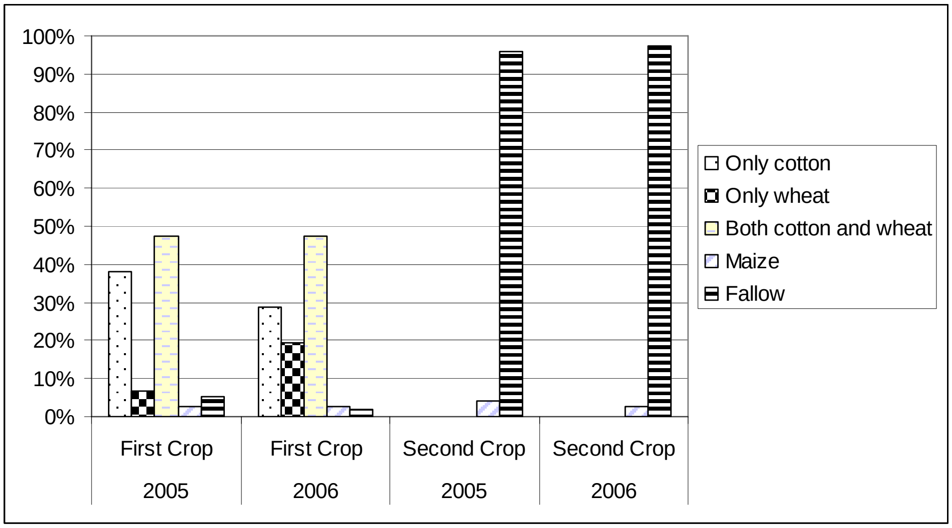

Figure 2.4.3.5 Land use in the target area

During 2005, farmers in the target area grewn mainly cotton and wheat, and a small amount of maize as the first crops. The mean yields of cotton and wheat grown as the first crop in 2005 depending on the salinity groups, as estimated from the responses of farmers, is shown in Table 2.4.3.10. Only 14 farmers out of the total 150 reported that they planted double crops during 2005. Mainly it was maize with the exception of one farmer who reported having planted cotton as double crop (with the yield of 0.8 t/ha). The average yield ranged between 1.9-2.2 t/ha, with the yields in the low salinity zone higher than in the high salinity zones.

Table 2.4.3.10 Mean cotton and wheat yields by salinity level, 2005

Salinity level	**Cotton**	**Wheat**
High	1.7	1.1
Medium	1.8	2.0
Low	2.0	2.6

The rise in salinity has had a noticeable impact on the agricultural productivity in the area. All other factors being equal, with the price of raw cotton at around 300 USD/t, farmers in the high and medium salinity zones lost on average 116 USD/ha and 77 USD/ha as compared to low salinity group farmers because of salinity. In the case of wheat, at a price of 100 USD/t, farmers in the high and medium salinity zones lost on average 149 USD/ha and 66 USD/ha as compared to low salinity group farmers because of salinity. The yields and profitability of maize were also lower at the high salinity group (4.1 t/ha) than in the medium (5.0 t/ha) and low salinity (6.04 t/ha) groups.

On average, those farmers, who have been able to clearly remember when the salinity has become a problem in their plots, have indicated that it had become a serious problem since 2003-2004 (Figure 2.4.3.6). However, this information should be treated with caution since most of the farmers in the sample were been given their lands only in 2003-2004.

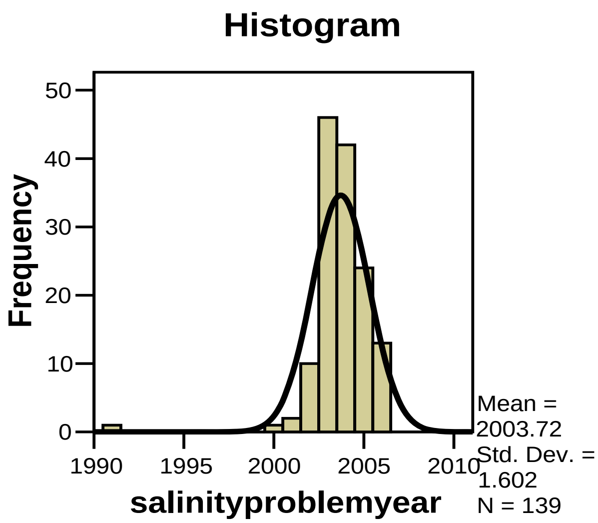

Figure 2.4.3.6 The year when salinity became a problem

Salinity has had a negative impact on the livelihoods of the majority of farmers across all the three salinity levels. Even though 100% of farmers in the high salinity and medium salinity groups have been negatively impacted by salinity, not all of them use salinity coping practices. However, when asked specifically about the change in their general livelihoods during the last year, only 25 farmers said that it has worsened (17%), 75 farmers (50%) felt no change, and actually 50 (33%) said that it has improved. These facts, in a way, suggest that farmers are using alternative livelihood strategies that compensate the income losses due to salinity (Table 2.4.3.11).

Table 2.4.3.11 Impact of salinity on livelihoods

Impact of salinity on livelihoods	Salinity Level		
	High	Medium	Low
Salinity negatively impacted my livelihoods	100%	100%	94%
I use salinity coping practices	92%	94%	96%
My livelihood improved during this year	19	12	19
There was no change in my livelihood during this year	21	29	25
My livelihood worsened during this year	10	9	6

3.5. FARMERS COPING MECHANISMS OF SALINITY BUILD-UP

3.5.1. HOW TO COPE WITH SALINITY: FARMERS' VIEW

The survey responses suggest that in the low salinity group, these strategies are livestock and livestock products, for medium and high salinity groups, these are renting out of farm machinery and implements. In addition, naturally, there could be other sources of off-farm income contributing to the livelihoods of the farmers in the area, even though, none of them mentioned that their family members went to other areas for work because of salinity problem.

When asked about cropping patterns and agricultural practices that they think would be more profitable than those they currently use, 50.7% - of farmers in the area have named livestock production, 34.7% named livestock production in combination with cultivation of alternative crops such as alfalfa and other fodder crops, 4% suggested cultivation of alternative crops, 4.7% - cultivation of cotton, 2% - cultivation of cotton,

wheat, diversified crops and livestock production together, 1.3% - poultry production, 0.7% - aquaculture, and 0.7% - cultivation of wheat. If taken together, almost 90% of farmers thought that livestock production and cultivation of alternative (mainly fodder) crops were more profitable than the current practices. This opinion was consistent throughout the three salinity levels (Table 2.4.3.12)

Table 2.4.3.12 Alternative more profitable livelihoods strategies, as suggested by farmers (%[19])

Alternative Strategies	Salinity Level		
	High	**Medium**	**Low**
1-cotton	2%	4%	1%
2-wheat	1%	0%	0%
3-livestock	26%	26%	24%
4-diversified crops	1%	2%	5%
5-cotton, wheat, livestock, diversified crops	1%	0%	2%
6-livestock, diversified crops	17%	18%	17%
7- fish	1%	0%	0%
8-poultry	1%	0%	1%

3.5.2. AGRONOMIC PRACTICES

With respect to immediate coping strategies to address salinity, all of the farmers said that it is possible to improve the soil fertility in their plots. When asked what can be used to improve the soil fertility in their plots, 76% of farmers indicated leaching in combination with more manure application, 13% said that in addition to leaching and manure application, land leveling should also be used more intensively. Contrasting this, 6.7% thought that manure application would be sufficient, while 2.7% said that leaching would be sufficient. Only 1.3% indicated that the drainage system should be improved.

The farmers indicated that they have a good knowledge of leaching, fertilizer application and land leveling; however, they indicated that their knowledge of water saving technologies was quite low. In terms of using these technologies, almost all of the farmers said that they use leaching, fertilizer application and land leveling, however; only 70% reported that they use water saving technologies (Table 2.4.3.13).

Table 2.4.3.13 Salinity coping practices: farmers' knowledge and use

Salinity coping practices	Knowledge of Technologies			Use of Technologies	
	Full	**Medium**	**Low**	**Yes**	**No**
Leaching	91%	9%	0%	99%	1%
Water saving technologies	25%	67%	7%	69%	31%
Fertilizer application	93%	7%	0%	99%	1%
Land leveling	93%	7%	0%	99%	1%

With regard to different salinity groups, the analysis revealed that in terms of average perceptions, farmers in the high salinity group are more confident about their knowledge of salinity coping technologies, however, in terms of use, those in the low salinity group, appeared to be using these technologies slightly more consistently.

Farmers in the high and medium salinity groups did not indicate that they invested in the cleaning of their on-farm drainage networks. In the low salinity group only 1 farmer said he has invested the equivalent of 31 USD in cleaning his on-farm drainage in 2006. All of the farmers are members of farmers' and water users' associations.

[19] The most important alternative strategies indicated by farmers are highlighted in blue background color

In total, 63.3% of farmers would like farmers' and water users' associations to help them in cleaning the drainage network, 26% of farmers have the desire that the associations should help them in learning more about water saving technologies and improving the operation of the drainage networks, 6.7% of farmers wanted the associations to help them with land leveling and cleaning of drainage networks, 3.3% needed advise on appropriate land management technologies and drainage. Thus, almost all farmers expressed their wish that associations help them to improve the drainage networks. All farmers also indicated their readiness to participate in this effort by contributing some funds.

Leaching, a traditional method of salinity management, is widely applied by farmers in the target area. If in 2004, almost 70% of farmers had leached their lands, and 30% did not leach, in 2005, 84% of farmers had leached their lands and only 16% did not leach. So, between these two years, the number of farmers who leached their lands increased by 20%, which may imply further exacerbation of the salinity problem.

The data shows, farmers in low saline areas have leached their lands more consistently than in other two salinity levels, with the high salinity group leaching the least (Table 2.4.3.14).

Table 2.4.3.14 Leaching by salinity groups

Salinity level	Indicators	Leached in 2004 (yes-1, no-2)	Leached in 2005 (yes-1, no-2)
High	Mean	1.30	1.18
	Std. Deviation	0.463	0.388
Medium	Mean	1.30	1.20
	Std. Deviation	0.505	0.404
Low	Mean	1.27	1.10
	Std. Deviation	0.446	0.306

In terms of phosphorus fertilizer application (total weight), the mean application has increased across all the salinity levels from, 117.2 kg/ha to 151.19 t/ha between 2005 and 2006. However, the low salinity group applied more phosphorus fertilizers than the other two groups in 2005 (126.86 kg/ha) in 2005, while in 2006, the medium salinity group applied the highest amount (158.94 kg/ha). Further, the high salinity group applied the least amount of phosphorus fertilizers during 2005 and 2006 (Figure 2.4.3.7).

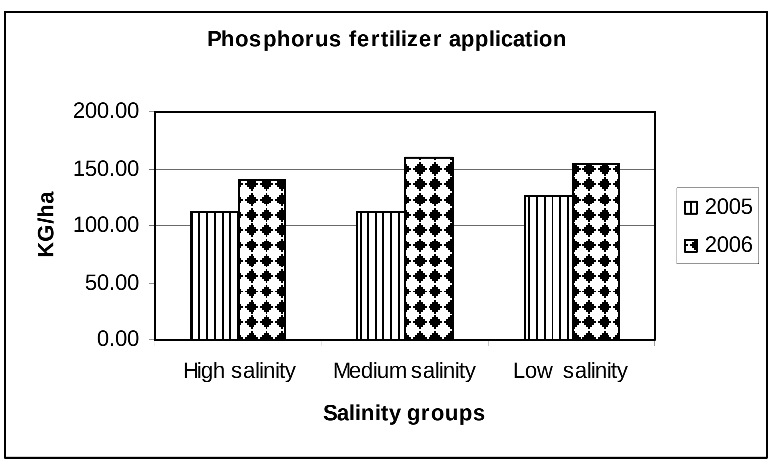

Figure 2.4.3.7 Phosphorus fertilizer application, kg/ha

In this regard, it should be noted that the phosphorus fertilizer requirement (active nutrient weight) in irrigated areas for cotton and wheat ranges between 100-165 kg P/ha according to the recommendations of the Ministry of Agriculture and Water Resources of Uzbekistan. As we can see from the above data, the farmers are applying significantly lower amount of phosphorus fertilizers (in terms of active weight, which is

about 21% of the total weight in "ammonium superphosphate", the traditional source of N- and P-fertilizers in Uzbekistan) than the recommended norms.

Contrasting this, almost 93% of all respondents are also applying manure to complement the inorganic fertilizers. In this regard, the farmers in the low salinity group are applying the manure more consistently than other groups, though the farmers in the high salinity group are spending slightly more money (i.e. applying more manure) on the manure than the other two groups (Table 2.4.3.15).

Table 2.4.3.15. Manure application

Salinity level	Manure application (mean, yes-1, no-2)	Manure total value (USD)	When manure is applied (Mean)	Std. Deviation of manure application time
High	1.06	16	2,005.47	1.080
Medium	1.08	15	2,005.57	0.620
Low	1.04	14	2,005.80	0.456

2.5.3. LIVESTOCK PRODUCTION

The total amount of livestock assets in all the 150 farming households makes up 125,948 USD, 90% of which coming from cows, bulls and sheep (Table 2.4.3.16). Table 2.4.3.17 indicates that the low salinity group overall, has the highest number and value of livestock assets, followed by the medium salinity group, while the high salinity group is lagging significantly behind. If analyzed from the point of view of farm size, medium size farm holders (cluster 3 with 35-42 ha) have the highest mean value of livestock assets, while those in clusters 4 and 5 (more than 35 ha) have the least value. Smallholder farmers (clusters 1 and 2), in general, have more livestock assets than large farmers (clusters 4 and 5).

Table 2.4.3.16 Number and value of livestock

Livestock	Total Number	Mean number per farming household	Total value (USD)	Mean value per farming household (USD)
Beef cattle	0	0	0	0
Milk cows	261	1.74	76,085	507
Breeding bulls	79	0.53	21,746	145
Horses	9	0.06	3,385	23
Donkeys/Mules	48	0.32	1,281	9
Sheep	224	1.49	16,078	107
Goats	34	0.23	1,285	9
Chickens	881	5.87	4,848	32
Ducks	83	0.55	995	7
Turkeys	36	0.24	246	2
Total	**1,655**	**11**	**125,949**	**841**

Those farmers in the lower salinity groups gained more income from the sale of livestock than those in higher groups, while those in the higher groups bought more livestock than those on lower salinity groups during 2005 and 2006. Interestingly, the income from sales was almost 8 times higher than the spending on acquisitions, which testifies that livestock is an important source of supplementary income for the farmers. The farmers in low salinity group have gained 7.5 and 1.7 times more income from livestock than farmers in the high and medium salinity groups, respectively (Table 2.4.3.18).

Table 2.4.3.17 Number and value of livestock by salinity group

Salinity levels	Indicators	Milk cows	Breeding bulls	Horses	Donkeys Mules	Sheep	Goats	Chickens	Ducks	Turkeys	Total
High	Mean	398	72	6	5	87	13	25	2	0	609
Medium	Mean	578	159	0	11	127	2	39	8	5	928
Low	Mean	546	204	62	9	107	11	33	10	0	982
High	Sum	19,912	3,577	308	275	4,369	662	1,240	92	0	30,434
Medium	Sum	28,892	7,962	0	538	6,342	77	1,953	408	246	46,418
Low	Sum	27,281	10,208	3,077	468	5,367	546	1,655	495	0	49,096

Table 2.4.3.18 Purchase and sale of livestock assets

Salinity level	Sell	Buy	Difference
High	772	331	441
Medium	2,178	264	1,914
Low	3,560	240	3,320
TOTAL	**6,509**	**835**	**5,675**

When each livestock and poultry component are considered as an enterprise irrespective of its value, the farmers in the target area have increased their total number of livestock and poultry during the last 2 years by 230 units, as presented in Table 2.4.3.19. Again, farmers in the lowest salinity group were more successful than in higher salinity groups in increasing their number of livestock and poultry (Table 2.4.3.19). Considering the value of livestock, our estimates show that the farmers in all the salinity levels increased their livestock assets, but those in the low salinity level increased them more than other groups (Table 2.4.3.20).

Table 2.4.3.19 Livestock dynamics, numbers

Salinity levels	Total beginning	Buy	Sell	Eat	Dead	Gave	Received Born	Total End	Difference
High	449	8	2	86	3	17	181	530	+ 81
Medium	612	37	22	149	10	24	223	667	+ 55
Low	594	27	12	129	1	22	231	688	+ 94

Table 2.4.3.20 Dynamics in livestock assets, (in USD)

Salinity level	Total beginning	Sell	Buy	Eat	Dead	Gave	Received Born	Total end	Difference
High	30,434	772	331	1,232	82	353	7,368	36,576	+ 6,142
Medium	46,418	2,178	264	2,469	336	260	5,931	51,198	+ 4,779
Low	49,096	3,560	240	2,588	291	1,982	8,270	55,825	+ 6,728

The analysis indicates that farmers at all levels of salinity do buy feed for their livestock and poultry from external sources. The highest amount of funds are spent on the feeding for cows, bulls, and sheep (Table 2.4.3.21). **Table**

2.4.3.21 Expenditure on animal feed (in USD)

Salinity level	Milk Cows	Breeding bulls	Horses	Donkeys	Sheep	Goats	Chicken	Ducks	Turkeys	Total
High	763	250	19	0	78	14	56	0	0	1,180
Medium	990	418	0	25	153	6	50	0	0	1,643
Low	1,230	951	0	4	272	15	77	9	27	2,585
Total	**2,984**	**1,619**	**19**	**29**	**503**	**35**	**182**	**9**	**27**	**5,409**

Livestock and poultry products (i.e. eggs, milk, meat, skin, etc) are mainly consumed domestically. In total, 13% farming households indicated that they sell milk, 2% sell bull skins, 1.3% sell mutton, 13.4% sell eggs. Major sources of income from livestock products are milk (48%) and animal skins (42%). Farmers in the low salinity group gain significantly more additional income from the sale of livestock products that those in the higher salinity groups (Table 2.4.3.22). With respect to farm size, farmers engaged in the sale of livestock products are mainly small and medium size farmers (Table 2.4.3.23)

Table 2.4.3.22. Sales of livestock products

Salinity level	Sales (USD)
High	704
Medium	124
Low	5,500
Total	**6,328**

Table 2.4.3.23 Sales of livestock products by farm size

Clusters	Area	Sales, USD
1	1-23 ha	1,130
2	24-34 ha	1,525
3	35-42 ha	3,595
4	42-55 ha	38
5	55-75 ha	40
Total		**6,328**

If we include the income from the sale of livestock products as well, and exclude the costs of purchase of feed, the low salinity farmers, in total, gained additionally 9,643 USD from livestock, while their counterparts in the high and medium salinity levels gained only 5,666 USD and 3,260 USD, respectively, over the past two years.

2.5.4. MACHINERY RENTING

It was estimated that the 150 farmers own in total almost 150,000 USD worth of various machinery and equipment, which makes the mean value of machinery ownership per farmer equal to 1,000 USD (Table 2.4.3.24)

Table 2.4.3.24 Number and value of farm machinery and implements

	Number			Value, USD		
Machinery types	**Sum**	**Mean**	**St.Dev.**	**Sum**	**Mean**	**St.Dev.**
Large tractor (>12 horse power)	13	0.09	0.28	93,594	624	4,080
Small tractor (<12 horse power)	17	0.11	0.32	43,000	287	874
Harrower	9	0.06	0.24	838	6	23
Plough	6	0.04	0.20	1,346	9	53
Water pump	12	0.08	0.27	4,231	28	114
Sprinkler	1	0.01	0.08	69	0	6
Motorized thresher	1	0.01	0.08	69	0	6
Hand thresher	6	0.04	0.20	88	1	3
Mill	7	0.05	0.21	3,485	23	129
Machine to process livestock feed	6	0.04	0.20	1,018	7	75
Motorized insecticide pump	7	0.05	0.21	90	1	3
Big cart	41	0.27	0.46	1,747	12	23
Small cart	35	0.23	0.45	407	3	6
Total	**161**	**1.07**		**149,982**	**1,000**	

In terms of salinity level groups, those in the medium salinity group possess machinery with the a value almost 4 times greater than farmers in the low salinity group, and 2 times greater than those in the high salinity group. With regard to number of units, medium and low salinity groups possess the same number of various equipments (60), while those in the high salinity groups possess almost 30% less units equipment than the other two groups. This can be explained by the fact that the farmers in the low salinity group possess large

numbers of relatively cheap equipment such as big and small carts, livestock feed processors, hand threshers, i.e. the equipment needed for the transportation of produce and fodder, as well as the equipment related to livestock production (Table 2.4.3.25).

Table 2.4.3.25 Number and value of farm machinery and implements by salinity group

Salinity level	Value, USD	Units
High	44,027	41
Medium	83,891	60
Low	22,064	60
Total	**149,982**	**161**

Sharing equipment is virtually non-existent. Out of the total 161 units of various equipments, the farmers reported that they share with others only 1 tractor and 1 water pump (both in the medium salinity group). Buying and selling of machinery is also insignificant. During the last two years, only 1 hand thresher and 1 big cart was bought by a farmer in the low salinity group, and only 1 pesticide pump was sold by a farmer in the medium salinity group.

The market for renting of the equipment seems to be relatively more active. The usual equipments which are rented out are large and small tractors, ploughs, water pumps, harrowers, sprinklers, mills and insecticide pumps. The largest sources of income from renting are realized with (1) small tractors, (2) large tractors, (3) water pumps, and in the declining order from mills, harrowers and ploughs. In total, the medium salinity group farmers gained the most amount of additional income from renting out various equipments, followed by high salinity group farmers (Table 2.4.3.26). In this regard, it is likely that low salinity farmers are renting equipment from the other two groups, especially small tractors and harrowers. However, the medium salinity group farmers are also spending a lot on repair costs to maintain their relatively larger stock of equipment. The analysis shows that if we look at the ultimate result, the high salinity group is gaining more net income from renting out the equipments that the other two groups (Table 2.4.3.26).

Table 2.4.3.26 Income from machinery (in USD)

Salinity level	Income renting out, USD	Repair Costs, USD	Net income, USD
High	2,512	478	2,033
Medium	3,903	2,027	1,876
Low	1,300	379	921
Total	**7,715**	**2,885**	**4,830**

The analysis also demonstrates that small and medium size farmers own almost 85% of the available machinery. They earn 95% of the total income from renting out of farm machinery and implements (Table 2.4.3.27). One probable explanation is that farm machinery and implements which previously belonged to the collective farms were distributed/privatized to farmers on per head basis, and not on the basis of land area ownership. As a result, currently, large size farmers are experiencing shortages of machinery and implements, and have to rent them from the small size farmers.

Table 2.4.3.27 Machinery ownership and income by farm size

Cluster	Land area	Share of machinery value (%)	Income from renting out, USD
1	1-23 ha	49%	2,415
2	24-34 ha	23%	3,207
3	35-42 ha	13%	1,673
4	42-55 ha	13%	208
5	55-75 ha	2%	212

2.6. POLICY DIMENSIONS

One of the major policies that affect farming practices anywhere in the world is the land tenure. In this regard, it should be noted that in Uzbekistan land is rented out to farmers, usually for 50 years, but, importantly, farmers have no choice but to cultivate cotton and wheat on most of their lands that are specifically allocated by the State cadastre. In addition, local administration can expropriate land in cases where the farmer is unable to fulfill the State annual quota/plan over three consecutive years. The plan production levels are based on the land quality characteristics and yield potential as registered in the State land cadastre.

The current absence of water pricing, whereby water is virtually free, is not conducive in facilitating the adoption of on-farm water saving technologies as well as to the productive management and use of water resources both at watershed and on-farm levels. Significant amounts of water are lost during delivery due to dilapidated irrigation systems in addition to on-farm wasteful use.

A lack of extension systems is a further institutional obstacle. Farmers' and Water Users' Associations are not yet fully playing their role in providing the required extension services and associated support to farmers.

Livestock production as an alternative strategy in enhancing incomes and livelihoods would require increased production of fodder crops, which will ultimately lead to more pressure for changes in cropping patterns in the area by re-orienting them from cultivation of cotton to more of wheat and fodder crops such as alfalfa.

Overall, an enabling policy framework is essential for combating salinity and related economic and social problems. Based on the results of the analysis, recommendation are made at the conclusion of this section..

2.7. SHORT-TERM REMEDIES VERSUS LONG-TERM SUSTAINABILITY

Farmers in the in the target area are adopting various coping strategies in an attempt to address issues associated with growing salinity, which has had a significant impact on their livelihoods. These coping strategies include both agronomic (better land leveling, fertilizer and manure application, etc), and alternative livelihood strategies such as livestock production and machinery renting. Even though the study did not analyze the off-farm income sources of the farmers, it is expected that a portion of their incomes originate from off-farm sources. However, it should be clearly highlighted that these remedies, in spite of being extremely helpful, are only short term measures. The increasing salinity problem in the area can only be addressed through the rehabilitation and maintenance of the drainage and irrigation systems.

3. CONCLUSIONS AND RECOMMENDATIONS

1. The study sheds light on the attributes of a typical farming household in the target area, consisting of 4-5 family members, headed by a male at the age of 35-55 years old, and who usually does not have much previous experience of agriculture, but has sufficient educational background to understand, learn and assimilate appropriate agricultural practices.
2. Elderly farmers, who have also slightly more family members, have slightly better experience in agriculture, are better placed than their younger counterparts, in terms of their land quality.
3. Since current farmers have highly varying professional backgrounds, with most of them having little or no previous experience of agriculture, capacity building and farmer trainings should become an important part of efforts for improving agricultural productivity and achieving the sustainable use of resources.
4. The pre-dominance of male farm heads underlines that the efforts on technology up- and out-scaling, farmer capacity building and knowledge dissemination should be conceived to target a male audience for the maximum impact on the ground. Even though, the distribution of land among farmers is somewhat unequal, whereby 50% of farmers have only 29% of land, in terms of salinity level, smallholder farmers seem to have slightly better quality lands than their bigger counterparts, with the farmers having medium size farms (24-55 ha) suffering the most from salinity. Thus, targeting salinity

management technologies at these medium size farmers, which represent 61.3% of the total land share in the target area, could deliver the biggest impact on the ground in the short run.

5. Farmers' perceptions on the level of salinity in their lands are best described as complacent. Therefore, more training and education efforts should be directed at increasing the awareness of farmers on losses due to soil salinity and practices to cope with salinity. This complacency may in part be associated with insecure property rights, suggesting that they do not want to report a negative impression of land quality for fear of being labeled a bad farmers not taking care of the land.
6. Cotton and wheat monocropping prevail in the target area, with an increasing share of wheat over the last two years. Double cropping is virtually non-existent. Introduction of double cropping, especially incorporating legumes, could provide significant opportunities for improving the soil fertility and enhancing the farmers' livelihoods.
7. Increase in the use of leaching over the last two years indicates that the salinity problem is worsening in the area. Farmers, who leach their lands more consistently, apply organic and inorganic fertilizers more consistently were found to have lower salinity soils.
8. Farmers are more skeptical about the functioning of inter-farm drainage networks, and rather complacent about the quality of functioning of their own on-farm drainage networks.
9. Livestock is an important source of additional income and livelihoods strategy for farmers in rural areas. Additional income from livestock also provides flexiblility with respect to capital to invest in timely farming operations. The analysis demonstrated that farmers in the low salinity group were more actively engaged in livestock production and actively supplementing their incomes from crop production with income from livestock than farmers in the higher salinity groups. This would suggest that smallholder and medium size farmers are more actively benefiting from livestock production than large size farmers.
10. The main livestock products that are marketed by farmers are milk, animal skin and eggs. In this regard, small scale dairy and skin processing technologies could contribute significantly to the livelihoods of smallholder farmers in the area.
11. Average machinery ownership in the target area is very small. The values of equipments reveal that the farmers mainly own old equipment, with very few cases of new equipment.
12. Medium salinity group farmers own the largest share of the equipments in terms of value, though the farmers in the high salinity group are earning the highest income among the three groups from renting out farm machinery and implements.
13. Small and medium size farmers are better placed than large size farmers in terms of machinery ownership.
14. Machinery cooperatives could be very useful for ensuring timely on-farm operations in the area. In this respect, large size farms would be the most susceptible and willing agents for this change, since they are suffering the most from shortage of farm machinery and implements. However, it should be noted that currently renting out farm machinery is an important alternative source of income for high salinity group and small and medium-size farmers, hence social and economic trade-offs should be weighed appropriately on this matter.
15. The analysis clearly indicates the economic losses caused by salinity due to decreases in the crop yields.
16. Over the last two years, the share of wheat in the agricultural production has increased at the expense of cotton.
17. Huge potential for double cropping remains under utilized with almost all land being left fallow after the first crops. With the increase of the share of wheat in the total land use, the opportunities for double cropping are further increased. Legume crops that have good market value and fodder for livestock, hence increasing farm income and improving soil fertility, should be introduced into the farming system.
18. In view of important livestock related activities, farmers in the low salinity group (and small and medium size farmers) will be the main beneficiaries and drivers for change in favor of double cropping with fodder crops. In addition, double cropping with legumes could also assist farmers in high and medium salinity groups to improve the soil fertility and raise incomes. Even though salinity is seriously impacting the livelihoods of farmers, farmers' overall living standards are supplimented up

by alternative livelihood strategies that they are adopting. These additional sources of income are derived predominantly from livestock production, machinery leasing, and off-farm income.

19. Most of the farmers would like to change their cropping patterns towards cultivation of alternative crops such as alfalfa, maize and other fodder crops. They also would like to re-orient their activities to livestock production.
20. The major area for collective action was indicated to be cleaning of drainage networks. Though farmers indicated that they are willing to support actions in this regard by contributing funds, only 1 farmer has invested individually on cleaning of his on-farm drainage over the last couple of years. More active contribution of farmers' and water users' associations is desired by farmers with regard to cleaning of drainage networks and providing them with extension services.

3.1. RECOMMENDATIONS

The study results have clearly shown that soil salinity has a negative impact on the livelihoods of farmers. Soil salinity is decreasing farmers' income from crop production due to yield losses. However, farmers are adopting various alternative livelihoods strategies to improve their livelihoods. Two such strategies that clearly came out from the results of the study are livestock production and renting out of farm machinery. To this, off-farm sources of income should also be added, even though, the exact extent of their importance is not covered by this study. To further facilitate the success of existing coping strategies and reduce the impact of salinity on the farmers' living standards as well as environmental sustainability, the following are recommended:

Recommendation 1. There seem to exist two options for public policy with regard to agricultural production in the area in order to raise the living standards of the farmers and ensure the sustainability of the functions of natural resource base: a) investing more and ensuring the proper operation of drainage networks, and/or b) re-orienting farmers from cotton-wheat rotation to the production of alternative fodder, legume, as well as other salinity-resistant crops. A medium term action in this regard, could be re-visiting the land use planning in a way that would allow farmers to grow cotton and wheat in low saline areas, and salinity- and drought-resistant fodder and legume crops in the high saline areas.

Recommendation 2. Huge opportunity could be capitalized on if farmers are allowed to grow double crops after the harvest of winter wheat.

Recommendation 3. Wide-scale dissemination of water saving technologies such as cutback irrigation, alternate furrow irrigation, sprinkler systems for high value cash crops, etc should become an important element of public policy through creating an enabling environment and strengthening the extension institutions (farmers' associations, WUAs, agro-firms). Appropriate water pricing could provide a strong incentive for improving the water use efficiency at on-farm level, however, the irrigation networks, where the major part of the water is lost, should receive a priority attention.

Recommendation 4. Credit and leasing facilities should be further increased for farmers to lease farm machinery and implements, small scale dairy, animal skin and meat processing units.

2.4.3 THE IMPACT OF SOIL SALINITY ON THE LIVELIHOODS OF FARMERS IN AKDEPE DISTRICT OF TURKMENISTAN[20]

1. INTRODUCTION

In Turkmenistan's Akdepe district soil salinity build-up is reducing the productivity of the natural resource base and impacting on the farmers' livelihoods in a very negative way. The majority of on-farm drainage systems need massive rehabilitation for normal functioning which they are not at the moment. The rise in salinity is also caused by increases in ground water level, uneven field leveling, cotton monocropping and lack of agricultural machinery for appropriate cultivation and tillage, vast water losses at on-farm level as a result of wasteful irrigation methods involving furrow irrigation, etc. This is endangering the livelihoods of already impoverished rural communities.

Akdepe district is located at the central part of Dashauz province. It borders with Kyoneurgench and Boldumsaz districts in north (which border with Uzbekistan), and in east and south-east with Gurbansoltan district, and in south with rangelands of Niyazov district, and in the west with rangelands of Boldumsaz district. The average annual temperature is +11.6º, the maximum temperature is +43º, the minimum temperature is (-32º). Precipitation in the winter occurs from September till March is 50 mm and in summer season from July till October 48 mm. The average annual precipitation is 98 mm. The duration of warm period is 186 days. The average number of days with snow cover on the ground is 10-15. Dust storms occur during 21 days per year, mainly in April, May, and June. Average annual air humidity 58%, with the minimum of 11%, and the maximum 75%. The total area of the district, including rangelands, is more than 1 million ha, of which about 60,000 ha are under irrigated agriculture.

In short, the Akdepe district is subject to cold winters and hot summers. Although the vegetation period is relatively short, crops such as cotton, wheat, rice, and fruits and grapes are grown. The climate of the district is not propitious for irrigated agriculture, as the soils could become highly saline due to high summer temperatures, low precipitation, low air humidity, which cause high evaporation as a result of which soluble salts are brought to the surface.

The landscape is generally a plain-type with a slope in north-west direction. The irrigated agricultural lands are divided into zones by sandy patches (deserts). The overall landscape of the district undergoes changes as a result of human activity, i.e. leveling works tend to make the surface more flat, and irrigation and drainage networks, their cleaning, the changes in their locations impact the landscape. The irrigated areas, generally, have a flat surface and are well suited to mechanized tillage and irrigation. Slopes are insignificant, which contribute to the rise in salinity and make it difficult to irrigate agricultural land using natural flow of water.

The soils of the district have the following salinity properties at 0-30 cm depth: low salinity- 25% of the total area, medium salinity - 35%, high salinity - 20%, extremely saline - 20% of the total area (no agriculture is possible on these soils), on the basis of last soil maps produced in 1990. The irrigation water comes mainly from canals originating from the Amudarya river. The quality of water is quite saline because of drainage waters that are returned to the river in the upstream portions of Amudarya in the territory of Uzbekistan. The population is a little more than 100,000 people, and there are about 15,000 households. More than 65% of the population is employed in agriculture.

The main changes having occurred in Turkmen agriculture after the Independence can be characterized as a shift from collective farming to a more individualized agriculture. The first step (1990-92) involved distribution of irrigated land to rural families, which more than doubled the total size of the household-plot sector to 133,000 hectares. The second step (1993-96) involved a national program for allocation of land to independent private farmers who were allowed to engage in commercial agriculture outside collectivist

[20] This component was led by ICARDA. NARS partners include Serdar Rozyev, Ministry of Agriculture, Turkmenistan, Redjeb Hakimov, Akdepe district administration.

frameworks. Today there are more than 5,000 such private farms in Turkmenistan (the numbers are very fuzzy) operating on 81,000 hectares. The third, and perhaps the most daring and radical step (1996-97) involved the transformation of former collective and state farms into associations of leaseholders. So-called "peasant associations" (*daikhan berleshik*) were summarily organized by presidential decree in place of the traditional collective and state farms, and each association was instructed to parcel out its large fields to individual leaseholders (typically heads of families).

The continuing existence of state orders in Turkmenistan is a legacy of the Soviet centrally planned system. Turkmenistan has liberalized much of its agricultural production and food trade, but the main strategic commodities—cotton and wheat (as well as the much less important rice)—remain subject to state orders. As in the past, production targets for wheat and cotton are assigned to large farming units—peasant associations in this case; and the association manager divides the overall quantities among the leaseholders so that the full target is met (or exceeded).

This highly bureaucratic system applies only to state orders, i.e., wheat, cotton, and rice, but it is designed in such a way that the leaseholder must deliver the entire output to state marketers: otherwise there will be no credit entry in the bank account to offset the debits for inputs. Commodities not subject to state orders, such as vegetables, milk, or eggs, are generally produced under different institutional arrangements on the family's household plot and are sold in the nearby market or through occasional private traders: there are no state marketers to deal with these commodities and the association is not geared to provide cooperative marketing services.

Ministry of Agriculture has transferred its former responsibility of fulfillment of state order for wheat and cotton production, as well as the functions of agricultural services, to the newly established associations and state concerns. Therefore, the Ministry has retained and strengthened only its policy role in agricultural sector.

Ministry of Water Management is specialized in designing, maintenance and construction of irrigation and drainage canals, as well as for the organization of training workshop to introduce modern irrigation techniques and saline water use in agriculture. Soil and water monitoring as well as hydro-ameliorative units, are the responsibility of this Ministry. Ministry of Water Management should monitoring the water management on field.

1.1. PROBLEM DEFINITION

The basic hypothesis for the study is that soil salinity in Akdepe district of Turkmenistan is leading to increased vulnerability of farmer livelihoods. Though, all other factors being equal, it is hypothesize strong relationships between the level of soil salinity and the livelihood levels of farmers are prevalent. Farmers adopt various coping strategies that affect livelihood outcomes in a manner that reduce the vulnerability caused by salinity build-up. Thus, the objective of the study is to analyze the relationship between soil salinity and rural poverty in the target area and to identify the existing coping strategies, both agronomic and socioeconomic, that farmers adopt to reduce the negative impact of soil salinity on their livelihoods.

The study aims to answer the following research questions:

1 How salinity impacts the livelihoods of farmers in the target area?
2. What coping strategies farmers are adopting against salinity? How successful are they? How and who can facilitate the success of these coping strategies?
3. What actions and alternative policy and institutional options should be adopted to improve the livelihoods of farmers in saline areas and to ensure the sustainability of the resource base?

2. METHODS AND MATERIALS

The methodology used for the livelihoods analysis in this study is a simplified adoption from the Sustainable Livelihoods Approach Framework developed by DFID (2001) with a focus on assessing the impact of soil salinity on the livelihoods of farmers, as well as farmers' coping strategies under various soil salinity levels in Akdepe district of Turkmenistan. The methodology has been described in the previous section and will not be repeated here.

2.1. SURVEY DESIGN

Sample criteria

Sample criteria were based on the following points:

- Area where the Project technologies are being tested
- The existence of high, medium and low salinity zones
- Random sampling from three salinity level zones

Sampling unit and sample size

For the purposes of this study, 120 farming households were randomly selected in the Akdepe district of Turkmenistan, 40 from each salinity zone. The salinity level was determined based on the existing salinity maps (which are based on the soil analysis conducted in 1990) as well as the classification used by the local administration. However, taking into account certain concerns about the reliability of this data and its accuracy in reflecting the current situation, this delineation should be treated with caution with respect to the absolute magnitudes of salinity (which is expected to be higher than what is reported), though it should be noted that relative salinity levels (which is more important for the purposes of this study) seems to be more or less accurately reflected.

2.2 SURVEY IMPLEMENTATION

Training enumerators

All the enumerators were the employees of the Dashauz provincial administration (where Akdepe district is located), where they are responsible for the agricultural sector in the province. They were provided orientation training on conducting farm level survey and developing the database. During the training, both theoretical and practical aspects for conducting the survey were presented. A field visit was undertaken together with the enumerators before the formal launch of the surveys in order to give them practical "on the ground" guidance for conducting the survey.

2.3. CREATING DATABASE

All data generated were entered into computer and e-database was developed in MS Excel. Then the data were transferred to SPSS -12 software for more detailed analysis.

2.4. DATA ANALYSIS

Both qualitative and quantitative methods were used in analyzing the results of the study. The survey data were analyzed using SPSS 12.0 and Microsoft Excel 2003. The survey respondents were clustered into three groups based on the level of soil salinity: (i) high salinity, (ii) medium salinity, (iii) low salinity, using the salinity data. The influence of salinity on ownership of various assets and farm profitability, as well as farmers' coping strategies were analyzed through descriptive statistics and comparing the mean results of selected indicators between salinity groups.

3. RESULTS AND DISCUSSION

3.1. HOUSEHOLD CHARACTERISTICS

3.1.1. HUMAN CAPITAL

The analysis indcated that 55% of farming units in the target area are headed by females and 45% by males. However, when the respondents made a distinction between the farmer head and household head, indicating that in all cases a male family member was the head of the household (Table 2.4.4.1). Most of the respondents, 95% are married, while 1% are separated, and 4% are widow(er)s (Figure 2.4.4.2).

Table 2.4.4.1 Gender distribution of farming unit heads and household heads in the sample

Gender	Farm Head	Household Head
Male	45%	100%
Female	55%	0%

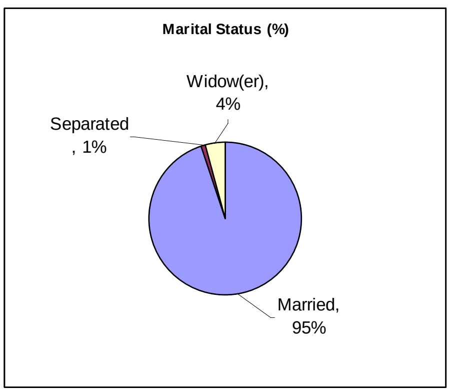

Figure 2.4.4.1 Marital Status

The female household heads were found to have, on average, slightly less saline lands than their male counterparts. The farmers in the low saline area are, on average, 4-5 years older that those in the higher salinity groups, though those in medium saline group are very slightly younger than those in the high saline group (Table 2.4.4.2).

Table 2.4.4.2 Age and gender by salinity level

Salinity level	Farmer Age	Farmer gender (1-male, 2-female)
High	40.63	1.50
Medium	39.40	1.53
Low	44.08	1.63

The mean age of farm heads is equal to 41.37 with standard deviation of 9.27, meaning that, on average, majority of farmers are between 32-50 years old (Figure 2.4.4.2). The age distribution of farmers in the high and medium salinity groups is more compact than of those in the low saline group (Figure 2.4.4.3). The households with lower salinity have on average more family members than those with higher soil salinity (Figure 2.4.4.4). All farmers previously were employed as agricultural workers in the previous farming cooperatives. In terms of education level, all farmers have at least the secondary level of education.

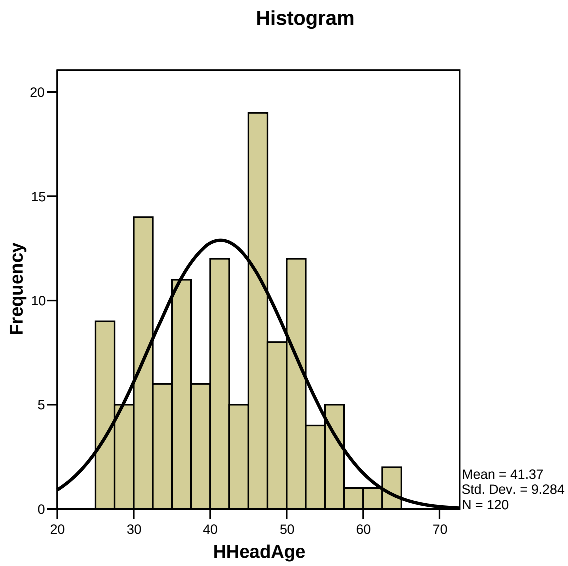

Figure 2.4.4.2 Age of farming unit head

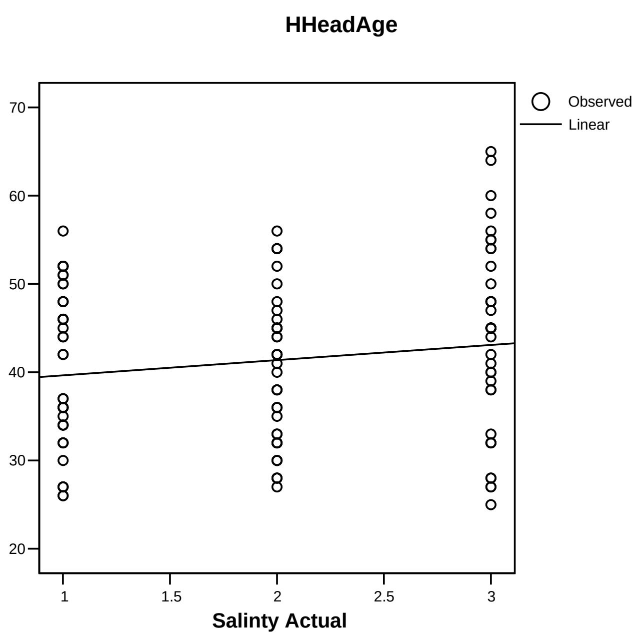

Figure 2.4.4.3 Age distribution by salinity level

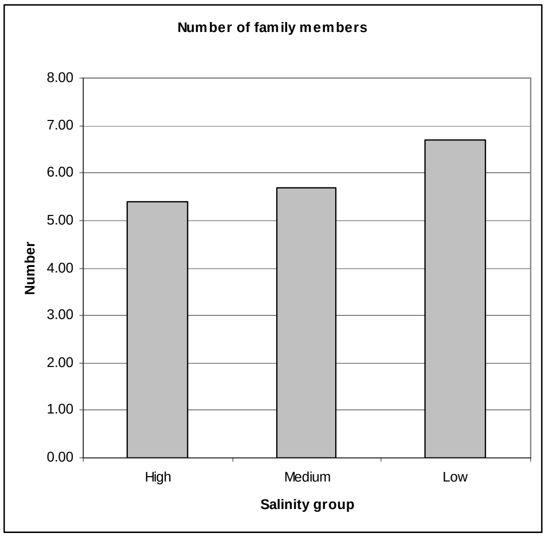

Figure 2.4.4.4 Number of family members

3.1.2. LAND ASSETS

All of the farmers in the target area are smallholders with the mean land area is equal to 2.02 hectares, and ranging between 1 and 4 hectares (Figure 2.4.4.5). Out of the total land area of 239 ha cultivated by the survey respondents, 34% of the land has high salinity, 31% medium salinity, and 35% low salinity, on the basis of classification used by the local administration.

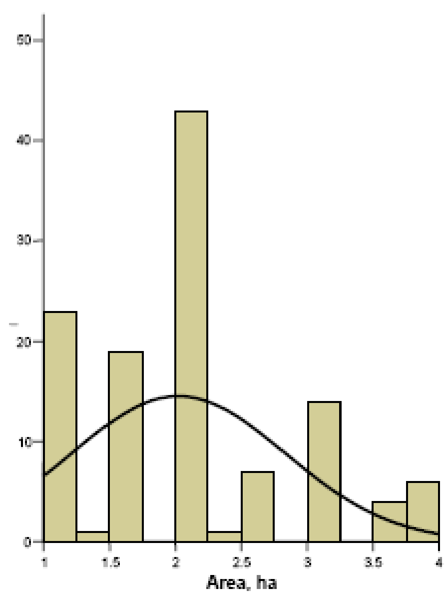

Figure 2.4.4.5 Average land area

In terms of farmers' perceptions on the extent of salinity in their plots, on average, they seemed to be aware and realistic of the salinity levels in their plots (Table 2.4.4.3). In addition, farmers reported that 2.7 hectares of land were abandoned because of salinity in the high salinity group, 3.7 hectares each in the medium and low salinity group.

Table 2.4.4.3 Salinity perceptions

Salinity level	no salinity	low salinity	medium salinity	high salinity	abandoned
High	12%	26%	25%	37%	3%
Medium	13%	33%	27%	27%	5%
Low	13%	30%	27%	30%	4%

All farmers have annually cropped lands. When asked about the crops they cultivated 90.0% have answered that they cultivated cotton as the first crop in their plots, while 10% cultivated wheat as the first crop. Double cropping is reported to be virtually non-existent. Almost all farming plots were irrigated. The only method of irrigation applied by farmers is furrow irrigation. All farmers have got their lands as rent following the dismantling of former collective farms. The last soil analysis was conducted in the area in 1988-1990.

3.2. IMPACT OF SALINITY ON PRODUCTIVITY

As reported by farmers, the yields of cotton are, surprisingly, higher after presumed start of salinity (in 2004-2005) than before. However, it should be noted that overall cotton yields are very low both before and after salinity, hence, the reference year that farmers have indicated for the rise of salinity does not truly reflect the actual year/period of salinity increase. The cotton area in high saline areas has decreased, while it has increased in medium and saline groups (Table 2.4.4.4). The yields of wheat as well were reported to be higher after salinity reference year than before. Again, if the wheat area has decreased among higher salinity groups, it increased among low salinity group (Table 2.4.4.5). As a result, it can be concluded that in spite of reported yield increases, the changes in the area indicate that salinity is actually having a negative impact on the agricultural productivity in the area, with the crop production being relocated from high saline to low saline areas. Double cropping is reported to be virtually non-existent.

Table 2.4.4.4 Cotton area and yield before and after salinity by salinity level

Salinity Level	Before	After
Cotton area (ha)		
High	2.10	2.05
Medium	1.60	1.85
Low	1.96	1.99
Cotton yield, t/ha		
High	1.0	1.0
Medium	1.1	1.3
Low	1.2	1.4

Table 2.4.4.5 Wheat area and yield before and after salinity by salinity level

Salinity Level	Before	After
Wheat area		
High	1.5	1.5
Medium	4.2	2.3
Low	2.8	3.3
Wheat yield, t/ha		
High	0.9	1.0
Medium	1.8	2.0
Low	2.5	2.8

Leaching, a traditional method of salinity management is widely applied by farmers in the target area. In 2004 and 2005, all farmers leached their lands, except for three farmers do did not leach in 2005.

In terms of their perception of the reasons for salinity farmers were unanimous in naming a rise in groundwaters. Salinity is reported to have become a serious problem since 2004-2005.

In terms of phosphorus fertilizer application (total weight), the mean application has increased across all the salinity levels from, 218 kg/ha to 249 kg/ha between 2005 and 2006. However, the medium salinity group applied more phosphorus fertilizers than the other two groups during both years. The high salinity group applied the least amount of phosphorus fertilizers during 2005 and 2006 (Table 2.4.4.6). Contrasting this, almost none of the respondents (except two) are applying manure to complement the inorganic fertilizers.

Table 2.4.4.6 Phosphorus application in 2005 and 2006, kg/ha

Salinity level	Phosphorus application in 2005	Phosphorus application in 2006
High	162	194
Medium	255	285
Low	238	267

In the target area, 100% of the drainage system was found to be open horizontal drainage. According to the farmers' perceptions, the quality of on-farm drainage networks is at medium to a bad level of maintenance. The farmers in the high saline area were the most pessimistic about the quality of drainage (Table 2.4.4.7). As for the quality of inter-farm drainage system, the farmers were unanimous in saying that it is functioning at medium level.

Table 2.4.4.7. Farmers' perceptions on the quality of drainage

Salinity	Excellent	Medium	Bad
High	10%	47%	43%
Medium	15%	46%	39%
Low	10%	52%	38%

According to farmers' responses, the level of ground waters is at about 1 meter in all the categories of salinity.

When asked about the quality of land leveling in their fields, all farmers said that it is at medium level. The last time the farmers leveled their lands was in 2006. On average, high salinity group spent 25 USD, medium salinity group 30 USD and low salinity group 40 USD for land leveling.

3.3. IMPACT OF SALINITY ON LIVELIHOODS

The secondary data, on-field observations and analysis of crop yields, as well as asset ownership across different salinity levels indicate that salinity has had a negative impact on the livelihoods of the absolute majority of farmers in the area. However, during the interviews farmers were reluctant to give their assessment of how salinity impacted their lives. All farmers indicated that they used alternative strategies to mitigate the impact of salinity. However, when asked specifically about the change in their general livelihoods during the last year, farmers in all salinity groups indicated that their livelihoods improved slightly. Those in the low salinity group were more optimistic than those in other groups. The high salinity group even though, on average, said that their livelihoods got better, they were the least optimistic than other lower salinity groups. In total, only 2 farmers said that their livelihoods got worse (1.7%), 40 farmers (33.3%) felt no change, and actually 78 (65%) said that it has improved. These facts, in a way, also suggest that farmers are using alternative livelihoods strategies that compensate the income losses due to salinity. However, the survey responses suggest that only low salinity group and to some less extent medium salinity group can derive these

alternative incomes out of the agricultural sector, while those in the high salinity zone, are probably getting these additional incomes for their survival from non-agricultural sources.

3.4. FARMERS COPING MECHANISMS OF SALINITY BUILD-UP

3.4.1. HOW TO COPE WITH SALINITY: FARMERS' VIEWS ON ALTERNATIVE STRATEGIES

When asked about cropping patterns and agricultural practices that they think would be more profitable than those they currently use, 24.2% of farmers in the area have named livestock and fodder (mainly alfalfa) production, 15.8% named livestock production only, 10% suggested cultivation of wheat and keeping poultry, 7.5% the cultivation of fodder crops and keeping poultry, 4.2% wheat and livestock, 3.3% cultivation of fodder crops only, 2.5% livestock and poultry, and 1.7% - wheat only. Only 0.8% of farmers (i.e. 1 farmer) thought that growing cotton as being profitable. However, worryingly, the largest share of farmers 27.5% did not know what livelihoods strategies could improve their livelihoods (Table 2.4.4.8.). So, in summary, farmers do not think continuing with cotton cultivation could improve their livelihoods instead they would like to re-orient their agricultural production more to livestock production, fodder crops, poultry and wheat cultivation. No farmer indicated that a family member migrated to other places because of salinity problem.

Table 2.4.4.8 Alternative strategies for improving livelihoods of farmers in the area

Alternative livelihoods strategies	(%)
Don't know	27.5%
Livestock and poultry	2.5%
Livestock	15.8%
Wheat and livestock	4.2%
Wheat and poultry	10.0%
Wheat	1.7%
Fodder crops and livestock	24.2%
Cotton	0.8%
Fodder and poultry	7.5%
Cotton and livestock	0.8%
Rabbits	0.8%
Poultry	0.8%
Fodder crops	3.3%
Total	**100.0%**

3,4.2. AGRONOMIC PRACTICES FOR COPING WITH SALINITY

As for immediate coping strategies against salinity, all of the farmers said that it is possible to improve the soil fertility in their plots. High salinity and medium salinity groups reported that they know approaches to combat salinity and ll use leaching, fertilizer application and leveling practices, while those in the low salinity group were slightly modest about their knowledge and use of these practices. Farmers in all categories of salinity know and use water saving technologies to less extent. When asked what can be used to improve the soil fertility in their plots, all farmers were unanimous in saying that the drainage networks should be improved.

All farmers have indicated investing in the cleaning of their on-farm drainage networks. On average, those in the low salinity group invested 39.7 USD, in the medium group 33.9 USD, and in the high salinity group 21 USD. None of the farmers are members of farmers' and water users' associations. All farmers indicated cleaning drains as the priority for collective action. In this regard, the farmers in the low salinity group have

expressed readiness to contribute 52.4 USD, in the medium salinity group 44.8 USD, and in the high salinity group 31.2 USD to achieve this end.

3.4.3. LIVESTOCK PRODUCTION

The total amount of livestock assets in all the 120 farming households totals 30,432 USD[21], 92% of which coming from cows alone (Table 2.4.4.9). Table 2.4.4.10 indicates that the low salinity group in overall, has the highest number and value of livestock assets. The high salinity group has the lowest number of livestock and poultry, but in terms of value, the farmers in the high salinity group reported that the per unit value of their livestock and poultry is almost double or even 4 times more for certain types of livestock than those reported by the low and medium salinity groups.

Table 2.4.4.9 Total livestock numbers and values

Livestock and poultry	Sum, nbr	Mean, nbr	Sum, USD	Mean, USD
Milk cows	263	2.19	27,928	232.73
Sheep	918	7.65	2,220	18.50
Goats	7	0.06	40	0.33
Chickens	2,436	20.30	242	2.02
Ducks	10	0.08	2	0.01
Total	**3,634**	**30**	**30,432**	**254**

Table 2.4.4.10 Total livestock numbers and values by salinity group

Salinity level	Milk cows	Sheep	Goats	Chickens	Ducks	Total
High (nbr)	56	152	7	664	0	879
Medium (nbr)	91	342	0	831	0	1,264
Low (nbr)	116	424	0	941	10	1,491
High (value)	9,508	636	40	80	0	10,264
Medium (value)	8,956	804	0	81	0	9,841
Low (value)	9,464	780	0	81	2	10,327

No selling of livestock and poultry was reported. However, farmers across all salinity levels bought livestock and poultry with the total worth of 10,509 USD, i.e. more than 30% of the total stock value. The value of the purchases by the medium salinity group was the largest, though in terms of numbers low salinity group purchased the most almost across all the categories. In this regard, the possible explanation is that low salinity group purchases younger and less expensive animals for future fattening and resale. However, this idea is not supported by the information on sales of livestock (Table 2.4.4.11).

Table 2.4.4.11 Value and number of livestock and poultry purchases

Salinity level	Value of purchases, USD	Number
High	1,866	325
Medium	4,407	511
Low	4,236	583

The most active purchasing was on chicken. Interestingly, this seemingly confused situation with the absence of sales is to a certain extent explained when one looks at the number of livestock and poultry consumed by the households (Table 2.4.4.12). The households seem to be purchasing livestock and poultry, and consuming them domestically. However, even this does not explain the absence of selling activity. So, either the farmers

[21] At the market exchange rate of the national currency manta equal to 1 USD = 25,000 manats. The official exchange rate is 1 USD = 5,000 manats.

were, for some reason, reluctant to give the information on livestock sales, or the livestock and poultry bought by them comes from external sources. At the end of the year, the farmers in the low salinity group were better off in terms of livestock dynamics since they have had the biggest number of additions to the stock of cows, by far the most expensive livestock assets in the district. The medium salinity group was the second, and the high salinity group increased their livestock assets to a much less extent then their counterparts in the other two groups.

Table 2.4.4.12 Livestock dynamics by salinity group

Salinity Actual	Cows	Sheep	Goats	Chickens	Ducks
Initial stock					
High	56	152	7	664	0
Medium	91	342	0	831	0
Low	116	424	0	941	10
Consumption					
High	0	56	3	258	0
Medium	0	80	0	346	0
Low	0	150	0	416	4
Purchase					
High	0	64	4	254	0
Medium	0	111	3	379	0
Low	0	147	3	415	4
Death					
High	0	0	0	29	0
Medium	0	2	0	35	0
Low	0	3	0	48	4
Birth					
High	32	49	2	29	0
Medium	36	115	0	35	0
Low	64	139	0	48	4
Sale					
High	0	0	0	0	0
Medium	0	0	0	0	0
Low	0	0	0	0	0
Ending stock					
High	88	209	10	660	0
Medium	127	486	3	864	0
Low	180	557	3	940	10
Annual change					
High	32	57	3	-4	0
Medium	36	144	3	33	0
Low	64	133	3	-1	0

The analysis demonstrates that farmers in all levels of salinity usually buy feed for cows, sheep and chicken, their major livestock assets. In total, in 2006 they spent almost 8,000 USD on feed for livestock and poultry, of which 48% was for feeding cows, 26% for chicken and sheep each (Table 2.4.4.13). None of the farmers reported having sold livestock products. It is highly probable that they were consumed domestically.

Table 2.4.4.13 Expenses on feed for livestock and poultry

Salinity levels	Milk cows	Sheep	Goats	Chickens	Ducks
High	766	370	12	438	0
Medium	1,192	850	0	801	0
Low	1,864	836	0	796	8
Total	3,822	2,056	12	2,035	8

3.4.4. MACHINERY RENTING

It was found out that the 120 farmers own in total 24,786 USD worth of various machinery and equipment, which makes the mean value of machinery ownership per farmer equal to be 206 USD. Major machinery and equipment assets are small tractors and water pumps. In terms of salinity level groups, those in the low salinity group possess almost 63% of the machinery and equipment. The remaining 37% belong to farmers in the medium salinity group, while the high salinity group virtually does not possess any farm machinery (except for 2 carts) (Table 2.4.4.14)

Table 2.4.4.14. Machinery ownership by salinity group, numbers and values

Salinity Level	Small tractors	Ploughs	Water pumps	Large cart	Small cart
Number, units					
High	0	0	0	1	1
Medium	5	22	14	5	3
Low	7	70	30	3	3
Total	**12**	**92**	**44**	**9**	**7**
Value, USD					
High	0	0	0	40	12
Medium	4,600	360	4,000	160	28
Low	7,040	1,360	7,000	160	26
Total	**11,640**	**1,720**	**11,000**	**360**	**66**

Sharing the equipment does exist, but is only of water pumps. In total, 21 water pump units are shared, out of the total number of 44 water pumps. The usual share of each party is 50%. The farmers did not buy or sell any type of machinery during 2006. Renting out of machinery is also not practiced among farmers. Only one farmer in the low salinity group rented out his small tractor, ploughs, and water pump, earning the equivalent of 240 USD in 2006.

4. CONCLUSIONS AND RECOMMENDATIONS

The study results have clearly shown that soil salinity has a negative impact on the livelihoods of farmers. However, if farmers in the low salinity group are adopting various agriculture-based alternative livelihoods strategies to improve their livelihoods, those in other groups are less hopeful about the potential of agricultural sector to improve their livelihoods. The strategies suggested by the farmers for improving the livelihoods are changing cropping patterns to cultivation of fodder crops and wheat, as well as more emphasis on livestock and poultry production. Specifically, the following conclusions can be drawn from the study:

1. The study gives some indications as to the typical farming household in the target area, which is a family consisting of 5-6 members, headed by a female or male at the age of 32-50 years old, and who usually have some previous experience of agriculture, as well as sufficient educational background to understand, learn and assimilate good agricultural practices.

2. The elder farmers, who also have slightly a greater number of family members, having slightly better experience of agriculture, are better placed than their younger counterparts, in terms of their land quality.
3. The gender structure of farm heads underlines that the efforts on technology up- and out-scaling, farmer capacity building and knowledge dissemination should be conceived to target both female and male audiences for the maximum impact on the ground.
4. The farmers' perceptions on the level of salinity in their lands are quite realistic. They are aware and are impacted by the salinity problem.
5. Cotton monocropping prevails in the area. In addition, there is a little wheat cultivation. Double cropping is virtually non-existent.
6. Leaching of the soils is the norm. The soil quality is at such a level that possibly no cultivation of cotton and wheat is possible without leaching.
7. Farmers are skeptical about the functioning of inter-farm and on-farm drainage networks.
8. Livestock, in Akdepe district of Turkmenistan, is used mainly for family subsistence. The analysis demonstrated that farmers in the low salinity group were more actively engaged in livestock production, and were able to increase their livestock numbers more than those in other groups.
9. Two aspects of livestock activities raise certain concerns: 1) absence of sales of livestock and poultry per se, 2) absence of sales of livestock products. However, these two aspects also reinforce the idea that livestock is a primarily subsistence, and not a commercial activity for the farmers in Akdepe.
10. Average machinery ownership in the target area is extremely small. The values of the equipments reveal that the farmers mainly own old equipment, with very few cases of new equipment.
11. The low salinity group farmers own the largest share of the equipments.
12. The farmers have reported that the crop yields were slightly higher after salinity. However, the overall cotton yields are very low.
13. Crop production is being relocated from high saline to low saline areas because of salinity.
14. Double cropping is not practiced.
15. Even though the salinity is seriously impacting the livelihoods of farmers, it seems only low salinity group is quite active in exploring alternative agriculture-based strategies to mitigate the effects of salinity. In other groups, salinity is so strong, that farmers are less hopeful about agriculture for improving their livelihoods.
16. Most of the farmers would like to re-orient their activities to livestock and poultry production. They also would like to change their cropping patterns towards cultivation of fodder crops and wheat.
17. The priority area for collective action was indicated to be cleaning of drainage networks, and the farmers are ready to contribute funds to this effort.

To further facilitate the success of existing coping strategies and reduce the impact of salinity on the farmers' living standards as well as environmental sustainability, the following are recommended:

Recommendation 1. There seem to exist two options for public policy with regard to agricultural production in the area in order to raise the living standards of the farmers and ensure the sustainability of the functions of natural resource base: a) investing massively and ensuring the proper operation of drainage networks, and/or b) re-orienting farmers from cotton production of alternative fodder, legume, as well as other salinity-resistant crops, as well as wheat. A medium term action in this regard, could be re-visiting the land use planning in a way that would allow farmers to grow wheat in low saline areas, and salinity- and drought-resistant fodder and legume crops in the high saline areas.

Recommendation 2. Huge opportunity could be capitalized on if farmers are allowed to grow double crops after the harvest of winter wheat.

Recommendation 3. Wide-scale dissemination of water saving technologies such as cutback irrigation, alternate furrow irrigation, sprinkler systems for high value cash crops, etc should become an important element of public policy through creating an enabling environment and establishing/strengthening the extension institutions (dayhans birleshik cooperatives, etc).

2.4.4 THE IMPACT OF PHOSPHOGYPSUM USE ON FARM-LEVEL INCOME FROM MAGNESIUM-AFFECTED SOILS IN KAZAKHSTAN[22]

1. INTRODUCTION

As discussed earlier studies we undertaken in the Turkestan region of Southern Kazakhstan to address the problem of Mg-dominant soils. In this section we discuss the outcomes of an economic assessment of applying phosphogypsum (PG) to these soils. Policy recommendations are suggested to address the constraints of large scale adoption of PG application as amendment for soil sodicity.

2. THE RESEARCH SITE

The International Center for Agricultural Research in the Dry Areas (ICARDA) initiated on-farm research on PG application in Arys Turkistan area, which is representative of the irrigated systems of Central Asia. Arys Turkestan region in southern Kazakhstan, has a total irrigated are of 70,000 ha stretching from south-east to north-west. Administratively, the region is located in the Ordobasin and Turkestan districts of Southern Kazakhstan province. Reclamation of land for agriculture in the area started in 1960s. There are 700 km of open and 770 km of closed irrigation-drainage channels. Cotton is the main agricultural crop with some limited production of grapes and livestock. The main sources of irrigation water are the Arys, Bugun and Karachik rivers. During the spring and winter, flows from these rivers accumulate in Bugun water reservoir. Southern Kazakhstan is one of the most important agricultural regions in Kazakhstan, where the majority of the country's irrigated agricultural land is situated, and has both the highest population density and the highest poverty incidence. As a whole in Southern Kazakhstan, 33% of the total 500 thousand ha of irrigated lands are affected by different degrees of salinity, which is leading to a decline in crop yields. The available water resources cover only 80% of the existing needs for water.

Out of nearly 3,400 farming units operating in the area, close to 91% are smallholder farmers, 6% agricultural cooperatives, and the rest joint stock companies and partnerships. The reforms in land tenure after the collapse of the Soviet Union have led to the break-up of the earlier established linkages among the agricultural producers, water management organizations and input suppliers. Importantly, links between agricultural producers and major markets for their products have also been ruptured. At on-farm level, the effect was especially negative on the proper operation of irrigation and drainage channels and on the availability of inputs. Privatization has also led to less diversity in agricultural production, with farmers preferring to produce high-value cash crops, mainly, cotton. The use of fertilizers has decreased due to their high price resulting from underdeveloped input markets, and due to farmers' lacking resources necessary to purchase required fertilizers.

Phosphogypsum application in the area can be beneficial both in terms of remediation of soil sodicity by impacting positively on the soil structure and restoring its water permeability, as well as improving soil fertility through supplying phosphates, calcium and other nutrients necessary for vigorous plant growth.

3. BIOPHYSICAL RESEARCH

Biophysical details of the trials initiated have been discussed and described previously and will not be repeated for brevity. Results from initial trials established prior to the current set of trials are presented in Table 2.4.5.1. The 4-year average cotton yield was in the order: phosphogypsum at 8 t ha^{-1} (2.6 t ha^{-1}), phosphogypsum at 4.5 t ha^{-1} (2.4 t ha^{-1}), and control (1.4 t ha^{-1}) (Vyshposky *et al.*, 2008). Yields initially rose by 93% on average for the lower PG application rate of 4.5 t/ha and 114% for the higher rate of 8.t/ha. This yield advantage declined steadily as the PG effects declined with time and reached about 57% higher for both

[22] This component was led by ICARDA. NARS partners include Valiahmed Mukhamedjanov, Natalya Gritsenko, Frants Vyshposky, Kazakh Research Institute of Water Management, Ministry of Agriculture, Taraz, Kazakhstan.

the lower and the higher PG application rates compared with the no PG application. The PG application of 4.5 t/ha increased cotton yields by 76% on average, while the 8.0 t/ha application increased by 91% (Vyshposky et al. 2008). Another trend of the data is that the difference in yield advantage of the two application rates dropped over the 4 year period ending with identical yield advantage over the control in the fourth year. The declining effects of PG application is, however, clear from the data in Table 2.4.5.1.

Table 2.4.5.1. Cotton yield as affected by different rates of phosphogypsum application (0, 4.5, and 8.0 t/ha) on a high-magnesium soil in southern Kazakhstan

	Treatments		
Years	**PG0**	**PG4.5**	**PG8.0**
2001	1.4	2.7	3.0
2002	1.4	2.4	2.8
2003	1.3	2.4	2.5
2004	1.4	2.2	2.2

This PG application will be required after several years since in order to sustain higher cotton yields were demonstrated in these trials.

4. ECONOMIC EVALUATION OF PG APPLICATION

4.1 RELATIVE PROFITABILITY OF PG APPLICATION RATES.

Abundant supplies of PG are produced in two chemical fertilizer factories in Taraz and Shymkent both located in Southern Kazakhstan. The cost of procurement either in Taraz or Shymkent, transportation and application are estimated at USD 29/t in 2001 and 36 in 2006. PG can be presently acquired almost free of charge from the dumping sites of the two factories both for agricultural and non-agricultural uses but with loading and transportation costs. Currently, the amount of PG in these open-air dumps is estimated to be more than 10 million tons. The procurement and application costs account only for 16% of the total cost, while transportation accounts for 86% of the cost of PG use. These percentages changed slightly in 2006 to 18% and 82% due to increased PG prices. The total cost of PG procurement, application and treatment in 2001 was estimated at USD 131 per hectare in 2001 at the lower rate and 233 at the higher rate (Table 2.4.5.2). This results in a 25% increase of PG cost due to a rise in transportation cost.

The PG transportation costs in Table 2.4.5.2 are calculated for the distance between Taraz and Arys Turkestan area, which equals about 320 km. In this regard, the transportation of 1 t of PG per 100 km by truck will be equal to 9.4 USD.

This analysis uses cotton yield data recorded from on-farm trials given in Table 2.4.5.1 and actual costs and prices observed during the period 2001-2004. Cotton prices were highly variable during the 4 years, rising from USD/t 185 in 2001 to 500 in 2003 and then dropping down to 341 in 2004. The profitability of PG application for a 4 years period is given in Table 2.4.5.3.

Table 2.4.5.2 PG procurement and application costs

Cost items		**2001**		**2006**	
	Units	**PG$_{4.5}$**	**PG$_{8.0}$**	**PG$_{4.5}$**	**PG$_{8.0}$**
PG costs	USD/ha	16.2	28.8	27	47.00
Application cost	USD/ha	1.8	3.2	3	5.00
Transportation cost	USD/ha	113.0	200.9	134	240
Total Costs	USD/ha	131	233	164	292
Total Costs	USD/t	29.1	29.1	36.4	36.4

Table 2.4.5.3 Profitability of PG application in 2001-2004

Designation	2001			2002			2003			2004		
		With PG			With PG			With PG			With PG	
	No PG	**4.5 t/ha**	**8 t/ha**	**No PG**	**4,5 t/ha**	**8 t/ha**	**No PG**	**4,5 t/ha**	**8 t/ha**	**No PG**	**4,5 t/ha**	**8 t/ha**
Cotton Yield, T/ha	1.4	2.7	3.0	1.4	2.4	2.8	1.3	2.4	2.5	1.4	2.2	2.2
Price, USD/T	185	185	185	368	368	368	500	500	500	341	341	341
Sales	**259**	**500**	**555**	**515**	**882**	**1030**	**650**	**1200**	**1250**	**477**	**750**	**750**
Ploughing	13	13	13	12	12	12	12	12	12	12	12	12
Making furrows	5	5	5	5	5	5	9	9	9	9	9	9
Pre-sowing irrigation	7	7	7	4	4	4	3	3	3	3	3	3
Harrowing	3	3	3	3	3	3	6	6	6	6	6	6
Chiseling	6	6	6	6	6	6	12	12	12	12	12	12
Seeds	11	11	11	12	12	12	7	7	7	7	7	7
Sowing	7	7	7	7	7	7	11	11	11	11	11	11
Cultivation, making furrows, dressing	36	36	36	26	26	26	15	15	15	15	15	15
Making water distribution furrows	6	6	6	6	6	6	6	6	6	6	6	6
Manual weeding	21	21	21	21	21	21	21	21	21	21	21	21
Manual cotton height reduction	10	10	10	10	10	10	10	10	10	10	10	10
Fertilizers	26	26	26	20	20	20	20	20	20	20	20	20
Irrigation	16	16	16	16	16	16	16	16	16	16	16	16
Water	41	41	41	19	19	19	19	19	19	19	19	19
Manual harvesting	51	93	103	50	91	101	44	91	94	50	91	91
Transportation of cotton	10	19	21	10	18	19	10	18	18	10	18	18
Total costs without PG	*268*	*317*	*329*	*226*	*273*	*285*	*218*	*273*	*278*	*226*	*273*	*273*
Purchasing and applying of PG	0	18	32	0	0	0	0	0	0	0	0	0
Transportation of PG	0	113	200.88	0	0	0	0	0	0	0	0	0
Total costs	**268**	**448**	**562**	**226**	**273**	**285**	**218**	**273**	**278**	**226**	**273**	**273**
Net profit	**-9**	**51**	**-7**	**289**	**609**	**745**	**432**	**927**	**973**	**251**	**477**	**477**
BCR	**0.97**	**1.11**	**0.99**	**2.28**	**3.23**	**3.62**	**2.98**	**4.40**	**4.50**	**2.11**	**2.75**	**2.75**

The net present values or discounted cumulative net benefits over the 4 years were computed for the two PG application rates and without PG application at a discount rate of 10%. The net annual farm income was increased by 116% (232 per hectare) with the application of PG at the lower rate (4.5 t/ha) relative to crops without PG application and by 129% (USD 258 per hectare) with the higher rate (8.0 t/ha). These results show that PG application of cotton on magnesium affected soils of Arys Turkestan region is highly profitable with current cost and price conditions. Although the higher rate has higher net income, it has lower returns to investment. This is demonstrated by the higher benefit cost ratios (2.53) of the lower application compared with the higher rate (2.46). This occurred because the additional income increase between the lower and higher rates were very low relative to the increase in costs. The higher rate requires additional investment of 11% over the lower rate (USD 129 per hectare) but with only 6% higher net income (USD 25 per hectare per year) over the 4 year period. Given these findings and given farmers' cash constraints and farmers' natural

tendencies to apply lower than recommended input levels in order to minimize risks, the lower PG rate has a higher chance of being accepted by farmers.

4.2 FACTORS THAT INFLUENCE THE PROFITABILITY OF PG APPLICATION

The main sources of risk in PG application are price fluctuations and changes in cost of transportation due to fuel cost changes or other macroeconomic changes. The cost of PG rises to about 30-40% of the total annual operation cost per hectare of cotton production. This is quite a substantial amount of cash which smallholders in the study area with average holdings of 25 ha would have to outlay prior to the planting season. Fuel price increases raise transportation costs and changes in the macroeconomic environment and general deterioration the terms of trade for agriculture, where the input costs rise faster than output prices, reduce the benefits of PG application reducing its feasibility. Such economic dynamics pose risks to producers and are particularly detrimental with respect to using higher levels of PG. The transportation cost of PG in 2006 increased by 18% from the levels of 2001. The effects of changes in transportation cost on relative profitability of PG application rates are given in Table 2.4.5.4. This sensitivity analyses show that as the transportation cost increases the net benefit advantage of the higher rate of PG application over the lower rate diminishes substantially until the two treatments reach almost identical net benefits at a transportation cost of USD 60 per ton.

Table 2.4.5.4 The effects of change in transportation cost on the profitability of PG application

	Transportation cost of PG from phosphate factories to the farms USD/t				
Treatments	**25**	**30**	**35**	**40**	**45**
PG0	212	212	212	212	212
PG4.5	459	454	448	443	437
PG8.0	492	482	472	462	452

Similarly, the effect of cotton price fluctuations on cash flow are presented in Table 2.4.5.3; the higher PG rate had negative net income in 2001 and had no income advantage over the lower rate in 2004. The higher rate of PG application will have 8% higher net benefits than the lower rate at cotton prices of USD 500 per ton but that net benefit advantage reduces to just 4% (or only USD 6 per hectare annual income) at prices of USD 200. Given those risks and given that farmers in the study area already face financial constraints the lower PG rate with its lower cost, lower potential risk, higher benefit cost ratio and internal rate of return (Table 2.4.5.5), is more likely to be accepted by farmers.

Table 2.4.5.5 Cash flow analysis, 2001-2004

	Treatments		
Items	**PG0**	**PG4.5**	**PG8.0**
Discounted cumulative costs (USD)	823	1,127	1,255
Discounted cumulative benefits (USD)	1,623	2,857	3,087
Net Present Value (USD)	800	1,730	1,833
Internal Rate of Return (%)	49	65	58

To give one more illustration, the sensitivity analysis indicates that the PG application becomes unprofitable when the cotton prices are at 135 USD/t and 132 USD/t for 4.5 t/ha and 8.0 t/ha application rates, respectively. Similarly, 8.0 t/ha application rate becomes unprofitable when the transportation price for PG is 272 USD per ton, while 4.5 t/ha application rate becomes unprofitable only when the transportation cost is 434 USD per ton.

5. ANALYSIS OF MULTI-YEAR APPLICATION OF PG

5.1 OPTIMAL INTERVAL BETWEEN PG APPLICATIONS OVER TIME

Assuming that farmers would use the lower PG application rate of 4.5 t/ha, and given that the effects of PG application lasts several years although in a diminishing trend, the question arise as to what would be the optimal intervals of the successive applications over time. Agronomic data on multiple applications of PG application over many years do not exist. We, therefore, investigated this question by first computing a time trend function of cotton yields using the 4 years data available. This gives an estimated rate of yield decline as PG effects decline. By using this function it is possible to project how long the positive yield effect of PG application lasts, which was estimated for up to 9 years.

Yield = 2.8 - 0.15 years, $R^2 = 0.88$

With this function we then developed different scenarios for the multiple applications. These scenarios are:

1. NOPG; no application of PG; NOPG
2. PGYR3; application with intervals of 1 year
3. PGYR4; application with intervals of 2 years
4. PGYR5: application with intervals of 3 years
5. PGYR6: application with intervals of 4 years
6. PGYR7: application with intervals of 5 years
7. PGYR8: application with intervals of 6 years
8. PGYR9: application with intervals of 7 years

Using the data observed during the period 2001-2004, we constructed the benefits and costs of PG application for different intervals for up to 16 years. The 16 years period is maintained for all scenarios to ensure that the results are comparable. The net returns (or net present values) of different options are presented in Table 2.4.5.6. These results show that applications with intervals of 3 year intervals (or application in the 5th year) results the highest net present value. The situation, however, change due to other factors including cost of PG, cost of borrowing money for PG financing and cotton prices. The effects of these factors on optimal intervals of multiple PG application over the years are discussed.

Table 2.4.5.6 Discounted cumulative costs and benefits and net benefits (per hectare) of PG application with different intervals over 16 years period[23]

Scenarios	Intervals between multiple applications	Number of applications	Discounted cumulative costs	Discounted cumulative benefits	Discounted net benefits	Annual net benefits
NOPG	No PG	0	2030	4264	2234	140
BYr3	1 year	8	4,488	7,923	3,434	215
BYr4	2 years	6	4,169	7,749	3,580	224
BYr5	3 years	4	3,987	7,569	3,582	224
BYr6	4 years	4	3,797	7,328	3,531	221
BYr7	5 years	3	3,729	7,228	3,498	219
BYr8	6 years	2	3,508	6,887	3,380	211
BYr9	7 years	2	3,465	6,814	3,349	209

The differences in the net annual cumulative net benefit of PG applications with different intervals are small, thus raising the possibility of using longer interval than shorter ones with little reduction in net benefits. Because shorter intervals involve more applications of PG application it means the costs will be higher and as a result the benefit-cost ratios are marginally higher with longer intervals.

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[23] In tables from 2.4.5.6 to 2.4.5.8, the most profitable options are highlighted with orange background color

5.1.1. THE EFFECT OF THE COST OF PG ON THE OPTIMAL INTERVALS BETWEEN APPLICATIONS OVER TIME.

The cost of PG and its effects on net returns is a main factor that will influence the adoption of PG. The cost of PG also affects farmers' choice on how to stage the applications since the effects of PG application lasts for several years in a declining trend. The analysis show that with current cost of USD 164 per hectare, applications of PG with intervals of 3 years (application in the 5th year from the previous application) results in the highest net returns. However, as the cost of PG application increases it becomes more profitable to increase the intervals between two applications. For instance, if PG cost doubles compared to current costs the most profitable option would be to apply PG with intervals of 4 years (application in the 6th year from the previous application). The optimal application interval will further increase to 6 years if PG cost reaches USD 500 per hectare. Much higher costs will eliminate the economic advantage of PG application (Table 2.4.5.7).

Table 2.4.5.7 Discounted annual cumulative net profit for the application of PG under different PG cost scenarios

Scenarios	Intervals between multiple applications	Phosphogypsum costs (USD/ha)			
		164	328	500	600
NOPG	No PG	140	140	140	140
BYr3	1 year	215	168	120	92
BYr4	2 years	224	192	160	140
BYr5	3 years	224	199	172	157
BYr6	4 years	221	200.1	178.6	166
BYr7	5 years	219	199.4	179.1	167
BYr8	6 years	211	196	179.5	170
BYr9	7 years	209	194	178.5	169

5.1.2. COST OF BORROWING CAPITAL FOR FINANCING PG.

Smallholder farmers in the study area do not often have sufficient cash to cover all production expenses and many of them will need to borrow finances to purchase PG. The main factor that will affect access to credit, other than availability of loans within reasonable distances, is the cost of borrowing money which is measured in terms of interest rate levels. High costs associated with the borrowing money due to high interest rates can reduce the net benefits from the application of PG. But the analysis show that capital cost at the range normally found in agricultural finance will reduce the comparative advantage of PG application over the no PG application but will not eliminate it. The application of PG will still be more profitable than without. We estimate that with 30% annual interest rate on short-term loans the PG application will be 54% more profitable than no application. The cost of borrowing money for financing PG procurement does not affect the interval between applications. The internal of 3 years between applications remains the option with the higher net income under all interest rates analyzed (ranging from 5% to 30%). Thus, availability of credit services would be more of a factor constraining the adoption of PG application on sodic soils than on interest rate levels. A review of current banking practices shows that the credit facilities are widely available for farmers, though the interest rates may vary highly between specialized government banks and various privately-run credit facilities. However, informal interviews with farmers have indicated that now almost all farmers are able to access and use these credit facilities in the study area. This raises the possibility of farmers' self financing PG application.

5.1.3. PRICE OF COTTON.

The price of cotton is the most important factor affecting the profitability of the crop and the feasibility of all input use including PG application. At current prices of USD360 per ton the application of 4.5 t/ha of PG gives the highest long term returns when applied in the intervals of 3 years. If the cotton price were to drop to USD 250 per ton (about 30% decline) the optimal interval for PG application would be 7 years with significantly reduced profitability (Table 2.4.5.8). With current cost structure, cotton production would hardly be profitable at prices lower than that.

Table 2.4.5.8 Discounted net annual cumulative benefits per hectare of applying PG under different cotton price scenarios

	Intervals between multiple applications	Simulating price of cotton effects			
		360	**300**	**250**	**200**
NOPG	No PG	140	95	58	21
BYr3	1 year	215	132	63	-5
BYr4	2 years	224	143	76	9
BYr5	3 years	224	145	79	14
BYr6	4 years	221	144	81	17
BYr7	5 years	219	143	81	18
BYr8	6 years	211	140	80	20
BYr9	7 years	209	138	79	20

6. THE AGGREGATE POTENTIAL ECONOMIC IMPACT

The discounted annual net farm income due to phosphogypsum application on cotton is estimated at USD 84 per hectare using 3 year intervals for multiple year applications for a 16 year period. This estimate is much more conservative than USD 233 net annual benefits estimated using only the observed 4 years data. The long term annual net benefit estimate is conservative because it uses a discount rate of 10% for benefits occurring in the future and accounts for other factors that may offset the yield advantages of PG application. Using the conservative estimate and an adoption rate of 40% of the total area of 134,000 hectares that are affected by sodicity the annual aggregate net benefits from PG use would be USD 4.502 million. Greater adoption rate by farmers will increase these benefits. This is a significant flow of economic benefits into poor rural communities in the region. Currently PG can be procured almost free of charge from sites where factories are situated but this may change once markets develop due to increasing demand for agricultural use. However, if domestic trade of PG develops and transportation service becomes competitive the benefits will still remain substantial.

6.1.Farmers' awareness.

During the previous centrally-planned large-scale collective farming, the State was the sole agent conducting soil rehabilitation activities, including the application of phosphogypsum. Presently, land improvement and rehabilitation activities are the responsibility of private farmers, who lack both financial capacity and expertise in land management because they were mostly employees performing specific tasks rather than farm operators. In addition, traditional agricultural extension services have not yet developed. This means that most farmers do not have information about the benefits of PG application on high magnesium soils. The projects mentioned in this paper are changing this situation and through trials, demonstrations, farmers' traveling workshops, field days and policy dialogue workshops building public awareness. Continuous extension service will be essential for constant follow of research information to farmers and that will enhance their awareness and adoption of new technologies.

7. POLICY IMPLICATIONS

The economic impact of the PG application from the field data presented in this study can be substantial, generating an aggregate annual flow of net benefits of over USD 4.5 million in the Southern Kazakhstan region. This would have direct impact on the livelihoods of the farmers, as well as indirect impacts on the regional and national economies through forward and backward linkages.

The main constraint facing the adoption of PG is what economists call "market failure". In other words the market does not supply PG where it is demanded. This happens because input traders do not supply it at local input outlets because it is seen as agricultural input and there is no information on its potential business among traders. Given its bulkiness and transportation costs it becomes inefficient and quite impractical for farmers to procure it. The role of public policy, therefore, is to address this market failure. One way of doing this is to provide a starter incentive for traders and for farmers so that a market will eventually develop. Traders can be given an incentive in the form of subsidies on transportation costs while farmers can be provided with information through field demonstrations and extension support. Once sufficient farmers' awareness is created and, as result, enough demand is generated, traders can operate as they do with any other input without subsidies. Public policy also should consider greater investment in farm advisory and extension services so farmers can receive useful farming knowledge and technologies on a regular basis. Although such services can be provided by the private sector, without public investment and incentives, it is likely that the private sector will give high priority to high paying sub-sectors within the agricultural sector.

Another important policy dimension of Phosphogypsum application in agriculture is related to its environmental impacts. Although the radionuclide elements are generally found to be at levels that can be safely used in agriculture (Al-Oudat *at al*., 1998; El-Marabet *et al*., 2003). However, monitoring the levels of radium-226 in PG stockpiles at the production sites is considered to be a wise environmental policy, for example in the United States (EPA, 1992) and (Papastefanou *et al*., 2006). The economic impact estimates in this study can be used as a reference when assessing the cost of the programs to enhance PG use in agriculture.

8. CONCLUSIONS

In this paper, we analyzed the profitability of two rates (4.5 t/ha and 8.0 t/ha) of PG application on cotton in sodic soils of Southern Kazakhstan. We found that the lower rate is more profitable and less risky given changes in cotton prices, transportation cost of PG, and borrowing of capital for financing PG purchases. An interval of 3 years between applications was also found to give the highest net returns over the longer term. Low farmers awareness of the impacts of PG due to lack of information and market failure in the domestic trade and transportation of PG are the main constraints facing the adoption of PG on sodic soils in the study area. With an adoption rate of 40%, the annual economic of PG is estimated at over USD 4.5 million. Pubic policy can develop incentives for the market to develop in the initial phase. It can also develop ways of improving access to credit and can increase farmers' awareness through agricultural extension and information services. These actions can increase the adoption of PG in large scale and bring significant farm level benefits to smallholders and for the wider economy. Monitoring of radium-226 is wise environmental policy and should be considered to avoid negative impacts.

9. ACKNOWLEDGEMENTS

The research activities on PG application in Arys Turkestan command area were funded by the Asian Development Bank (ADB) through a project RETA 6136 on "On-farm Soil and Water Management", which was conducted in six countries in Central Asia and the Caucasus. During 1999-2005 years, the Kazakh National Water Management Institute implemented the PG trials in the study area. Since 2005, these trials have continued in partnership with the same institute under a joint IWMI-ICARDA-ICBA project RETA 6208 on "Enabling Communities in the Aral Sea Basin to Combat Land and Water Resource Degradation Through the Creation of 'Bright' Spots", also funded by the ADB.

COMPONENT III.

CAPACITY BUILDING, KNOWLEDGE SHARING AND DISSEMINATION

Studies undertaken within the context of Components I and II within the project have implicitly built into them aspects of capacity building and knowledge sharing as a means of disseminating outcomes to a wider audience. The gap between knowledge generated through scientific pursuit and imparting it to agricultural producers is still in its infancy in these emerging economies of Central Asia. The lack of formal institutional structures that cater for traditional extension services is a significant barrier to knowledge sharing. This process is further exacerbated by the non-enabling policy environment that does not provide incentives for farmers to make long term investments in land and water resources stewardship.

Throughout the world one will always find farmers who are able to produce higher yields of crops even under unfavorable environments as well as developing coping strategies that have a significant impact on their financial viability. Such bright spots are to be found here in Central Asia, and these examples formed the basis of the conceptualization of this project. Further, scientific advances soil and water saving technologies in the region are being generated by dedicated and resourceful scientist in the region. It is clearly evident from experiences in the past that if these innovations and strategies were to be adopted by a greater number of farmers in the region, significant positive benefits to community livelihoods and the environment would result. However, currently there are no effective instruments and incentives for delivery of knowledge from science to the farm level and among farm communities. Over the course of this project a concerted team effort by all participants was undertaken in order to address this impasse through a significant number of activities that included training courses, workshops and other knowledge sharing events.

Training courses were presented that covered a range of subjects, including special courses on participatory rural appraisal (PRA); effective communication skills and interviewing techniques; outcome mapping, evaluating technologies addressing salt-prone land and water resources; advances in biosaline agriculture with reference to Central Asia; procedures and tools for salinity related data processing and statistical analysis. A great number of young national scientists involved into the project have benefited from these training courses that will play a critical role in dissemination of findings of the project to farmers and specialists in the years ahead.

To enhance capacities of local institutions one PhD student and 2 MS degree students carried out their research within the context of the project. The research area covered important subjects of bio-drainage technology, saline water use and mulching, soil erosion and GIS application for salinity mapping.

A special workshop was organized on production and utilization of salt tolerant forage crops and halophytes in Samarqand Karakul Sheep Breeding Institute to share knowledge on salt tolerant varieties of crops and halophytes. Local scientists and farmers participated in the workshop and brought to the workshop their issues and immense knowledge and invaluable experiences.

Round Table meetings were organized in Gulistan and Tashkent cities on Licorice production technology on abandoned salt affected lands with participation by scientists, farmers, local and regional authorities. Feedback from these round tables allowed discovering gaps in adoption of licorice production by farmer communities. The round tables created linkage between farmers, scientists, local and regional authorities.

Round Table meeting on application of phosphogypsum was organized at Southern Kazakhstan State University with participation of scientists, farmers, local and regional authorities. Participants of the workshop discussed results and further needs for wide application of PG to reclaim sodic compacted soils of Southern Kazakhstan. Participants of the workshop indicated that the area where PG application can improve soil properties exceeds 100 000 ha.

The most efficient and effective way to enrich the farmer communities with knowledge and new approaches in the management of salt-affected areas was found to be in a Farmer Knowledge Fair organized at Gulistan

State University. Over 400 farmers participated in the event and were exposed to new soil and water conservation technologies. Over 20 international and local research institutions were able take advantage of this opportunity to make direct contact with farmers and get their feedback through the face to face and workshop discussions.

Selective presentations by project staff and collaborative scientists were made at a range of events that included formal research seminars, media and peer reviewed journal articles. Further extension based brochures were prepared in local languages to disseminate the outcomes of research from the project. Added to this the project team had annual meetings to discuss working plans and findings of their studies. Through these events national partners and collaborative international centers were involved in the project planning and implementation processes.

3.1 TRAINING AND CAPACITY BUILDING

Training of socio-economists on PRA tools, effective communication skills and interviewing techniques
Three training workshops were organized by IWMI within the framework of the project for the NARS partners. The first training workshop was organized at the Scientific and Research Institute of Water Resources in Taraz, Kazakhstan over the period June 13-16 with the participation of 20 people. The second training workshop was organized at the Gulistan State University during July 12-14, 2005, 2005 with participation by 32 people, including project staff and bachelor degree students with majors in socio-economics. The third training workshop was organized for the Turkmen NARS and was held in Dashauz during September 7-10, 2005 with participation of 16 people, including project staff and bachelor students. The participants of the course had the opportunity of being exposed to effective communication skills that will further contribute to their professional development and assist in data collection associated with interviews and implementation of PRA tools.
The methodology adopted for the training included visual presentations, group exercises, games, picture puzzles, and discussion sessions. Furthermore, an overview of the previous days deliberations was conducted in order to generate feedback on training from the participants perspective and clarify any areas that may have arisen or confusing issues. To assess the whole training, the participants were requested to score the training expectations against the training results at the end of the workshop. The overwhelming majority of the participants indicated that they gained more from the training than they had expected which is taken as indicative of a successful workshop. This form of training was useful not only for project implementation, but also the building of capacity within local social scientists, whose role was extremely important in effecting changes the region.

Training on the multiplication of salt tolerant materials

The International Center for Biosaline Agriculture (ICBA) organized a 5-day training course in collaboration with ICARDA and IWMI in Tashkent from December 12-16, 2005. The course was attended by 16 participants, including scientists of Regional Cotton Research Institutes, Karakul Research Station and Uzbek Plant Research Institute. The course content was divided into eight sessions, covering different aspects associated with germplasm evaluation, multiplication and data collection for salt tolerant plants and halophytes. The afternoon session was set aside for discussions and hands on training with the participants. A field trip was organized to visit the Uzbekistan Plant Research Institute where participants were briefed on *in-situ* collections of germplasms and those in the gene bank, where they have more than 47,000 accessions of different species.

Training course on Evaluation of Technologies Addressing Salt-prone Land and Water Resources and Rural Livelihoods

A training course on the socio-economic evaluation of technologies addressing salt-prone land and water resources and rural livelihoods was conducted in Tashkent, Uzbekistan (9-12 April 2006). In partnership with IWMI and ICBA, ICARDA organized this course within the framework of the two ADB-funded projects; Soil and Water Project, and Bright Spot Project. In total, 17 participants — 5 from Uzbekistan, 5 from

Kazakhstan, 3 from Kyrgyzstan, and 4 from Tajikistan — were trained on technology evaluation methods such as partial budget analysis, sensitivity analysis, long-term analysis using the NPV-method, simulation of scenarios and other related aspects. The participants of the training course were from NARS institutions, including Tashkent Irrigation Institute, Uzbekistan; Cotton Institute, Uzbekistan; Kazakh National Institute of Water Management, Kazakhstan; Institute of Soil Sciences, Tajikistan; and Kyrgyz Institute of Irrigation, Kyrgyz Republic. The training was conducted under the supervision of Aden Aw-Hassan, Senior Socio-economist from ICARDA Headquarters.

A similar socio-economic training was organized in Urgench, Uzbekistan (1-3 July, 2006) for the Turkmenistan socioeconomic team.. During the training, an overview of the feasibility assessment of agricultural technologies was presented, where the importance of an accurate feasibility analysis for the adoption and dissemination of new technologies was highlighted. Moreover, the methods of economic evaluation, economic indicators applied in the estimation of viability of technologies, budgeting techniques, sensitivity analysis for input and output prices were taught to the participants. Training also included a brainstorming session and discussion, at which participants evaluated the innovative agricultural technologies and assessed the current situation in agriculture of Turkmenistan.

Training course on "Advances in Biosaline Agriculture with reference to central Asia"

A training course on "Advances in Biosaline Agriculture with Reference to Central Asia and the Caucasus" was held in Tashkent, Uzbekistan from 15-21 May, 2006. This course involved 44 scientists, young researchers and technicians from all the eight CAC countries. It was organized by ICBA in close collaboration with ICARDA and IWMI. The main goal of the training course was to give an opportunity for the trainees to get acquainted with modern methods and technologies of managing saline water, degraded and marginal lands. The training course included lectures by Drs. Abdullah Dakheel, Shoaib Ismail, Nurul Akhand from ICBA and Hassan El-Shaer from Desert Research Center, Egypt. The presentations were focused on characterization of genetic resources and potential use of salt-tolerant crops and halophytes; testing salt-tolerant forages in livestock feeding systems; as well as irrigation technologies and drainage management systems under saline arid and semi-arid environments. The trainees also visited a research site in Galaba, Uzbekistan. Dr. Lyudmila Shurova explained the benefits of cultivation of mixed cropping of alfalfa in standing wheat crop. The role of Licorice in the reclamation of salt affected and abandoned lands was also demonstrated.

During the discussion session, the participants requested to formalize a network of specialized working groups on evaluation of halophytes and sustainable plant, land and saline water resources-use in the region. The following action points were brought out:

- To conduct a survey on biodiversity of halophytes for each country of the CAC region and to develop unified criteria of evaluation, characterization and conservation of halophytes and salt-tolerant crops, taking into account their abundance, type of soil salinity, salt tolerance levels, as well as seed morphology and ecology;
- To generate a data-base on bio-saline agriculture for CAC;
- To test salt tolerant forages suitable for livestock feeding systems;
- To introduce and test non-conventional salt tolerant plants and modern low-cost technologies in small-scale production systems.

Training on Outcome Mapping

The cornerstone of successful community based land rehabilitation activities is the readiness for collective action. The centre-piece of collective action is how knowledge is shared among the members of the group. During the round table meeting held in May 2006 the Farmer Learning Alliance (FLA) on Licorice production was created. Members of the Learning Alliance consited of 11 farmers from Galaba Farm Association, specialists having experience in licorice production from Gulistan State University and from the Botany

Institute; representative of local and regional authorities, representatives of WUAs, banks and the project team.

In October 27, 2006 Ikbal Yusupova, Bright spots staff, conducted the second training on outcome mapping and creation of monitoring and evaluation systems to facilitate the activities of the FLA and set the framework for these activities. Among 20 participants of the training course were members of the FLA, including bright spots farmers.

Objectives of the training were:

1) To devise a framework for supporting the Learning Alliance activities and develop a strategy for its sustainable operation;
2) To outline the key concepts for managing participation of all stakeholders
3) Develop the techniques for building group capacity to promote up-scaling of the project results.

Training course on procedures and tools for salinity related data processing and statistical analyses

In partnership with IWMI and ICBA, ICARDA organized a specialized short training course within the scope of the Salinity Bright Spot Project from 26 to 30 March 2007 in Tashkent, Uzbekistan. The course focused on procedures and tools for salinity related data processing and statistical analysis. The specific objectives of the course were:

- To share knowledge on the spatial and temporal variation in soil and water quality and the implications for synthesis of pertinent data
- To become acquainted with procedures and tools for salinity related data processing and statistical analysis
- To assist researchers in carrying out data management and statistical analysis of the project data and their interpretation

The course assisted the participants in carrying out data management and statistical analysis of the experimental data and their interpretation. The course covered the spatial and temporal variations in soil salinity at the field scale and water quality, basic principles of design and analysis of experiments, design and analysis of single factor experiments in randomised complete blocks (RCB), design and analysis of multi-factor experiments, split-plot experiments, and strip-plot experiments in RCB. Introduction to Genstat for Windows — software used for statistical analysis — and its use for management of data was provided to serve as the computing platform throughout the course. Besides the training on the statistical methods, data brought by the participants was used to demonstrate data management, statistical analysis, interpretation and presentation of the results.

In total, 12 participants were trained to use GenStat software. The course participants were from the NARS institutions and included the Tashkent Irrigation Institute, Samarqand Branch of Academy of Sciences of Uzbekistan, Kazakh National Institute of Water Management, and Regional Offices of ICARDA, IWMI and ICBA. A follow-up strategy was discussed with the participants. It was decided to use of GenStat Discovery Edition 2 (license should be procured, which is free of any charges). The training was conducted by Murari Singh, Senior Biometrician from ICARDA Headquarters.

Workshop on "Production and utilization of salt tolerant forage crops & halophytes"

A workshop on the "Production and utilization of salt tolerant forage crops/halophytes" was undertaken on 5-8 June 2007 in Samarqand. Ten participants from Kazakhstan, Tajikistan and Uzbekistan participated in the workshop. The workshop was organized by International Center for Biosaline Agriculture in collaboration with Samarqand Karakul Sheep Breeding Institute. The workshop covered important aspects in the

production of salt tolerant crops and halophytes under saline environments; potential utilization of halophytes and sorghum as animal feed; nutritional values of halophytes and approaches for improving nutritive values of halophytes as animal feeds. During the second day of the workshop, the participants visited experimental sites at Kyzyl Kesek in Madanyat farm where studies are being undertaken on improving the productivity of native halophytes using saline artesian waters.

3.2 POSTGRADUATE STUDENTS

Ph.D. student — Tulkun Utkurovich Yuldashev
Research Topic — Use of tree plantations as a biological approach for rehabilitating degraded lands and managing elevated groundwater tables.

A study on the role of tree plantation in the management of elevated groundwater tables forms part of a PhD program of Mr Tulkun Yuldashev. The details of the study and the results to date have been discussed previously under Component 1. Results to date indicate that initial groundwater levels in 2006 and 2007 had a gradually lowering trend from March to September due to evaporation and transpiration associated with tree and crop species.. Under tree plantation sites, the average groundwater level in 2006-2007 was by 0.11-0.49 m lower in comparison with none tree plantation sites during summer months. Among different tree treatments the maximum reductions of groundwater levels in 2006-2007 was observed under the arboretum of mature trees (0.18-0.56 m), followed by an ash-tree plantation established in the fall of 2003 (0.18-0.28 m) and an ash-tree plantation established in the fall 2004 (0.07-0.14 m) when compared to a control having no trees. In September 2006 and 2007 groundwater changes were not significant that may be explained by lowering transpiration rate of the trees. The first-two year analyses reveal that tree plantation together with reducing groundwater level reduced the accumulation of salts by 18-42% at the end of cotton season in 2006-2007. Another positive effect of tree plantation is reduction of environmental impacts and it has direct benefits for farmers through the production of wood for construction and fuel.

The study will be completed in late 2008. The Ph.D. student, Tulkun Yuldashev, is jointly supervised by R.K. Ikramov of the Central Asian Research Institute for Irrigation, SANIIRI, Ministry of Agriculture and Water, Tashkent, Uzbekistan; and Manzoor Qadir (ICARDA-IWMI).

MS D. Student – Ruslan Kalandarov
Research Topic - Using saline water for irrigation of cotton and mulching on highly saline soils of Mirzachul steppe

INTRODUCTION

From June to October 2006 Mr. Ruslan Kalandarov, a graduate student of the Tashkent Institute of Irrigation and Melioration was involved in project field activities. He carried out studies on "Conjunctive use of highly and moderate saline waters and mulching for irrigation of cotton". The experimental site was located at Akaltyn district of Syrdarya province of Uzbekistan. The study area has no access to canal water and is characterizes by highly saline soil and shallow ground water. The design of the experiment consisted of two factors: quality of irrigation water and mulching. Mr. Kalandarov participated in the field studies from its inception in June 2006 until the cotton was harvested in October. Additional soil chemical, physical, and microbiological analysis was undertaken in different laboratories located in Tashkent. The hypothesis of the studies was that saline water could be used to augment deficits in irrigation water shortages throughout the season and mulching has a positive impact on increasing the biological activity of soil that could reduce negative consequences of saline water use for irrigation.

EXPERIMENTAL SITE AND METHODOLOGY

Study area located in central part of Shuruzyak depression belongs to Mirzachul steppe of Syrdarya province. Based on USDA classification the soil is classified as a silt loam soil. The soil is highly saline with gypsum content over 4% in the topsoil. Only drainage water with salinity about 2000-3000 g/l from open drains called Shuruzyak is available at the site along with the ground water pumped by tube wells that have salinity levels of over 4000 g/l.

The experimental layout was a randomized complete block design with three replications. The total number of experimental plots was 18 (6 treatments × 3 replications). Cotton was used as the test crop. Agricultural practices and plant protection measures were uniformly applied to the treatments. Drainage water from open drain (moderately saline), ground water from vertical tube well (highly saline) and their mixture was used for irrigation of cotton. Winter wheat straws was used as the mulch material at an application rate of 2 t/ha. Three types of quality waters was used for irrigation: drainage water from open drain (moderately saline); ground water pumped from the vertical wells (highly saline); mixture of drainage and ground water in a ratio 1:1. Irrigated furrows were either with or without a mulch cover. Soil samples were collected from each treatment in four layers (0 – 15, 15 – 30, 30 – 60, 60 – 90). Sampling was undertaken twice at the beginning and end of the studies. Soluble ions were determined using water extraction in ratio 1: 5. Soil samples for microbiological analyses were collected from the crop rhizosphere. Sampling was udertaken three times in mid June, August, and October, respectively. Soil air sampling for CO_2 analyses was undertaken on three occasions that coincided with microbiological analysis.

RESULTS

The studies proved that soil salinity from July to October increased in all treatments by 20% when moderate saline and mixture of different quality of waters was applied and by 30% with high saline water irrigation. In all treatments from July to October Cl^- ion accumulated in the topsoil. Ground water table was at 1.5 m in the beginning of the studies and gradually reduced to 3 m to the end, which indicates high capillary raise from the ground water table. Soil moisture content was 24% higher in the treatments with mulching compared to no mulch treatments. Mulching affected the quantity of micro- organisms involved into ammonification processes. Treatments without mulch the number of the organisms did not change significantly through out the study, while in the treatments with mulching numbers increased 18 times. The number of oligonitrophils, nitrogen-fixing micro-organisms increased by 47 times in the mid season in the treatments with mulching while no change was registered in the treatments with no mulching. In addition the number of micromycets that contribute to rotting vegetation and decomposition of organic substances increased by 254 times in mid season in the treatments with mulching while no change was registered in no mulch treatments. The same picture was registered for Actinomycets, contributing to decomposition of cellulose and chitin. They number increased 7 times after irrigation, while no change was observed when no mulch was applied.

Concentration of CO_2 in the soil air was also affected by mulching. Mulching increased the concentration of CO_2 in the top 0-20 cm soil from 0.6-1% to 2.2-2.5% in the end of the study period. Changes in the soil microbiology and air condition affected the growth and yield of cotton. Yield of cotton increased by 14% in the high saline water use treatment and mulching as compared to no mulching with the same quality of water. Yield of cotton increased by 6% in the conjunctive water use treatment and mulching as compared to no mulching with the same quality of water.

CONCLUSION

Results obtained from the field studies proved that mulching of furrows increases the number of soil microflora, reduces physical evaporation and that way arrested the accumulation of salts in the topsoil. Yield of cotton under mulching treatment was 6-14% higher as compared to no mulching.

MS D. student - Ms. Indira Ergasheva
Research Topic - Remote Sensing and GIS applied for soil salinity mapping - correlation with crops yield

INTRODUCTION

From June to October 2006 Ms. Indira Ergasheva, graduate student of the Tashkent Institute of Irrigation and Melioration was involved in the project activity. She carried out studies by using the methodology of soil salinity mapping using multi-annual satellite images and collection of ground truth data from soil salinity measurements by EM38 meter and reported yield data of main crops (winter wheat and cotton) from fields of Galaba farm, located at Bayaut district of Syrdarya province of Uzbekistan. The hypothesis of the study was that soil salinity influences on yield of main crops (winter wheat and cotton) differently and this correlation was analyzed.

METHODOLOGY

The seasonal (for April and August – months of maximum vegetation condition of two main crops) Landsat satellite images on 1998 – 2001 years were pre-processed and for each image subset for the Galaba farm area the raster layers of Normalized Difference Vegetation Index (NDVI) were calculated. For each year from the pair of seasonal images the maximum annual NDVI raster layer were calculated and the annual layers were stacked in multi-annual maximum NDVI layer. The unsupervised classification was applied to this layer for ranging of the multi-annual maximum NDVI values to the soil salinity gradation (no salinity, low, moderate, high and very high salinity) and creation of soil salinity map. Ground truth data was collected: a) by EM38 meter measurements for analysis of soil salinity variability, b) by farmers interviewed and from statistical agency of Bayaut district (crops yield data).

RESULTS

Because the high spatial variability of soil salinity, the correlation between the soil salinity measurements at points and pixels of multi-annual maximum NDVI values (linked to the soil salinity gradation) is rather low, but when the average values for fields was calculated as EM-38 measurements, as NDVI, the coefficient of linear correlation has increased up to 0.6802. The correlation between average for field values of multi-annual maximum NDVI and collected data of crops yield was very low. It was because the collected data from local authority did not reflecting the actual yields but the planned one. Farmers have a duty to fulfill the state order on main crops yield (planned yield depending from the soil fertility of field) and they were not willing to provide the actual yield data. There was only available the measured data of the crops yield from 5 cotton and 4 wheat fields. The polynomial correlation of second order between the actual yield data and the multi-annual maximum NDVI values, average for fields is rather high: for cotton – 0.9378 and for wheat – 0.9857. This is a very preliminary result, because of very limited number of fields with the actual yield of main crops.

CONCLUSION

Results obtained from the study has demonstrated that integrated use of Remote Sensing and Geographical Information System is highly useful for soil salinity mapping and assessing actual yields of main crops. Limited data available demonstrated high correlation between soil salinity and crops yield. Further studies are necessary to make analysis with the extended data of actual yield of main crops.

3.3 Knowledge Sharing and Dissemination

Knowledge sharing and dissemination activities were carried out in two directions: (1) producing booklets and information sheets and distributing among farmer communities; (2) establishing and promoting Learning Alliances for two main technologies under the project, namely:

(1) Production of Licorice to reclaim abandoned salt-affected soil of Galaba farm of Syrdarya province in Uzbekistan;
(2) Using PG to reclaim sodic compacted soil of Ikan farm of Southern Kazakhstan.

Eight farmers joined forces to produce Licorice roots for establishing a crop on abandoned soils of Galaba farm. The Learning Alliance consisted of linking farmers with scientists of Gulistan State University and representatives of local and regional authorities. The project team assisted in the establishment of the Learning Alliance, organizing round tables and issued guidelines for the community on Licorice production. The most important event organized under this component was a Farmer Knowledge Fair which was attended by over 400 farmers. Along with the project team over 20 institutions, including international, local and regional, contributed to this event.

Nineteen farmers joined a Learning Alliance in Ikan farm with aim to improve productivity of their land through the application of PG to magnesium dominated soils. By joint efforts and support from the researchers of Kazakh Institute of Water Management they were able to transport over 400 t PG from Taraz city, located 300 km from the Turkestan area. This union has achieved great success in adopting this technology on over 100 ha area. Several round tables were organized with participation representatives of district and provincial level authorities to discuss issues of the Learning Alliance. Round table organized at Southern Kazakhstan University was a great success and scope for further up-scaling of technology adoption has been secured.

A number of brochures, leaflets, technical bulletins was issued to share generated knowledge with farm communities. Details of the events conducted and list of the brochures issued are given below.

Out-scaling a farm-level technology - Using Licorice to reclaim abandoned saline soils on 100 ha area at Galaba farm

It is estimated that annually between 2-3% of the irrigated area of the Mirzachul steppe, one of the largest irrigation regions of Central Asia with about 1 million ha of irrigated land, is taken out of crop production due to salinization. The application of excess surface waters to fields results in the development of elevated water tables that mobilize salt, bring it to the soil surface. When soil becomes highly saline farmers abandon affected fields leaving behind large tracts of saline/waterlogged soils. The rehabilitation of these areas often requires significant financial investment. A recent study undertaken on an abandoned salt affected field in the Mirzachul steppe of Uzbekistan has demonstrated the efficacy of Licorice naked in bring these soils back into production after 4 years.

Licorice naked was established in the fall 1999 on abandoned highly saline soils located in the farm association Navbahor, Bayaut district. After the first year in 2000, when the crop was established, annual forage production is increased from 3.6 in 2001 to 5.1 t ha^{-1} in 2003. In addition, root harvest undertaken in 2002 and 2003 resulted in yields 5.6 and 8.5 t ha^{-1}. After 4 years under Licorice the field was reverted back to a cotton/wheat rotation. The yields of both crops were significantly higher than crops grown on adjacent saline fields. Yields of wheat after Licorice increased from 0.87 t ha^{-1} on saline fields to 2.42 t ha^{-1}. Similarly, cotton yields increased from 0.31 t ha^{-1} to 1.89 t ha^{-1}. There are three main factors that contributed to bring these abandoned soils back into economic production. They are: (1) lowering the water table; (2) reduced amount of salts in the profile; (3) increasing the organic carbon. This study prove that Licorice can serve as an effective alternative approach to reclaim abandoned saline soil. Based on results from this experiment it was proposed to apply this approach to reclaim abandoned soils of Galaba farm association.

Galaba farm is located in the central part of the Mirzachul steppe. Average annual temperature is +12.9ºC, average monthly temperature ranges from -1.8ºC in January to +26.7ºC in July. Precipitation occurs mainly in winter-spring season. Long term average of annual precipitation is 324 mm while potential evapotranspiration amounts to 1600 mm. This data would indicate a high dependence of crop production on irrigation. The soil is a silt loam, meadow- serosem and meadow. The soil bulk density varies from 1.36-1.46 g cm^{-3} in the top 0-20 cm, from 1.40-1.48 g cm^{-3} in the 20-50 cm depth and increases from 1.47-1.50 gcm^{-3} at 50-100 cm depth. This soil texture is one of the reasons for the accumulation of salts at topsoil. Average water percolation rate is 5.1 mm hr^{-1}. Field capacity increases from 24.4% in the topsoil to 26.8% at the 50-100 cm depth.

The total area of the farm association is 3115 ha, of which 1726 ha belong to private farmers. Over 400 ha of irrigated land have high and over 700 ha moderate salinity levels. Over 1700 ha of land has been abandoned by farmers due to water-logging and salinity issues. Farmers grow mainly cotton and wheat. Cotton crop occupies over 1100 ha and wheat over 750 ha of irrigated land. Yield of cotton rarely exceed 1.6 t ha^{-1}. The source of irrigation water is the Syrdarya River. Salinity of irrigation water is in range of 1200-1400 mg L^{-1} and ground water is 3000-5000 mg L^{-1}. In spite of irrigation water shortage due to several other factors there is a trend of increasing ground water table. In 2003 average ground water table at the farm was 185 cm and in 2004 at 165 cm.

In 2005, a group of farmers decided to grow Licorice on 100 ha of abandoned land released from the state tax by a decision of the Governor of the Syrdarya province. These fields were out of production for the last 15-20 years. Farmers undertook coarse leveling of the land, and then tilled to a depth of 25-30 cm deep. Before sowing of the Licorice roots the area was chisel ploughed to a depth of 20-23cm. Roots of Licorice were harvested in October-November and then planted on the selected fields 18-20 cm deep. Inter-row spacing was 90 cm wide and between planting 25-30 cm. Survival rate was at 80-85%. Irrigation was applied at a rate of 80 mm. Changes of the soil salinity from 2005-2007 are presented in Table 1.

Table 1 Changes of the soil salinity at the Licorice grown fields

Period	Soil depth	**TDS**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**HCO_3^-**	**SO_4^{2-}**	**Cl^-**
	cm	G kg^{-1}			mmolc L^{-1}			
Fall, 2005	0-15	9.1	3.87	9.28	6.29	1.37	15.50	2.56
	15-50	13.3	4.75	11.94	7.92	1.95	20.31	2.41
	50-100	20.7	4.78	14.90	11.25	2.45	21.87	2.36
Fall, 2006	0-15	11.1	2.20	7.03	4.51	1.07	10.89	2.30
	15-50	10.3	2.89	6.42	4.50	1.11	10.55	2.69
	50-100	11.2	2.63	6.43	4.34	1.11	10.26	2.54
Fall, 2007	0-15	8.1	0.90	6.35	2.61	0.39	10.86	0.91
	15-50	7.5	1.10	6.35	3.35	0.38	9.79	1.07
	50-100	7.2	0.90	4.90	2.74	0.41	9.28	1.16

The data presented in the table clearlyindicate a reduction in tops soil salinity. Further there is clear evidence to suggest that the groundwater leave has declined with the growing of licorice (Figure 1)

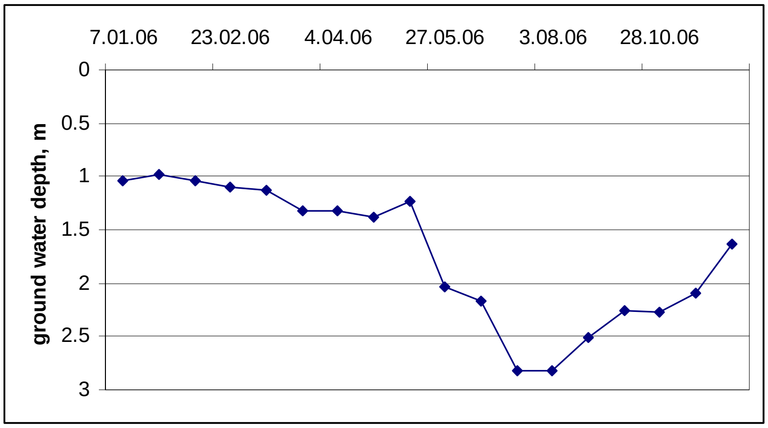

Figure 1. Changes of ground water depths at the study area

As consequence of this decline in groundwater table, soil salinity reductions were obtained in the target area. For the same period, TDS of ground waters declined from 4933(±73) in 2005, 5033(±60) in 2006, to 3633(±80) mgL^{-1} in 2007.

Farmers expect to get yields of roots of Licorice starting from Fall 2009. In the interim period starting from 2006 farmers have harvested green mass of Licorice. Yield of green mass of Licorice totaled 26 (+3.5) t ha^{-1} in 2006 and 2007. In the Fall of 2007, the biomass of roots was 3.8 (0.7) tha^{-1} based on some sample harvests. Based on the advice from the cooperating scientists farmers decided to wait until 2009 when they expect three times more.

ROUNDTABLE MEETINGS

Round Table Meeting at Gulistan State University

A round table meeting on up-scaling licorice production on abandoned soils and strengthening farmers learning alliances was organized on 6 June 2007 at Gulistan State University. In total 22 farmers, representatives of local authorities, scientists, students and lecturers of the university participated in the event. Regional Governor of Syrdarya province allocated 100 ha area of abandoned land in Galaba farm to farmers with no land tax during the first five years. During the meeting participants discussed their findings and issues associated with the growing of licorice. Participants at the meeting indicated the need for long term low interest rate credits. In addition, farmers requested an extension of the tax free period from 5 to 10 years.

Round Table Meeting at Tashkent Institute of Irrigation and Melioration

On August 16, 2007, a roundtable meeting within the framework of the ADB-funded project on "Rehabilitation of Degraded Land" was held at the Tashkent Institute of Irrigation and Melioration with participation of 30 people. The main objective of the meeting was to present the project findings and generate a dialogue between the policy makers, farmers and other stakeholders on the possibilities of up-scaling the results of the project for rehabilitating abandoned land through bio-remediation and creation of 'Bright Spots' through active participation of farmers.

The ADB Country Director appreciated the project achievements and described it as a successful initiative with a potential of creating greater impact. He suggested sharing more detailed results of the project with policy makers and other stakeholders. He showed his commitment to support these activities in future as well. The participants also highlighted the need for more knowledge sharing through the creation of dialogue between farmers, scientist and policy makers.

Roundtable meeting at Shimkent, Kazakhastan

A roundtable meeting was held in Shimkent on 28 September 2007. Farmers from Kazakhstan, Turkmenistan and Uzbekistan attended the roundtable. In total, 93 participants attended the roundtable meeting. The representation from Kazakhstan included Heads of Southwest Research and Production Center of Agricultural Researches, Heads of South-Kazakhstan State University (SKSU), Head of KazAgro Innovation, scientists from Kazakh Scientific Research Institute of Water Management (KSRIWM), teachers and students of SKSU, and farmers.

During this meeting, presentations were made to elaborate the results of phosphogypsum technology and the experiences gained so far. After the presentation, participants had a comprehensive discussion on different aspects of the reclamation of saline-aodic soils through the application of phsphogypsum technique. Issues regarding the availablility of gypsum and its costs were also discussed. Researchers were pf the view that the use of phosphogypsum on magnesium-affected soils is beneficial to enhancet productivity and incease farm income. The out-scaling of the phosphogypsum technology within the framework of two ADB-funded projects — Soil and Water Project, and Bright Spot Project — has translated the on-farm research into an income generating option for the farmers relying on the soils affected by elevated levels of magnesium. Out-scaling of this technology has already been done on more than 100 ha. At the same time, experience has shown that the main issue in dissemination of phosphogypsum (PG) application technology is remoteness of phosphogypsum factories from the irrigated lands in Arys Turkestan region in southern Kazakhstan. The discussion of this problem by the participants of the roundtable meeting has shown the necessity to get the support from the government in order to make every effort in dissemination of the phosphogypsum technology to a much larger area, in particular:

- To promote and facilitate the delivery of phosphogypsum to Arys Turkestan area by alternative type of vehicles, in particular, by railway and others under the prices that should not exceed charges for its delivery
- To petition the Ministry of Agriculture of Republic Kazakhstan for allocation of the credits to farmers in order to cover the PG delivery costs
- To pay expenses towards the monitoring of soil salinity and levels of magnesium in soils with the purpose of estimating phosphogypsum application rates in the farmer fields' areas where phosphogypsum to be applied
- To study additional sources for enhancement the soil fertility
- To urge the international organizations to continue facilitating the process of phosphogypsum use to improve the productivity of high-magnesium soils
- To recommend manufacturers (phosphate fertilizer factories) to support application of phosphogypsum because the present situation with dumping of phosphogypsum can lead to the negative ecological situation.
- To stimulate a market mechanism of phosphogypsum selling by involving businessmen and their support
- Training farmers on phosphogypsum application practices and methods and involving postgraduate students in research addressing the productivity enhancement of magnesium-affected soils

Round table meeting on Rehabilitation of Degraded and Abandoned Lands in Turkmenistan

Round Table meeting in Turkmenistan was held in Dashaguz on 6th November, 2007. The major discussion point was around salt tolerant crops/ halophytes experiments in Turkmenistan. Among the participant there were farmers, project staff, Mr S. Roziev, National Coordinator; Mr B. Kariev, Deputy Head of the

Agricultural Department of the Dashaguz province. After seeing a short movie on crops/halophytes species performance including seed production and rate of trees survival at the Akdepe Experimental Site discussion started. Farmers were surprised with the performance of introduced crops under saline conditions. General agreement was that the project has achieved very promising results.

Farmers Knowledge Fair

IWMI, ICARDA and ICBA jointly with other international and national institutions organized Farmers' Fair on technologies for remediation of saline soils on 28 August, 2006 in Gulistan. Over 20 national and international organizations such as ICBA, ZEF UNESCO Khorezm project, CIP, AVRDC, Uzbek Research Institute of Agricultural Mechanization and Electrification, Research Institute of Cotton Growing, Central Asian Research Institute of Irrigation (SANIIRI) and others actively participated in this Farmers' Fair with their exhibits and handout materials on different aspects of saline lands' management. About 400 farmers from all administrative districts of Syrdarya province attended the Farmers' Fair. Dr. Djalalov, Khokim of the Syrdarya province opened the fair. There were three main pavilions on soil and water conservation technologies, conservation tillage and water saving, and halophytes and salt tolerant plants, respectively. Each organization had own booth where technology was presented.

The Farmer's Fair allowed participating organizations to get detailed feedback and exchange opinions with farmers in the discussion session after the exhibition. At the closing session, the participants unanimously accepted that such events are timely and extremely useful for the development of agriculture in the region and these should also be organized in other parts of Uzbekistan. The Farmer's Fair is a good example of successful sharing of experience among scientists and farmers and other stakeholders.

Farmers' day in Kazakhastan

The farmers' day was organized on 27 September 2007 where the farmers from the nearby areas visited phosphogypsum farms. Researchers from ICARDA and IWMI along with the national partners were also present. The farmers showed considerable interest and volunteered to contribute 30-50% of the cost of phosphogypsum application to the affected fields.

CGIAR-CSO Forum (2006)

Four representative from IWMI Central Asia were invited to the event, namely, Ikbal Yusupova, IWMI CA, Janibek Kamilov, Director of Japalak Water User's Association, Kyrgyzstan, Khabibjon Kushiev from Gulistan State University, Tursunboy Avezov, Galaba farm Learning Alliance leader. They shared their experience on the collaboration between the CGIAR centers and the achievements to the date.

Throughout most of November, a diverse group of researchers and development professionals kept up a continuous stream of informative and constructive messages in the CGIAR's first facilitated online dialogue about its partnerships with civil society organizations, or CSOs. Referred to as a "Virtual Conversation," the dialogue was the positive prelude to a day-long, face-to-face Forum – involving CSOs, Members of the CGIAR, staff of the Centers and Challenge Programs it supports and others – at the CGIAR Annual General Meeting (AGM06) in early December.

Nearly 160 people registered for the conversation, and around 700 participants took part at the AGM. Many of those engaged in the Virtual Conversation had been invited to take part in the Innovation Marketplace, another event at AGM06 designed to allow CSO representatives and their CGIAR partners to share insights and experiences from their collaborative work across the developing world. The Virtual Conversation gave them an opportunity to get to know one another in advance, through virtual introductions, and to exchange information about their work. This encompassed a wide range of topics, such as crop improvement, land management, biodiversity conservation, organic farming, enterprise development, farmer participatory research and the use of new information and communications technologies (ICTs) for rural development.

Promotion of seed production of alfalfa and other crops for wide dissemination of salt tolerant crops

The overall objective of the activity is strengthening the capacity of project partners, both farmers and the NARES groups, in the management and remediation of saline affected lands by improvement of seed production and seed multiplication at the local level. This activity also included training and consulting of farmers on seed ecology and biology of germination, as well as seed production for further dissemination within farmers, mostly under saline environments of Syrdarya province.

Seeds of alfalfa (Medicago sativa), local cultivars of Sorghum bicolor, Triticale and rice (Oriza sativa) and different species and varieties of fodder legumes (Table 2.) were distributed to the pilot farm in Galaba, Syrdarya province. Seeds of alfalfa (1.5 ha), Triticale (0.5 ha) and some varieties of winter legumes (0.02 ha each) were sown on the saline waste lands in autumn 2006. In 2007, seeds obtained from the pilot farm sites were distributed among large group of farmers.

Table 1 . List of salt-tolerant crops used for seed multiplication at the Galaba Farm

Name of species /cultivars	**Number of registration/origin**	**Locality and date of collection**	**Properties**	**Date of sown at Galaba farm**	**Area of cultivation (ha)**
Medicago sativa a)		Kyzylkesek/ Central Kyzylkum, 10.08.06	Salt-drought and frost tolerant variety	20.09.06	0.25
b)		Syrdarya province, 30.07.06.	-	-	2.0
Sorghum bicolor	IC-637	Nurata collective Farm, Kushrabad district	Drought and moderately salt tolerant	In spring 2007	0.5
Triticale	IC-638	Nurata collective Farm, Kushrabad district	Drought and moderately salt tolerant	20.09.06	0.5
Lens culinarius	PLIP 96-41 ICARDA	Andijan region, summer 2006	Drought-salt tolerant	October 2006	0.02
Lathyrus sativus	JFLS 433 SEL 520 (ICARDA)	Institute of grain and leguminous crops, Andijan	Drought-salt tolerant	October, 2006	0.02
Lotus corniculatus	Wild population	Fergana Valley	Drought and moderately salt tolerant	October, 2006	0.02
Mellilotus officinalis	Wild population	Fergana Valley	Drought and moderately salt tolerant	October, 2006	0.02
Brassica napus L.	Wild population	Fergana Valley	Drought and moderately salt tolerant	October, 2006	0.02

Appendix 1. List of events under Bright Spots Project

	Title	Place and dates	Number of participants	Participants
I.	**Training courses**			
1	PRA Tools, Effective Communication Skills and Interviewing Techniques	June 13-16, 2005 in Taraz, Kazakhstan	20 people	Socio-economists involved in the project, PhD and MS degree students
2	PRA Tools, Effective Communication Skills and Interviewing Techniques	July 12-14, 2005 in Gulistan, Uzbekistan	32 people	Socio-economists involved in the project, PhD and MS degree students of Gulistan State University
3	PRA Tools, Effective Communication Skills and Interviewing Techniques	September 7-10, 2005 in Dashauz, Turkmenistan	16 people	Socio-economists involved in the projects
4	Multiplication of seeds of Salt Tolerant Crops	December 12-16, 2005 in Tashkent, Uzbekistan	16 people	Young plant scientists involved in the project
5	Evaluation of technologies addressing salt prone land and water resources and rural livelihoods	April 9-12, 2006 Tashkent, Uzbekistan	17 people	Project staff and partners involved in socio-economic research
6	Evaluation of technologies addressing salt prone land and water resources and rural livelihoods	July 1-3, 2006, Urgench, Uzbekistan	2 people	Project implementing staff involved in socio-economic research
7	Advances in Biosaline Agriculture with Reference to Central Asia and the Caucasus	May 15-21, 2006 in Tashkent, Uzbekistan	44 people	Young plant scientists from all CA countries
8	Outcome mapping and Participatory Planning, Monitoring and Evaluation tools	October 27, 2006 in Gulistan, Uzbekistan	20 people	Socio-economists involved in the project; Ph and MS degree students
9	The Procedures and Tools for Salinity Related Data Processing and Statistical Analysis	March 26-30, 2007 in Tashkent, Uzbekistan	12 people	Young scientists involved in the project; students of the Tashkent Irrigation Institute
10	Outcome mapping and Participatory Planning, Monitoring and Evaluation tools	November 7, 2007, Dashauz, Turkmenistan	6 people	Socio-economists; farmers
11	Outcome mapping and Participatory Planning, Monitoring and Evaluation tools	November 15, 2007, Taraz, Kazakhstan	4 people	Socio-economists
II.	**Workshops & Fairs**			
1	Technologies for Remediation of Saline Soils	August 28, 2006 in Gulistan, Uzbekistan	More than 400 farmers and 100 experts	Policy makers, farmers, researchers, students

Contuniation of Appendix 1

	Title	Place and dates	Number of participants	Participants
2	Up-scaling of Phosphogypsum (PG) Application for Remediation of Mg-dominated Soil	July 22, 2006 in Arys Turkistan, Kazakhstan	More than 80 participants	Farmers and local authorities; the project staff
3	Production and Utilization of Salt Tolerant Forage Crops/Halophytes	June 5-8, 2007 in Samarqand, Uzbekistan	10 people	Farmers; local researchers; the project staff
4	Phosphogypsum usage for remediation of magnesium-dominated soils in irrigated areas.	September 27, Eski Ikan, Kazakhstan	100 farmers and 30 experts	Farmers and local authorities; the project staff
5	Sharing with the experience of bright spots and socio-economic research results	May 29, 2007, Eski Ikan, Kazakhstan	28 farmers and 6 project staff	Farmers and local authorities; the project staff
III.	**PhD studies**			
1	Tulkun Yulfashev, PhD on Use of tree plantations as biological ameliorant for the degraded lands	Galaba Farm, 2006-2007		
2	Ruslan Kalandarov, MSc studies on Using saline water for irrigation of cotton and mulching on highly saline soils of Mirzachul steppe	Akaltyn site, 2006		
3	Indira Ergasheva, MSc studies on Remote sensing and GIS applied for soil salinity mapping – correlation with crops yield	Galaba farm, 2006		
IV.	**Other**			
1	National Planning Meeting	February 13-20, 2006 in Tashkent, Uzbekistan; Taraz, Kazakhstan; Dashauz, Turkmenistan.	60 people	The project staff from Kazakhstan; Uzbekistan and Turkmenistan
2	Annual Steering Committee Meeting	April 6, 2006 in Tashkent, Uzbekistan	25 people	The project Coordination Committee
3	Annual General Meeting of CGIAR and CSO Forum	December (4 days) 2006 in Washington D, USA	700 participants (4 participants from IWMI CA office, out of which 3 CSO partners)	CBO members, experts, scientists
4	National Planning Meeting	10-11 February, 2007, Taraz, Kazakhstan; February 14, 2007, Tashkent, Uzbekistan, 4-5 March 2007, Dashauz, Turkmenistan	41 participants	The project staff from Kazakhstan; Uzbekistan and Turkmenistan

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	Title	Place and dates	Number of participants	Participants
5	The 3rd Steering Committee Meeting	April 2, 2007 in Tashkent, Uzbekistan	25 people	The project coordinators and leading reseachers
6	Round Table Meeting on Up-scaling Licorice Production on Abandoned Soils and Strengthening Farmers Learning Alliances	June 6, 2007 in Gulistan, Uzbekistan	22 participants	Policy makers; Lecturers and students; the project staff
7	Round Table Meeting on Generating a Dialogue between the Policymakers, Farmers and other Stakeholders	August 16, 2007 in Tashkent, Uzbekistan	30 people	Policy makers; lecturers and students; the project staff
8	Round Table Meeting on Phosphogypsum usage for remediation of magnesium-dominated soils in irrigated areas.	September 28, 2007, Shymkent, Kazakhstan	30 participants (additionally 65 University staff and students)	Representatives of the Provincial authorities; lecturers and students; the project staff
9	Round Table Meeting on Rehabilitation of Degraded and Abandoned Lands in Turkmenistan	November 6, 2007, Dashauz, Turkmenistan	16 people	Representatives of local authorities; farmers and the project staff