Holistic Natural Resources Management Needed for Sustainable Agriculture

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Abstract

We provide an overview of the present status of the key agricultural natural resources base, and then recommend a strategic direction for the future of agriculture, by focusing it around Holistic Natural Resource Management (HNRM), which would ensure sustainable economic growth for a post-COVID world.

The prevailing trend of a reductionist, commodity-specific approach to agricultural technologies may have served us well in the past, but it should now be replaced by a more holistic approach that embraces systems-based technologies, to meet the contemporary challenges of food, nutrition, and livelihood security, as well as to provide ecosystem security. National and international agricultural research and development institutions need to reform and reorient their programs accordingly.

The vision for Doubling Farmers' Income (DFI), recently adopted by India, can be a model for other developing countries if the vision is appropriately modified to integrate sustainability and productivity objectives, and then implemented effectively on the ground.

Introduction

Rapidly rising population growth and diminishing arable land, particularly in the developing countries, has increased the stress on the natural resource base (Lal, 1991). The COVID-19 pandemic and its disastrous impact worldwide have brought into sharp focus the intersection of nature, public health, and economy. In addition to the severe impact on the industrial, manufacturing, and service sectors, agriculture and food systems have also been badly shaken up. In India, for example, where about 65% of the population resides in rural areas, a massive reverse migration of urban workers into rural areas has created an intense need for new growth pathways in rural India.

Agriculture is as old as civilization itself, if not older. From the period of hunters-gatherers settling down around 12,000 years ago, through domestication of plants and animals and shifting cultivation, to present-day modern farming, humans have

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been modifying nature ruthlessly and unsustainably to meet their demand for food, nutrition, and livelihood security. Globally, increasing food production to meet the needs of rapidly growing and increasingly prosperous populations has been one of the most important challenges for humanity, especially during the last 100 years. The challenge has been met largely through expanding areas under "modern" intensive farming techniques; but in the run to produce enough food for all, nature has also been abused in many different ways.

It is only during the past 30 years or so that the importance of restoration of nature has gained attention, through the advocacy of sustainable farming. This increased awareness of the need for a sustainability perspective has also led to changes in the research programs. For example, many of the traditional agronomy teaching and research programs have been widened to include "Natural Resource Management Programs (NRMP)." In September 2015, at the United Nations Summit on Sustainable Development (UN, 2015), the international community endorsed a universal agenda, entitled 'Transforming our World: the 2030 Agenda for Sustainable Development', which incorporated Sustainable Development Goals (SDGs) for the member nations to achieve. The preamble to the SDGs urged that we "take the bold and transformative steps which are urgently needed to shift the world onto a sustainable and resilient path." The SDGs laid emphasis on advancing the vision to end hunger, improve nutrition, and achieve economic growth through sustainable farming, by integrating both productivity and environmental concerns. The timely achievement of those goals is also now hampered by the pandemic.

In the past, the global agricultural research and development (R&D) activities were mostly "seed-centric," focusing on a quantum jump in crop yields to meet the urgent and much needed food and feed security demands. The technological aspects were related mostly to the availability of high-yielding varieties, chemical fertilizers and pesticides, and access to irrigation. Policy support also mainly enthused farmers to adopt such "green revolution" technologies. However, the adoption of such technologies occurred largely in regions endowed with abundant natural resources. Even within such resource-endowed regions, indiscriminate and excessive use of chemical inputs has resulted in considerable degradation of natural resources.

Even though the so-called Green Revolution helped large populations to escape hunger, it mostly bypassed the large and poorly endowed rainfed and arid areas of the world. R&D activities for sustainable and green agriculture, which aimed to integrate biological (agro-biodiversity) and physical (climate, land, and water) resources, received attention only towards the end of the 20th century. The present crisis of the Covid-19 pandemic, with its severe stress on global food, nutrition/health, and livelihood security reminds us again of the urgent need to find a proper balance between productivity and sustainability.

In this context, as a multi-disciplinary team of agricultural technologists and natural resource management (NRM) specialists, we aim to provide an overview of the present status of the key agricultural natural resources base, and then to recommend a strategic direction for the future of agriculture, by focusing it around holistic NRM, which would ensure sustainable economic growth for a post-COVID world.

Climate and Climate Change

Agriculture the world over is extremely vulnerable to weather and climate. In India, for example, heat/cold waves, highly variable rainfall, increased incidence of extreme weather events such as the erratic onset, advance, and retrieval of monsoon, shifts in its active/break cycles, and the intensity and frequency of monsoon systems, often seriously affect agricultural production in the country (Chattopadhyay, 2011).

Evidence from observations of the climate system has led to the conclusion that human activities are contributing to a warming of the Earth's atmosphere. Between 1850 and 2000, energy use by the human communities increased by a factor of 15 or so (Smith, 2017). Over the course of time, the use of fossil fuels has changed quite dramatically. Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases are increasing steadily since 1750 as a result of human activity (IPCC, 2013). Warming from such anthropogenic emissions (from the pre-industrial period to the present) will persist for centuries, and it will continue to cause further long-term changes in the climate system, with associated impacts.

The global average surface temperature warmed by 0.85°C between 1880 and 2012 (IPCC, 2013). Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C (IPCC, 2018). Global warming is likely to reach 1.5°C between 2030 and 2052, if it continues to increase at the current rate.

Most of the problems people have with weather and climate come from extremes. Changes in many extreme weather and climate events have been observed since about 1950 (IPCC, 2013). Over the past 100 years, fifteen of the hottest summers have occurred since 2000 (IPCC, 2018), and the world is already facing climate change-induced impacts, such as rising sea levels, changing rainfall patterns, increased droughts, and more erratic storms. Increases in the frequency of droughts and floods are projected to negatively affect local crop production, especially in subsistence sectors at low latitudes. On 20 May 2020, Super cyclone Amphan made landfall, the most powerful storm to do so in the Bay of Bengal region in 20 years. Winds gusting up to 185 km/h pounded the coast of the Indian state of West Bengal. Huge waves swept over the Indian and Bangladeshi coast. Trees were lifted out of the ground, city streets turned into rivers, and tens of thousands of people lost their homes. Recently, wildfires in the west coast of USA caused severe damage to both people and environment.

Annual losses from weather disasters such as hurricanes, hailstorms, or wildfires over the world frequently run into hundreds of billions of dollars. In total, weather-related natural disasters have caused losses of some US$ 4,200 billion since 1980 and killed nearly a million people (Munich Re, 2019). Government of India's economic survey

(2018) estimated that an annual loss of US$ 9-10 billion was attributable to weather-related natural disasters resulting from climate change (Srinivasa Rao et al. 2019).

Land/Soil and Water

Land and water are both essential resources for agriculture. The prudent management of these resources ensures crop productivity and sustainability. No matter who we are, where we live, or what we do, we all depend on water every single day for our existence. About 70 to 80% of water resources are being used for agriculture alone. We should appreciate the fact that water in all its forms — rainfall, streams and rivers, lakes, drinking water, and moisture in the soil — is valuable for us. We should plan to manage these essential resources (land and water) in a comprehensive manner, so as to build a productive and healthy environment for farmers, and a stronger economy for the country. While doing so, it is important to recognize that these two are very closely linked.

Land management is vital to optimize the use of water in both rainfed and irrigated agriculture. Watershed-based farming systems have been shown to make the best use of rainwater. Runoff from land surfaces during the rainy season can be collected in small ponds and reservoirs, and reused for supplemental irrigation to crops, during spells of dry weather later in the season. It can also be used to replenish ground water reserves. In clay soils, ridge and furrow systems are efficient in ensuring proper drainage during the wet season. In semi-arid locations, the practice of furrow diking (also known as tied-ridging), provides water conservation for optimum crop production.

Rainwater harvesting is a valuable and exciting technique, applicable to both rural and urban environments. In agriculture, rainfall that exceeds the infiltration capacity of the soil results in runoff, which can be collected into farm ponds for subsequent use. Rainwater from roof surfaces can be collected in tanks and cisterns, and used for a variety of purposes, such as landscape irrigation, laundry, sanitation, and, with adequate treatment, for drinking purposes as well. Farmers in villages should embrace rainwater harvesting for these multiple uses, and agricultural universities should help in educating farmers to use their water resources efficiently.

The importance of maintaining the nation's agricultural soils cannot be overstated: soils are the basis of the nation's capacity to produce high crop yields and bountiful pasturelands, and, for all practical purposes, they are a finite resource. Land and soil degradation are a major threat to our food and environment security, and the extent of problems resulting from degradation is more pronounced in rainfed regions. Land-cover/land-use changes occur as a result of erosion, changes in drainage, floods and droughts, as well as from human-induced changes. Intensive tillage practices cause declines of soil organic carbon (SOC) stocks, owing to oxidation of organic matter, destruction of soil aggregates, and reduction in water infiltration. Loss of SOC from erosion is more pronounced on sloping land areas, owing to drainage from the soil.

Soil erosion is a form of soil degradation that causes the displacement of the upper layers of soil by wind and water. Although soil erosion occurs under natural conditions, human activity on the land accelerates that process by changing the land use and land cover (LULC). In the 20th century, India has experienced a 6-fold increase in population (200 million to 1200 million) coupled with economic growth (especially after the 1950s), which has resulted in LULC transformations. For the next decade, one major goal should be to increase the resiliency of agricultural systems to adapt to rapid changes and extreme conditions. One important objective is to reduce soil loss and degradation. The component technologies for soil health restoration and enhancement are available. Some of the existing transformative tools and practices that better protect soils include reduced, modified, or no-tillage methods (also called "conservation tillage"), crop rotations, use of cover crops, split application of fertilizer, dripline irrigation, and controlled or slow release of nutrients.

Now, there is also a better understanding of the causes, extent, severity, and processes of land degradation in traditional crop-tree and livestock production systems. What is needed perhaps is focus on improved soil, water, nutrient, and vegetation management technologies/strategies to build soil organic matter (humus), coupled with policies to increase biomass production for enhancing ecosystem resilience in the marginal areas. The amount of nutrients naturally present in soils varies widely, and it is generally insufficient to support high demands of crop production. For example, nitrogen, which is widely available in the atmosphere but more limited in soil, frequently becomes the first nutrient constraint on crop production. Too little nitrogen application leads to lower crop productivity, world hunger and malnutrition, and soil degradation. Phosphorus is another essential nutrient for plant growth.

Sustainable soil management is crucial in minimizing land degradation, rehabilitating degraded areas, and ensuring the optimal use of land resources. It has been realized that for sustainable development of degraded lands, the involvement of people (the landless and the intended beneficiaries) is very much essential. It is necessary to improve the transfer of technology (and practices) to farmers to reduce soil loss through converging research in soil sciences, technology adoption, and community engagement.

Diversified Farming Systems: Agri-Horti-Animal-Tree Systems

The planet is full of diverse biological resources, found both below and above ground. It has been noted that among more than 100 million species on earth, humans know only about 1.6 million species. Of the 350,000 plant species in the world, about 20,000 are known to be edible. About 7000 species of plants have been cultivated or collected for food. Among these, about 150 plant species are commercially cultivated, with 30 crops providing 90% of the world's caloric intake. Humans, as the dominant species, have been utilizing this most important resource, biodiversity, for survival since the time of hunting, gathering, and domestication of plants and animals. Agricultural biodiversity, therefore, is fundamental and central to all creation of life.

The evolution of modern agriculture from the age of hunting and gathering, shifting cultivation, subsistence mixed farming into intensive cultivation during the last century, has seen agriculture gradually moving towards monoculture. It is only during the past two decades or so that agri-biodiversity has regained its importance in the scheme of sustainable agricultural development.

The advance of agricultural science and technology during the past 100 years saw rapid growth in agricultural productivity and production. The wide diversity of genetic resources collected by botanists, geneticists, and plant breeders was used as a base for breeding new crop varieties and hybrids for higher productivity and resistance to physiological and biological stresses. Similarly, animal breeders used animal genetic resources to develop new breeds. Large-scale monoculture with these improved cultivars and intensive farming dominated globally, replacing the traditional mixed farming, particularly in developing countries. Though the "green revolution" technologies helped many countries in Asia and Latin America in attaining food self-reliance, the damage to the environment caused by intensive and chemical-based cultivation was noted in the 1980s, resulting in renewed interest in cropping systems and mixed farming systems. Thus, the monoculture cropping pattern was gradually followed up with research on multiple cropping, involving sequential double cropping, relay cropping, ratoon cropping, crop rotation with legumes, etc. Simultaneously, interest in intercropping has also regained importance in rainfed areas.

Agronomic research and development have resulted in various cropping systems for different agroclimatic regions to maximize productivity and minimize risks within specified environmental constraints. Two key components that evolved from this research were temporal and spatial considerations for optimum utilization of resources. Cropping systems design considerations included (a) utilizing the entire growing season, (b) maximizing light interception by the crops for photosynthesis, (c) minimizing evaporation losses from bare soils, (d) maximizing stored moisture and nutrient usage, and (e) minimizing biological stresses from weeds, pests, and diseases. Past research has clearly shown that spatial and temporal cropping pattern strategies, such as mixed cropping or intercropping, delayed planting, ratooning, etc., make for better utilization of resources such as light, water, and nutrients, resulting in both enhanced productivity and minimized risks. It has also been established that land productivity can be increased substantially through a well-managed crop rotation system, using both cereal and legume crops. Considerable emphasis has been placed on developing cropping systems that include legumes as they (legumes) represent one of the major building blocks of successful continuous cropping systems throughout the world.

Diverse cropping systems involving annual and perennial crops, including trees (agroforestry), for optimum land use and greater returns have become popular in some countries during recent years, their rate of adoption is still low. Agroforestry schemes, where nitrogen-fixing woody species are being used, such as alley cropping (in Asia and Africa), have contributed to improved soil fertility, reduced wind erosion, and higher and more stable grain yields, in addition to providing fodder for livestock.

Resource-use patterns of agroforestry systems have been studied, to determine the competition below and above the ground among crops and trees for nutrients, and to develop optimum land-use systems. Recently, such agri-sylvicultural systems have been further extended to agri-horticultural systems, by including fruit and nut trees to diversify and enhance total productivity. In addition to providing food, animal feed, and wood, such systems also provide improved nutrition, as well as a much-needed source of cash income to farmers, and the same time contribute to enhancing ecosystem services.

In many areas of the world, agriculture is increasingly practised in marginal and fragile environments, with extreme variability in climate (precipitation) and other risks, such as unstable and inefficient markets. The gradual integration of animal agriculture with crop production is being practised in order to enhance agronomic efficiency, to diversify and stabilize farm incomes and conserve natural resources. The integrated crop-horti/tree-livestock systems are now being recommended increasingly in tropical small farm systems, to add income stability and sustainability to the farming systems.

Recently, in an effort to optimize the overall productivity and stability of integrated crop-tree-livestock production systems, comprehensive resource management models and expert systems have also been developed for different ecosystems. We discuss them next.

Integration of Technologies

Traditionally, agronomic research to improve the production of a specific commodity has involved testing component technologies, alone and in combination, to harvest synergies and increase total factor productivity. R&D efforts on holistic resource management to combine productivity and sustainability, however, require a longer term, more complex systems approach.

Agricultural R&D that adopts such a systems approach has evolved significantly during the past 40 years. For example, the watershed management approach, initiated by International Agricultural Research Centres (IARCs) such as ICRISAT during the 1970s, combining different components such as land and water management, soil health, cropping/farming systems (crop-livestock systems), and integrated nutrient and pest management is now well known throughout the rainfed areas of Asia and Africa. Similarly, other IARCs, though a majority of them were initially commodity-centric, have recently included natural resources management in their mandate, thus focusing on long-term sustainability of their target commodity-based production systems. Eco-regional and production systems approaches are being increasingly adopted for targeting technologies for specific agroclimatic regions. An integrated genetic and natural resource management approach, involving active participation from farmers and communities, is also becoming popular in recent years in some areas. Involving farmers and policymakers early in the technology development and transfer process has helped in accelerating the adoption of technologies under subsistence smallholder farming systems.

As the concept of "sustainable agriculture" became popular during the last 20 years, many alternative systems of farming have gained attention. There has been little progress, however, from concept to practice. For example, "conservation farming" was developed and adopted in the Indo-Gangetic rice-wheat production systems, to arrest degradation of the resource base and extend the growing period. Similarly, "organic agriculture" is being promoted, discouraging the use of chemicals in agriculture. Recently, another system, called "zero budget natural farming," is being promoted with the rejection of external input use. Each of these systems has its niche, but the R&D communities are yet to quantify the specific advantages of these different systems over the presently recommended systems of farming. There is a general consensus that there should be a menu of different technologies and systems made available to farmers, and it is for the farmers to choose the appropriate systems for their use, thus empowering farmers.

Until recently, socioeconomic considerations have received comparatively little attention while designing and integrating production systems in R&D efforts. Though economic factors and adoption rate evaluations were considered satisfactorily, equity and sustainability (ecology) components are being addressed only recently. Increased emphasis is required on monitoring sustainability, risk-aversion, and resilience, particularly in research and development programs devoted to natural resource management. Post-production technologies and marketing considerations are other key elements which have received emphasis rather late in systems research and development.

Smallholder agriculture is now seen as important not just for food security but also as a source of livelihood security, food and nutrition security in rural areas, and rural economic growth. There is an increasing emphasis now on the growth of total rural income. Integrated farming for market-oriented agricultural development strategies is being recommended, by including new elements such as systems diversification, equity (including gender), better nutrition, greater resilience, market and climate risk aversion, and long-term sustainability, in addition to the more familiar aspects, namely higher production and incomes. Public-private-producer partnerships, through a consortium approach, are also being promoted for sustainable intensification of agriculture and agribusiness, aimed at rural prosperity.

In developing holistic systems, modelling is of specific help, in particular when the objectives are clear. Depending on the purpose, appropriate model(s) can be chosen to address some specific problems. The approach and selection of models will depend on the specific intention for assessing the impacts of specific factors and practices on farmers' livelihood improvement. The selection of models may be different for assessing the impacts of the introduction of specific farming systems practices on soil health. Collaborative efforts are being continued around the world for model development and, more importantly, for their applications. As a result, many useful models/tools are available. However, it may be necessary to adopt and sometimes develop new tool(s) for addressing specific problems that are faced by farmers/farming communities in specific locations at a particular time i.e. solutions need to be contextual. This would require discussion with individual farmers and groups of farmers, to collect the required data inputs for making appropriate decisions.

Priorities for the Future

Integrated research on multiple commodities

There are historical reasons for the commodity-specific approach of the past. The first significant revolution in agricultural development evolved about a century ago, immediately after the Spanish flu pandemic and the great depression period in the United States of America (in the 1920s and 1930s). High-yielding cultivars, coupled with appropriate agronomic packages, first revolutionized agricultural production in the USA. Thereafter, a similar approach was adopted when large parts of Asia and Latin America were threatened or faced with food shortages, resulting in the so-called Green Revolution in the 1960s and 1970s. Those technologies, mostly seed-centric, largely achieved the food security objectives of those times.

The contemporary challenges of malnutrition, public health, and ecosystem degradation, coupled with climate change and increasing poverty, however, call for an alternative approach to agricultural research and development. Post-COVID agriculture should aim not only at achieving food security, but also try to ensure nutritional, ecological, and economic security for the aspiring world. In addition to providing the best varieties of seeds and improved technology to farmers, all governmental and institutional support should ensure their holistic well-being as well, as envisaged in Agenda 2030 which has been endorsed by countries. That includes provision of adequate health care and vaccination against pandemics like COVID-19, when the vaccine becomes available. It should be understood that the health of the planet and the people are well connected and both are important. We call for a holistic approach, cantered on resource management, putting natural resources and diversity (multiple commodities) in the front and centre, rather than continuing the past approach of commodity-specific improvements, to achieve the contemporary global challenges.

History has shown us that disasters and pandemics can serve a purpose if humanity can learn from the past and change its course. The global disruption caused by COVID-19 has served as a sample of what other challenges like climate change and environmental crises will do to us all, unless humankind restrains itself from exploiting nature thoughtlessly. Humanity should understand and consider itself only as the guest of nature and not the other way around. This is not being altruistic but truly being practical if we want continue as a successful species. Similarly, agriculture, which depends largely on natural resources, should realize this reality and change its course, evolving an appropriate science, with its code of ethics rooted in ecological balance i.e. Truth, Food & the Environment. Agricultural research and development need a renewal of attitude from a narrow, disciplinary approach, to a holistic systems approach, with a more benevolent attitude towards nature, science, and progress.

This approach is more urgent today as agriculture provides the main base for food security, as well as for nutritional, ecological, and economic security.

The success of agriculture is intrinsically tied to holistic natural resource management (HNRM). Water scarcity, increased weather variability, floods, and droughts are examples of stresses on food and agricultural production. Climate change is a major concern in India because of alterations in temperature and precipitation, the rise of sea level, and degradation of natural resources and environment. Dramatic changes in land-use patterns compound the problems of climate change. In the next decade, the major goals for food and agricultural research should include enhancing the efficiency of food and agricultural systems, as well as increasing the sustainability and resiliency of agricultural systems to adapt to rapid changes and extreme conditions. Innovative technologies for productivity, conservation/restoration, resilience and risk-aversion, and improved diets are much needed, but they must at the same time keep emissions and land use (in general) within the environmental limits.

In summary, there should be a paradigm shift in our approach to agriculture. It would be short-sighted to assume that one or two years of good rainfall, along with the easing of the pandemic, will help restore previous levels of production or human well-being. In the future, agriculture should be more resilient and be able to bounce back faster after a natural disaster, and thus enable individual farmers to be less dependent on the State, confident in making his/her own decisions. This will require a highly collaborative and coordinated research among many sectors, disciplines and actively engage with farmers who are the ultimate implementers of the results.

UN 2030 Agenda and Sustainable Development Goals (SDGs)

The SDGs of the UN, which address hunger, health, poverty, economy, and environment, should identify common ground with natural resources management at the centre, which can be a point of entry for intervention by partner agencies. The member countries need to work together beyond borders, to respond to these challenges. We need to strengthen collaboration and build a cooperative framework to tackle these unprecedented challenges.

Among the 15 global SDGs, SDG1 (Poverty), SDG2 (Zero Hunger), SDG3 (Health), SDG13 (Climate), and SDG14 (Land) have direct relevance to agricultural research and development. However, almost all of the 15 SDGs do have key elements concerning global agricultural development. At the national level, agricultural missions will have to take a holistic approach to combine all the agricultural-related elements from different SDGs and involve all the stakeholders actively for achieving the common goal. The overarching principle should be to find congruence between productivity and conservation/sustainability, aiming for win-win situations and requires re-thinking on the current strategy for agricultural research and education.

The world is facing two pandemics: while the health toll of COVID-19 is well known, we are yet to fully recognize the negative effects that it has had on food and nutrition security, resulting in a crushing blow to the livelihoods of millions in the developing countries. Overcoming those effects and transforming agri-food systems, coupled with the acceleration of much-needed sustainable economic growth, requires innovative ideas and political will. Global and national institutions need to find solutions to increase resilience across food ecosystems by adopting modern technologies, alternative marketing channels, and strengthening rural supply chains. All this needs to be achieved without hurting the nature. The Food and Agricultural Organization (FAO) of the United Nations has recently launched a new program to mitigate the impacts of the pandemic, while strengthening the longer-term resilience of food systems and livelihoods. Innovative technologies for resilience and risk-aversion, with appropriate financial support through partnerships at all levels, are an integral part of these initiatives. Precision farming that conserves natural resources, such as water, is being emphasized in such global partnerships. All these solutions are needed not just meet the immediate post-COVID-19 situation, but for the future as well.

Global agricultural research systems including International Agricultural Research Centres (IARCs) of the Consultative Group for International Agricultural Research (CGIAR) need to reorient their programs to meet the new challenges and realities. Reforming and consolidating these institutions to shift their focus more on natural resources management to harness nature rather than exploiting it, with a holistic systems perspective, requires full commitment from the international community, including donors, management, and human resources of these global institutions.

India's vision of Doubling Farmers' Income (DFI)

The Government of India has recently undertaken an ambitious mission to implement Prime Minister's vision of "Doubling Farmers' Income (DFI)" by 2022. The government has very rightly transformed its thinking beyond "Food Security" to "Income Security" by reorienting its interventions in the farm and non-farm sectors, with a view to double the income of farmers by 2022. To get there, agriculture has been rightly recognized as the tool to ensure food and nutrition security, generate productive employment that will result in income gains, to produce raw materials to support food and non-food products, and to support secondary agriculture in producing goods which will feed the industry and energy sectors. The Vision document authored by the Committee on Doubling on Farmer's Income also calls for adoption of sustainable technologies and management practices that adhere to agro-ecological principles as a basis of the wider production system. A guiding principle of DFI has been laid down that agriculture must reconcile the needs of both farmers and consumers, as well as ensure improved nutrition and ecology (Dalwai, 2018).

In 14 volumes, the well-compiled reports of the Dalwai Committee name the three primary pillars for agricultural transformation: productivity gains, cost efficiency, and monetization of the agri-produce. Surprisingly, conservation and restoration of the natural resource base were not considered as an important pillar by this Committee although, sustainable technologies and practices do figure under "support" pillars, along with risk management as a part of the ecosystem. The DFI vision identifies six distinct sources that can contribute to income growth: improvement of crop and livestock productivity, resource-use efficiency, increase in cropping intensity, diversification towards high-value crops, improvement in real prices received by farmers, and shift from farm to non-farm occupations through secondary agriculture. Again, natural resources management was not explicitly highlighted, but it is implicit under resource-use efficiency, diversification, and cropping intensity.

The proposed vision covers major areas of a broader agriculture and links in the agricultural value chain, including the need to reduce risks in farming (for example through crop insurance, diversifying farming, contract farming, etc.), optimizing input use by harnessing technologies and innovation, efficient water management, easing farm credit flows, opening farmers' access to markets, incentives for behavioural changes of farmers, modernizing farmers' practices along with reviving traditional and sustainable farm practices, strategies to enhance exports, promotion of post-harvest technologies, and support to the bioeconomy. Since the idea of DFI was introduced in 2017, a paradigm shift has occurred in its policies and programmes; sustainable technologies to promote soil organic carbon have gained attention through schemes on organic farming and conservation agriculture.

With strong political will, bold policy reforms were also initiated to promote DFI. Some of these recent initiatives include market reforms to break the monopoly of traders and public marketing institutions, and moves towards establishing a large common national market, interstate market access, amending the essential commodities act, liberalization of land lease and export of commodities, removal of structural weaknesses related to the small size of land holdings, and greater bargaining power for farmers to negotiate risks, etc.

The DFI vision and its associated flagship schemes have driven productivity higher, and some success stories are available. The Central government is committed to pursuing this vision, as evidenced by the series of reforms undertaken during the recent Covid-19 lockout period. However, focussed attention on the integration of natural resources' technologies with commodity production technologies for sustainable productivity and economic and ecological security is not clearly visible. Importantly, we note two key missing links. First, the existing public institutions and the present agricultural technologists are not fully attuned to the new vision of DFI. Second, a comprehensive on-the-ground implementation plan for the DFI strategy is yet to be seen.

In the short term, the potential of DFI can perhaps be best demonstrated by a well-coordinated program through initial pilot projects, with public-private-farmer partnerships at selected benchmark locations. Though agriculture is the State's responsibility, initially the Central government should provide leadership in bringing all the stakeholders on a consortium mode to implement the pilot programs in a few selected agroclimatic regions. The limiting natural resources, such as land/soil, water, and diversity can be the entry points for such large-scale pilot programs. In the longer term, public agricultural technology institutions, such as the Indian Council of Agricultural Research (ICAR) and state agricultural universities, should be reorganized and revitalized to meet the new challenges and implement the new vision of DFI. The past commodity-specific, production-centric approach needs to be reoriented towards a holistic approach, centred on multi-commodity systems, to achieve the DFI vision of inclusive food, nutrition, economic, and ecological security.

India’s DFI vision can be a game-changer and be a mirror for other developing countries only if the missing links discussed earlier are corrected, and if technologies for natural resources management are adequately integrated to achieve an “evergreen revolution”.

Conclusion

The linkage/nexus of nature with public health, agriculture, and economy is now well known. The COVID-19 pandemic has aggravated the already existing sustainability crisis attributable to variabilities induced by climate change, natural resources degradation, poverty and hunger, as well as the need to create livelihoods for millions of youth. It is now imperative that agriculture, which plays a major role in meeting all these challenges, embed natural resources conservation and sustainability as its core strategy, if it has to play a transformative role in securing the future of generations to come. The commodity-specific, production-centric approach needs to make way for a holistic, multi-commodity systems approach, with efficient management of natural resources at the centre of such systems. Innovations to accelerate the transition towards sustainable agriculture and food systems, along with resilience and risk aversion measures to maintain the health of both the people and the planet should be at the core of future agriculture.

Globally, the UN SDGs address the issue of natural resources and sustainability well, but those goals should be realigned and integrated with those pertaining to zero hunger and poverty reduction to meet the contemporary challenges associated with agriculture. Global R&D institutions, such as the IARCs, need to reorient their programs to focus more on holistic systems than on individual commodities. India’s vision for a new agriculture, which reconciles the needs of farmers for a higher income with the needs of consumers (and communities as a whole) for improved nutritional and environmental security, seems well thought out. Its strategic plans also include the integration of primary and secondary agriculture, thus importantly linking agriculture with the industrial and service sectors, resulting in promoting a “Bioeconomy.”

However, the implementation of India’s DFI plans needs further clarity, particularly with regard to harnessing the congruence between productivity and sustainability. Again, such a vision calls for effective public-private-community partnerships and urgent institutional reforms. Collaboration and cooperation are the key to success. The DFI vision can be a model for other developing countries only if the vision is appropriately modified to integrate the sustainability and productivity objectives. But, with such a step, post-COVID agriculture can chart a new and much needed course for our world, which can be called the "evergreen revolution," to match the last "green revolution" observed about 50 years ago.

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