



Best Management Practices for Sustainable Agriculture

Gouranga Saw^{1,2*} and Santoshi Choudhary²¹Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi (110 012), India²ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh (493 225), India

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Corresponding Author

Gouranga Saw

✉: gourangasaw8612@gmail.com

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Abstract

The present estimate of the number of people on Earth is 8 billion, but by the middle of the century, it is predicted to reach 9 billion. Simultaneously, the cultivable farm land is being lost to expanding urban areas, industrialization and climate change. The recent World Bank Report estimated that to feed 9 billion people, food production needs to scale up by 70% by 2050. In the present context, the significance of sustainable agriculture is crucial in ensuring the sustenance of the population and mitigating the adverse effects of climate change. Environmental protection, resource conservation, soil fertility maintenance and improvement are the key goals of sustainable agricultural practises. Sincere efforts have been taken to discuss the various sustainable agriculture methods and practices in this assessment.

Keywords: Biological control, Conservation agriculture, Habitat management, Natural farming, Precision farming, Sustainable agriculture

Introduction

In order to produce food, sustainable agriculture relies on the already-existing cycles of soil nutrients, water and energy, producing food that is healthful and devoid of artificial substances that can be detrimental to people's health is the aim of these systems. Rather than relying on artificially formulated fertilizers, growth regulators, pesticides and additives for livestock feed, these systems actually try to maintain soil fertility and productivity through crop rotation, green manures, proper cultivation through mechanical means and mineral-bearing rock. Sustainable agriculture is having the goal of protecting and enhancing consumer social and economic conditions as well as preserving the health and welfare of society. Agriculture must be managed in a way that not only makes it sustainable over the long term but also beneficial by implementing the right crop production, post-harvest processing and quality-improvement technologies (Gahukar, 2009). Sustainable agriculture involves the effective stewardship of natural resources within the realm of agriculture, aiming to fulfill the ever-changing needs of humanity while concurrently safeguarding and enhancing environmental quality and the management of natural resources. In this context, agricultural systems centred around labour-intensive

practices and low-input ecological organic farming emerge as promising alternatives, presenting the potential for sustainability within the agricultural framework in India (Srivastava *et al.*, 2016).

Climate change, biodiversity loss, soil degradation, compaction and depletion, as well as the high cost of inorganic chemical fertilizers and plant protection chemicals, are problems associated with modern agriculture that have stagnated yield levels in recent years and increased health and environmental risks. Consequently, developing an ecologically healthy, financially viable and long-lasting farming culture is urgently needed. Development of technologies and practises that do not harm the environment, are easily accessible to farmers and eventually increase food yield are necessary for sustainable agriculture (Pretty, 2008).

Organic Farming

Organic agricultural techniques prioritise social, economic, and environmental sustainability while avoiding synthetic inputs (Stockdale *et al.*, 2001). As of the World of Organic Agriculture Report published in February 2018, India holds the distinction of having the largest number of organic farmers globally. It is home to more than 30% of the 2.7 million organic growers worldwide, or 8,35,000 certified

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organic producers. The global organic agriculture market and its products have grown in value. We can restore the ecological equilibrium with the help of organic farming. The free certification programme for organic farmers offered by the Center, Paramparagat Krishi Vikas Yojana (PKVY), serves as an illustration. The northern Indian state, Sikkim, succeeded in 2016 in making the switch to entirely organic farming. Several Indian states, including Goa, Rajasthan, Kerala, Mizoram, and Meghalaya, have also declared their aim to switch to fully organic farming (Kumar *et al.*, 2019).

A farming method known as organic agriculture gives the health of people, ecosystems, and soils top priority. It depends on biodiversity, biological processes, and locally adapted cycles while avoiding inputs that can have unfavourable impacts (Asokan and Murugan, 2018). Important elements include maintaining levels of organic matter in the soil to maintain fertility over time, promoting soil biological activity, using appropriate mechanical treatments sparingly, achieving nitrogen self-sufficiency through legumes and biological nitrogen fixation, effectively recycling organic wastes like crop residue, livestock manure, and weeds, and controlling pests and diseases primarily with natural predators, crop rotations, diversity, and composting. To minimize the duration between the application of NPK to the soil and its depletion, extensive initiatives are implemented to sustain soil fertility. This involves recycling all forms of waste, usually achieved through composting, to reintroduce essential nutrients back into the soil (Chhonkar, 2002).

The imperative of feeding an expanding global population has compelled numerous nations to resort to the application of fertilizers and chemicals to boost agricultural yields. Despite meeting the immediate demands for food, the sustained and excessive reliance on pesticides has led to issues concerning soil health, risks to human well-being and environmental harm. Consequently, farmers in industrialized countries are being urged to transition from conventional farming practices to organic methods (Yadav *et al.*, 2013). Organic farming can be financially successful and people choose organic food since it is both healthful and morally right. However, organic farming techniques have many environmental advantages that go beyond only financial and ethical considerations. For example, they decrease exposure to pesticides and other chemicals, promote water conservation, create healthy soil, stop soil erosion, support animal health and welfare, promote biodiversity, *etc.*

Agricultural Sustainability via Organic Farming

Organic farming refrains from employing any inorganic agricultural methods that may compromise the integrity of the agro-ecosystem. Through organic agricultural practices, the production of nutritious food is achieved while upholding the balance of nature to mitigate issues related to pests and soil fertility. To address the myriad environmental and social challenges associated with chemical-based agriculture, there is a pressing need to promote and embrace organic farming. Beyond its environmental implications, the reliance on synthetic chemicals poses a substantial risk to livelihoods

of organic farmers. Not only does the adoption of inorganic fertilizers and pesticides contribute to environmental concerns, but it also imposes considerable economic hardships on agricultural practitioners. The enduring health and financial stability of farmers are jeopardized by unsustainable farming practices, with the growing usage of fertilizers and pesticides adding to the overall increase in agricultural prices. The persistent use of artificial fertilizers depletes the soil's fertility, which permanently lowers agricultural productivity. It causes declining productivity and increased production costs, making farming unprofitable. Agriculture can only be regarded as sustainable if it continues to be economically viable over time. Organic farming ensures sustainable economic growth, unlike contemporary agriculture that relies on artificial fertilizers and pesticides (Chandrashekar, 2010).

Additionally, organic farming proves to be financially advantageous, driven by the heightened market value of organic products. A well-crafted agricultural sector plan has the potential to foster augmented agricultural productivity, enhance food security, generate employment opportunities in rural areas and alleviate poverty, all while ensuring the preservation of the natural resource base (Soumya, 2015). To eliminate poverty, promote regional integration, speed human development and raise agricultural output, this new plan must be implemented with good governance, infrastructure, private sector participation and performance. Therefore, it is evident that a major transformation in agriculture is required to implement more sustainable practises. This has to be done to protect the environment and boost the agro-ecosystem's productivity. Policies must be in place to encourage agricultural operations that promote long-term social and environmental sustainability. The use of local resources is prioritised more in organic farming, which empowers farmers and the rural community (Asokan and Murugan, 2018).

Natural Farming

The terms "Farming," "Eco-Agriculture," or "Eco-friendly Agriculture" are suggested as innovative strategies aimed at improving both modern and traditional agricultural practices with the overarching goal of preserving the environment, communities and public health (Mishra, 2013). Natural farming is characterised as using just livestock and no chemicals in the farming process. This agricultural system is characterized by its diversity, incorporating a harmonious blend of crops, trees and cattle, all grounded in a robust agro-ecological foundation. This allows for the best potential use of functional biodiversity. Regenerative agriculture, a well-known technique for protecting the environment, is considered to include natural farming. It has the power to control how much land is used and to store atmospheric carbon in soils and plants, where it will be helpful rather than destructive.

Aims of Natural Farming System

To increase farmers' net earnings as a result of lower costs, lowered risks, equivalent yields and income from

intercropping in order to make farming sustainable and aspirational. Promoting the creation of essential biological inputs by farmers using locally sourced, farm-grown and natural resources will markedly diminish production costs.

Significance of Natural Farming System

- Minimize cost of production.
- Ensure better health.
- Employment generation.
- Environment conservation.
- Reduce water consumption.
- Livestock sustainability.

Zero Budget Natural Farming: An Environmentally Sustainable Approach for Andhra Pradesh

By adopting Zero-Budget Natural Farming (ZBNF) on 6 million farms and 8 million hectares of land by 2024, the government of Andhra Pradesh will become the first farming state in India to be entirely chemical-free. This announcement was made on June 2, 2018. The term “Zero Budget” denotes the cultivation of crops, (including intercrops, order crops and multiple crops) with zero net cost. Among the local materials used for seed treatments and other inoculations are cow urine and manure. Consequently, because their input costs are lower, ZBNF farmers can increase their incomes more easily. ZBNF crops support soil fertility retention while also being resistant to climate change. The Sustainable India Finance Facility (SIFF), a ground-breaking collaboration between UNEP, BNP Paribas and the WAC, provides funding for this programme. This initiative is both a social and environmental endeavour, rendering farming economically viable for small landholders through improving ecological services and biodiversity in agriculture. It endeavours to minimize farmers’ costs while concurrently boosting incomes and rejuvenating ecosystem health through the implementation of diverse cropping systems. These systems are designed to curtail external inputs and rejuvenate soils through the utilization of in-situ resources.

Integrated Farming System (IFS)

An integrated farming system is a method of farming on a specific farm specific farm that incorporates growing crops, rearing livestock, poultry, fisheries, beekeeping, *etc.* to support & satisfy the farmer’s needs in as many ways as possible. Consequently, integrated farming systems become more important to promote agricultural sustainability by increasing farm output, which will lessen environmental deterioration, enhance the quality of life for resource poor farmers and reduce environmental degradation. Agriculture, dairy, fish farming, goat and sheep husbandry, mushroom cultivation, horticulture, poultry, piggery, forestry, poultry and vermiculture are some of the industries that make up IFS. There are other IFS models that have been identified, including labour-intensive systems for small regions and farming systems that include crops, animals, and forests, fisheries, and crops (Dar *et al.*, 2018). The IFS has four

main objectives: (1) maximizing the yield of all integrated components (2) restoring agro-ecological balance; (3) natural pest and disease management and (4) reduction in chemical reliance, fostering a healthy society and maintaining a thriving ecosystem (Manjunatha *et al.*, 2014).

Integrated Farming System for Sustainable Development

The waning economic sustainability of agriculture presents a considerable hurdle, especially in regions characterized by arid and semi-arid conditions. By lowering manufacturing costs and/or increasing productivity through the use of sustainable management, the IFS holds out a lot of promise for boosting profitability. By utilizing waste as a raw material for various enterprises, the Integrated Farming System (IFS) can effectively reduce production expenses (Manjunath and Itnal, 2003; Ravisankar *et al.*, 2007). This method also reduces reliance on external inputs (Wilkins, 2008; Ryschawy *et al.*, 2012). The foundation of the agricultural system rests on the belief that fostering individuals’ learning capacity, study skills, problem-solving abilities and effective communication will enhance their capacity to adapt to change (Meena *et al.*, 2018).

It fosters intuitive, creative work in addition to logical, methodical analysis and integrates the scientific method, systems thinking and experiential learning. In order to plan crop production, select cropping methods and integrate various companies to build integrated farming systems with sustainable agriculture production, the idea of integrated system study takes into account the many farm enterprises and resource inputs. Depending on the region’s latitude and irrigation techniques, the effects of climate change on crop productivity under Integrated Farming System (IFS) approaches for sustainable agriculture will differ (Gangwar *et al.*, 2013). Crop yields will increase in certain places while decreasing in others.

Using livestock dung to magnify nutrients that promote soil fertility and decrease the need for chemical fertilizers is the best way to increase agricultural productivity (Gupta *et al.*, 2012). Crop wastes can be fed to animals. Due to the integration of various enterprises, each with a specific economic significance, farm output is produced more sustainably. Reusing trash in a system reduces the need for external high-energy inputs, protecting priceless natural resources in the process. The agricultural method allows the farmer to sell eggs, milk, honey, silkworm cocoons and edible mushrooms, among other products, for a consistent income stream all year round. This will lessen reliance on solitary businesses and lower the risk to lenders as well (Devendra, 2002). The integrated farming system strives to effectively manage resources, achieving both economic success and environmental sustainability; all while meeting the diverse needs of farm households.

Strategies for Sustainable Pest Management

Habitat Management

Habitat management is a part of conservation biological control strategies involving altering ecosystems to increase

natural enemies' access to resources and support their optimum functioning. It is possible to apply habitat management on farms, with crops, or in landscapes. These strategies recognize that agricultural landscapes often fail to offer natural enemy resources at the ideal time or location. The necessity for habitat management is closely linked to the biological characteristics of certain pests and natural enemies, as well as the attributes of the ecosystems they inhabit. Agricultural systems are often challenging habitats for natural enemies due to frequent and intense disturbance regimes (Townes, 1971; Powell, 1986; Letourneau, 1998; Landis and Marino, 1999). That holds true for yearly monocropping systems since they are less successful at eradicating the target pest and at establishing natural enemies (Beirne, 1975; Hall and Ehler, 1979; Stiling, 1990). Several immediate factors, such as the presence of pesticides, a lack of adult food sources and the absence of alternate hosts, have been identified as hindrances to the effectiveness of natural enemies in agricultural systems (Rabb *et al.*, 1976; Powell, 1986; Dutcher, 1993). These factors can be seen as direct outcomes of the disturbance regimes imposed on these systems (Landis and Menalled, 1998). One impediment to the effective application of biological control is the widespread use of pesticides, especially in crop production systems. Past conservation initiatives primarily concentrated on creating more specialized insecticides or employing strategic pesticide usage to mitigate their adverse impacts on natural enemies (Ruberson *et al.*, 1999). More recently, attention has shifted towards conservation strategies that seek to enhance the habitat quality for natural enemies (Landis *et al.*, 2000).

Approaches to Habitat Manipulation

a) **Top-down-Control:** In this scenario, herbivores at the second trophic level are controlled by natural bio-agents operating at the third trophic level. This particular strategy is employed in "Augmentative Biological Control."

b) **Bottom-up Control:** The first trophic level's cover crops and green mulches, which alter insect habitats, can also directly influence pests and offer "bottom-up" control. In "Conservation Biological Control," this kind of strategy is used to manipulate habitat. He called the non-natural enemy effects that result in pest control, the "resource concentration theory," which describes how inputs from other plant species successfully "diluted" the resource (the crop) (Root, 1973).

Conservation Biological Control

Conservation Biological Control involves altering the environment to enhance the longevity, reproduction, behaviour and survival of natural enemies, thereby increasing their overall effectiveness. These conservation strategies might work to improve advantageous conditions or lessen unfavourable ones. Alternative conservation strategies aim to manage secondary adversaries, enhance available resources, minimize mortality, or modify the characteristics of the host plant to favor natural enemies (Van den Bosch and Telford, 1964; Rabb *et al.*, 1976). Given

its significance in enhancing the effectiveness of natural enemies, the conservation of biological control should serve as the fundamental element in all biological control programs (Gurr and Wratten, 1999). While various forms of biological management have garnered attention, it's noteworthy that conservation biological control has received comparatively less focus (Ehler, 1998). This pattern has started to change, though (Pickett and Bugg, 1998; Barbosa and Benrey, 1998).

Pest Control via Ecological Engineering

The concept of pest management through ecological engineering represents a novel approach to pest control methods, emphasizing the utilization of cultural techniques to modify habitats and promote biological control. In contrast to high-tech methods such as genetically modified crops and synthetic pesticides, this approach relies on a foundation of informed ecological understanding (Gurr *et al.*, 2004). Ecological engineering is the process of symbiotically integrating technical design with ecological self-design to link society's economy with the environment. Odum is credited with introducing the term "ecological engineering," which can be understood as human intervention in nature using minor additional energy inputs to manage systems primarily fueled by natural sources (Odum, 1962). The objective of ecological engineering is to supply resources for natural enemies, including honey (Baggen and Gurr, 1998), pollen (Hickman and Wratten, 1996), alternative prey (Abou-Awad *et al.*, 1998), alternative hosts (Viggiani, 2003; Yele *et al.*, 2022), as well as physical refuges, nests and lekking locations (Sutherland *et al.*, 2001).

Ecological Engineering for Above-Ground Pest Control

- To attract natural enemies and prevent the development of insect populations, increase the amount of flowering vegetation and suitable income crops towards the perimeter of the orchard. This is done by placing shorter plants closer to the primary crop and taller plants further away from it.
- Plant flowering vegetation inside the orchard's bunds.
- It's best to leave natural weeds like *Ageratum spp.*, *Tridax procumbens*, *Alternanthera spp.*, etc. alone because they serve as a nectar supply for natural enemies.
- Applying wide-ranging chemical insecticides is not recommended. Prior to using chemical pesticides, one should also consider the plant's capacity for compensating.

Ecological Engineering for Underground Pest Control

- Leave crop leftovers and/or living vegetation on top of soils all year long.
- Enhance below-ground soil biodiversity by incorporating organic substances such as crop residue, farmyard manure or vermicompost.
- Minimize tillage to protect naturally occurring enemies that are hibernating.
- Administer a nutrient-balanced dose using biofertilizers.
- Use rhizobacteria and mycorrhiza to encourage the growth of plant (PGPR).

- Use *Pseudomonas fluorescens* and species of *Trichoderma* to soil, nursery treatments and seedlings and other planting materials.

Chocolate-Box Ecology

Critics have dubbed the practise of manipulating habitats for improved pest management as “Chocolate-Box Ecology.” To ensure that natural adversaries have enough honey, pollen and food to eat, floristically diverse vegetation is added. Experts are now more regularly filter plant species to find the most desirable species or utilise a number of entry requirements to obtain the proper botanical composition in place of this basic form of habitat alteration (Pfiffner and Wyss, 2004). According to these tactics, a variety should be chosen based on its “proper sort,” not its quantity (Polaszek *et al.*, 1999). Researchers and practitioners are actively formulating a range of approaches to ensure that pertinent forms of diversity are employed for pest control within the context of ecological engineering (Gurr *et al.*, 2004).

Push-Pull Strategy

Originating in Australia and introduced as an insect pest management (IPM) strategy, the “push-pull” concept was coined by Pyke *et al.* in 1987. Push-pull strategies encompass the use of stimuli to make a protected resource unappealing or unsuitable for pests (push), coupled with attracting them toward a preferred source (pull), facilitating effective pest removal. These strategies seek to alter the behaviour of insect pests and their natural adversaries by employing a varied set of stimuli to impact the abundance and distribution of both harmful and beneficial insects. Pest control methods aim to lessen pests’ population density around the resource that is being protected, such as farm animal or crop. By employing cues that hide the host’s appearance, or are deterrent or repellent, pests are deterred or repulsed from this resource (push). With the help of highly visible and alluring stimuli, the pests are simultaneously drawn (pulled) to other places where they are concentrated, like traps or trap crops, which makes it easier to get rid of them (Cook *et al.*, 2007).

Intercrops and trap crops are used in conjunction with farmer-friendly plants that also take advantage of natural enemies as part of the strategies. Following trials of prospective hosts and non-host plants in Kenya, these plants were chosen (Khan *et al.*, 2000). Specifically, Greenleaf (*D. intortum*) and silverleaf (*D. uncinatum*) desmodium, or molasses grass act as repellents (push) against stem borers. In contrast, *Sorghum vulgare sudanense* and *Pennisetum purpureum* serve as locations where most stem borers are drawn (pull). Stem borer infestation was decreased when maize and molasses grasses were planted together, although *Cotesia sesamiae* parasitism was also elevated (Khan *et al.*, 1997). When cultivated in close proximity to maize or sorghum, Desmodium release these compounds along with significant quantities of additional sesquiterpenes. These compounds not only act as deterrents against pests like stem borers but also play a role in inhibiting the parasitic *Striga hermonthica*.

Beetle Bank

Building a raised earth bank and planting perennial grasses on it to provide an appropriate overwintering habitat for natural enemies inside fields is known as “beetle bank” (Wratten, 1992). Natural enemies could prefer non-crop vegetation as a place to lay their eggs. *Coleomegilla maculata* (Coleoptera: Coccinellidae) has been found to lay more eggs on an indigenous weed called *Acalypha ostryae folia* than on the sweet corn. *C. maculata* was significantly more prevalent in maize plots with *A. ostryae folia* as a boundary than in plots without a barrier (Cottrell and Yeargan, 1999).

Classical Biological Control

Classical Biological Control entails the deliberate introduction of a non-native biological control agent into an area infested by pests to achieve long-term pest control and establish a sustained presence of the control agent. The objective is to reinstate the equilibrium between natural enemies and pests, which was disrupted when the pest migrated to a novel area without its native adversaries (Eilenberg *et al.*, 2001). The successful management of the *Paracoccus marginatus*, stands out as one of the significant achievements in the realm of classical biological control. *Anagyrus loecki*, *Pseudleptomastix mexicana* and *Acerophagus papaya*, three foreign parasitoid species known for their effectiveness in suppressing the *Paracoccus marginatus* in its native habitat, were introduced from Puerto Rico (Shylesha *et al.*, 2010). This exotic bioagents were able to establish them in every release region and control the papaya mealybug infestation on several crops. According to estimates, farmers in Maharashtra, Karnataka and Tamil Nadu annually saved INR 1,623 crores.

Cover Crops

Cover crops are a vital component of a successful sustainable farming system because they are carefully tended to reduce soil erosion and stop deep-layer nutrient loss from surface runoff and leaching. Since they are sown to provide soil coverage and enhance its physical, chemical and biological attributes, legumes are commonly employed as cover crops; optimal cover crops should exhibit rapid germination and emergence, resilience to adverse weather conditions, capacity to fix atmospheric nitrogen, absorption of soil nutrients through deep-rooted growth, efficient biomass production within a shorter timeframe, ease of cultivation without competing with primary crops, tolerance to insect pests and diseases, weed-suppressing capabilities and cost-effectiveness in cultivation (Kaur *et al.*, 2017). Overwhelmingly, cover crops can support the production of sustainable agriculture. Improving soil well-being, cover crops play a crucial role in alleviating groundwater pollution by minimizing soil erosion from both water and wind, enhancing soil structural attributes like aggregate stability, improving soil hydraulic features such as water infiltration, strengthening soil organic carbon (SOC) levels, and the microbial population, and reducing nitrate nitrogen leaching. Moreover, cover crops contribute to adapting to climate change and assist in curbing greenhouse gas emissions. Furthermore, the species chosen (grasses, brassicas, non-

legumes and legumes), the planting and harvesting dates and the kind of harvest (mechanical vs. chemical) all affect the benefits of using cover crops (Sharma *et al.*, 2018).

Crop Rotation

Crop rotation stands out as a vital practice in sustainable farming methodologies. It involves planting various crops in the same location at various times of the year or different years. This technique reduces the usage of pesticides and herbicides, which can bioaccumulate in various species, particularly predatory birds. Because pests do not have a reliable food source when crops vary from year to year, pesticide use is kept to a minimum. With the shift in crops, pest reproductive cycles are also disrupted, which prevents their numbers from rising quickly. Crop rotation also reduces the usage of fertilizers, which frequently end up in agricultural runoff and cause eutrophication. Soybeans and other legumes are planted to help the soil naturally restore nitrogen and other nutrients when crops deplete the land's natural resources rather than artificially introducing new ones. Crop rotation is essential for increasing the productivity of related crops by improving the physical, biological, and chemical characteristics of the soil; it also reduces bulk density, improves soil structure, increases soil organic matter content, and stimulates soil microbial biomass and concurrently decreasing soil electrical conductivity (EC) while augmenting soil pH (Ouda *et al.*, 2018).

Agroforestry for Sustainability

Agroforestry is the deliberate integration of shrubs and trees into livestock and crop production systems with the objective of producing social, economic, and environmental advantages (USDA National Agroforestry Centre, 2021). The goal of agroforestry is to achieve a balance between the protection of forest resources, the utilisation of the potential agricultural ecosystem benefits that trees may offer and the contribution of agroforestry to the diversification of agricultural products and markets (Schultz *et al.*, 2019).

Advantages of Agroforestry

- Encompassing enhanced pollination from diverse pollinators.
- Enhancement of health of the soil.
- Reduced water requirements coupled with improved water quality.
- Improvement of quality of air.
- Enhanced control of pests.
- A multi-story canopy cover, providing a diverse range of shade and sunlight conditions beneficial for both plants and animals.
- Varied agricultural businesses that market fruits, nuts, flowers and timber.

Role of Agroforestry in Environmental Sustainability

Due to world's continuously expanding population, the traditional African farming paradigm is no longer viable. The country's natural resources are being used unsustainable

due to rising food demand, which is placing further pressure on the country's forests and their products. Because of these advantages, one sustainable land management strategy that increases productivity, fosters stability, and encourages environmentally responsible development is agroforestry (Wilson *et al.*, 1990). Incorporating trees into farming systems not only provides valuable resources such as wood, food and animal products but also plays a crucial role in mitigating environmental issues. By improving mineral recycling and establishing microclimates that support agricultural growth, this approach establishes a comprehensive ground cover that serves as a protective measure for the soil (Adedire, 2004). According to Evans (1992), the advantages of agroforestry from an economic, environmental and social perspective greatly aid in the sustainable growth of society. Agroforestry has been demonstrated to meet sustainable development standards and to have no negative environmental effects, they continued.

Precision Farming

Precision farming, a contemporary and scientifically grounded practice, gained increasing popularity towards the end of the 20th century. It involves the utilisation of hypotheses and technology to effectively control the geographical and temporal variability inherent in every aspect of agricultural production. Serving as a system for more efficient resource management in agriculture, precision farming presents a wide range of possible advantages, encompassing food safety, rural economic development, profitability, sustainability, on-farm quality of life, crop quality, productivity and environmental protection (Abhilash Joseph *et al.*, 2020).

Precision farming involves the targeted application of inputs, delivering what is needed precisely when and where it is needed (Zhang, 2019). With the accessibility of more data, precision farming is continuously evolving, bolstered by the integration of advanced farm knowledge systems. According to a 2016 report from the USDA, precision agriculture technologies have contributed to enhanced operating earnings and net returns (Schimmelpfennig, 2016). To ensure the sustainability of agricultural produce, there is a rapid implementation of new technologies on farms. But there are risks and compromises in implementing this technology.

Components of Precision Farming

Since measuring and understanding variability is an essential component of precision farming, the key components of a system for managing it must be effective. Global Positioning Systems (GPS), Remote Sensing (RS), Soil Testing (ST), Geographic Information Systems (GIS), Variable Rate Technology (VRT) and Yield Monitor (YM) are some of the information- and decision-based precision farming tools. With precise guiding and navigation systems, farming operations will be possible even in high places and bad weather. All of these technologies are accessible in India, where agricultural officers who have undergone agricultural

training facilities' training can apply them (Ali, 2013).

Advantages of Precision Farming

Precision agriculture offers benefits to both the environment and growers, establishing a connection between these two aspects as environmental health significantly impacts agricultural practices. The following are some benefits of this control system:

- Lowering the price of resources and supplies like fuel, seeds, water, etc.
- Retaining the health of the soil by reducing pesticide use.
- Lessening agriculture's reliance on weather.
- Maximizing genetic potential of the crops produced.
- With the use of precision farming, farmers may greatly raise the quality of their output while also cutting costs.

Precision Farming to Preserve Sustainability

Sustainable agriculture aims to provide for the current needs of society, especially in the food business, without causing harm to the environment. Farmers may cultivate crops and soil as efficiently as possible while preserving resources by using precision agriculture. For instance, VRT reduces the production process' dependency on chemicals, increasing the field's overall yield over time. Hazardous material emissions are reduced by optimising transportation costs (Bucci *et al.*, 2018). Sustainable agriculture strives to meet the present societal needs, particularly in the realm of food production, while avoiding detrimental effects on the environment. No matter the size of production, these issues may be solved by everyone with the use of technologies like EOSDA Crop Monitoring.

Vermicomposting

Earthworms and microorganisms are used in vermicomposting, a biological and chemical process that recycles nutrients. Vermicompost is therefore thought of as a biofertilizer with a high nutritional content and a range of communities of microbes (Pathma and Sakthivel, 2013). Since vermicompost contains right amounts of nutrients copper, calcium, iron, manganese, zinc, potassium, magnesium and phosphorus, it is a high-quality manure that supports the growth and enhanced quality of crops. The chemical, biological and physical qualities of the soil are enhanced by the use of vermicompost. The soil is now more porous and permeable to both dirt and water due to altered soil structure. Vermicompost is rich in nutrients that promote healthy plant growth and development, including amino acids, vitamins, enzymes, antibiotics and hormones. Vermicompost provides plants with a balanced diet and increases their resilience to insects, diseases and pests. Vermicompost increases the soil's ability to hold water, lowering watering requirements. The price of expensive chemical fertilizer inputs is also reduced, cutting the overall cost of production. Vermicompost can be made using a number of weeds that are harmful to crops, such as *Ageratum*, *Eupatorium*, *Parthenium* and *Lantana* (Kumar *et al.*, 2018).

Sustainability through Vermicompost

Sustainable agriculture aims to develop and protect soil while also maintaining the natural world and our resources. Vermiculture techniques may reduce the demand on fossil fuels, repair degraded soils, handle the world's waste issues and keep costs down (Hussaini, 2013). In order to perform sustainable agriculture, one must utilise innovative techniques developed by farmers and agricultural scientists as well as draw on their traditional knowledge and methods, putting what was useful and timely into physical activity. A number of requirements for fully sustainable agriculture would be achieved by the employment of vermiculture methods and vermicomposting. A sustainable agricultural production system necessitates the augmentation of crop quantity and stability for future needs, encompassing the conservation of biotopes (crop diversity), safeguarding air, soil and water quality within the ecosystem of farms, protecting the biodiversity of animals, plants and other organisms, conserving the groundwater table, ensuring the well-being of everyone and reducing water and energy consumption. A variety of microorganisms found in vermicompost can increase the soil's ability to retain moisture, lowering the requirement of irrigation water. Additionally, sustainable agricultural practices can enhance the chemical, physical and biological characteristics of soil. Efficient planning for sustainable agriculture holds the promise of delivering economic prosperity for farmers, ecological stability for farms, and security of food for the population. To address this, initiating a "Vermiculture Revolution" based on earthworms becomes imperative. Leveraging the biological activity of earthworms ensures environmental sustainability and economic viability for the well-being of future generations. Economic, environmental and social improvements, as well as how they interact, are the foundation of sustainable development.

Good Agricultural Practices (GAP) for Sustainable Agriculture

Good Agricultural Practices (GAPs) represent a voluntary standardized system designed to promote sustainability and equity, particularly for small-scale farmers. These technologies are used in the efficient cultivation of crops (Mausch *et al.*, 2006). Integrated crop, pests and nutrient management are examples of GAPs used in commercial agricultural production (Akkaya *et al.*, 2005). GAPs enable on-farm production and post-harvest procedures to be socially, economically and environmentally sustainable, ultimately yielding nutritious and secure agricultural products, encompassing both non-food and food items (Akkaya *et al.*, 2005). GAPs include a variety of component technologies, including those that support social acceptability, financial feasibility, environmental sustainability, food quality and safety. GAPs should be viewed as a set of numerous good crop practices from which farmers can select those that are suitable to their specific farming location (Mkanthama, 2013). The ultimate purpose of GAPs is to create more wholesome, environmentally friendly and economically viable agricultural goods while maintaining the workforce's

economic viability and safety.

Benefits of Good Agricultural Practices

GAPs provide advantages to three groups; farmers and their families make up the first category which will eat nutritious and safe meals. The consumers make up the second group which will receive better-quality, healthier food that has been produced sustainably. The general public makes up the final category. An improved environment will be enjoyed by them (FAO, 2004). GAP technologies were created with the recognition that they are widely acknowledged as the most efficient methods for proper water and soil management, as well as for the cultivation of crops and livestock. This technology lowers production costs, enhances crop-growing techniques and decreases waste.

Adoption of these excellent agricultural practices is required in the current farming scenario. Crop rotation, sowing crops at the proper time and with the proper geometry, good quality organic and green manure crops, summer ploughing, utilizing disease and pest-resistant varieties, along with the use of Indigenous technical knowledge (ITK) are some of the techniques. Some of them are discussed below.

Summer Ploughing

Implementing deep summer ploughing contributes to enhanced water infiltration and reduced unproductive surface water evaporation in watersheds, promoting the development of soil structure and accumulation of soil organic matter. Moreover, it also kills dormant and resting stages of insect pests and reduces pest load in subsequent seasons.

Crop Rotation

Crop rotation improves soil organic matter and also improves and maintains the soil fertility. The removal of weed, pest and disease infestations is another benefit of crop rotation. To create more sustainable agricultural systems, diverse rotations are essential (Schonhart *et al.*, 2011).

Restoring Waterbodies or Wetlands

Avoid irrigation water runoff and implement water conservation strategies like wetlands and recycling. Improve the way the water cycle works to store more moisture in the soil and reduce water and associated harmful runoff.

Integrated Pest Management (IPM)

For efficient pest management, keeping track of the equilibrium state between pests, diseases and beneficial organisms in all crops on a regular and quantitative basis is critical. Mostly preventive approaches are used as alternatives to therapeutic practises for managing pests and diseases in organic farming (Haldhar *et al.*, 2017). Following certain procedures can help reduce insect pest occurrence and population. A thorough examination of basic characteristics, such as plant shape, size, colour and leaf hairs, as well as natural chemicals (both repellents and attractants) that influence the outcome of insect crop invasion, is necessary for farmers to select cultivars or types. The disease incidence has decreased with the use of resistant cultivars. Maintain a clean environment around fields and

greenhouses. Select the best planting season to avoid peak pest population. Yellow sticky traps are recommended for greenhouse whitefly management, as they serve as effective tools for monitoring and controlling the population. Most pheromone traps attract males, providing early indications of potential pest issues. Additionally, females may be more effective than traps at luring males to the region when they are present.

Use of Good Quality Organic Manure

One of the most widely utilised manures, cow dung, urine and slurry from biogas plants, as well as sheep, chicken and goat droppings, are extremely rich in potassium, phosphate and nitrogen. Following the harvest of the primary crop, several crops, primarily legumes, are grown as green manures. The soil surface surrounding the plants is covered with mulch to create growth-promoting conditions. This might entail regulating the temperature, lowering the salinity and controlling weeds (Kumar and Lal, 2012).

Livestock Health

Reduce the danger of infection and disease by maintaining clean bedding in housing conditions and good pasture management. Consult a veterinarian when needed for advice to prevent illness and health issues. By thoroughly cleaning and disinfecting the housing, keeping an eye on disease occurrence and providing sick or injured animals with the appropriate care in cooperation with a veterinarian, one can ensure good hygiene conditions.

Indigenous Technical Knowledge (ITK)

For those who developed the indigenous technical knowledge (ITK) systems that involve environmental management, it has always been a matter of survival (George *et al.*, 2000). The ITKs can be widely categorised into three groups: (a) Cultural practises that helps to eradicate pests; (b) Mechanical and physical methods like yellow and blue sticky traps are employed (Bissdorf, 2008); and (c) Utilizing organic ingredients, such as Aloe vitex extract for controlling hairy caterpillar, armyworm, semi looper, rice stem borer and addressing bacterial and fungal diseases, as well as using coriander (*Coriandrum sativum*) for controlling spider mites.

Conclusion

The transformation in agricultural technology must transition from a focus on production to a one-centred around profitability in order to adapt to the evolving dynamics of the agricultural sector. Although the rate of resource-conserving technologies (RCTs) adoption by Indian farmers is encouraging in this regard, conservation agriculture is still only 50% developed at the present time. The conservation of agricultural systems that will result in sustainable farming will be the most important component of farming in the future. The environment is improving rapidly for the growth of sustainable agriculture. Farmers, development professionals, researchers and policymakers are becoming more aware of new prospects. In addition to serving their present economic interests, they growing recognise the potential and significance of these practices

as the foundation of ecological sustainability and further intensification.

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