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Sustainable agriculture: Trends and opportunities for 21st Century

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Abstract
The green revolution has been a major boost to the agriculture sector throughout the world including India. The food production of the country increased by many fold during the 1960s and 1970s and has continued to increase since then. But, the boom of green revolution could not last long as we witnessed stagnation in the productivity of our farm lands along with soil and crop health degradation. This forced the scientific and farming community to look for efficient and ecologically safe farming systems which led to the evolution of the concept of 'sustainable agriculture'. Sustainable agriculture is a holistic concept of agriculture which helps in meeting the needs of the present generation without affecting the future generation. It helps in maintaining optimum crop production along with maintaining soil health, conservation of natural resources and preserving ecological balance and biodiversity in agroecosystems. This review aims to create a paradigm for future studies on new and innovative techniques for sustainable crop production.

Keywords: Bio-intensive farming, organic farming, precision agriculture, Sustainability

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INTRODUCTION

Agriculture characteristically plays a significant role in the lively hood of the people of developing countries as compared to that in the developed ones. It forms the backbone of rural development and overall economy especially in countries like India. For example, it contributes up to approximately 15.87 per cent of India's GDP and provides employment directly or indirectly to more than half of our population. With production of agriculture activity of $375.61 billion, India is 2nd larger producer of agriculture product. Agriculture sector contributes 6.4 per cent to Indian economy which is higher than the world average and accounts for 7.39 percent of total global agricultural output (Anonymous, 2019). It forms the backbone for subsistence of the economically weaker sections of the society. The increase in agricultural output of the country between 1949-50 and 1973-74 was 2.7 per cent per annum. It was only slightly higher than our population growth rate at that time. In comparison, the rate of agricultural output during the first half of the century was a mere 0.8 percent per annum. Over the last few decades, the agricultural output has increased by many folds. The current food grain production of the country in over 280 MT which is the highest ever recorded in the Indian history. The major reason behind this was the green revolution that began in the late 1960s. The green revolution technologies were a major boost to the agriculture sector throughout the world including India.

William Gaud, whilst Director of the United States Agency for International Development (USAID), coined the word 'Green Revolution' in 1968 (Anonymous, 2011). The entire reign of green revolution could be divided into three phases. The first phase (1945-1955) was marked by the beginning of crossing programme in rice at the Central Rice Research Station, Cuttack. Though programme did not succeed initially, it lead to the search for new genes which later on lead to the development of the high yielding photo-insensitive dwarf varieties during the second phase. The third phase is characterized by the integration of advanced technologies along with the government policies (Swaminathan, 2017).

Apart from the high yielding varieties, the green revolution technologies included the high input of fertilizers and agrochemicals, improved irrigation and farm mechanization which all together resulted in the enhanced yield of the crops namely rice and wheat. It enabled us to transform from a

begging bowl to a leading exporter of food grains. But the boom of green revolution did not last long as we started witnessing the stagnation in the productivity of our farm lands due to the unscientific use of the green revolution technologies. The high amount of fertilizers applied in the soil has rendered it lifeless and unfit for cultivation in many parts of the world. The exploitation of the ground water has enhanced the soil salinization and lowering of water table in many parts of the country. The introduction of new high yielding varieties lead to the loss of many traditional cultivars/ land races which were rich in genes for many novel characteristics like disease resistance and nutritional qualities (Khor, 1995). Moreover, the benefits of green revolution did not penetrate deeper into the economically weaker sections within the farming community which enhanced the income disparity in the society. It made their living conditions worse due to the deflation in the prices of their farm outputs, higher price of inputs and increased price of the farm lands. Despite such a large hike in total food production, the per capita food availability has shown only a slight increase i.e., 144 kg per year in 1951 to 171 kg in 1971. It still remains stagnated at around 170-180 kg per year. As a result, we still are far behind (103rd out of 119 countries) in the International Food Policy Research Institute's Global Hunger Index in 2018 (Bouton, 2019). Thus, it can be revealed that, though green revolution helped in enhancing the food production by many folds, it left many black marks in the agriculture system of the country. This review reiterates the evolution and significance of sustainable agriculture and the major sustainable farming systems namely organic farming, bio-intensive farming and precision agriculture.

Evolution of sustainable agriculture: The concept of sustainable agriculture emerged out of limitations and demerits of green revolution. The FAO has defined sustainable agricultural development as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (Anonymous, 2014). It integrates various agricultural practices to ensure sustainable agricultural production. It includes a spectrum of farming systems, ranging from organic system that attempt to eliminate the use of synthetic chemical inputs to those involving the proper use of synthetic chemical inputs.

The idea of sustainable agriculture has gained prominence with the publication of the Brundtland report and the evolution of concept of sustainable development (Tait *et al.,* 2000). Similar to the concept of sustainable development, the notion of sustainable agriculture is ambiguous in its meaning, broader in its scope and extremely difficult to implement under the present circumstances (Culleton *et al.,* 1997). In the anticipation of solving this issue and making the concept more tangible, there have been plentiful attempts to describe sustainable agriculture. The main objective of sustainable agriculture is to maximize the benefits from the existing agriculture assets and minimize the threats to the environment from the current practices of intensive agriculture (Goldman, 1995). It aims to develop agricultural systems that conserve the natural resources, are profitable and productive, enhance the health and safety and protect the environment over the long term.

The first important milestone in the evolution of sustainable agriculture was the "humus farming movement" which stressed the importance of maintaining the humus content in the soil to preserve soil health. Books like *The Field Book of Manures or the American Mulch Book* (1855) and Charles Darwin's *The Foundation of Vegetable Mould, Through the Action of Worms, With Observations on Their Habit* (1881) and Albert Howard's *An Agriculture Testament* (1943) promoted the concept of humus farming movement. The second important movement took place during the beginning of twentieth century and was centered on the concept of "complex farming systems". The writings of F.H. King-*Farmers of Fort Centuries* (1911) and *Soil Management* (1914) stressed this concept. Third and fourth movement conceptualized the biodynamic farming and organic agriculture, respectively. The Brundtland Report "*Our Common Future"* (1987) set the fair stage for the evolution of an inclusive sustainable agriculture concept. It constructed foundation for the convening of the 1992 Earth Summit and the agreement of Agenda 21, the Rio Declaration and to the establishment of Commission on Sustainable Development.

Sustainable farming systems: Sustainable agriculture focuses on utilization of farms' own resources. A farm is known as sustainable when it produces high quality produce, is environmentally safe and at the same time satisfies the producers and is profitable. According to Dr. M.S. Swaminathan, "The greening of agriculture requires the greening of both the technology and public policy. Producing more food and agricultural policies from less land, water and energy is a task that will call for the integration of the best in modern technology, with the ecological strengths of traditional farming practices." The concept of sustainability in agriculture can be viewed in different perspectives *viz.,*

Sustainability as food security: Maximizing food production within constraints of profitability (Douglass 1984).
Sustainability as stewardship: Controlling environmental damage (Lowrance *et al.,* 1989).
Sustainability as community: Maintaining and reconstructing the rural value system (Brown 1984)
At present, the concept of sustainable agriculture has to be viewed in three major dimensions, namely, economic, social and environmental dimensions. Sustainable agriculture is an effective solution for establishing and strengthening a secure agriculture and food system along with a safe, healthy and sustainable future (Brodt *et al.,* 2011; Lichtfouse, 2009). It also encompasses the concept of conservation agriculture which includes wide variety of innovative agricultural and animal husbandry practices like waste treatment facility, emergency animal mortality management, animal mortality facility, etc (Ansari and Tabassum, 2018). In this review, we have discussed the most important sustainable farming systems, namely organic agriculture, bio-intensive agriculture and precision farming.

Organic Farming: The adverse effects of green revolution technologies, decreasing productivity of farm lands and increasing health consciousness in the society has provided a big boost to the organic farming sector all across the globe including India. As per United States Department of Agriculture (USDA, 1995), organic agriculture is an 'ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity'. International Federation of Organic Agriculture Movements (IFOAM, 2005) has defined organic farming as "a holistic production system that sustains the health of soils, ecosystem and people. It relies on ecological processes, biodiversity and cycles adapted to local condition, rather than input with adverse effects. Organic agriculture combines innovation, tradition and science to benefit the shared environment and promote fair relationships and good quality of life for all involved".

India ranks 9th in the World's organic agricultural land and 1st in terms of total number of producers (FIBL & IFOAM year book, 2018). As on 31st March 2018, the total area under organic farming in India registered under NPOP is 3.56 million hectares (APEDA, 2018). India produces 1.70 MT of certified organic produce and around 5 lakh tones of organic produce which amount to over 515 million USD annually. Madhya Pradesh ranks first in terms area under organic farming; followed by Rajasthan, Maharashtra and Uttar Pradesh. Recently, Sikkim has been declared as an organic state.

The four major underlying principles of organic farming include care, health, ecology and fairness (IFOAM 2012).

Care: This principle refers to the careful management of farm lands and natural resources in a responsible and precautionary manner to protect the well being and health of environment and current as well as future generations. Sufficient precautions are to be taken while adopting new technologies in organic agriculture. It states that responsibility and precaution are key concerns in technology choices, development and management in organic agriculture.

Health: Organic agriculture helps in sustaining and enhancing the health of soil, plant and animals. It stress on the concept that the health of individuals and communities is closely associated with the health of the ecosystems. The role of organic agriculture lies in the production of nutritional rich and safe food and maintaining healthy soil to enhance the health of all living organisms in ecosystem.

Ecology: Principle of ecology is based on sustaining ecological balance through maintenance of genetic and agricultural diversity and conservation of natural resources. Organic management practices should be locally adapted to protect the ecological diversity of the region. There is a need for reusing, recycling and efficient management of resources to maintain ecological balance and environmental quality.

Fairness: It is characterized by equity, justice, respect and stewardship of all the stakeholders involved. It aims to provide good quality life with reduced poverty with sufficient amount of safe and nutritionally rich farm products. It also emphasis that animals should be provided with safe and hygienic living conditions in accordance with their natural behavior, physiology and well being.

Organic farming practices

Soil and nutrient management: The basic philosophy of organic farming is "feed the soil not the plants". The nutrients should be supplied to soil which should act as reservoir for plants. This will help in maintaining a healthy soil rich in microbial diversity. It has been reported than organic soil has increased soil microbial biomass and activity to 20-30 and 30-100 percent, respectively (Stolze *et al.,* 2000). The enhanced microbial community will in turn improve the soil physical and chemical properties leading to healthy soil. Organic farming practices were found to improve the soil properties such as soil structure and texture, porosity, buffering capacity, aeration, etc (Papadopoulos *et al.,* 2014; Parthasarathy *et al.,* 2014). The important soil management practices under organic agriculture include the crop rotation with leguminous crops (Viridi *et al.,* 2005), green manuring, cover cropping, mulching (Altieri and Nicholas, 2005), minimum tillage of the soil (Gracia-Moreno *et al.,* 2013), conservation of soil microbes by enhanced addition of organic manure to the soil, etc. Growing of leguminous crop and green manuring the field

helps to enhance the soil nutrient contents particularly the nitrogen and micronutrient content of the soil. For example, green manuring in rice saves up to 45-120 kg N/ ha (Ladha *et al.,* 1988). Hence, some of the organic soil management practices can also be successfully incorporated with the conventional farming systems to improve soil health.

Crop protection: Crop protection in organic farming systems is achieved mainly through the conservation of natural enemies, plant products and few biocontrol agents. Organic agriculture fields have a higher conservation rate of the friendly insects and biocontrol agents. For example, in organic rice fields, predatory insects like spiders, ants, wasps, etc can control up to 95 percent of the insect pests affecting the crop (Alvares, 1999). The secondary metabolites of plants such as neem, pongamia, tulsi, lantana, etc and many essential oils have been successfully exploited as efficient botanical pesticides for the management of insect pest and diseases both under field and storage conditions. Even cow urine has got antimicrobial and insect deterrent properties that are being exploited under organic farming systems.

Weeds are a constant trouble to the crop and cause a significant yield reduction. Weed management in organic farming is achieved through many cultural, physical and biological practices. Selection of crop cultivar plays crucial role as its morphology, crop canopy and its nutrient uptaking habit affects the crop weed competition (Aulakh and Ravisankar, 2017). Crop rotation too plays a significant role for the management of many crop associated weeds. For example, *Phalaris minor* in wheat can be effectively managed by crop rotation with other *Rabi* crops such as crucifers. Modification in spacing and sowing time such as narrow row spacing of 15 cm (Mahajan and Brar, 2001) and bed planting of wheat (Aggarwal and Goswami, 2003) also help in managing the weeds. Biological control of weeds is achieved by use of living entities like fungi, bacteria, insects and even animals like goats and cattle. It has been reported that allelo-chemicals present in sorghum and eucalyptus checks the photosynthesis and respiration of many weeds and slower their growth (Cheema *et al.,* 2003 ; Khaliq *et al.,* 1999).

Bio-intensive farming: The concept of bio-intensive farming meets of the drawbacks of green revolution as it has reached out the small and marginal farmers and increased the profitability of agriculture in small land holdings in developing countries like India. It stresses upon the words of Bill Gates *i.e.,* "the next green revolution has to be greener than the first. It must be guided by small holder farms, adapted to local circumstances and sustainable for the economy and environment". The basic methodologies of bio-intensive farming are derived from the ancient Chinese, Greeks, Mayans and other European farming practices. These methodologies were fine tuned to sustainable "Grow Bio-intensive" method by John Jeavons and Ecology Action in 1974. Later on Rajbhandari developed the holistic approach and concept of bio-intensive farming system to address the cultural, socio-economic and political aspects (Rajbhandari and Gautham, 1998). The basic underlying principles of bio-intensive farming include the mixed farming, crop rotation, organic recycling, participatory research and extension, self reliance and sustainable natural resource management. It focuses on achieving maximum crop yield from limited farm area along with increasing biodiversity and sustaining soil fertility. Thus, it differs from the green revolution both technological as well as the socio-economic aspects.

Rajbhandari (2002) has defined bio-intensive farming system (BIFS) as a 'biologically intensive mixed farming system, which relies on the intensive engagement of the farmers; optimization of organic recycling through crop rotations; integrated plant nutrient management (IPNM); and integrated organic pest management (IOPM) with the use of bio-pesticides, botanical pesticides, and biota'. The basic components of bio-intensive farming include double dug raised beds, composting, bio-intensive planting, companion planting, carbon farming and calorie farming. The characteristic features of BIF include the empowerment of people's organization, conservation and utilization of biodiversity, eco-friendly production systems, equal access to resources and use of technologies. It is a production system that promotes an intensive mixed farming system that relies on intensive engagement and empowerment of small farmers and all other stake holders and optimum use and recycling of resources (Rajbhandari, 2017). Shiwakoti and Rajbhandari (2016) have reported a positive impact of BIFS on household income and empowerment of women in Udayapur district of Nepal. As a result of adoption of BIFS, women were involved in group meetings and had an increased access to resources and decision making power.

Moreover, health, the nutritional condition and hygiene of the family were improved after adopting BIFS. Thus, it focuses on the holistic development of the farms while maintaining the sustainability in crop production. BIF system has demonstrated its contribution to environmental sustainability; and it addresses most of the adverse effects of the green revolution. It has been advocated as efficient participatory approach to address the concerns like ecological and land degradation, food security and livelihood of people in developing countries (Rajbhandari, 2011).

Precision farming: It is a new scientific approach

towards farm management that uses information technology to make sure that the plants and soil receive accurately what they require for optimum health and productivity. PF technologies started to appear on a commercial scale in the early 1990s and help to adequately address the heterogeneity in the field through technology and precise data analysis. The United States Department of Agriculture (USDA, 2003) has defined it as ' a management system that is information and technology based, is site specific and uses one or more of the following sources of data: soils, crops, nutrients pests, moisture and yield, for optimum profitability, sustainability and protection of the environment'. Besides precision agriculture, precision livestock farming is also an emerging field in various parts of the world (Busse *et al.,* 2015). It enables farmers to increase their profit from their farms through better management by application of appropriate and need based inputs. It helps them to save the input costs of seeds, fertilizers and other agrochemicals.

Moreover, it enhances the natural resource use efficiency and reduces the environmental pollution due to agrochemicals. The three basic pillars of precision farming (PF) are:

Technology: Computer, internet, global positioning system, remote sensing, geographic information system, crop and yield mapping technologies, variable rate technology (VRT), decision support systems, etc.

Information or database: Information on crop, soil, climate, etc

Management: Precision agriculture service provider

The basic goal of precision farming is to achieve profit, sustainability and conservation of environment. According to the father of Precision Farming Prof. Pierre C. Robert, precision agriculture is not just the injection of new technologies but it is rather an information revolution, made possible by new technologies that result in a higher level, a more precise farm management system. It mainly means adding the right amount of treatment at the right time and the right location within a field. Through more precise use of inputs, PF has the potential to reduce the economic and environmental costs such as pesticide residue in both ecosystem and harvested produce (Finger *et al.,* 2019). Advances in the informational, sensor based, robotic and data processing technologies have made the PF more efficient, accurate and widely acceptable (Walter *et al.,* 2017). For small farmers in developing countries, precision farming brings substantial yield improvement with minimal input use (Fountas *et al.,* 2004).

The basic framework of the PF lies in the collection and structuring of data followed by adoption of crop management practices through adequate integration of technologies. The georeferencing tools such as GIS and GPS are used to prepare field map although out the crop production right from land preparation to harvesting of the crop. The diagnostic tools such as the sensor based technologies are used for accurate monitoring of the environment as well the crop parameters like pests, nutritional disorders, water stress, etc (Corwin and Lesch, 2005; Shaw *et al.,* 2016). Finally the application tools are employed for site specific adoption of crop management practices (eg. VRTs) such as pest control, fertilizer application, irrigation, etc using the data generated (Robertson *et al.,* 2012). Thus, it helps in enhancing the efficient utilization of resources and has a great potential to contribute to the sustainable agricultural development.

Conclusion

Thus, the concept and practices under the sustainable agriculture, presents an effective alternative to the conventional agriculture. The organic, bio-intensive and/or precision farming systems will enable us to overcome the ill effects of the green revolution technologies and help in maintaining an efficient and ecologically safe agroecosystems that will produce enough food for the present generation without compensating the needs of future ones. The practices such as the resistant varieties, crop rotation, green manuring, minimum tillage, biological pest control and precision agriculture technologies will help in sustaining the food production while maintaining the soil health, ecosystem balance and biological diversity. They will help in better use of natural resources there by reducing the amount and dependence on the external synthetic inputs. There is a need for more intensive research on the sustainable farming practices to make it more effective and economical through an integrated approach involving all the stake holders of agriculture and government machineries. Moreover, we need to popularize the benefits of such farming systems among the farming community by proper extension activities.

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