

Key Points

- While global food trade continues to grow, so are concerns about food safety and nutritional impacts. Food safety and environmental integrity are closely linked and vital to global food security.
- Hidden costs of the food system far outstrip the value of global food trade, and costs could be greater for less developed countries as they have lower capacity to prevent and mitigate impacts.
- The costs of lax food safety standards in emerging economies spill over to advanced economies through international trade, immigration, global poverty, and social instability.
- Public policies for prevention and mitigation can improve the health and well-being of farmers and consumers and safeguard the environment.
- Increasing farm production without relying on harmful agricultural chemicals needs to be embraced as a crucial goal: new knowledge systems provide greater capacity for improving food system safety and integrity. Enhanced data collection and investment in capacity building are crucial for addressing inequalities.

Achieving Food System Stability and Well-Being: A New Role in Global Development Finance

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1. Introduction

Food insecurity is a pervasive problem affecting 1 in 10 people. Food insecurity is closely linked to poverty. While food consumption is a matter of private interest, meeting food security for all is an established public goal. Food security has far-reaching implications for economic stability, public health, social equity, environmental sustainability, and global interdependence. Therefore, it requires coordinated efforts at the policy level—at the international, national, and local scales—to ensure that everyone has access to sufficient, safe, and nutritious food.

The term “food system” encompasses all the elements and activities related to producing and consuming food, along with their effects on economic, environmental, and health outcomes. Food systems are globally interconnected—intensive production systems, trade, and human movements hasten and broaden the environmental footprint of food systems. In connection with natural circulation systems on land, water, and air, food systems augment pollution pathways and distribute impacts globally. The global food system faces a triple challenge:

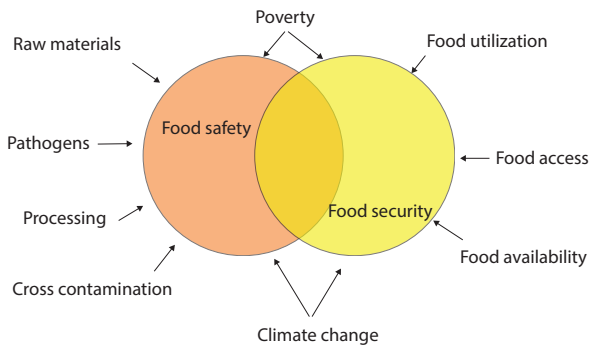
1. Food security and nutrition: Ensuring adequate food supply for a growing population—overcoming inequalities in access, availability, and utilization, and safeguarding stability, nutritive values, safety, and reliability.
2. Livelihoods: Supporting the livelihoods of millions of farmers and others in the food chain—safeguarding production systems and income streams.
3. Environmental sustainability: Feeding and supporting livelihoods while protecting the living environment—primarily air, water, soil, and biodiversity.

Food security has long been a global development goal. Safety and security are mutually reinforcing concepts. Food safety and food security are interrelated in ways that have a profound impact on the quality of human life (Figure 1). Yet, gains in food supply security have come with increasing risks to food safety and nutrition, causing consumers to question the reliability of the food commodities they purchase.

Policies for food security have begun to take a new shift. While increasing food supply has been the primary focus, addressing the drivers that create risks to food system stability is now becoming even more crucial.



Figure 1: Interrelationship of Food Safety and Food Security



Source: Hanning et al. (2012).

Foremost, raising the health and safety credentials of food has become a global concern, driven by a need to minimize the risk of unsafe food that could expose people to food-borne diseases, human health impacts, and heightened environmental risks. With global food trade continuing to grow, the food system is highly geographically dispersed. While food trade is crucial for meeting demand, maintaining sanitary and phytosanitary standards (SPS) and compliance with allowable chemical residue levels (CRL) is a growing challenge in ensuring food is always safe even if it is not traded, such as in subsistence production systems. Without such assurances, food could become a source of harm and a factor compromising economic growth and well-being.

In developed economies, the balance of evidence is shifting, and several successful litigations have paved the way for greater collective action. Some governments, such as the European Union, and many environmental and health agencies are increasingly concerned.

While the emphasis on meeting various credence requirements to convey adherence to social and environmental standards is growing in advanced economies, insidious health risks are also rising. Even in settings where efforts are being made to promote Good Agricultural Practices (GAP) designed to mitigate compliance risks, noncompliance is constraining prospects for enhancing the safety of food commodities sold in international markets. This diminishes the well-being associated with those gains, creating numerous risks and vulnerabilities. The coronavirus disease (COVID-19) pandemic has highlighted some of those risks, emphasizing sources of resilience and vulnerabilities, including safety, reliability, and nutritive values.

Policy Complexity

Poverty and climate change are two key factors that influence well-being in food safety and security. Climate change disrupts production and delivery systems and raises systemwide costs. As climate-linked vulnerabilities become widespread, episodic droughts and floods exacerbate connected risks. Floods destroy crops, harm assets, and distribute pollutants into groundwater and waterways, raising biodiversity and human health risks. Local impacts transmit more widely via markets, creating instability and volatility.

The costs of lax food safety standards in emerging economies spill over to advanced economies through international trade, immigration, global poverty, and social instability.

If we think of high-income consumers' demand for safe, high-quality food as creating a positive externality in terms of improved health and well-being, biodiversity, and food-loss reduction benefits, the free market will produce less than the optimal amount of quality product. That is what is happening now.

Information asymmetry means that the suppliers of inputs know the real cost of their products, and the rest of society only knows of the immediate benefits of crop protection. Then, suppliers' legitimate promotional effects can overcome the consumer push for quality improvements. The question will then be how to make the market efficient. One possibility is to tax pesticide use. This is a hard-order task as most believe that the market is working. A private solution through negotiation does not exist in this case because farmers and consumers are numerous and not well organized. Their interests are represented by the state, and scientific knowledge is at best non-conclusive.

If we think of food safety as a public good, then we have the usual free rider problem as everyone benefits, and persuading people to share costs would be hard. Then again, we need governments to ensure food safety through public policies. In this case, intervention is justified as the benefits of quality improvements would reduce the social risk of harm, such as in public defense paid through taxes, and the low-income group would be the free rider.

There is also a new opportunity for financiers—both in the development and business sectors.

2. The Opportunity

COVID-19 has highlighted new opportunities in food systems, emphasizing sources of resilience and vulnerabilities, including safety, reliability, and nutritive values. With the pandemic moving into its endemic phase, consumers are showing greater interest in health and wellness as a safeguard against future risks. Millennials, having experienced many disruptions in their lifespan, are naturally more concerned (McKinsey & Company 2024)(Figure 2).

Food contamination is a serious risk. In advanced markets, improved hygiene and handling protocols along the production process can manage microbial and pathogenic risks. Control programs such as Hazard Analysis and Critical Control Points (HACCP) have been designed and implemented to reduce such food safety risks.

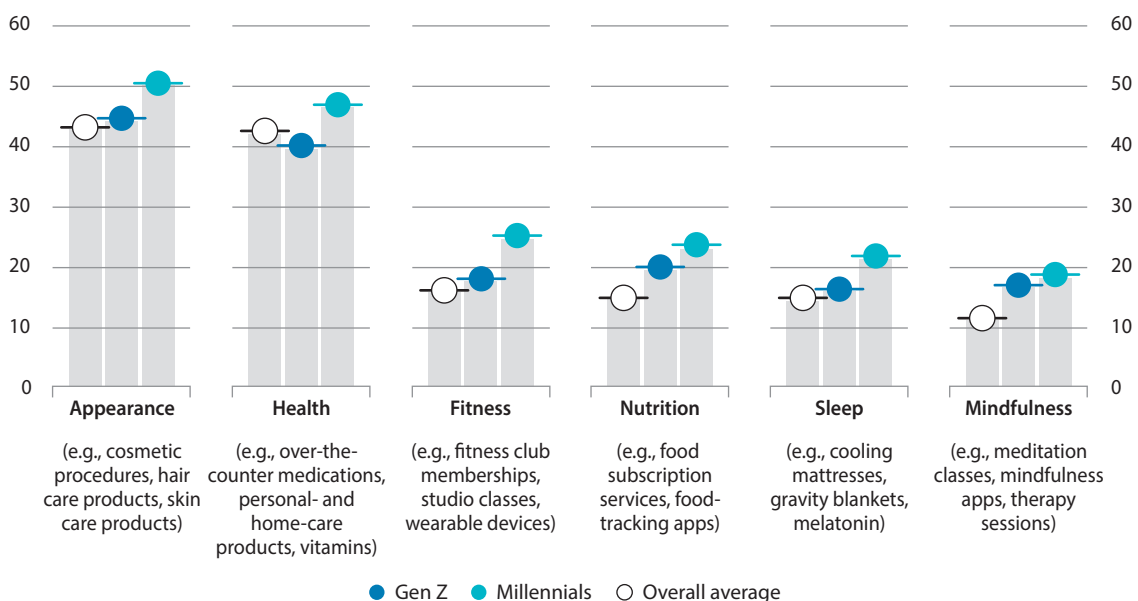
Raw materials used in production, such as synthetic fertilizers and pesticides, derived from fossil fuels, have risen in importance as a source of food safety risks. Several human exposure routes and pathways create pesticide exposure risks (Figure 3) (EEA 2023). Uncontrolled production practices expose farmers and consumers as

they are hard to detect along the supply chain. Materials can spill into the environment through runoff and spray drifts, affecting water quality and biological diversity. Often, poor comprehension of hazard pathways, narrow choices, and pressure to meet urgent needs encourage risky behaviors. Costs are passed across the system, including to consumers in distant markets. Inadequate monitoring and information sharing hinders policy actions, even in advanced economies.

The rising cost of living and competitive pressures force suppliers to cut costs. The use of banned substances, inferior products, and lack of compliance with safety protocols increase food safety risks. Lack of resources and safeguard mechanisms, such as unsafe practices, and the inability to fund track and trace mechanisms escalate supply chain risks, exposing farmers, food handlers, and consumers.

Chronic impacts take time to uncover, and complex causal pathways make proving liability costly and ineffective as a remedy. The disposal of waste and unsold goods also adds to environmental costs and compromises future production capacity because pollutants accumulate in the living and physical environment, generating long-term hazards.

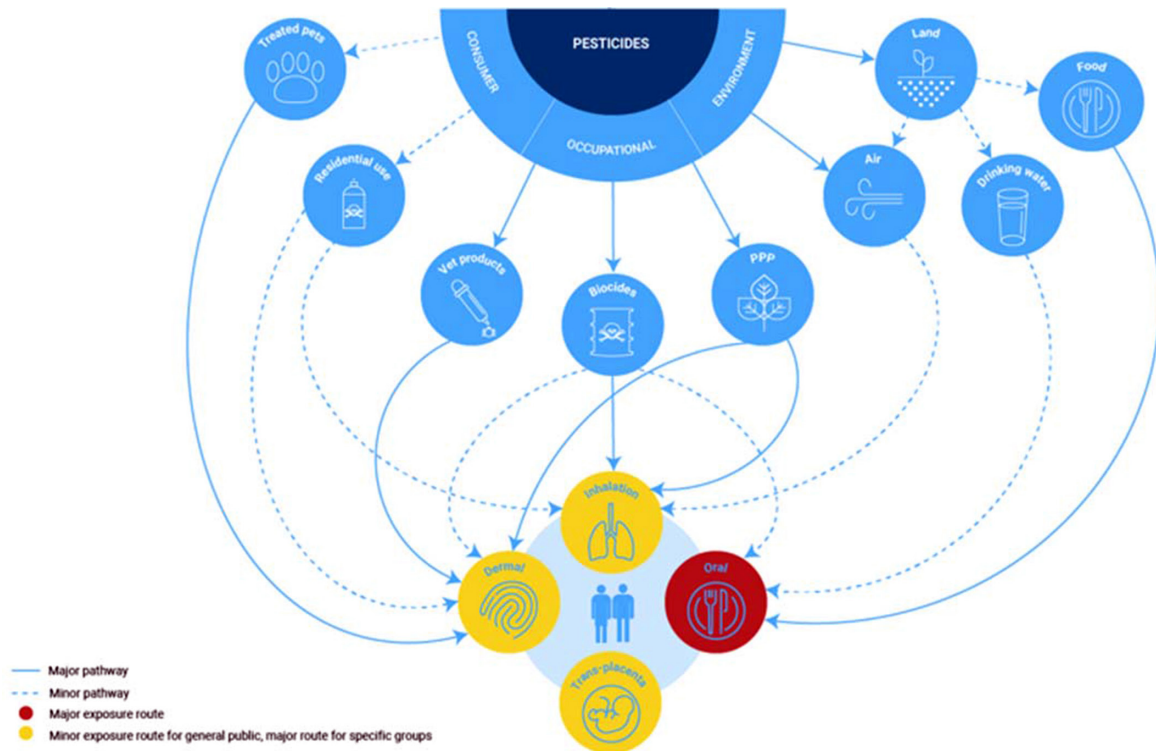
Figure 2: United States Health and Wellness Purchases by Product/Service Type and Generation
(% of respondents, n = 2,007)



Note: Average across all products in each category. Percentage of respondents who purchased at least once in past 12 months.

Source: McKinsey Future of Wellness Survey, August 2023.

Figure 3: Human Exposure Routes and Pathways for Pesticides



Note: Bold line denotes a major exposure pathway, whereas dotted line denotes a minor pathway. Red circles denote a major exposure route. Yellow circles denote a major exposure route for the general population which may nevertheless be a major route for specific groups.

Source: European Environment Agency (2023).

The persistence of pesticides and their derivatives in the environment is a serious concern because of their environmental impacts. Pesticides can enter living organisms through food, water, or air, and accumulate or build up in body tissues or the body fat of humans and animals. This process is called bioaccumulation. Pesticides can also enter organisms directly from water through gills or epithelial tissues of aquatic species, leading to bioconcentration to harmful levels and causing fish to die, for example. When pesticide levels accumulate through multiple processes in a food web, they can lead to biomagnification, where toxicity levels reach certain thresholds over time and cause harm (Sandanyake et al. 2022, Katagi 2010).

Combining Safety and Security

Food safety and environmental integrity are closely linked and vital to global food security: without safety, delivering stability and well-being would be impossible.

Let us examine the situation and what can we do about it.

Global food trade is growing. From 2000 to 2021, global trade in food grew by 350%, reaching \$1.7 trillion. Food now represents about 8% of total merchandise trade globally, compared to 6% in 2000 (UNCTAD 2024). With 1 in 10 people facing hunger worldwide, trade is crucial to improving access to food. However, fair trade requires well-functioning markets that take all costs into account.

Much of the food is not traded. It is less well-known that around two-thirds of global agricultural output does not enter global value chains and is either consumed by producer households, or locally, and lost without being captured in trade. When markets are well-connected, such as in Australia and New Zealand and Europe and North America, a large proportion of food produced is traded both domestically and internationally, with greater exposure to scrutiny. Asia is a vast continent with varying levels of food trade. Countries like the

People's Republic of China and India have large domestic markets and significant agricultural production. Their food exports may not be as high as their production levels due to internal demand.

Internal trade lacks safety protocols, and consumers cannot differentiate between unsafe produce. In all these countries, the market recovery of food varies widely, and food is lost or wasted without being used for its intended purposes. Inputs that go into unused produce could have been used elsewhere and represent missed opportunities. They also burden the environment without creating benefits.

Smallholder farmers are most affected. Smallholders, who operate small plots of land (< 2 hectares), mainly produce for their own needs and sell a portion to buy other goods or to earn a living. Mostly working on the fringe of formal markets, they contribute about one-third to the global food supply. As trade opportunities expand and production systems change, their share is likely to grow. Meeting food standards and safety protocols remains a challenge for them. Food standards and compliance vary widely, with evidence of unethical and fraudulent practices. Pressures of poverty and insecurity, as well as lack of information and supporting infrastructure, are lead contributors.

The Economic Cost

While the exact economic value of food systems varies in different contexts, quantifying this value precisely can be complex due to interconnected factors. Nevertheless, we explore some relevant insights:

- **Hidden costs:** Some estimates suggest that food systems generate around **\$12 trillion** in hidden social, economic, and environmental costs. That is many times the realized value (\$1.7 trillion) of global food trade. These costs include health-related expenses, environmental degradation, and other indirect impacts. Most environmental impacts occur through land use change, or at the stage of **agricultural production**. These costs are not accounted for in prices paid, representing a massive market failure. Remedial action is paid through public programs, raising government expenditure and overburdening the tax system. Countries with debt burdens and immediate economic pressures accumulate these hidden costs, endangering future generations.
 - **Business opportunities:** Sadly, business activities have contributed to these unintended consequences, or externalities, creating large public costs. Failure in regulatory and governance arrangements is largely to blame, as well as incomplete knowledge that has driven shorter-term profit motives. The time is now to transform the food system from one seeking instant gratification to one in favor of long-term reward.
 - **Transforming the food system:** This requires optimizing public spending and mobilizing private capital for sustainable production. New food services and greenhouse mitigation opportunities could create \$4.5 trillion in new business annually, according to estimates. They can also create new jobs outside the food system, improve knowledge systems, and foster social harmony by narrowing inequalities.
 - **Hidden benefits:** It is often overlooked that rural households are diverse, with livelihoods drawn on a mix of on- and off-farm income sources alongside food production for family consumption. They contribute to protecting biodiversity, preserving traditional knowledge, and enhancing local institutions and public goods. With new opportunities, massive labour resources locked in low-value farming can be better utilized to generate improved quality of life in rural settings.
 - **Balancing trade and local production systems:** The key lesson from COVID-19, of the value of domestic production systems, should not be forgotten. The mutually beneficial aspect of trade is its strength. Trade improves dietary diversity, enhances nutrition security, and promotes productivity. Yet, orientating international trade to provide better food and nutrition security for all nations is fraught with challenges. Strong local production systems that draw on local comparative advantage will also promote trade and create jobs. Distortions, such as those arising from subsidies, inappropriate technology, and barriers to knowledge diffusion and investment, hinder trade and compromise well-being.
- The economic value of food systems extends beyond the mere monetary values realized in global food trade. It encompasses health, livelihoods, and environmental well-being, making it a critical focus for policy makers, financiers, and other influencers of public goods. The challenge is to bring the global food system in harmony with local needs and aspirations for strong communities.

3. Managing Pesticides, One of the Most Widespread Pollutants in the World

Pesticides, used both in agricultural and domestic applications, are one of the most widespread pollutants (Donley et al. 2022, EEA 2023). Modern society's comfort with the use of pesticides has rapidly evolved in a context where convenience has overridden consequence, leading to a level of complacency, where the role of nature as the largest and most effective pest controller is grossly overlooked in both management and policy decisions.

The unprecedented ease and widespread use of pesticides and related agricultural practices have evolved within a system of values and a shift in ideologies that have favored capital accumulation, control, and expansion over balance and coexistence with the land and people (Donley et al. 2022). Climate change and the other public pains we bear have their roots in those values and ideologies.

As the food system becomes sensitive to shifts in environmental and social values governing supply and demand, the opportunity is now to bring a balance in ideology toward greater social well-being. The need is to fend off instant gratification and create consensus on a vision. We propose working towards developing a vision, encapsulating the following: *ensuring the welfare of all stakeholders of the food system is promoted and protected by the development and adoption of sound pesticide use standards and practices across the globe.*

Without such a vision, the world will risk not attaining global development goals and jeopardize much of the development agenda. If safety is not a consideration in security, the beneficiaries of development are exposed to a continuing risk of harm, including chronic disease and premature death, through widespread pollution impacts of unmitigated risks in pesticide use in the food system.

The overall challenge is to build a food system that is safe, reliable, and resilient: one that meets the needs of today and safeguards the lives of tomorrow. This is to be achieved in an evolving global setting that exposes everyone to interconnected risks through trade and the movement of people.

First introduced as a cautionary practice under strict regulations, agrochemicals are an essential part of farming. Wider availability, ease of access, and broader

familiarity mean that these highly dangerous farm inputs are frequently used, and misused, as a safeguard tool to increase yield while grossly discounting their potential for harm.

There is a growing body of knowledge that is contributing to an enhanced awareness of the potential risks of cancer and other social health and environmental harm on farmers themselves, and to consumers and the broader natural environment associated with some farm management practices. Yet, for farm producers, the benefits significantly outweigh the costs because the benefits received as income are immediate and real, and the costs are insidious and take time to realize, as in the case of environmental damage and life-long illnesses.

There is no denying that the global food supply has increased manyfold. The visual quality, reliability, and range of food offerings in the market are at an all-time high, and the world is meeting contingencies well. The COVID-19 experience taught us that organized systems, as in Australia and New Zealand, fared well even during the worst times, displaying a high level of resilience. In advanced markets, clean and green products fetch higher prices, encouraging investment in quality-assured supply systems that cater for credence market demand. For instance, traceability systems are growing rapidly, and consumer assurance is gaining as a viable tool to gain high-end markets. Input suppliers are responding with safer alternatives and precision farming technologies are showing promise at the intensive margin, while conservation farming approaches are gaining ground at the extensive margin.

Widespread food fraud—cheating consumers through adulteration, malpractices, and false claims—overcomplicates the market failure (Ehmke et al. 2019) where food supply and profit concerns downplay critical food safety and environmental sustainability requirements. Interest group pressures complicate public policy development, perpetuating the pursuit of narrow private gains at wider social costs. The result has been a growing global externality, where the full costs are not accounted for in decisions. With close links to other global externalities in climate change, biodiversity, and land degradation, it is becoming a silent contagion.

Motivating a move away from deep-rooted bad behaviors at the household, small business to global business is the key development challenge. Converging global collective action for food system stability and well-being recognizes the need for concerted action. New strategies that address joint failures in market and governance

arrangements are widely called for. The complexity offers an influential opportunity for responsible global financing to leverage necessary change, overpower the contagion, and enhance overall well-being.

Essentially, the food system is becoming a vehicle that transmits risks across the globe. Food is eaten by both the poor and the more affluent alike, and insidious risks conveyed via food can infringe on the lives of those living in rural hamlets to royal houses because food is a universal commodity that supports life. When science is unable to pinpoint sources and causes with certainty, supply chains that market those products for the obvious benefits prosper, while the risks are borne by the public. Prevention, instigated through strong public policies, and acknowledged as risks in financial decisions, stands out as the pathway to remediation and the minimization of associated social and environmental depletion. Negligence by governments, financiers, and businesses could carry future risks of liability both in the ethical and legal sense.

4. How Can We Facilitate Food System Harmony?

To shift the focus toward the health and well-being of farmers and consumers, we can take several strategic steps, comprising prevention and mitigation:

1. **Promote sustainable practices:** Encourage farmers to adopt sustainable agricultural practices that prioritize soil health, biodiversity, and reduced synthetic inputs. This benefits both farmers and consumers by ensuring healthier produce and minimizing environmental harm. Precision agriculture technologies that use in-field sensors and aerial imagery allow farmers to map nutrient needs and apply them judiciously. This reduces chemical usage while optimizing crop yield. Smart irrigation systems help conserve water and enhance crop health. Such practices need to be tailored to farmer circumstances and be cost-effective.
2. **Education and training:** Farmer training on nutrition impacts, hygiene, and the safe handling of agricultural chemicals can persuade behavioral change. To be effective, consumers who pay for farm produce also need to be educated about the nutritional value of clean, fresh produce and the importance of a balanced diet.
3. **Fair pricing and income:** Ensure fair pricing for agricultural products. When farmers receive

reasonable compensation, they can invest in their health and well-being. In developed economies, such behaviors are encouraged through effective markets. Cooperative models and direct-to-consumer sales can help achieve this in emerging economies. Attempts to keep food prices low through government subsidies are counterproductive. Income support to vulnerable groups stimulates growth.

4. **Reducing food loss and waste:** Educate both farmers and consumers about minimizing food loss and waste. Unrecovered food in supply chains and wasted food after purchase affect everyone's well-being and strain resources. Smart business practices that save inputs and optimize output recovery need to be promoted.
5. **Diversification:** Nature is diverse. Encourage farmers to diversify their crops and income sources, including livestock and poultry. This reduces reliance on a single crop and provides better nutrition for both farmers and consumers. Organic produce, regenerative agriculture, and low-input farming can help improve incomes and reduce waste. Producing less in many places can be better than wasting produce in high-cost industrial systems.
6. **Local food systems:** Promote local food systems where consumers have direct access to fresh produce from nearby farms. This saves energy, strengthens community bonds, supports local economies, and ensures fresher, healthier food.
7. **Labelling and transparency:** Transparent labelling helps consumers make informed choices. Highlighting organic, pesticide-free, or sustainably produced foods empowers consumers to prioritize health and helps farmers adopt good agricultural practices. Adopting such changes in emerging markets could be supported through farmer groups and other collective efforts. Building trust is an important pathway.
8. **Access to healthcare:** Improve access to healthcare services for farmers. Regular health check-ups, mental health support, and preventive care are essential to manage risks and encourage safe behaviors. Telemedicine and mobile clinics can be valuable in rural areas, as was proven during the pandemic.
9. **Collaboration:** Food security is a global public good. Achieving public good outcomes requires collaboration among stakeholders—farmers, input suppliers, financiers, policy makers, and consumers. Collective efforts can drive positive change.

10. **Research and innovation:** Knowledge is the key. Investing in research on nutrition, food safety, and sustainable practices, such as precision agriculture and smart farming, and track-and-trace monitoring systems can benefit all parties. Digital technologies can help bridge knowledge gaps rapidly and effectively and promote sustainable rural transformation.

A holistic approach that considers the interconnectedness of farmers, consumers, and the environment is crucial for promoting health and well-being across the food system.

Policy and Institutional Change

The *externalities* associated with farm inputs can have significant economic implications. Ineffective public policies and poor regulatory systems have led to growing safety risks that undermine development progress.

1. **Policy Alignment and Integration**
 - Elevated global energy prices have led to increased production costs for farm inputs, particularly fertilizers. This has increased the cost-effectiveness of local solutions derived from nature. As the world is moving away from fossil fuels, bioremediation technologies in farming represent a proactive step.
 - The impact of high energy prices varies across commodities, with crop production being more energy-intensive than livestock production. Holistic crop-livestock production systems offer complementary benefits.
 - Policies that cushion producers from energy market shocks retard innovation and misallocate resources. Smart farmers adopt new ways and mitigate costs. Promoting small-scale local solutions adds to national strength and global benefits.
 - Social support for vulnerable groups and safety nets during crises strengthen communities and empower entrepreneurship. Aligning incentives and removing impediments to self-reliance are crucial.
 - Policy coordination across the agriculture, education, health, and environment sectors through integrated policy and planning brings efficiencies and minimizes conflicts.
2. **Monetary Assessment of Externalities**
 - Knowing the costs is crucial in minimizing them. Assessing externalities in agriculture

is crucial because they generate social costs and profits for the current generation while compromising future well-being. Knowing the relative costs and benefits helps manage the trade-offs better, from planning and design to the implementation of development projects.

- Assessment and communication of externalities in agriculture, such as sources and impacts on land degradation, biodiversity, and human health, would help balance the trade-offs between economic, environmental, and social impacts in both public policy and private investment decisions. Better information can improve the well-being of both current and future generations.

3. **Reducing Negative Externalities**

- Best management practices tailored to local contexts can minimize negative externalities through cost-efficient preventive actions. Taxes and charges can be used to control downstream losses by mitigating external impacts, as can knowledge-based incentives for practice change.

Externalities associated with farm inputs are missed opportunities for improving well-being. Understanding the sources of costs and quantifying them can help in designing sustainable agricultural practices and informed investment and policy decisions.

5. Why Have We Not Taken These Opportunities in the Past?

Simply, we did not know the gravity of the mistakes. Growing knowledge systems offer us new clues, but uncertainty prevents us from moving into swift action. The intolerable nature of costs, death, despair, and destitution calls for concerted efforts and precautionary actions. There are several non-regret policies derived from improving knowledge systems.

Would Farm Production Be Possible Without Harmful Agricultural Chemicals?

Yes, new knowledge gives us new hope. Increasing farm production without relying on harmful agricultural chemicals needs to be embraced as a crucial goal. Here are some strategies and alternatives:

1. Precision Farming and Technology Choices

- In-field sensors and aerial imagery allow farmers to map nutrient needs and apply them judiciously. This reduces chemical usage while optimizing crop yield (Colaço et al. 2024). Optimality ensures value for efforts.
- For example, smart irrigation systems help conserve water and enhance crop health, ensuring more usable produce and more money.

2. Integrated Pest Management (IPM)

- IPM combines biological, cultural, and chemical methods to manage pests effectively.
- Biological control: Introduce natural predators or parasites to control pests.
- Crop rotation: Alternating crops disrupts pest life cycles and improves nutrient cycling.
- Trap crops: Plant specific crops to attract pests away from main crops.
- Policies that mandate pesticide residue testing and compliance with food safety will encourage IPM and related sustainable practices.

3. Organic Farming

- Avoids synthetic chemicals: Organic farming relies on natural processes and avoids synthetic pesticides.
- Enhances soil health: Organic practices improve soil structure and nutrient content while helping to mitigate greenhouse emissions.
- Protects ecosystems: Organic methods promote biodiversity and reduce harm to beneficial insects.

4. Low- and Non-Chemical Alternatives

- The FARM program, led by the United Nations Environment Programme, encourages farmers to adopt low- and non-chemical alternatives to toxic agrochemicals. *It aims to facilitate a transition toward better practices.* Promoting such measures can encourage local production and reduce reliance on high-cost production systems.

5. Companion Planting

- Certain plants repel pests when grown together. For example, marigolds deter nematodes, and basil repels flies. Drawing on traditional knowledge systems can help promote such practices.

6. Natural Extracts and Biopesticides

- Neem oil, garlic, and chili pepper extracts have insect-repellent properties.
- Biopesticides derived from beneficial microorganisms are safer alternatives. These can become complementary approaches in developing holistic farming systems to meet food security with safe practices.

7. Soil Health Management

- Healthy soils support robust plant growth and reduce the need for chemical inputs.
- Practices like cover cropping, composting, and crop residue management enhance soil health and improve water retention.

Transitioning away from harmful chemicals requires collaboration among farmers, businesses, policy makers, and consumers. By adopting these alternatives, we can achieve higher farm production while safeguarding human health and the environment.

Is Regenerative Agriculture a Practice Viable Only in Rich Countries?

Regenerative agriculture is not limited to rich countries; it can be practiced globally. Let us see what it is all about.

1. Universal Principles

- Regenerative agriculture focuses on soil health, biodiversity, and sustainability.
- These principles apply regardless of a country's economic status.

2. Benefits for All

- Regenerative practices enhance soil fertility, water retention, and carbon sequestration, making input-output efficiencies.
- Small-scale farmers in developing countries can benefit by adopting these practices. It could leave more money in their hands.

3. Local Adaptation

- Regenerative techniques can be adapted to local contexts, considering climate, crops, and available resources.
- Practices like cover cropping, crop rotation, and agroforestry are accessible to all.

4. Community Resilience

- Regenerative agriculture strengthens local food systems, reducing dependence on

external inputs. Sourcing local inputs with lower concentrations of nutrients, such as green matter, compost, and farm manures, creates new economic activity and land use options.

- It empowers communities to produce nutritious food sustainably.

5. Challenges

- Access to knowledge, training, and resources can be a barrier, as can fears about not being able to feed the world.
- Policy makers can prioritize regenerative practices and support smallholders through new investment, entrepreneurial development, and market links.
- Full-cost accounting and life-cycle analysis can illustrate that fears about supply security are unfounded. Reducing current food loss and waste alone could meet any potential increase in demand.
- Improved data collection, monitoring, and analysis can play a crucial role.

6. Affordability

In discussions relating to food system transformation, affordability is always raised as a barrier. Regenerative agriculture is often discarded as a practice suitable only to fringe farmers in rich countries. Yet, it is a practice that transcends economic boundaries, benefiting both rich and developing countries alike.

Promoting regenerative agriculture in low-income regions could complement sustainable food production, economic resilience, and environmental well-being. In fact, shifting cultivation, which predated green revolution technology, was a regenerative agriculture practice. The push to intensify farm production marginalized such practices, rather than improving them with new knowledge. Here are some strategies to explore its benefits:

1. Financial Support and Incentives

- Grants, low-interest loans, and market links can help farmers afford the initial transition to regenerative practices.
- Income support programs and market mechanisms that reward environmental services (e.g., carbon sequestration, biodiversity, water quality) can complement incomes and encourage adoption.

2. Education and Training

- Providing technical support and training during the transition process is crucial.
- Collaboration with farm organizations and experts can build capacity.

3. Community-Based Approaches

- Engaging local communities in regenerative practices can boost food production.
- Fostering knowledge-sharing among farmers through farmer-to-farmer networks can build confidence and social acceptance.

4. Agroforestry and Diversification

- Agroforestry systems combine trees with crops or livestock, diversifying income streams and enhancing resilience.
- Encourage diverse crop rotations in field crops, and intercropping in tree crop systems, such as coconut plantings and horticulture crops.

5. Market Access and Fair Pricing

- Facilitate access to markets for regenerative products. Already, some farmers enjoy premium prices in advanced markets.
- Advocate for fair pricing that reflects the true value of sustainable practices.

6. Policy Support

- Governments could create an enabling environment through policy frameworks that promote regenerative agriculture and similar systems.
- Incentivizing sustainable practices through regulations and start-up support could promote adoption.

7. Knowledge is Power

- Farmer field schools and demonstration plots allow farmers to learn from each other and convince themselves of benefits and costs.
- Sharing success stories and best practices through knowledge hubs can extend benefits.

8. Research and Innovation

- Investing in research on regenerative techniques suitable for specific regions will remove misunderstandings and spur innovation.

- Adapting practices to local contexts is crucial for maximizing local comparative advantage—the primary basis of mutually beneficial trade.

9. Partnerships and Collaboration

- Involving NGOs, universities, and private sector actors can minimize conflicts and improve credibility.
- Collaboration with international organizations could help share experiences far and wide.

10. Empower Women Farmers

- Gender-inclusive approaches ensure that women have equal access to resources and knowledge. Women hold local knowledge passed on through generations.
- Women play a crucial role in sustainable agriculture.

Promoting regenerative agriculture and other sustainable practices requires a holistic approach that considers economic, social, and environmental dimensions. By empowering local communities and fostering sustainable practices, we can create positive change even in low-income regions.

Can We Transition from Input-Sensitive High-Yielding Varieties That Are Common in Conventional Farming?

Over the past decades, society has invested in numerous improvements in crops and livestock systems that have high input use requirements. When prices were low and the costs of use were not known, that was a judicious approach. Now that knowledge is changing, transitioning from high-yielding crop varieties that are highly fertilizer-sensitive requires a thoughtful approach. Rapid switch-over is impossible and unwise.

1. Research and Breeding

- Investment in research for developing low-input or fertilizer-efficient crop varieties is already taking place. This can also contribute to drought tolerance and tastier food.
- Breeding programs can focus on traits like nitrogen-use efficiency and root architecture providing greater resilience to emerging conditions under climate and social change.

2. Soil Health Management

- Improve soil health through practices like cover cropping, composting, and crop residue incorporation.
- Healthy soils can support crops with reduced external inputs.

3. Precision Agriculture

- Use precision nutrient management to apply fertilizers only where needed.
- Soil testing and targeted application optimize fertilizer use.

4. Crop Rotation and Diversification

- Rotate crops to break pest and disease cycles.
- Diverse cropping systems enhance soil fertility.

5. Agroecological Approaches

- Agroforestry, intercropping, and polyculture reduce reliance on external inputs.
- These systems mimic natural ecosystems and promote sustainability.

6. Education and Extension Services

- Train farmers on sustainable practices.
- Extension services can disseminate knowledge about alternatives to high-input varieties.

7. Market Incentives

- Create markets for organic or low-chemical-input produce.
- Consumers willing to pay a premium can drive demand for sustainable crops.

8. Policy Support

- Governments can incentivize the adoption of low-input varieties through targeted assistance and extension support.
- Regenerative agriculture policies can promote sustainable practices.

9. Farmer Networks and Knowledge Sharing

- Encourage farmers to share experiences and learn from each other.
- Peer-to-peer networks foster innovation and build confidence.

10. Long-Term Vision

- Transitioning takes time. A long-term vision and commitment are essential.
- Balancing short-term productivity with long-term sustainability is crucial.

The shift toward sustainable, low-input agriculture benefits not only farmers but also the environment and future generations.

What About Crop-Livestock Integration?

Crop-livestock integration plays a vital role in sustainable farming, offering benefits that enhance both productivity and environmental well-being. Let us explore its significance:

1. **Enhanced Soil Health and Fertility**
 - Incorporating livestock (such as cattle, sheep, or poultry) into crop farms (including grain, vegetable, or orchard crops) contributes to soil organic matter and the efficient use of water.
 - Livestock manure enriches the soil, improving water retention, fertility, and nutrient availability.
 - Healthy soils support robust crop growth and sustainable production.
2. **Diversification of Income Streams**
 - Integrating livestock provides additional sources of income for farmers.
 - Income from livestock products (such as meat, milk, or eggs) complements crop revenue.
 - Diversification enhances farm resilience against market fluctuations.
3. **Weed and Pest Control**
 - Livestock grazing can help manage weeds by consuming unwanted vegetation.
 - Some livestock species (like ducks or geese) also feed on insects and pests.
 - Reduced reliance on chemical herbicides and pesticides benefits both the environment and human health.
4. **Minimized Expenditures**
 - By integrating livestock, farmers can minimize expenses related to:
 - Chemicals: Reduced need for synthetic fertilizers, herbicides, and pesticides.
 - Fuel: Less reliance on machinery for weed control.
 - Fertilizers: Livestock manure serves as a natural low-cost fertilizer.
5. **Improved Soil Health**
 - Livestock grazing and manure deposition enhance soil structure and microbial activity.
 - Soil health directly impacts crop productivity and resilience.
6. **Synergy Between Crops and Livestock**
 - In an integrated system, crop and livestock interactions create synergy.
 - Livestock consume crop residues, reducing waste and recycling nutrients.
 - Crop residues provide feed for livestock during non-growing seasons.
7. **Environmental Stewardship**
 - Sustainable agriculture aims to balance productivity with environmental conservation.
 - Crop-livestock integration contributes to ecosystem balance.
 - It allows for food production without negatively impacting the fragile environment.

In summary, crop-livestock integration fosters a holistic approach to farming, benefiting both farmers and the planet. By synergizing crop and livestock activities, we can achieve sustainable production while safeguarding natural resources.

7. Do We Need a Paradigm Shift?

Integrating various sustainable approaches within a circular economy paradigm could create a more resilient and resource-efficient system. These principles are increasingly being used in global sustainability policy discussions.

1. **Smart Circular Economy Paradigm**
 - The digital technology and knowledge diffusion it facilitates offers opportunities to advance both sustainability and competitiveness, by addressing information asymmetry.
 - Digital technologies can support circular economy principles by enabling new business models and product redesign.
 - The convergence of circular economy and digital technologies is still underexplored.
 - In this context, the smart circular economy paradigm emerges, utilizing digital tools

throughout the product life cycle to implement holistic strategies and create value. Value-adding is at the core of productivity improvement, which feeds into economic growth.

2. System Thinking and Socioeconomic Analyses

- Circular economy discussions have evolved from earlier technocentric views to more holistic perspectives that embrace resource use efficiency, social acceptance, and sustainability.
- Socioeconomic considerations related to resource scarcity, consumption, and waste better articulate net well-being.
- It encompasses the entire production–consumption nexus and informs opportunities for both reformist (incremental changes) and transformational (systemic shifts) approaches in creating change.

3. Policy Integration

- Policy makers can play a crucial role in advancing circular economy logic.
- Identifying policy gaps and integrating resource-efficiency-enhancing measures improves net well-being.
- The cross-scale integration of policies that promote sustainable practices across sectors and stakeholders is an effective way to accomplish systemic change.

4. Life Cycle Thinking

- Circular approaches require considering the entire life cycle of products—from cradle to grave.

- Considering connectivity from conception to end of life offers opportunities to optimize resource use and address environmental and social trade-offs at every stage.

5. Collaboration and Ecosystem Focus

- Shift the focus from individual organizations to the entire ecosystem and value chain. Working in isolation restricts opportunities and creates unintended consequences.
- Collaboration with stakeholders, including suppliers, manufacturers, consumers, and waste management entities, offers new opportunities for collective benefit.
- Leveraging synergies across the ecosystem facilitates circular outcomes.

6. Environmental Impact Assessment of Digital Technologies

- While digital tools enhance circular practices, assessing their environmental and social impact is crucial to avoid unintended costs.
- While uncertainty in knowledge and processes remains a challenge, understanding the potential rebound effects by evaluating the trade-offs between digitalization and sustainability could minimize future costs.

Integrating these approaches within a circular economy paradigm requires interdisciplinary collaboration, innovative thinking, and a long-term vision. Full consideration of socioeconomic factors, including the political economy and development context, is crucial in realizing the benefits of digitalization and rural transformation and fostering the systemic change desired for achieving food system stability and resilience (Mallawaarachchi and Rahut 2023).

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