SUSTAINABLE AGRICULTURE PRACTICE: A REVIEW OF EMERGING POLICIES AND PRACTICES IN INDIA

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Abstract
Sustainable agriculture is argued to significantly contribute to national growth by ensuring long-term food security, promoting economic stability, and preserving environmental health by adopting practices such as crop diversification, bio-intensive integrated pest management, agroforestry, organic farming, precision agriculture, crop rotation, cover crops, rotational grazing and inclusion of locally adapted breeds & resistant variety, lower tillage, and chemical inputs. The transition from traditional to sustainable agriculture requires a systematic approach involving work at both micro and macro level. Most of the government policies related to agriculture are made at agroecosystem level (macro level) and fail to cover the individual farm level (micro level). Studying the farm in relation to the agroclimatic zone in which it is located can help increase productivity with limited resources. In India, nearly half of the labour force is engaged in agriculture and allied sectors and a large section of them are small and marginal farmers having resource constraint. It is pertinent to explore sustainability of the farm practices of these farmers and its impact on social economic and environment aspects. This paper discusses the different sustainable farming practices that have been practiced since ages. The paper also throws light on the importance of developing the right integration of select best practices for optimal results. An effort has also been made to discuss the importance of agriculture sustainability index using soci-economic and ecological dimensions, for deciding the sustainability mix suited to different farms.

Keywords – Sustainable Agriculture, Organic Farming, Vermicomposting, Integrated Pest Management, Agroforestry, Agriculture Sustainability Index.

Introduction

Climate change is argued to be one of the most important problems needing immediate attention (FAO, 2022). With almost one-third of total global emissions coming from agriculture, there is a need to find more sustainable alternatives to conventional farming (World Bank, 2024). While on one hand agriculture is contributing to climate change, it is also being adversely affected by the vagaries of climate change (EPA, 2024). The significant increase in carbon emission level globally can influence the global economy via the effects on the agriculture's total production rate (Avgoustaki & Xydis, 2020). Although green revolution launched under the leadership of Prof. M.S. Swaminathan, popularly known as the Father of India's Green Revolution, is credited with saving millions of people from starvation by enhancing productivity and production of wheat and rice crops during the 1960s-70s (Pathak, 2023). But at what cost? To fulfil the objective of self-sufficiency in food, farmers were encouraged to increase their yield. Most of the practices followed under green revolution including adoption of high yielding seeds for cereals, increase in farming area, planting two crops in rotation annually, heavy usage of chemical fertilisers & pesticides causing leaching of the groundwater and advanced mechanised farming & irrigation practice contributed to climate change (Shanmugavel, 2023). Indian government's schemes aligning with green revolution like MSP also favoured high yield. This incentivised farmers to employ artificial measures to maximise their yield from small land holdings. The external inorganic inputs interfered with the natural internal recycling of nutrients and the excess amount of unused fertilisers and pesticides resulted in toxicity and pollution of ground water. Two food crops grown in rotation in a year resulted in depletion of natural resources and groundwater because of high irrigation & nutrient demand. Although modern developments in agriculture have many benefits and help mitigate the impact of erratic climatic conditions and malnourishment, they come at a significant cost. Most prominent being soil erosion, emission of greenhouse gases, depletion & contamination of ground water, air pollution and loss of crop diversification exposing crops to pests and diseases. This damages the environment and contributes to climate change. Reversing this damage will require extensive efforts by all the stakeholders of agroecosystem. Farmers need to adopt farm practices which can help mitigate these effects like optimal and site-specific use of chemical pesticides & fertilisers, replacing inorganic inputs with organic inputs where feasible and use of drip or sprinkler irrigation, use of vermicompost and practicing organic cultivation & precision farming. In-spite of being highly dependent on environment, agriculture is the highest contributor to climate change with significant changes in climate caused by different factors, most prominent being the greenhouse gases (IUCN, 2020). Almost twenty five percent of total greenhouse gas emission is contributed by agriculture (John, 2021).

With the effects of unsustainable agriculture practice becoming more pronounced, the demand for switching to sustainable methods is growing. Much attention has been given to sustainable agriculture development off late by the researchers, government, and policy makers, accompanied with efforts to develop framework for measuring the sustainability construct for agriculture with clearly defined operational indices (Zhen & Routray, 2003). Sustainable development gained momentum with the publication of Brundtland Report in 1987, it called for a strategy that united development and the environment described by the now-common term sustainable development (ARE, 1987). Since then, agriculture sustainability has been widely discussed in the International Forum as a vital factor for achieving the sustainable development goal of United Nations (FAO, 2017). Sustainable development is an important goal and cannot be left to chance. Handling such crisis situations with immense impact needs robust and sustainable systems & policies (Rotondo, 2022). Present situation is alarming and calls for an immediate solution, before it becomes too big to handle. Agriculture is facing the challenge of ensuring food security for a growing global population without compromising environmental safety (Shanmugavel, 2023). Measures like timely harvesting, proper storage, seed banking, rotation of crops, and pest management can help mitigate this problem (Girardin, 2000). Government schemes rewarding farmers for employing environment friendly practices on farm like carbon farming and sequestration, improved nutrient & water management, efficient management of limited resources, soil management, integrated pest management, integrated nutrient management, agroforestry and precision agriculture can go a long way to achieve the goal of sustainable farming (IUCN, 2020). A robust sustainable agroecosystem can be built through diversity, co-creation & knowledge sharing, efficiency, human & social values, recycling and resilience (FAO, 2024). Diversity can be increased by introducing diverse variants of same crop species, mixed cropping & intercropping, crop rotation with nitrogen fixing plants and less demanding crops in terms of nutrient and water. Using more variant strains of same crop increases resistance to vagaries of climate change. Diversity in crops and livestock helps increase resilience against pest infestation and diseases. Co-creation of knowledge is very important as agriculture sustainability is a multidimensional concept and involves multiple stakeholders at multiple levels. Hence the different stakeholders and systems need to work in synergism. These practices are driven by culture and communities they have their roots deep rooted in our tradition and can be learnt from our age-old tradition. Resilience can be improved through a systems approach. According to this farming practices are affected both by those internal to farm and also by the environment or the ecosystem in which the farm is located. We cannot achieve sustainability by studying the farm in isolation. We need to study the farm in context of the environment and agroclimatic zone in which it is located. Landscape context and farm characteristics are key to farmers' adoption of agri-environmental schemes, an instrument of the European Union’s Common Agricultural Policy (CAP) to foster sustainable farming practices that contribute to the conservation of biodiversity, ecosystem services, climate change mitigation and adaptation (Paulus, 2022). Managing natural resources involves the sustainable use of land, water, air, minerals, forests, fisheries, and wildlife (Feng, 2023). Promoting internal recycling of nutrient can help reduce dependence on external inputs. Overuse of raw materials and employment of unsustainable practices, reduces the potential of agro- ecosystem to provide for the future generation. Natural resources have the capacity to regenerate but the process is slow. When natural resource is used properly, it goes longer and with time also regenerates. An agriculture ecosystem relying on internal cycling sustains better compared to that dependent on external input. Need for efficient use of nutrients like nitrogen and phosphate, proper management of soil, water & severe drought condition has proven very demanding on farmers. Toxicity and pollution of soil and water caused by chemical fertilizer and pesticides percolates to quality of yield leading to reduced farmer income (FAO, 2024). There is a call for replacing inorganic fertilisers & pesticides with more natural and organic options. This also helps cut down on the greenhouse gases and carbon footprint. Farm practices which can enhance soil structure nutrient and aeration can contribute to higher quality produce and increase resilience. External treatment with short term interest has led to incapacitating the internal cycling of nitrogen & phosphorus two of the most vital nutrients. This has economic repercussions as farmers are buying these nutrients from market at high cost, causing their input costs to increase. Conservation of soil structure & health like organic matter, minerals, air, water, and microbial organisms is equally important for sustainability. Organic particle in soil helps absorb carbon dioxide, maintains soil structure for better drainage & water absorption and acts as buffer against toxins and acidity. It is estimated that agriculture uses about 72% of freshwater and about 33% of land is degraded because of toxicity, acidification, salination & pollution of soil caused by synthetic chemicals used for enhancing the yield. Choice of crop in annual crop rotation and in mixed cropping is another important factor. Between 2000 to 2010 production of soybeans, livestock and palm oil alone accounted for almost 40% deforestation in the tropical region. Measures should be taken to ensure the heavy nutrient demanding crop should be grown with less demanding crop in annual rotation. This ensures that nutrient and water used by one crop is replenished in the second rotation. Nitrogen fixing crops are also very important to avoid dependence on external sources. Most of the forest has been cut to convert into arable land for cultivation. Forests are known to harbour over 60,000 different species of trees, 80% of the world's amphibian species, 75% of bird species and 68% of mammal species (FAO, 2023). They are known to absorb huge amount of carbon dioxide. Cutting of forest has resulted in a loss of all these benefits. Emissions from agriculture ecosystems was estimated to be 16 billion tonnes of carbon dioxide in 2020, an increase of 9% from 2000 (FAO, 2023). With growing demand for agri-products, the pressure is increasing on agriculture to meet the demand of the growing population, however conventional practices have not been able to meet this demand (Setsoafia, 2022). Meeting the ever-increasing demand with more aggressive agriculture practices can increase the pressure on the planet further worsening the condition. More intensive conventional farming practices need to be replaced with more sustainable practices. Unlike developed countries in developing countries, sustainable agriculture emphasises majorly on preservation of natural resources (Zhen & Routray, 2003). Sustainable agriculture is far from mainstream in India, it has been recorded that less than five million (4%) farmers are practicing sustainable agriculture (Niti Gupta, 2021). Traditional farming practices have been known to employ unsustainable practices causing degradation of the environment and soil structure. In-spite of government's efforts to shift the farmers to sustainable practice, conversion rate has been very low. Some of the reasons acting as hurdles in the way are lack of information and relevant knowledge about sustainable practices, support from government, funding, awareness and understanding of technology and social barriers. Economic factors like cost of input, marginal returns, risk implications, risk of loss of productivity, access to credit and appropriate inputs and increased labour requirement have been mentioned in literature as barriers to the adoption of sustainable farming (Rakholia, 2024). Achieving sustainability in agriculture is vital for the growth of developing countries like India (Mukherjee, 2020). Gap assessment and the reasons for this gap can help in understanding the present situation better. Use of quantitative analysis for understanding where we are lacking can be useful in developing policies and measures to fill the gap. There is a need to develop a sustainability index with well-defined operational indices for measuring the sustainability of the most prevalent farming practices in India (Wirén-Lehr, 2001). Although researchers have not arrived at any consensus about sustainability construct, there is agreement that sustainable development involves a comprehensive and integrated approach to economic, social, and environmental processes (Sathaye, 2007). This is typically realised as the balancing of trade-offs between seemingly equally desirable goals within these three categorisations, although uses vary

(Purvis, 2019). Researchers and policy makers can use this model to develop a sustainability index with clearly defined measurable and quantifiable operational indicators.

Some of the current best practices in sustainable agriculture

Although in nascent stage sustainable agriculture practices are prevalent and successfully implemented world over. Some practices are more widely used as they have developed as a methodological approach over a period of time because they have been given high priority on policy agenda from the beginning (Muhie S. H., 2022). Some of these prominent approaches include organic farming, vermicomposting, agroforestry, precision farming, and integrated pest management. Established through ages these practices have proven their effectiveness in promoting agricultural sustainability.

Organic Farming (OF)

According to the definition given by the United States Department of Agriculture (USDA), organic farming (OF) refers to a system which avoids and largely excludes the use of artificial inputs like fertilizers, pesticides, hormones, feed additives and depends on crop rotation, crop residue, animal manure, off-farm organic waste, mineral-grade rock additives & biological systems of nutrient mobilization, ensuring plant protection optimally (Gamage, et al., 2023). OF promotes sustainable farming through soil & water management, ecological balance and recycling of limited nutrients & resources. Usage of more organic matters in agricultural practices can reduce the adverse effect on the environment by saving its natural cycles on recovery process and organic farming may enhance the food quality too (Gamage, et al., 2023). The objective is to create a self-sufficient system with increased internal recycling of farm-derived resources and minimum dependence on external inorganic inputs. Such systems are also more resilient. Growing awareness about the toxic impact of artificial fertilisers and pesticides on plant and human health has led to the growing consciousness towards “return to nature” lifestyle. Organic farming could prove to be the panacea, with its emphasis on internal recycling. Although growth in the size of land and market coupled with increased farmer’s awareness of the ill-effects of inorganic cultivation has led to an increase in farmer readiness to adopt organic farming, compared to the number of countries that have adopted organic farming India lags behind with organic cultivation having only 1.5 percent share of total agricultural land (Muhie S. H., 2022). The size of land under organic cultivation is highest in Australia with 35.7 m ha, followed by Argentina with 3.6 m ha and China with 3.1 m ha (Mahanta, 2021). With organic food contributing 1% - 2% of food sales world over and an average projected growth of 10% to 50% annually, there is a need for regulatory framework and policies favouring the cultivation of organic crops (Mahanta, 2021). It is an efficient practice as it scores high on all three dimensions viz. environment, economic and social, thus fulfilling the triple bottom-line validation (Elkington, 2004). It is an example of a self-sustaining system because of its dependence on internal recycling of resources and farm waste. The emphasis is on maintaining the natural ecological structure by using farm produced organic fertilizers coupled with high quality produce. Organic farming has been a part of our agriculture since the earlier times when artificial fertilisers were not required, it was changed during the green revolution emphasising on enhanced productivity and self-sufficiency of food, with government providing MSP cover to foodgrain crops and promoting high volumes and large farms, farmers shifted to artificial input for increasing their productivity to get maximum benefit from policies favouring green revolution. The inorganic practices employed by farmers led to soil pollution, reduced fertility, decrease in biodiversity, and lower food quality. Hence need was felt to revert to the age-old organic practice. Organic farming aims to increase productivity while establishing ecological balance. It is a proactive approach to problems created by inorganic practices. Farmers use organically produced manures, composts and Nitrogen fixing crops (Nielsen, 2019). With the growing demand for restoring the ecology which otherwise would not be able to sustain the needs of the future generation, environment and health-conscious customers are demanding organic products leading to an increase in opportunity for both land under cultivation of organic crops and market for organic food (Srutek, 2008). According to FAO this practice works on four principles – health, ecology, fairness and care (CEEW, 2021). Health indicates promoting the health of soil, crops, human, and animal. Ecology is about maintaining the ecological balance by developing a system similar to natural ecological system and recycling. Principle of fairness means organic agriculture should promote fairness in environment. Principle of care indicates that care should be taken while practicing organic farming to prevent environmental damage.

Organic cultivation makes use of organic waste like crop and animal waste from farm, vermicompost etc. to ensure soil health and maintain soil nutrient. Biological materials rich in beneficial microbes (biofertilizers) are used for releasing nutrients to crops (Mahanta, 2021). Effort is made to fulfil the nutrient needs through nutrient recycling and reduce dependence on inorganic external inputs. Use of organic manure, cover crop, animal manure, rotation of crops and mixed farming is made to facilitate enhancement of biological activity, and soil fertility.
India is the fifth largest in the world for organic food with almost 2.6 Mn hectares covered by organic crop cultivation, with an increase of organic agriculture land under cultivation by 145.1% in the last 10 years (Agarwal, 2023). India also boasts of having 4.43 Mn farmers involved in organic cultivation, which is largest in the world. In the year 2022-23 India is recorded to have produced around 2.9 Mn MT of certified organic products including different varieties of food and non-food crops like Oil Seeds, Sugar cane, Cereals & Millets, Cotton, Pulses, Aromatic & Medicinal Plants, Tea, Coffee, Fruits, Spices, Dry Fruits, Vegetables, Processed foods etc. (Agrawal, 2023). Indian government launched two schemes for promoting organic farming, "Paramparagat Krishi Vikas Yojna" and "Mission Organic Value Chain Development for North-East Regions" under National Mission of Sustainable Agriculture in the year 2015 (ASFAC, 2024). Through farmer producer organization farmers are provided support at various levels starting from procurement of raw materials to post-harvest support in packaging, branding and transportation. Paramparagat Krishi Vikas Yojana is a centrally sponsored scheme for promoting organic farming across India; registered farmers are issued certificate and support for input procurement, capacity building and setting vermicompost units and the funding is in the ratio of 60:40 by the Central and State Governments respectively (Amarender, 2017). The Scheme had a target to form 10,000 clusters of 20 ha each and bring nearly two lakh hectares of agricultural area under organic farming by 2017-18 (DAC & FW GOI, 2017). Organic Value Chain Development for Northast Regions was launched exclusively for seven sister states Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and Meghalaya with the objective of developing certified organic production through value chain approach (CEEW, 2021). The scheme aimed at developing certified organic production in a value chain mode to link growers with consumers and to support the development of entire value chain starting from inputs, seeds, certification, to the creation of facilities for collection, aggregation, processing, marketing and brand building initiative (ASFAC, 2024).

Vermicomposting (VC)
Vermicomposting (VC) is a practice of composting by employing earthworms for producing high quality compost. For vermicomposting to be successful temperature has to be maintained between 10-32°C as earthworms are active only at this temperature (CEEW, 2021). The waste is decomposed by earthworms through feeding, fragmentation, aeration, turnover, and dispersion, as well as enzymatic digestion by the associated microbes (Ankita C, 2023). Vermicompost, rightly called 'gold from garbage" is a vital ingredient in organic farming (NABARD, 2019). The process helps recycle the nutrients locked in organic waste and contributes to zero waste management. Although, commonly used on small scale the method has some challenges which prevent scaling it to larger levels. Developed in 20th century this practice has been adopted by several countries. It makes use of earthworms and microorganisms for converting waste into manure. Most of the organic components

are degraded and the residuals are transformed into stabilized vermicompost, which is rich in nutrients, hormones, and humic substances (Sharma & Garg, 2019). VC enhances soil biodiversity by promoting beneficial microbes, enhancing plant growth directly by producing plant growth-regulating hormones and enzymes, and indirectly controlling plant pathogens, nematodes, and other pests (CEEW, 2021). Vermicomposting has some advantages over other sustainable farm practices like it is an eco-friendly and zero-waste technology for waste management and almost all types of nontoxic organic wastes may be subjected to vermicomposting after some preprocessing, low energy consumption and less greenhouse gas emission (Sharma & Garg, 2019). It is one of the best methods to recycle agricultural and domestic waste, allowing for the safe disposal of garbage and preventing environmental pollution that could pollute landfills. Vermicompost maintains a stable physical soil structure because of the presence of soil macropores and organo-mineral complexes that allows adequate porosity, good aeration, water holding capacity, microbial activity, balanced mineral nutrients, and colloidal buffering capacity (Gupta, et al., 2021). It also minimizes fertilizer use and related emissions (CEEW, 2021). In India, vermicomposting has been practiced for decades. This practice also has its disadvantages like basic ingredient in vermicomposting is organic manure which is more costly compared to inorganic chemical fertilizer making it less cost effective and economic. Other factors acting as hurdles in successful implementation of vermicomposting are farmers' short-sightedness, lack of necessary infrastructure, lack of subsidies and farmers' knowledge of the process (Hamid R, 2023). The need for continuous supply of organic waste & water, a certain temperature, and moisture level makes the process complex as this combination is not easy to maintain (Pajura, 2024). The combined effect of all these problems has prevented the large-scale commercialization of vermicompost (Sharma & Garg, 2019). An understanding of the reasons for application failure can help in the augmentation of organic farming and popularization of vermicomposting for environmental sustainability (Sharma & Garg, 2019). With an aim to promote vermicomposting Indian government has launched schemes offering financial support and subsidies to farmers for setting up their own vermicompost units like RKVY - Remunerative Approaches for Agriculture and Allied Sector Rejuvenation, Mission for Integrated Development of Horticulture, National Mission for Sustainable Agriculture and National Food Security Mission (AGRICOOP, 2014). The involvement of influential people in practical demonstrations for farmers and farmers sharing experiences about vermicomposting and its promotion through social media can help in this direction (Hamid R, 2023). Although vermicomposting is gaining popularity in the country it is mostly being practiced by individual farmers to fulfill their own requirements, commercial production of vermicompost is yet to come up on a large sink in the country (NABARD, 2019).

Precision Farming (PF)

Precision farming (PF) also known as site-specific crop management is an approach to farm management that uses information technology to ensure that the crops and soil receive exactly what they need for optimum health and productivity (CEEW, 2021). Information related to soil and climate condition, fertiliser and water requirement is collected through sensors and is used to administer site-specific inputs. PF is all inclusive term used to describe farming tools based on observing, measuring, and responding to within-field variability via crop management, made possible through global positioning system (GPS) or geographic information system (GIS), which enable farmers to respond to field irregularities (USDA, 2024). It was born with the introduction of GPS, GIS, yield monitors, and other data generators in all three crucial phases of agricultural operations in the 1990s (Karunathilake, 2023). PF merges data collection and remote sensing with GPS and GIS to allow farmers to respond to in-field variability with their crop management (AGRIVI, 2024). This provides a data-driven strategy for efficiently growing and maintaining crops on cultivable land, enabling farmers to use the resources at their disposal in the most judicious way (Javaid, 2022). GPS technology facilitates farmers to precisely locate and map their fields, empowering them to manage their farmland according to site-specific conditions and field variabilities (Karunathilake, 2023). PF involves collection, processing and analysis of time-specific, site-specific and individual field data to estimate variability for better decision making for efficient resource utilisation, better productivity, higher quality, higher profitability and sustainability of agriculture (Mizik, 2022). The gathered temporal, spatial and individual farm data is combined with other information to support decision making according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production (Springer , 2024). Rather than employing similar inputs across the entire field the approach aims to manage and distribute them on a site-specific basis to maximise long term cost benefit as well as prevent any wastage (CEEW, 2021). PF is important for sustainable crop production and ecosystem health (Ahmed, 2024). It has the potential to contribute to the broader objective of meeting the growing demand for food, ensuring the sustainability of primary production, based on a more accurate and resource-efficient approach to crop and livestock management (António Monteiro, 2021). Advanced technology is used to study the field variability and helps farmers decide the right amount of nutrient & water requirement for their field. Satellite Positioning system makes use of satellites to monitor crops, Geographic Information System collects information and helps understand the site-specific factors affecting crop; Remote sensors for collecting information on soil properties, plant fertility and water status; Grid soil sampling for site specific soil management; Remote sensing for evaluating crop health; Variable rate technology for automation of application of inputs like raw materials, seeds, fertilisers, pesticides and water; Laser land levellers for levelling slopes; Combine harvesters with yield monitor for reducing waste; Leaf coloured charts to assess the nitrogen requirement of plants (CEEW, 2021). IoT based technology enables farmers to precisely monitor crop health & growth and assists farm workers to assess pest attack and plant diseases in real time (Karunathilake, 2023). Greenhouse gases such as carbon dioxide, methane, etc., are also measured through automated sensors (Nowak, 2021). Smart farming also enables measurement of nitrogen content in soil that helps farmers to determine the amount of fertilizers to be used in farm lands (Prem, 2023). Remote sensors like global navigation satellite system are used to create maps for soil & yield for a specific site. These maps can be used for decision making related to input requirement for a specific location. Precision farming makes use of internet of things (IoT) with AI based smart devices like unmanned aerial vehicles. These smart devices reduce human resource requirement, are more efficient and can adapt to all working conditions. Employment of drones, AI based irrigation system, satellite imaging & sensors for monitoring crop health and soil water requirement can help farmers make informed decision. With its focus on efficient management of limited available resources PF is a big leap towards achieving sustainable agriculture development. Variation in soil accounts for major variation in production, hence precision agriculture involves strategies to improve the soil variation measurement and mapping (Taylor, 2023). Precision farming (PF) is a farm management technology which makes use of IT for understanding the specific needs of crops and soil. Rather than following one size fits all, crops are administered only what they need for good productivity. This helps in reducing the wastage and cost of production because inputs are managed on site-specific basis (CEEW, 2021). Understanding of the variability within and between farms is the basis of precision agriculture. Use of different technologies for site specific management of resources helps in sustainable and efficient distribution of limited resources. The different precision agriculture techniques can be broadly categorised into two types “soft” and “hard”. Soft technologies are based on observation and experience and intuition unlike hard precision farming which makes use of statistical analysis and scientific tools like GPS and remote sensing etc. Customized leaf colour chart (CLCC) for nitrogen management in rice developed by ICAR National Rice Research Institute (NRRI) and Tamil Nadu, Precision Farming Project (TNPFF), for drip irrigation are good examples of low-cost precision agriculture techniques (Elanchezhian, 2020). The National Mission on Micro Irrigation initiative of government of India launched in 2010 for drip/sprinkler irrigation systems and Bringing Green Revolution to Eastern India (BGREI) for seven states providing financial support for Laser Land Leveller, a precise water management technique, are some of the examples of government schemes for promoting precision agriculture (CEEW, 2021). Site-specific information on soil nutrient, fertility and water absorption capacity, weed infestation and weather conditions is important as this may differ for different sites. Site specific information helps in administering only what is required. The success of PF depends on multiple factors like farm size, capital availability, cultural sync with the new technology, training & comfort for adopting new technology and supporting policy. PF is less successful in developing countries unlike developed countries because of the small farm size, lack of financial support, lack of supporting policies and difficulty in accessing technologies, readiness to adopt new technologies, adoption cost of new technologies and greater diversity between farms. PF practices are employed at various stages of plant growth like soil mulching and preparation, sowing and harvesting. But it is not limited to crops, farmers involved in livestock rearing are also experiencing benefits of PF (Monteiro, 2021). The projected growth in world population demands increased food availability. An ever-growing demand of food coupled with limited availability of resources, calls for new technologies which could help increase productivity with limited available resources. With the growing demand on natural non-renewable resources there is a constant threat to sustainable long-term availability of food. Sustainability demands use of resources by the present generation judiciously to ensure its availability for the future generation. Precision farming with its emphasis on administering only what is required based on the information collected through technology about soil nutrient and water requirement of crops in specific area comes as a panacea for all food related problems. Precision agriculture is more suited to larger farms where it is easier to run advanced technology, hence less popular in developing countries like India. In India majority of the farmers are small and marginal and have small landholdings not fit for technology application (Rakholia, 2024). But despite proven benefits, its acceptance in agricultural practice remains low, there are even known cases where farmers initially purchased and used technology, but then stopped using it due to lack of profitability or other reasons (Munz, 2024). some practices have been prevalent in India and abroad. It is difficult to estimate the area under PF, but the area covered under precision irrigation techniques like drip, sprinkler and micro-irrigation can be approximated to about 9.2 million hectares in 29 states (CEEW, 2021). Although PF technologies emerged roughly at the same time as genetically modified seeds, the adoption rate of precision agriculture is generally accepted to be slower (Nowak, 2021). Cost of adoption of PF is high just like any other new technology, this acts as a major barrier in the largescale adoption, because the farming community of most of the developing countries is poor, hence government intervention in the form of financial support & funding can go a long way in scaling the adoption of PF in developing countries like India. Lack of technical know-how and fear of new technologies are also acting as major roadblocks in the successful implementation of PF in developing countries, government schemes providing technological support and education can help overcome these challenges.

Agroforestry

Agroforestry is a practice of growing trees along with non-tree crops or animals on the same farm for increased agriculture sustainability; and often contributes to soil conservation and fertility (CEEW, 2021). It is defined as a land use system integrating trees and shrubs on farmlands and rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability (FAO, 2014). It is a dynamic, ecologically based, natural resource management system that, through integration of woody perennials on farms and in the agricultural landscape, diversifies and sustains production (FAO, 2024). Traditional agroforestry systems are considered as the classic example of sustainability due to their important role in conserving biodiversity, advancing food security and maintaining environmental health (Kurmi, 2024). Land-use options that increase livelihood security and reduce vulnerability to climate and environmental change are necessary (ICAR, 2009). Traditional resource management adaptations, such as agroforestry systems, may potentially provide options for improvement in livelihoods through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change (Singh V. K., 2011). The importance of agroforestry extends far beyond mere agricultural productivity. It holds the promise of addressing pressing global concerns such as climate change and biodiversity loss. With India committing to ambitious climate goals, including a net-zero target by 2070, agroforestry emerges as a crucial strategy for carbon sequestration and ecosystem restoration (kumar, 2024). However, realizing these goals necessitates concerted action and effective implementation of the National Agroforestry Policy (ICAR, 2024). It involves combining on-farm and off-farm tree production for sustainable land and resource management (Nair, 2008). Agroforestry benefits farmers by providing them perennial source of income and a diverse plantation on farm with the benefits of natural ecosystem. Intercrops such as soybean and cereals may significantly improve the growth of young plants paired with them (David, 2009). Agroforestry unlike monocultures can better manage pest infestation and promote soil quality by continuous internal recycling of nutrients reducing dependence on toxic external inputs. Monoculture is the practice of cultivating one crop and is dependent on external inorganic inputs like chemical fertilizers and artificial pest control measures, which can harm both crop and human health. It also has negative impact on the soil health and productivity and can promote pesticide resistant weeds. According to ICAR-Central Agroforestry Research Institute, agroforestry is estimated to cover about 25 mn ha. in the 15 agroclimatic zones of India. UP, Maharashtra and Rajasthan lead the coverage with 1.9, 1.6 and 1.6 million hectares respectively (CEEW, 2021). But Jharkhand, Andhra Pradesh and Telangana fair better on the percentage of total sown area devoted to agroforestry with Jharkhand, Andhra Pradesh and Telangana having 21%, 19% and 14% respectively (CEEW, 2021). Traditionally most sought-after practice in India, agroforestry is an important sustainable agriculture tool promising farmer income, nutrition, energy, and environmental security. Woody plantation provides for the wood requirement. Agroforestry is reported to meet almost half of fuelwood demand, two-thirds small timber demand, 70-80 percent of plywood, 60 percent of the raw material for paper pulp, and 9-11 percent of the green fodder requirement of livestock (CEEW, 2021). India took a pioneering step by adopting the National Agroforestry Policy (NAP) in 2014 (AGRICOOP, 2014). This policy, a culmination of concerted efforts by various stakeholders at national and international levels, marked a significant milestone in mainstreaming agroforestry development (ICAR, 2024). The policy recommends setting up a Mission or Board with an initial corpus of Rs 4000-5000 crore annually to address the development of agroforestry sector in an organized manner (Agriwelfare GOI, 2023). As a follow-up to the policy, the Sub-Mission on agroforestry under National Mission for Sustainable Agriculture was launched in 2016-17 to encourage and expand tree plantation on farmland, with the motto of “Har Med Par Ped”, along with crops in a cropping system (DA & FW, 2023). Agroforestry is one of the strategies proposed for achieving the target of creating an additional carbon sink of 2.5 to 3 billion tons of carbon dioxide (Prasad, 2024). It is an answer to the problems of unsustainable farming practices. Mixing woody vegetation like trees and shrubs with other crops and livestock works in the benefit of the farmer by reducing the cost of pest management and external nutrient application and the profit earned from agroforest converts into higher farmer income (Pantera, 2021). Agroforestry system has many benefits like better pollination due to the presence of diverse pollinators, improved soil health, lower water needs and better water quality, improved air quality, improved pest control, multistory canopy cover that provides varying levels of shade and sun for animals and plants, diversified farm enterprises that sell fruits, flowers, nuts, and woods (SAREP, 2024). Multiple methods have been employed by farmers in India under agroforestry.

Alley cropping is a practice in which trees or shrubs and agricultural crops are grown in alternate rows with the trees pruned to limit the shading of the agricultural crop (Grebner, 2022). The trees may include valuable hardwood veneer or lumber species; fruit, nut or other specialty crop trees and shrubs; or desirable softwood species for wood fiber production (FS USDA, 2024). Windbreak involves linear plantings of trees & shrubs that are strategically integrated into an agricultural landscape to provide socio-economic and ecological benefits that can occur when trees are deliberately managed in an agroecosystem (Smith, et al., 2021). Anything like trees, shrubs, tall perennial or annual plants that will attain a sufficient height to create the desired wind shadow may be included in windbreak (University of Missouri, 2021). Silvopasture is an integration of trees and

livestock on the same land for providing both short- and long-term income sources (USDA, 2024). Intercropping is the practice of growing two or more crops in close proximity, in the same row or bed, or in rows or strips that are close enough for biological interaction (Nguyen & Drakou, 2021). Tree-based intercropping with early rapid growing trees is considered to be a potentially useful land use system for mitigating negative environmental impacts from intensive agriculture such as nutrient leaching and greenhouse gas emissions (David, 2009). Intercropping includes growing of a cash crop with a cover crop or two or more cash crops together (Charles L. Mohler, 2009). Since crops are very different in their response to physical and environmental stress, it is not uncommon for a crop to thrive in an environment in which another crop develops (Vlaiculescu, 2022). Taungya practice is a system of forest management in which land is cleared and planted initially by food crops and then desirable tree species are planted on the same plot (kalame, 2011). The resilience of these systems is associated with economic and social factors which have made the cultivation of trees an adaptive strategy of land use for the inhabitants of the highlands of southern China (Menzies, 1988). Teak is by far the most popular tree species used in taungya (FAO, 2024).
Some of the barriers that prevent the farmers to shift to agroforestry from monoculture cropping pattern are insecurity of land tenure, lack of financial support, lack of technical know-how & support and limited access to planting material. An agroforest system is based on self-sufficiency with internal recycling of material and less dependent on external input, which calls for diverse species for the different functions like recycling and generation of nutrients, pollination, pest control, water management and management of microclimate. Hence the farmers should focus on including functional diverse species for ensuring a self-sufficient agroecosystem following the rules of a natural ecosystem (Willmott, 2023).

Integrated Pest Management (IPM)
Pest is defined by Cambridge dictionary as an insect or animal that has the potential to damage pathogens, weeds and insects attacking crops. Pesticides can help increase yield variability by controlling pest damage to crops (Brunelle, 2024). Although the effect of chemical fertilizers and pesticides have enhanced crop yield, they have resulted in altered soil health, restricted plant growth, decreased crop quality, and an unbalanced cost-benefit ratio (Thakur, 2021). Pesticides are highly pervasive in the environment, with about 7% of net annual applied pesticides leaching to aquifers, and more than 10% residing in soil, leading to several pollution hotspots presenting risks to the environment, biodiversity and human health (Brunelle, 2024). The average pre-harvest crop loss attributed to plant pathogens represents up to 35% of total crops, even in their presence (Vlaiculescu, 2022). Sometimes pest related loss of yield could be as high as the amount of food sufficient to feed one billion people (Sharma P. , 2024). This loss of food crops is huge and should be checked. One way of doing this is by using synthetic pesticides. Although efficient in controlling pests these inorganic inputs have their disadvantages. Chemical pesticides cause toxicity in plant and water. They affect the quality of crops; excess amount is carried with the flowing water to rivers and underground water and can be harmful when consumed by human and animal. Hence farmers need to include natural means of pest control like cover crops, alley cropping, crop rotation, pest-resistant plants, and pest-free rootstock planting. Integrated pest management (IPM) is one such solution which includes the integration of the best pest control measures (Muhie S. H., 2022). It aims at reducing the use of artificial pesticides, reducing the cost of inputs at the same time minimising the risk to the environment, plant, animals and human. It promotes the use of natural methods of pest control. IPM includes methods such as simultaneous management and integration of organic & inorganic techniques, regular monitoring of pests and natural enemies, use of decision thresholds, as well as pesticide product management or substitution and entire agroecosystem redesign (Muhie S. H., 2022). It can help achieve sustainable intensification by getting higher yield from same size of land with less damage to the environment. Action threshold plays a vital role in IPM. Based on the study of pest life cycles and their interactions with environment an action threshold is created (EPA, 2024). Action

threshold is the level of pest population or environmental damage indicating pest control intervention requirement. It helps the farmers decide when they should introduce pest control measures. Defining threshold contributes to optimal use of pesticide control measure and helps in cost saving. Inorganic methods should be employed only when pest population crosses economic threshold level, before that it can be controlled by natural organic methods, without disturbing the balance of the natural ecosystem. Nanotechnology is an emerging trend in pest management and aims at utilizing measures directed at improving crop productivity through efficient nutrient management, leading to increased nutrient utilization and thus increasing crop yield (Thakur, 2021).

Need for Agriculture Sustainability Index

With indications of conventional farming practices being unsustainable in India (Purvis, 2019). No one method fits all situations hence best methods need to be integrated to get the optimal results. Most of the farming practices discussed above are useful in achieving agriculture sustainability but the same methods may not be suitable to all situations, hence selection should be made judiciously. An integrated system with some of the best farming practices is what we need. A trade-off needs to be made based on comparative analysis of different methods using standard sustainability indices (Dmytro, 2020). Literature has recorded different methods for measuring the sustainability of farm practices, like cost–benefit analysis, Batelle method, critical volumes and ecological saturation (FAO, 2024). Existing methods of evaluation have shown their inadequacy in measuring the ecological impact of farm practices. Researchers need to develop a standard sustainability index which is both quantifiable and generalisable. The most common model of sustainable development gaining popularity offlate is the triple bottom line model, proposed by John Elkington in the year 1994 (Elkington, 2004). The triple bottom line (people, planet & profit) states that a production system should commit to measuring its social and environmental impact in addition to financial performance rather than solely focusing on generating profit or the standard bottomline (Miller, 2020). On similar lines Zenh and Routray (2003) proposed agriculture sustainability index for measuring the sustainability of farm practices in developing countries around socio-economic and environmental dimensions (Zhen & Routray, 2003). For measuring the environmental sustainability, they proposed operational indicators like amount of fertilizer and pesticide used, irrigation water used, soil nutrient content, impact on groundwater table, water use efficiency and nitrate content of both groundwater and crops. A farm practice showing ecological accountability also converts into higher farmer income because of improved soil condition or health on account of less or no external inputs like chemical fertilisers and facilitates internal cycling of nutrients like nitrogen and phosphorus resulting in lower input costs (Altenbuchner, 2017). Choice of farm practices also impacts crop's natural cycle and its productivity. Sustainable development cannot be achieved in isolation it needs to integrate economic, social and ecological factors for better results (Brennan, 2022). Economic accountability can be measured by their impact on crop productivity, net farm income, cost-benefit ratio of production, and per capita food grain production. (Smith & et. al., 2017). One of the biggest hurdles in adoption of new improved technologies is lack of capital and government funding. Considering large number of small and marginal farmers, capital formation in agriculture is critical for boosting agriculture production and productivity (NABARD, 2024). A community which is cash strapped will never want to switch to a more risky and expensive technology. Some of the researchers point out that sustainable agriculture may come at a higher cost proving the fears of farmers to be true (OECD/FAO, 2023). Social accountability is reflected through indicators like food self-sufficiency, equality in food and income distribution among farmers, access to resources and support services, and farmers' knowledge and awareness of resource conservation, family time, work life balance (Smith & et. al., 2017). Culture & society play an important role in adoption of a new technology as only those technologies which are culturally and socially desirable are easily adopted (Rodriguez, 2008). Farmers may be reluctant to change an age-old practice that has been running through generations in family or community. Social wellbeing of farmer is another important aspect of farm sustainability and plays an important role in adoption of a new practice. Lack of knowledge of the impact of inorganic practices on environment is another barrier. Hence for successful implementation of sustainable agroecosystem, it is important for the new sustainable methods to show accountability for all the three pillars of triple bottom line – people, planet & profit (Elkington, 2004). Government and policy makers need to come up with operational indicators for measuring economic, social & ecological accountability of the agriculture system (Sabillon, 2021). It is difficult to accurately define a permanent measure for sustainability index for agriculture in an ever-changing world (Naik S. S., 2023). Once an index is defined researchers need to keep revisiting and making amendments in the constructs based on contemporary trends and demand. A combined analysis of the impact of socio-economic and ecological factors on farm practices can give more clarity on most feasible sustainable agriculture practices (Blasi, 2016). Due to the complex nature of the different dimensions of sustainability, it is better to first analyse individual dimensions and then integrate the three to get a complete measure (Sands, 1999). Time and space are equally important for the successful implementation of sustainable agriculture. Hence measurement of sustainable agriculture should be contextual to the farming system being studied (Brennan, 2022). The indicators should be prioritized based on spatial and temporal characteristics under consideration (Zhen & Routray, 2003). There is an urgent need to develop sustainability index and operational indicators fitting temporally and spatially with the farming system in question. It is complex because sustainability includes multiple dimensions with different measurement standards and systems, hence combining them into one index can be challenging.

Conclusion

Smallholder farmers (farm area <2 ha) are among the most vulnerable towards climate change, since their farms are mostly located in regions directly affected by climate change, in low and lower middle-income countries (Nguyen & Drakou, 2021). Given these environmental and human health concerns, the United Nations has called for global actions to reduce reliance on synthetic fertilizers and pesticides as part of the Sustainable Development Goals, and numerous public policies have been implemented at the national or regional level in this regard, however, these policies face many obstacles that limit their effectiveness (Brunelle, 2024). Reducing chemical inputs in agriculture requires a system change. Several agronomic options have proven effective in reducing chemical inputs or mitigating their negative impacts (Bhan & Behera, 2014). Involving all stakeholders, from the chemical input industry to consumers, and designing appropriate policy frameworks are key to address this issue (Michelson, 2023). Combining different policy instruments, such as standards, taxes and subsidies, in a simplified and coherent way to increase effectiveness and ensure better coordination in the adoption of sustainable practices (Brunelle, 2024). Adoption of sustainable agricultural practices (SAP) is essential for economic, social and environmental adaptation to climate change (Nguyen & Drakou, 2021). Organic farming, agroforestry, precision farming, integrated pest management and vermicomposting are only few of the methods of sustainable farming. These practices could prove to be more successful when used in combination rather than singly. An optimal integration of two or more techniques can prove more efficient than using single approach in silos. Some of the practices discussed in this paper have been in practice for a long time either alone or in combination with others and have proven beneficial and environment friendly. Hence, may be implemented for better results. An assessment of the sustainability of prevalent practices on socio-economic and environment dimensions can help the farmers find gaps and plug it using the most suitable sustainable practices. Efforts in the form of information support, policies and programs favouring sustainable agriculture, economic support, and campaigns to spread the awareness of the ill-effects of conventional unsustainable practices will go a long way in motivating farmers to adopt sustainable farming practices (Rodriguez, 2008).

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