Int. J. Agriworld, Vol. 4[1] January 2023
©2020 SVPSS, India
Online ISSN: 2582-7537
Journal's URL:http://www.svpss.in/ijaw

DOI: https://doi.org/10.51470/IJAW.2023.04.01.26

Received 28.12.2022 Revised 15.01.2023 Accepted 20.01.2023

REVIEW ARTICLE **OPEN ACCESS**

Sustainability in Agriculture and Its Impact on Mankind

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Abstract

Agricultural systems globally are encountering significant obstacles due to a surge in food demand caused by population growth, escalating hunger and malnutrition rates, adverse impacts of climate change, excessive exploitation of natural resources, declining biodiversity, and the issue of wasted food. These difficulties could compromise the ability of the planet to satisfy current and future nutritional requirements. Stated differently, less people have sufficient access to sufficiently healthy food. Sustainable agriculture aims to harness natural resources in a manner that allows them to replenish their productivity while minimizing adverse effects on ecosystems beyond the immediate field. One approach that farmers use in their pursuit of these ends is to think about ways to make the most of what nature already has going on, or to build their farming systems such that they incorporate important ecological services. Establishing biologically-integrated agricultural ecosystems which depend heavily on endogenous nutrition cycle and energy cycles can frequently result in an economically feasible manufacturing system with minimal potentially hazardous interventions. In simpler terms, sustainable agriculture can make the best use of non-renewable resources, satisfying human food and fibre demands while also improving the quality of the environment. It will improve the standard of living for farmers as well as society as a whole.

Keywords: Sustainability, Agricultural management, food security, smart farming, water management

Introduction

Our agricultural systems are constantly being challenged by the rising need for food due to population growth, the negative impacts of climate change, the over use of natural resources, as well as the loss of biodiversity. These difficulties have the potential to weaken the capacity of the world to fulfill its current and future food requirements. Simply stated, a smaller number of individuals possess sufficient access to an ample supply of nourishing sustenance (Jaman *et al.,* 2022). Sustainable agriculture refers to the generation of agricultural products by controlled use of natural resources and to minimize harmful impacts on ecosystems (Munonye and Eze 2022). Farmers aim to achieve these objectives by strategically leveraging existing natural processes and integrating essential functions of natural ecosystems into their farming systems. By creating agro-ecosystems that are biologically integrated and rely on endogenous nutrient and energy cycles, it is frequently feasible to sustain an economically viable manufacturing system with reduced reliance on potentially harmful interventions (Agarwal and Kumar, 2020; Jaman *et al.*, 2022; Das *et al.,* 2022). For instance, farmers who desire to achieve a greater degree of environmental sustainability may contemplate methods to diminish their reliance on harmful pesticides by using natural mechanisms to control pest populations. Sustainable agriculture has the potential to optimize the utilization of finite resources, thereby meeting human demands for food and fiber while simultaneously improving environmental conditions. It will improve the overall well-being of farmers and society. When the natural resources are highly challenged due to unplanned agriculture and food production, the ability of future generations will be under threat to flourish them. The demise of ancient civilizations in the Mediterranean area, Mesopotamia, Pre-Columbian southwest U.S., and Central America is attributed to natural resource deterioration caused by non-sustainable agricultural and forestry methods. So, a series of practices should be implemented to utilize our natural resources in a sustainable way and to bring a healthy living atmosphere for future generation. The farmers must consider strategies to exploit existing natural processes and integrate essential functions of natural ecosystems into their agricultural systems in order to achieve these objectives. The following steps should be followed to reach sustainability in agriculture.

Crop Rotation:

Crop rotation is an essential agricultural technique that entails the cultivation of various crops in a sequential manner on a shared plot of land. Crop rotation, which is implemented to improve soil fertility, increase yields and manage pests and diseases, is defined by the gradual switching of the crops that are cultivated in a field (Shah *et al.,* 2021). Crop rotation is a method that may be used to maintain soil health and productivity, enhance soil nutrient levels, and disrupt the presence of pests and diseases. Crop rotation systems maintain a harmonious equilibrium between soil fertility and health, ensuring sustained productivity over the long term. They combat water shortages and promote efficient water management through water conservation. We should investigate the advantages of crop rotation.

Soil Health:

Crop rotation maintains the soil health by time to time farming the local crops. Without sacrificing crop output, crop rotations can be assigned to suitable landscape units according to soil characteristics and slope to greatly minimize nutrient and sediment loss (Jiang *et al.,* 2021). The practice of crop rotation plays a crucial role in preserving soil fertility and structure, hence facilitating the proliferation of advantageous microbes like nitrogen fixing bacteria, phosphate solubilizing bacteria, mycorrhizal fungi etc. These microorganisms possess the ability to outcompete or impede the proliferation of detrimental diseases inside the soil and enhance plant immunity through alteration of plant metabolisms (Nadarajah and Abdul Rahman, 2021). Different crops have distinct root systems and necessitate varying quantities of nutrients. This reduces nutrient loss, soil erosion, enhances nutrient cycling, enhances soil structure and microbial activity, and reduces the accumulation of parasites and maladies associated with specific crops. In relation to water, the implementation of crop rotation has the potential to enhance both soil water content and crop water efficiency through the incorporation of water-retaining crops within the cropping system (Yu *et al.,* 2022). These variables collectively lead to the improvement of soil health and productivity. Farmers can boost soil stability by altering the root systems and canopy heights of their crops, instead of persistently cultivating the same crop which can lead to soil erosion due to weak root systems. As for example, if farmers can farm crops with deep passing roots, that can hold the soil well decreasing chance of erosion brought on by wind or water (Das *et al.,* 2022). Different crops needs different amount of nutrients. If same type of crops are being cultivated throughout the year that can quickly deplete the nutrient levels in the soil. The Nutrient shortages and imbalances may be overcome by alternating nutrient-demanding crops with ones with different nutritional needs. If leguminous plants are cultivated that can fix atmospheric nitrogen which replenish the soil and avoiding the need for artificial nitrogen fertilizers. Similarly root exudates of few plants can enrich soil through solubilisation of phosphorus (Mazumder and Sarkar, 2019).

Pest Control

Agricultural fields suffer significant damage from many pests, such as pathogens and weeds. Weeds can impart negative influence to growth and development of crop (Sarkar *et al.,* 2017; Das *et al.,* 2018). Rotating specific crops can effectively inhibit the growth of weeds. Cover crops such as legumes can be employed in rotation to suppress weeds and enhance soil structure, resulting in enhanced crop productivity by reducing resource competition. Crop rotation can smartly manage diseases and pests in agricultural settings. The life cycles of pests and pathogen break down due to crop rotation (Zohry and Ouda 2018). The cultivation of diverse crops disrupts the life cycle of numerous plant diseases, as these organisms frequently depend on a particular host plant for their survival and reproductive success. By implementing crop rotation, the essential conditions for their flourishing are deprived. Crop rotation also discourages weeds that decrease soil nutrients and it strengthens crops, increasing their resistance to pest and disease attacks by controlling nutrient levels and preventing nutrient shortages. Crops rotation creates the suitable environment for helpful insects, predators, and microorganisms that naturally manage pests and breaks up the life cycles of diseases and pests, which lowers their populations.

Yield Improvement

Implementing a strategy of rotating a larger variety of crop species in a certain order is a highly effective method to mitigate the adverse effects of agricultural production on the environment and sustain high crop yields (Tariq *et al.*, 2019). Different crops draw upon different nutrient profiles, leaving behind residues that replenish the soil. It also prevents nutrient depletion and enhances soil fertility, soil health, nutrient availability. It optimizes pest control, disease pressure and microbial activity which collectively improve the crop productivity and leads to higher yields.

Cost Saving

Crop rotation practice can effectively reduce the production and maintenance cost of agricultural land (Smith *et al.,* 2017; Feng *et al.,* 2021). Crop rotation reduces pest and weeds growth by breaking their life cycle. Decrease the cost of chemical pesticides and herbicides. Crop rotation increases soil fertility, enhancing nutrient cycling and adding nitrogen-fixing legumes decreasing synthetic fertilizers dependency. In this way, farmers can save money.

Environmental Benefits

Crop rotation encourages biodiversity as it protects natural ecosystems, promotes preservation of soil, water, and wildlife habitats. It mitigates greenhouse gas emissions by improving nutrient cycling, promoting soil health, and augmenting the organic matter content in the soil. It will protect our environment by minimizing the use of synthetic fertilizers, lessens the emissions of nitrous oxide, a strong greenhouse gas.

Crop Management

Effective crop management strategies can enhance agricultural production and lead to higher crop quality and yields. Crop management refers to the implementation of agricultural techniques aimed at enhancing the growth and advancement of crops. The process begins with the preparation of the seedbed, followed by the planting of seeds, the care of the crop, the harvesting of the crop, and finally the storage and sale of the harvested produce. Proper seedbed preparation is a crucial step in enhancing crop growth and development. The ideal seedbed is uniformly firm which is enriched with adequate soil moisture, and the competing weeds should be removed near the surface. "Good seed-to-soil contact required" is a phrase frequently observed on seeding documents. Seed germination is very important step in the crop management. For best results, seeds density in a given area of land must be optimum otherwise it is challenging to get the seed into the ground. The seedbed is typically prepared using either the standard tillage approach or the reduced or no-tillage method. In the traditional conventional tillage method, deep plowing is done (20cm) to expose large quantities of soil organic matter for aerial oxidation. In the reduced or no-tillage practices, the soil organic matters re left for long time which slowly decomposed in the nature to benefit soil health and improve crop yields.

Cover Crops

Cover crops are often cultivated to safeguard and enhance the quality of soil (Chetan *et al.*, 2022). Unprotected soils are susceptible to degradation from rain, wind, and sun, which can harm both the soil itself and its value ecosystems. Some common examples of cover crops include ryegrass, sorghum, millet, oats, barley, red clover, and white clover. Cover crops improve soil health, inhibit weed development, boost soil's water retention capacity, and mitigate soil erosion during non-growing seasons. Several studies suggest that cover crops have a beneficial effect on soil water content by decreasing runoff and enhancing infiltration and the ability of the soil to store water. Cover crops are sown in a sequence with other crops, which might result in higher crop production and offer a suitable environment for advantageous predatory insects. Utilizing cover crops can enhance nitrogen accessibility in the uppermost layer of soil, hence enhancing soil fertility and diminishing total expenses on fertilizers (Cordeiro *et al.*, 2019). Another well-documented advantage of crop rotations that involve maintaining soil cover throughout the year is the capacity to trap and retain both residual nitrogen and freshly mineralized nitrogen.

Smart Water Management

The collection, treatment, distribution, and recycling of water are all components of a smart water system. The unplanned use of water, which is a renewable resource, is a threat as a result of the growing population. The agricultural sectors are also constantly challenged to provide nutritious cuisines as a result of the daily scarcity of fresh water. Agriculture is being impacted by the ongoing climate change, which is resulting in temperature increases, changes in precipitation patterns and snow cover, and a probable increase in the frequency of droughts and floods (Sarkar, 2015). One estimate is that agricultural production must be doubled by 2050. Although 75% of the earth's surface is covered in water, only a small percentage (3%) is classified as freshwater. Forests and croplands are dependent on freshwater. It is imperative that water resources are utilized effectively to attain social, environmental, and economic benefits, as up to 80% of freshwater is consumed for agricultural purposes. With the return of approximately 60% of precipitation to the oceans, the availability of freshwater is being strained by the growing population and diets.

Implementation of the most effective irrigation strategies. In order to optimize water utilization, it is imperative to implement appropriate technological, resource, and application management strategies amid a diminishing irrigation supply. Sustainable water management in agriculture can be accomplished through the following methods

- Water loss management
- Installation of efficient irrigation systems (Drip irrigation, capturing & storing water, irrigation scheduling)
- Adoption of innovative irrigation methods (hydrophonic, vertical farming)
- Reuse of insignificant waters (saline water, wastewater, and runoff water) for agricultural purposes

Plants require water for food preparation. Adequate fresh water supply provides proper plant growth which is good for us.

Nutrient Management

Soil sustainability is the long-term preservation of soil fertility and productivity, which in turn improves crop production over time. In order to enhance soil nitrates, legumes (Grain/forage) absorb atmospheric nitrogen gas, which is subsequently deposited as nitrates in their leaves, roots, and nodules. Consequently, they possess considerable potential to sustainably enhance soil fertility and productivity (Cherr *et al.*, 2006). The legumes have a positive impact on the production of subsequent crops in the rotation and the sustainability of the soil, as they increase the nitrogen and organic content of the soil (Dhakal *et al.*, 2016). Forage legumes, including Stylosanthes, Crotalaria, Sesbania, and Desmodium, can be employed to mitigate soil erosion due to their soil-covering growth behaviours (Singh *et al.*, 2018). Additionally, forage legumes, such as Stylosanthes hamata, can be employed to improve compacted soil (Lesturguez *et al.*, 2004). The production of legumes in a pasture involves minimal disturbance of the topsoil, which leads to a reduced rate of erosion and the accumulation of soil organic carbon and humus over time.

Biofertilizers can be an extremely effective approach to sustainable agriculture. They are employed to directly supply nutrients to cereal plants. Biofertilizers are predominantly composed of microorganisms, including bacteria, fungi, and blue green algae. The rhizosphere of the plant is supplemented with these organisms to improve their activity in the soil. They indirectly assist the plants by enhancing the availability of nutrients in the soil or by facilitating the efficient fixation of nitrogen. Their mode of action is distinct and can be implemented independently or in conjunction. It has been determined through systematic research that efficient cultures are capable of flourishing in specific soil and climatic conditions. These cultures are produced on a large scale in laboratories and subsequently distributed to producers. For optimal plant growth, a balanced and adequate supply of nutrients is necessary. However, only a small portion of these nutrients are released annually from the soil through biological and chemical processes. Consequently, fertilizers are employed to augment the nutrients that are already present in the soil (Chen, 2006). The microbial processes, including the control of soil-borne maladies, the improvement of soil health, and the enhancement of soil properties, are significantly influenced by microorganisms from bio-fertilizers. Bio-fertilizers are a cost-effective solution for modest producers to enhance crop productivity. These are renewable, cost-effective, and low-cost sources of plant nutrients that can be used to supplement chemical fertilizers.

Bio-Pesticide

Bio-pesticides are certain types of pesticides isolated from some natural materials such as animals, plants, bacteria and certain minerals and are used to control agricultural pests and pathogens. Commercially, bio-pesticides include microorganisms that control pests (microbial pesticides), naturally occurring substances (biochemical pesticides), and pesticidal substances derived from plants containing added genetic material (plant incorporated protectants). Recent registered global bio-pesticide products include bacteria (104 products, mostly are *B. thuringiensis*), fungi (12 products), viruses (8 products), nematodes (44 products), protozoa (6 products), and arthropod natural enemies (107 products) (Waage, 1996). These are used in agriculture for the purposes of insect control, disease control, nematode control, etc. Bio-pesticides are usually inherently less toxic than conventional pesticides.

Types of Bio-Pesticides

Bio-pesticides are specific categories of pesticides derived from natural sources such as animals, plants, microbes, and minerals. They are utilized to manage agricultural pests and infections. Bio-pesticides encompass microorganisms that regulate pests (microbial pesticides), naturally occurring compounds (biochemical pesticides), and pesticidal substances originating from genetically modified plants (plant integrated protectants). The most recent biopesticide products that have been registered globally consist of bacteria (104 items, predominantly *B. thuringiensis*), fungus (12 products), viruses (8 products), nematodes (44 products), protozoa (6 products), and arthropod natural enemies (107 products) (Waage, 1996). These are employed in agriculture for the purposes of insecticide, fungicide, nematicide, etc. Bio-pesticides often possess lower toxicity compared to conventional pesticides.

***Bacillus thuringiensis* (Bt)**

Varieties Bacterium *B. thuringiensis* (Bt) are the most widely used microbial pesticides that are capable of controlling large number of insects in different crops. Bacterium *B. thuringiensis* can kill specific insect pests by encoding a specific protein. *B. thuringiensis* is a rod-shaped, Gram-positive bacterium that can kill insect larvae in order Lepidoptera, Diptera, and *Coleoptera Homoptera*, Orthoptera, Hymenoptera, Mallophaga, and nematode, mites, protozoa by encodes large number of toxic crystal proteins like Cryprotein, δ-endotoxin, or insecticidal crystal protein (ICP) (Lacey and Goettel, 1995).

Fungi

Fungi have significant role as bio-pesticide in controlling plant disease as weeds. Fungi are a very common member in almost every environment on earth and known for their diverse nature. Most common commercial bio-pesticides are *Trichoderma species* and *Beauveria bassiana*. *Trichoderma harzianum* and *Purpureocillium lilacinum* are known to control fungal plant pathogens and plant-parasitic nematodes, respectively (Agosin and Aguilera, 1998). These species can naturally kill pests at high rates. Entomo-pathogenic fungi specifically attack target pests in crop production and causes little harm to beneficial organisms, including pollinators which is rare for many chemical insecticides.

Baculovirus

Baculoviruses are found in arthropods mainly in insects. These highly pathogenic viruses have been used effectively against various potential insect pests in their native form as biocontrol agents (Popham *et al.*, 2016). Inspite of this, this type of baculoviruses are very less exploding in the field of agriculture and horticulture.

Plant-Derived Insecticides

Plants derived natural compounds have been playing a crucial role in developing defensive wall from insect pests since ancient times. Plants and some insects are living together for almost 3.5 million years on the earth. Their coexistence has allowed them lots of time to develop strategies for offensive and defensive work. Plants have adopted several techniques to protect them from predators; as for example, they have developed many compounds in the form of dust or powder of crude preparations which are highly toxic in nature. These compounds are either water soluble or organic solvent soluble extract of insecticidal components of plants. Many chemicals have shown repellent, antifeedant effects like Azadirachtin affects the physiological activities of insects.

Neem

More than 2400 plant species are conferring pest-control effects throughout the world. It is observed that few plant-derived compounds like neem, onion, black pepper, sweet flag, custard apple, garlic, holy basil, pyrethrum, derris, common lantana and common ginger show important insecticidal properties in theirs seeds or seed kernels (Sarkar *et al.*, 2018). Several study report reveals that neem shows exceptional impact on the immature and very soft-bodied stages of plant pests like mealybugs, thrips, whiteflies, and various caterpillars (Weinzierl, 1998). Neem has proven itself as extremely attractive insecticide in the green farming area due to its selective activity against plant pests without damaging mammals.

Biochemical Pesticides

Biochemical pesticides have large similarities with the conventional chemical pesticides. Conventional pesticides are synthetic molecules which are used to destroy the pests by their cell toxication. Biochemical pesticides are the substances which are plant growth regulators like pheromones that repel or attract pests and interfere with the growth or mating of insect pest. It is found that pheromones can interfere insect mating and destroy their life (Suckling and Karg, 1998). The Biochemical pesticides are based on naturally occurring mixture consists of a plant essential oil, or it may contain a mixture of isomers molecules in the case of insect pheromones.

Technology in Agriculture

Application of modern biotechnological tools in agricultural fields has accelerated the sustainable agricultural productivity which ensures world's food security, increasing food quality and reducing poverty. Biotechnological tools have huge contribution on fulfilling desired nutritional requirements of increasing population by enhancing agricultural production (Sharma *et al.*, 2010). The crop and livestock production can be improved to reach the growing demands of the consumer within economic, environmental, and ethical restrictions of society by using these tools. Among different biotechnological tools, genetic engineering and genomics are playing a major role in agricultural sustainability. These tools can efficiently improve and reach to our specific target by precisely characterizing genetic resources (Steinwand and Ronald, 2020). These tools manage the agricultural production by controlled utilization of the environmental recourses with least environmental damages. Biotechnological tools not only improve the number of a species of crop varieties but also enhance the propagation of endangered species and enrich the current levels of biodiversity and genetic diversity (Abdullah et al., 2011). Utilizing genetic engineering or recombinant DNA techniques, specific genes should be identified, isolated, and altered which can be reintroduction into living cells to produce new varieties of crops and overcome the traditional difficulties, enhancing the food, fiber, and other agricultural product productions.

Genetic engineering can also be used along with other technologies in agriculture in a variety of ways, including:

- Higher crop productivity
- Herbicide, Insect and virus Resistance
- Delayed Fruit Ripening
- Frost Resistance
- Decreased use of water, fertilizer, and pesticides, which lowers food prices
- Reduced impact on natural ecosystems
- Less runoff of chemicals into rivers and groundwater
- Increased worker safety
- Hydrophonic, Aerophonic, farming under artificial light.

Conclusion

According to the trends, as we are moving faster, the global population will reach approximately 9 billion by 2050. The farmers around the world will be under high trouble to meet this growing demand to supply more protein-rich diets to this huge population. The global gross farm yield jumped by an average of 2% each year, mainly due to the target oriented investments in research and technology which driven to Green Revolution in between 1970 and 1990. We have to secure food of all people to have physical and economic access to sufficient safe and nutritious food which will meet their dietary needs and preferences for their healthy life. Since 1990, aggregate farm yield growth is not satisfactory. The food production rate is not balanced with population growth. May be due to old farming techniques as well as limitations in agricultural lands. May be due to the unplanned utilization of natural resources by huge population. Our basic goal is not only to produce food, but also to deliver quality food and to cut the cost to bring it within purchase limit of all classes. So, sustainable agriculture is the only route opened which enables skillful utilization of environmental resources and fulfills the nutritional requirements of all economic status. Up gradation of farming strategies, by replacing local seeds with certified seeds, use of crop specified nutrients, installation of smart irrigation system and plant safety measures will enhance the crop yields. The impact on crop yields due to constantly changing climate condition will also be overcome by implementing sustainable agricultural strategies.

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CITATION OF THIS ARTICLE

Samanta, S. (2023). Sustainability in agriculture and its impact on mankind, *Int. J. Agriworld*, 4 [1]: 26-33.