

Impact of Innovation of Agriculture to Protect the Environment

Dr. Kamlesh Singh¹ and Dr.(Smt)Anita Singh²

1 Associate Professor Department of AH & Dairying, KAPG Collage Prayagraj-211001

2 Principle KMV Inter collage Sevapuri-211403 Varanasi

ABSTRACT

In a world of 9.5 billion people, global demand for food, fiber, and biofuels has to be met with minimal possible increases in land, water, fossil fuels, and the minerals used to produce fertilizers. The problem is debated at three levels: first, that agriculture will not be able to produce enough because it will come up against both biophysical and environmental limits that restrict yields; second, that the need to expand and intensify agriculture will destroy the broader environmental values of forests, wetlands, marine systems, and their associated biodiversity; and third, that there are institutional obstacles to the diffusion and adoption of the innovations that could solve these problems.

Introduction

Although there is debate on these issues, there is also strong consensus that we are witnessing unprecedented changes in our major agricultural systems (1). Major shifts are occurring in the way food and other agricultural commodities are produced, in the scale at which this happens, in the geographical locations of agriculture, and perhaps most notable, the agencies and actors driving these processes (2). Growth in demand for agricultural products will mainly occur in markets of emerging economies, particularly in the most populous countries. Therefore, the ways in which China, India etc. growing food demand will be major determinants of environmental change at a global scale (3). The papers highlight innovations in agriculture that could contribute to producing more food without increasing environmental pressures. It is collectively consider how agricultural science is responding to environmental challenges. Agricultural land is now required to deliver multiple environmental and production services (4). The issues are often beset by “wicked problems”. The papers explore implications of different combinations of technologies, institutional arrangements, and policies on the agriculture–environment nexus (5) and attempt to link the global resource management discourse with the realities faced by poor farmers in developing countries. They endorse four strategic objectives: ensuring production of adequate food, alleviating poverty, achieving better health and nutrition for a growing population, and conserving the natural resource base upon which all of this depends (6).

Agricultural innovation is essential to address environmental problems in a world that must soon support more than 9 billion humans. Poverty and food insecurity go hand in hand (7). For the 2 billion malnourished poor in developing countries, short term food security is inevitably a higher priority than long-term environmental sustainability. A large proportion of rural poor in the tropics live in regions with marginal land and climate for agriculture (8) or in areas with more favorable climate that lie at the interface between agriculture and remaining carbon-rich and biodiverse natural ecosystems such as rainforests, wetlands, grasslands, and savannas (9). Feeding 9 billion people and lifting rural poor out of poverty is a prerequisite for maintaining the planet’s environment. Many people are leaving rural areas

and seeking employment in manufacturing and services in cities. However, this opportunity is not open to all. Large numbers of poor farmers continue to practice extensive agriculture. Inevitably they will continue to encroach on hitherto uncultivated lands unless they can adopt innovative systems that allow for agricultural intensification and development of agricultural equipment industries, farm inputs, and food processing capacities. To this end, much agricultural research continues to focus on how to increase productivity on this existing farm land. Improved efficiency in the use of land and agricultural inputs is already contributing to environmental goals. Quantifying food production capacity of currently farmed land has focused on estimating “yield gaps” (i.e., the difference between current farm yields and the potential that can be achieved with good crop and soil management). However, increasing productivity is necessary but not sufficient to ensure food security, reduce poverty, improve nutrition, and maintain the natural resource base for sustainable development (1).

Many practicing agricultural scientists are working to solve immediate problems of poor farmers. A marked shift is occurring in the way agricultural research is conducted and farm communities to encourage experimentation and innovation. A recurring theme is the use of concepts such as Integrated Agricultural Research for Development (IARD) (10). IARD and other integrated approaches are seen as best practice in achieving rural innovation rather than as a magic bullet (10). This collection of papers exemplifies the evolution of understanding of agricultural innovation practices and provides empirical evidence on policies and technologies that allow more crops to be produced on less land, with more efficient use of inputs and under conditions of global change. One major area of uncertainty has been the impact of agricultural intensification on land use (3). Studies in different situations have come to contrasting conclusions on the extent to which intensification can lead to “land-sparing” (11). Several studies have shown that it is difficult to make simple generalizable statements about the land-sparing role of agricultural intensification and that effects are highly context specific (12). Analysis of the land-saving claims made for the Asian green revolution. It is clear that negative impacts of higher food prices on poverty and hunger under this scenario would likely have dwarfed the welfare effects of agricultural expansion. More food was produced and some natural habitats were spared. However, it also emerges that parallel changes in policies, infrastructure, markets, and other dimensions of the agricultural landscape made significant contributions to these changes. This work highlights the need for improved understanding and models that fully capture the interacting economic, political, social, and biophysical contexts of agricultural innovation within the IARD framework (13).

Governance and institutions mediate all changes in rural landscapes. Nitrogenous fertilizer is essential for modern agriculture, and the lack of access to it is a major obstacle to yield increases. However, its misuse has negative impacts on water quality and climate through emissions of nitrous oxide, a greenhouse gas (GHG) 300 times more potent in global warming impact than carbon dioxide (14). Industrial production of reactive nitrogen, mostly used to fertilize food crops, now exceeds the global total produced from all natural sources. Although atmospheric N₂ is relatively inert, reactive nitrogen, including ammonia nitrate, and organic forms including nucleic and amino acids, and other amines and amides are required as building blocks of all living organisms. Simple, specialized systems with their economies of scale and high yields are consistent with a model of economic rationalization. Complex, biodiverse systems appeal on grounds of ecological efficiency and aesthetics and possibly confer resilience to external shocks to agricultural systems (15). An empirical study of biological diversity and pollination in coffee growing regions of southwest India shows

that, whereas on farm biodiversity values may have been exaggerated, they are nonetheless significant and complement positive effects on productivity that can be achieved with improvements in crop management (16).

Fish are vital sources of food for many of the world's people, both rich and poor. Conventional wisdom holds that the move to intensive aquaculture to meet burgeoning demand is inevitable. Fish would therefore join trees and commodity agricultural crops in being produced in intensive industrial systems, and harvesting from near natural ecosystems would become less important. However, evidence is presented (17) that, for many, especially the poor in developing countries, wild capture fisheries will continue to be vital resources for decades to come—and with proper management they have the capacity to meet greatly increased demand. Natural aquatic systems can yield multiple products and values so perhaps the juggernaut of intensification and simplification will not always overwhelm traditional diverse production systems. Timber and environmental services from managed natural forests (18), diverse products and services from agroforests, and mosaics of production and conservation uses (4) may represent alternative scenarios for the agriculture–environment nexus (15).

Land cover, especially in the tropics, will continue to change—probably at increasing rates. This change will have multiple implications for human societies. There will be surprises, “black swans,” that will derail our best laid plans (19). One unintended consequence is that the opening up of the forest frontier by agricultural expansion is bringing people into closer contact with the wild animal hosts of diseases that can spread through human populations. New plant diseases and plants will also challenge future food production. These are just examples of a diversity of shocks that will inevitably introduce volatility into the continuing dynamic at the agriculture–environment nexus. All of the challenges identified in these papers will need to be addressed in a context of changing climates. Global circulation models tell us much about the large-scale, long-term changes that may occur, but they are very uncertain tools when applied at local levels to address day-to-day realities of smallholder farmers who will bear the brunt of changes. Four case studies are presented that illustrate the uncertainties of global climate models and their limitations in addressing the short-term needs of poor farmers. Farmers have extensive capacity for local short-term adaptation. Global models have to be drawn upon carefully to enhance longer-term transformational changes in the ability of farmers to cope with the uncertainties of climate change (20).

Food production and nature conservation will compete for the same land (4). Evidence is presented of progress in developing a set of 10 principles that can be used with multiple stakeholders working at landscape scales to reconcile conflicts (4). Many tradeoffs are best addressed at these meso-scales, and much progress is being achieved through integration of multiple uses in mosaic landscape (4). Achieving better outcomes at this scale has been difficult for existing sectoral institutions, but the solution is not to replace those institutions but rather to facilitate the interactions among them and equip them to negotiate between conflicting and competing goals. The papers in this special feature show that progress is indeed being made. Agricultural technologies are becoming more resource use efficient. There are rapid improvements in achieving fertilizer use efficiency. Intensification has and will continue to allow land to be saved. Agricultural and fishery systems that include biodiversity will continue to be important (4). Policies and institutions that can operate across the agriculture–environment nexus are emerging in countries where some of the greatest

challenges are being felt (21). Agricultural scientists are observing the principles of sustainability science and engaging with farmers and communities to address the wicked problems of achieving short-term production goals while ensuring long-term sustainability (10).

However, significant challenges remain. Tradeoffs between intensification and intensification are poorly understood, and we lack robust, spatially explicit models to guide policies governments could use to properly direct the form and location of future agriculture that meets food demand while conserving natural resources. There is only weak evidence on the role of biodiversity in supporting progress toward higher crop yields and ensuring greater system resilience. The future of irrigated agriculture is critical. Expansion of irrigated area could allow yield increases while greatly reducing pressures on conversion of forests and wildlands. If institutional obstacles could be overcome, then payments for carbon sequestration and storage in crops and soils could transform smallholder agriculture in the tropics—but enormous technical obstacles lie in the way of achieving payments to farmers for environmental services. The significant gains in ecological efficiency achieved in industrial agriculture in some developed and middle income countries, especially in fertilizer and water use efficiency, need to be recognized and applied more broadly in the tropics using technologies adapted for smallholder farmers.

CONCLUSIONS

The conclusion that emerges is that a radical rethink is needed in the orientation of agriculture. Research has to underpin innovations that will allow more food, fiber, and biofuel to be produced but in ways that alleviate rural poverty, improve diets and health, and allow increases in stocks of the environmental assets upon which all depends. Progress towards these four goals requires new ways of organizing research, new ways of setting priorities, and more subtle ways of assessing outcomes and impacts. The solutions will not be narrow sectoral or technical innovations but nested sets of innovations at the scale of the plant, the agronomic system, the landscape, and the institutional environment.

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