Chapter

Strategies and Programs for Improved Nutrient Use Efficiency, Doubling Farmer's Income, and Sustainable Agriculture: Indian Context

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Abstract

Since the Green Revolution era, the farming sector exploited the soils for food, fiber, fodder, etc., with high input responsive varieties that excavated vast amounts of chemical fertilizers. The burgeoning population of the country calls for a commensurate increase in food production to satisfy the demands of its inhabitants. Further, due to innovative mechanization in agriculture, specialization, and government policy programs, the productivity of food has soared. Subsequently, it ensued greater productions and minimized food prizes. Regrettably, intensive agricultural operations degraded the soil quality and now reached such a stage where without external inputs, growers unable to achieve their targeted yields. India has lost 68% innate productive capacity of agricultural soils. This plunder of land's quality continues unabated, further resulting in low nutrient use efficiency and insufficient yields of agroecosystems. Therefore, this is high time to realize the dreadful impacts of intensive crop production on the natural ecosystem. Irrefutably, both soil and its nutrients are the wondrous gifts of nature to humankind; utilizing them sustainably is imperative. The present chapter highlights the impacts of non-judicious nutrient management on soil productivity, nutrient use efficiency, and novel technologies required to promote sustainable agriculture and achieve the target of doubling farmer's income in India.

Keywords: Food security, sustainability, nutrient use efficiency, technologies

1. Introduction

The agriculture sector is the primary source of livelihood for over 58% of the Indian population and a key contributor to the health of the country's economy as it contributes approximately 17.1% to India's gross value added (GVA). It generates an

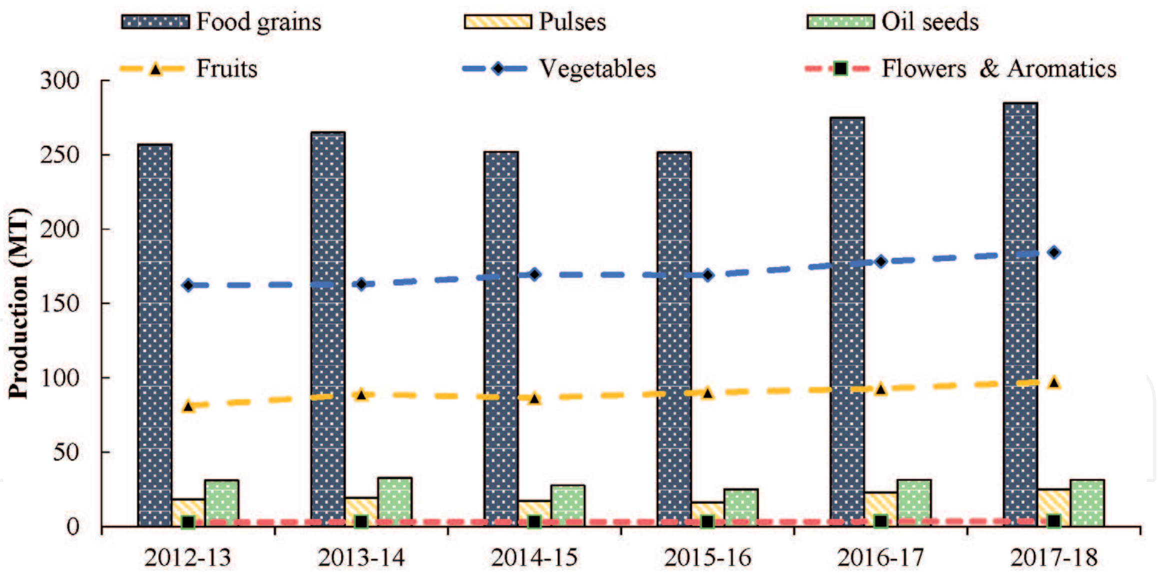

Figure 1.
Production rates of different agricultural produce in India [1].

employment opportunity for 44% of its workforce. Agriculture in India, continues to make impressive progress, while food grain production at record 296.7 million tons (Mt) and total oilseeds production at record 33.4 Mt., during 2019–2020. Such increments were also observed in other major crops. Current production estimates show that food grains, pulses, oilseeds, fruits, vegetables, and flower and aromatics are about 284.83, 25.23, 31.31, 97.35, 184.39, and 3.65 Mt., respectively. The production rates of different agricultural produce in India for the period from 2012 to 2013 to 2017–2018 are presented in **Figure 1.** Despite this remarkable growth in production in India, about 14.8% of the population and 38.4% of children remain malnourished. As per evaluation of the Global Food Security Index (GFSI), India ranked 76th out of 113 countries.

Only agriculture can help us achieving food security in the country. Since the green revolution (GR) in India, growers are cultivating high-yielding varieties under the irrigated condition with high amount of fertilizer nutrients and pesticides, saved millions of lives from starvation, and transformed India into a self-sufficient country in food production; also from the status of a "hungry nation" to that of a "food exporting nation" [2]. But, because of burgeoning population pressure and restricted land usage, it has become a serious challenge. Intensive agricultural operations involving continuous tillage and chemical fertilizers and pesticides are a concern in terms of environmental issues and soil degradation in the post-green revolution period. Increasing food demand has laid more stress on the agricultural soils for increased productivity. The total NPK fertilizer consumption during 2018–2019 was 27.23 Mt. and it is likely to increase to around 48.0 Mt. by 2050.

The persistent decline in nutrient use efficiency, soil fertility status, and environmental quality are the key constraints coming in the way of achieving sustainability in Indian agriculture. Specifically, in the Indian soils, nutrient use efficiency (NUE) is very low. It varies from 30 to 50% for nitrogen (N), 15 to 20% for phosphorus (P), 60 to 70% for potassium (K), 8 to 10% for sulphur (S), and 1 to 2% for micronutrients [3]. The unutilized N is lost through several mechanisms such as leaching, denitrification, volatilization, etc., pollute the groundwater and atmosphere. Considerable amounts of P and K are also lost through soil erosion. As per the estimation, annually, over 5.3 billion tonnes (Bt) of soil is lost through water erosion that ultimately results in the loss of about 8 million tonnes (Mt) of plant nutrients (NPK). Finally, there exists a huge yield gap (difference between the achievable and the actual yield) in most of the crops of India.

Yet the production of food, fiber, and raw materials must be enhanced in a sustainable manner to the demands of the ever-growing and progressively affluent population of India. Whereas the inorganic inputs supplying for the food production may never be completely replaced by the organic amendments but with appropriate management strategies/technologies, we could be able to achieve higher nutrient use efficiency, minimize the adverse impacts on the environment, and double the farmer's income that brings sustainability in the agricultural production system.

2. Technological options suitable for Indian agriculture

2.1 Enhancement of soil organic carbon

Improving SOC in agricultural soils is now a global challenge for environmental safety [4, 5] as it is the most realistic approach to regulate soil degradation [6] and improve soil productivity to achieve higher crop yields [7–10]. It has several benefits on soil quality maintenance as showed in **Figure 2**. Mahmood et al. [11] revealed in his experiment that incorporation of OC into the soil system through sheep manure (SM), farmyard manure (FYM), and poultry manure (PM) alone or amalgamation with chemical fertilizers significantly improved the soil organic carbon status as well as the available total nitrogen (TN), total phosphorus (TP) and total potassium (TK) (**Figure 3**) over the control and complete inorganic treatment. Improvement in soil fertility always has a direct benefit on crop yields as the availability of all essential soil nutrients increases through the addition of C input. There was an increase in crop yields (kg ha^{-1}) for every Mg ha^{-1} increase in SOC stock in the root zone. A field experiment conducted to evaluate the effect of C input under various crop production systems showed that an improvement in crop yields (kg ha^{-1}) such as 170 for pearl millet, 145 for soybean, 150 for castor, 160 for upland rice, 18 for

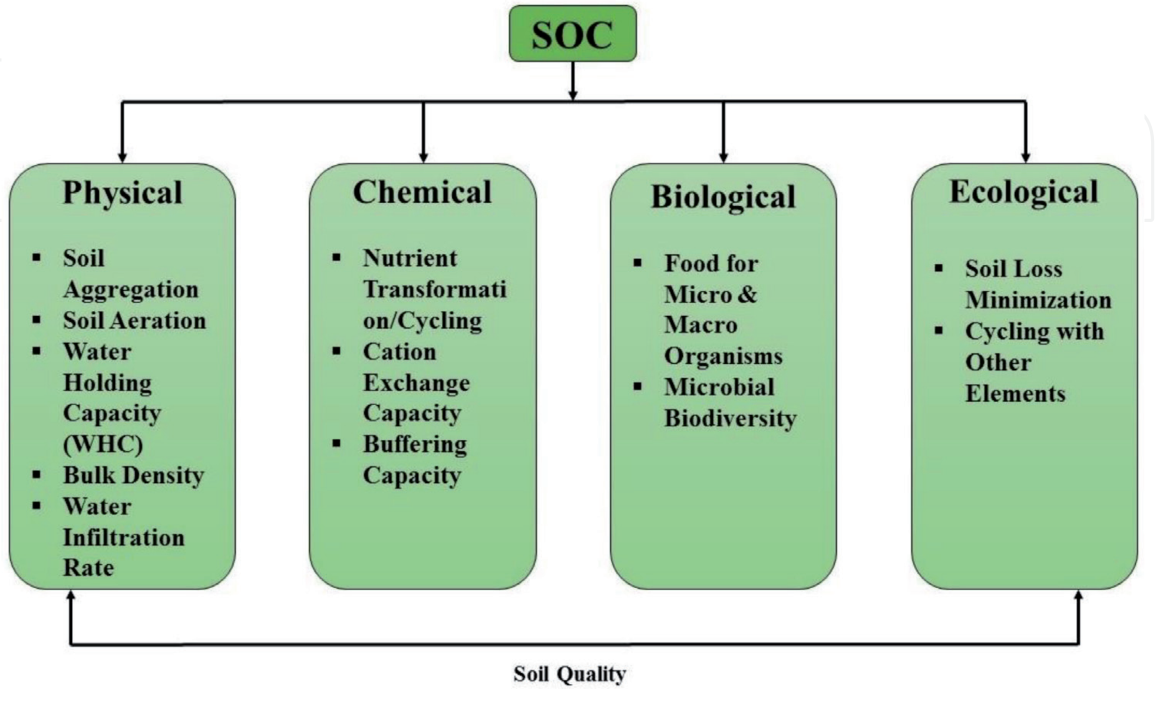

Figure 2.
Important SOC functions in soil quality maintenance.

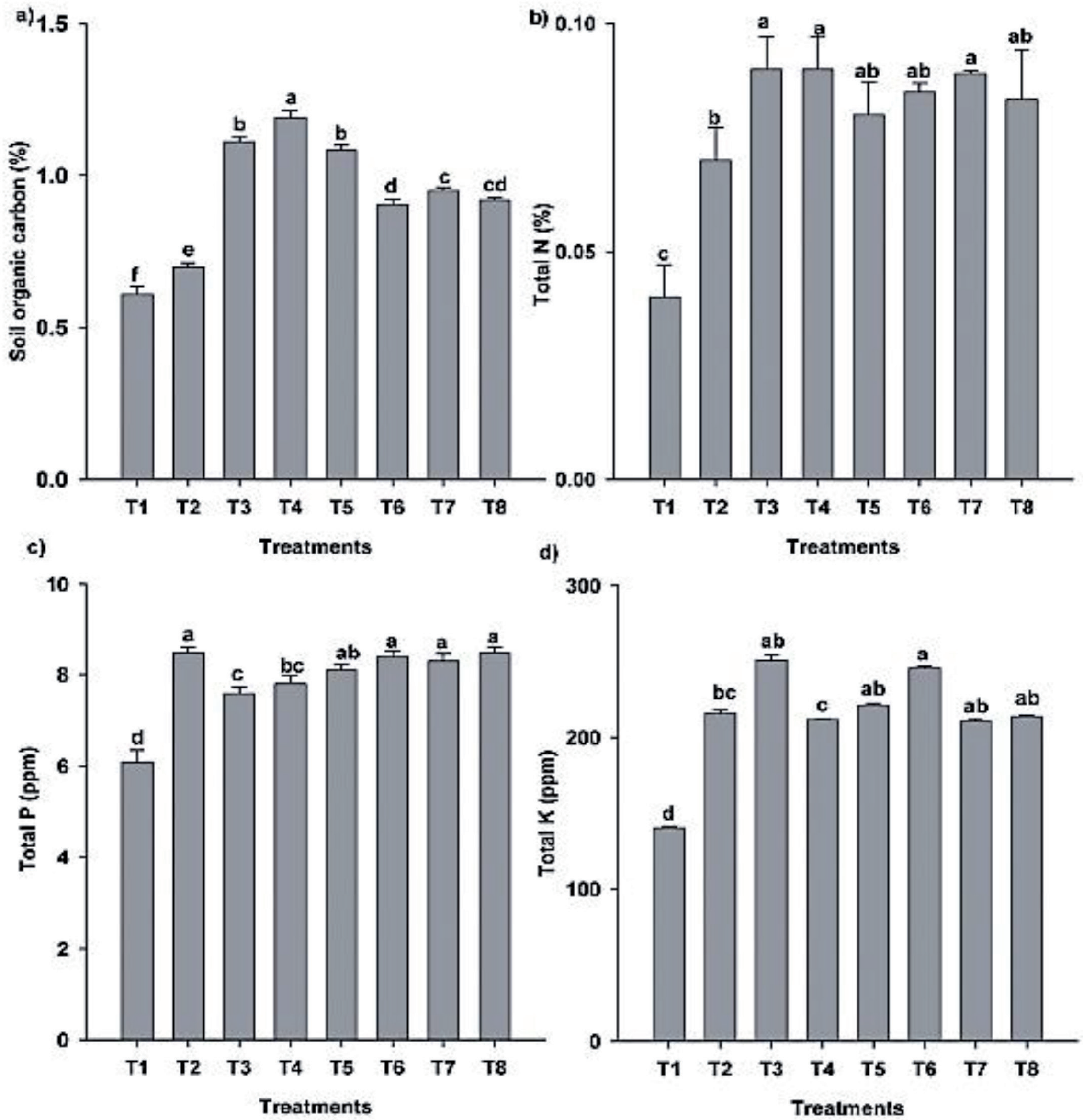

Figure 3.
Residual Impact of sheep manure (SM), farmyard manure (FYM), and poultry manure (PM) on (a) SOC (%), (b) TN (%), (c) TP (ppm), (d) TK (ppm) after crop harvest (Source: [11]). ***T1:*** *Unfertilized control;* ***T2****: NPK at 250–150-125 kg ha^{-1};* ***T3:*** *SM at 15 t ha^{-1};* ***T4:*** *FYM at 16 t ha^{-1};* ***T5:*** *PM at 13 t ha^{-1};* ***T6:*** *NPK at 150–85-50 + 8 t ha^{-1} SM;* ***T7:*** *NPK at 150–85-50 + 8.5 t ha^{-1} FYM;* ***T8:*** *NPK at 150–85-50 + 7 t ha^{-1} PM 2.2.*

lentil, 90 for winter sorghum, 33 for groundnut, 124 for finger millet, 101 finger millet, 13 for groundnut, 145 for soybean, and 59 for safflower (**Table 1**).

2.2 Organic manures and green manures

Manures are the decomposed heterogeneous organic mixture that are made up of farm wastages like crop residues, cow dung, and household wastages. Manure releases the plant nutrients very slowly, thus the initial requirements of the crop met by supplying fertilizer nutrients for optimum growth and development. Farmyard manure (FYM) contains almost all the essential plant nutrients that are needed for crop growth. Farmers in India could easily manage the FYM preparation and its application in the field as the cost of inorganic fertilizers are high which is unable to afford by small and marginal farmers. However, the availability and efficiency of manure are highly dependent on the method and amount of its application, time to incorporate, and decomposition rate by soil microorganisms.

Green manures (GM) where leguminous crops are incorporated into the soil during the flowering stage that makes the soil fertile and increases crop productivity.

Cropping system	Mean annual C input ($Mg\ C\ ha^{-1}\ year^{-1}$)	Yield increased ($kg\ ha^{-1}$)	Reference
Pearl millet- Cluster Bean- Castor	0.2–1.9	Pearl millet- 170 Cluster Bean- 140 Castor- 150	[12]
Groundnut	0.5–3.5	Groundnut- 13	[13]
Finger millet	0.3–3.1	Finger millet- 101	[14]
Groundnut-Finger millet	0.3–3.0	Groundnut- 33 Finger millet- 124	[15]
Soybean-Safflower	1.9–7.0	Soybean- 145 Safflower- 59	[16]
Winter Sorghum	0.6–3.4	Winter Sorghum- 90	[17]
Rice-Lentil	1.1–5.6	Upland rice- 160 Lentil- 18	[18]

Table 1.
Effect of mean annual C input on Crop yields under various cropping systems.

These manures are a great source of biologically fixed N and organic carbon. The area for green manuring crops is limited to 7 Mha in India [19] and has also not expanded over the last few decades. Probably, the low price of urea N, intensification in crop production, scarcity of land, and irrigation water are the main factors for the long-term reduction in GM use. Legume crops like mungbean/cowpea or typical GM crops like *dhaincha*/sunn hemp can be grown and incorporated into the soil. GMs have the capacity to meet the N demands of the crops. A 40–45 days old GM crop can supply 100–125 kg N which is equal to the N requirement for cereal crops [20] Even after harvesting the pods, residues can be incorporated into the soil, which saves around 60 kg N ha^{-1} in succeeding crops like rice or maize [20, 21].

2.3 Integrated nutrient management

Integrated nutrient management (INM) is a technique of combined usage of chemical fertilizers, organic amendments, and bio-fertilizers in farming which is an economically feasible and environmentally benign way of managing plant-available nutrients. This concept originated at the beginning of the 1990s because of the widespread emergence of multi-nutrient deficiencies and soil degradation. Thus, INM comprises major objectives such as soil fertility maintenance, sustenance of crop productivity, and improvement of the farmers' profitability. The amalgamation of inorganic fertilizers with organic amendments aids in the provision of improving soil productivity by improving soil C storage [10, 22]. The INM-induced SOM build-up aids in the provision of improved soil structure and water holding capacity that directly enhances crop yields.

A long-term field experiment showed higher grain yield and sustainability yield index (SYI) of maize and black gram under the INM treatment (conjunctive use of fertilizers and organic amendments) as compared to sole inorganic treatment and control (**Figure 4**) [10]. Such improvements in yields may be due to the continuous addition of C inputs that creates a congenial environment for plant growth by modifying the soil's physical properties [23, 24]. The importance of INM practice for increasing soil health, nutrient use efficiency, crop yields, and decreasing environmental pollution has been recorded by several researchers in the Indian subcontinent [25, 26]. The location-specific INM strategies working better under various cropping systems are summarized in **Table 2**.

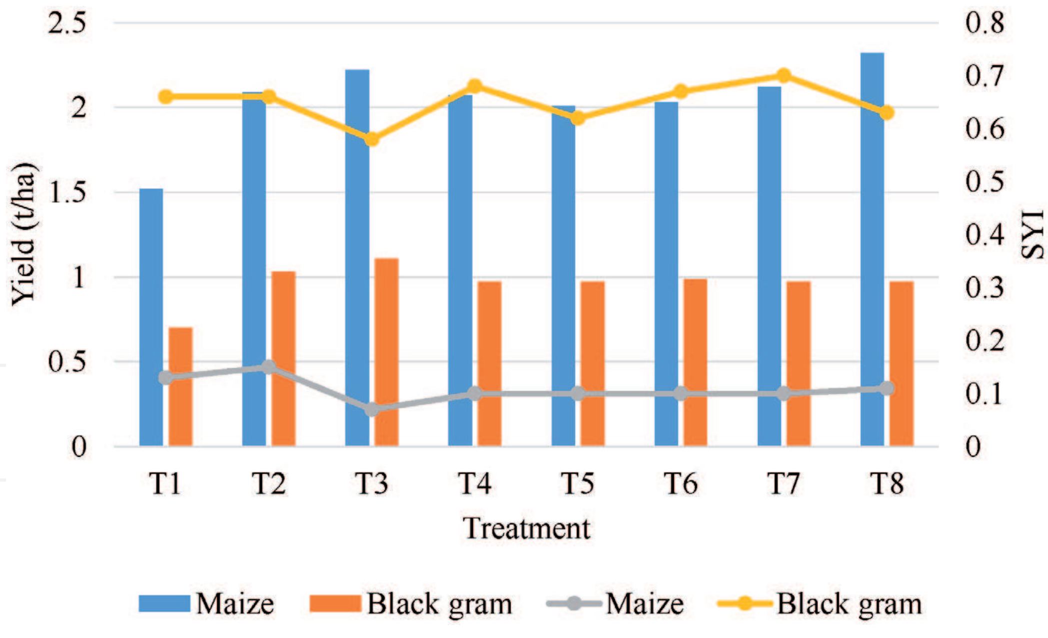

Figure 4.
Mean crop yields and sustainability yield index of maize-black gram system as influenced by the INM approach (Source: [10]). T1: Control; T2: 100% RDF of NP; T3: 25 kg ha^{-1} N (FYM) + 25 kg N (Urea) + 30 kg P ha^{-1}; T4: 25 kg ha^{-1} N (Compost) + 25 kg N (Urea) + 30 kg P ha^{-1}; T5: 25 kg ha^{-1} N (Crop residue) + 25 kg N (Urea) + 30 kg P ha^{-1}; T6: 15 kg ha^{-1} N (FYM) + 10 kg N (Crop Residue) + 25 kg N (Urea) + 30 kg P ha^{-1}; T7: 15 kg ha^{-1} N (FYM) + 10 kg N (Compost) + 25 kg N (Urea) + 30 kg P ha^{-1}; T8: 15 kg ha^{-1} N (FYM) + 10 kg N (Green Leaf) + 25 kg N (Urea) + 30 kg P ha^{-1}.

2.4 Conservation agriculture

Traditional agriculture, based tillage, and other management operations lead to soil erosion problems, surface and groundwater pollution [27]. Conservation agriculture (CA) technology involving three basic principles such as minimum soil disturbance, efficient and diversified crop rotations, and surface crop residue retention aids in the provision of enhancing/improving soil organic carbon storage. Tillage and residue management greatly influence the soil's physicochemical and biological properties [28]. Zero tillage (ZT) for crop production has been identified as an important practice to increase soil aggregation and C sequestration [28] as compared with traditional systems i.e., conventional tillage (CT).

Adoption of ZT in wheat production in India, reduced the cost of production by Rs 2,000 to 3,000 ha^{-1} ($ 33 to 50) [29]; enhanced the soil quality, [30]; improved C sequestration and mitigation of Green House Gas emissions [31]; reduction in weed population *Phalaris minor* in wheat (Malik et al., 2005), enhanced water and nutrient use efficiency [31, 32] and overall increments in production and productivity (4–10%) [33]. The practice of ZT significantly increased the soil total nitrogen content (**Figure 5**) in both rice-wheat and rice-maize cropping systems in both districts studied in West Bengal [34]. CA adoption in India is still in the initial phases. Over the past few years, the adoption of ZT expanded to cover about 1.5 Mha [32].

2.5 Pulses in crop rotation

Meeting the N demands of the crop efficiently with fewer N losses and more use efficiency is a critical challenge for the food production community [35]. Many researchers reported that pulse crops can significantly improve soil nitrogen availability, soil water conservation, and increase total system productivity. Gan et al. [36] reported that the practice of growing pulses helps in biological fixation of atmospheric N_2, increases total grain production by 35.5%, protein yield by 50.9%,

Location/system	Kharif	Rabi
Rice-wheat		
Jammu, Jammu and Kashmir Palampur, Himachal Pradesh	50% NPK through fertilizers +50% NPK through FYM 50% NPK through fertilizers +50% N through organic sources such as FYM green manure and wheat straw	100% NPK through fertilizers
Kalyani, West Bengal	50% NPK through fertilizers +50% N through FYM/green manure or rice straw	100% NPK through fertilizers
Navsari, Gujarat	75% NPK through fertilizers +25% N through FYM or green manure	
Faizabad, Uttar Pradesh	50% NPK through fertilizers +50% N through FYM or green manure	100% NPK through fertilizers
Rice-rice		
Jorhat, Assam Karamana, Kerala	75% NPK through fertilizers +25% N through rice straw 50–75% NPK through fertilizers +25–50% through FYM or crop residue or green manure	75% NPK through fertilizers
Siruguppa, Karnataka	50–75% NPK through fertilizers +25–50% N through rice straw or *glyricidia* green leaf manure	100% NPK through fertilizers
Rajendranagar, Telangana	50% NPK through fertilizers +50% N through *glyricidia* green leaf manure	100% NPK through fertilizers
Rice – Maize		
Kathalgere, Karnataka	75% NPK through fertilizers +25% N through FYM or paddy straw or*glyricidia* green leaf manure	100% NPK through fertilizers
Pearl Millet – Wheat		
S.K. Nagar, Gujarat	50–75% NPK through fertilizers +25–50% N through FYM/wheat straw/sunhemp	75% NPK through fertilizers
Bichpuri, Uttar Pradesh	50–75% NPK through fertilizers +25–50% through FYM or green manuring	75% NPK through fertilizers
Sorghum – Wheat		
Akola, Maharashtra	50% NPK through fertilizers +50% N through FYM or wheat straw or *Leucaena* loppings	100% NPK through fertilizers
Rahuri, Maharashtra	50% NPK through fertilizers +50% N through FYM	100% NPK through fertilizers

Table 2.
Best INM treatments practicing under various cropping systems of India.

and fertilizer-N use efficiency (FUE) by 33.0% over the summer fallow system. Diversifying cropping systems with pulses such as dry pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medikus), and chickpea (*Cicer arietinum*), etc. can serve as an effective alternative to summer-fallowing in rainfed dry areas. These pulses could increase the systems' productivity and decreases the negative impacts on the environment.

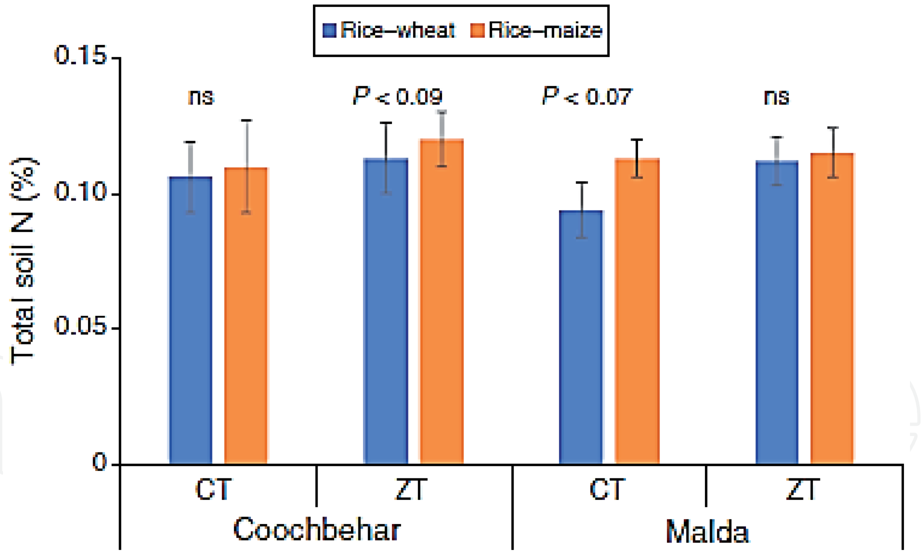

Figure 5.
Effect of ZT and CT on total soil N (0–10 cm) under rice–wheat and rice–maize systems at different districts of West Bengal (Source: [34]).

The inclusion of pulse crops in the crop rotation aids in the provision of improved crop yields and decreased N fertilizer requirements [37] and enhanced nitrogen use efficiency [38]. Pulse crops provide a large portion of N requirements to subsequent cereal crops and maintain economic returns [39]. Reduction in N fertilizers requirements naturally reduced the cost of cultivation thereby benefiting the farmers with less expenditure. Long-term experiments revealed that crop diversification with pulses and oilseed can help farmers to improve overall agricultural sustainability [40].

2.6 Fertigation and foliar spraying

Fertigation is a technique of supplying plant nutrients along with irrigation which helps in increasing crop yields or N fertilizer efficiency in many conditions with different crops [41]. Supplement of N and P fertilizer through fertigation technique significantly enhanced the wheat grain yield by 16% as compared to top-dressed N [42]. The fertigation process allows the soil to absorb up to 90% of supplied nutrients, while it is only about 10 to 40% under dry fertilizer or granular application. It ensures saving in fertilizer quantity of about 40–60%, because of better fertilizer use efficiency and reduced leaching losses [43]. Application of liquid biofertilizers and mineral fertilizers along with drip fertigation in green gram cultivation significantly increased the number of pods plant, number of seeds pod^{-1}, test weight, seed yield, and haulm yield [44]. Manikandan and Sivasubramaniam [45] reported that drip fertigation with 100% recommended dose of fertilizer through water-soluble fertilizers + foliar feeding with 0.5% $ZnSO_4$ resulted in the highest onion bulb yield and quality. Various advantages of fertigation in agriculture production are illustrated in **Figure 6**.

The positive effects of foliar spraying of zinc nano-fertilizer on vegetative growth parameters of pearl millet [46] on and snap bean plants [47] are reported. Foliar application of micronutrients increases the vegetative growth, consequently higher production capacity which reflected in the quality of barley [48] and faba bean [49].

2.7 Water-soluble fertilizers

Water-soluble fertilizers are 100% soluble in water which is suitable for foliar application due to their low salt index to reduce the potential for the burning of

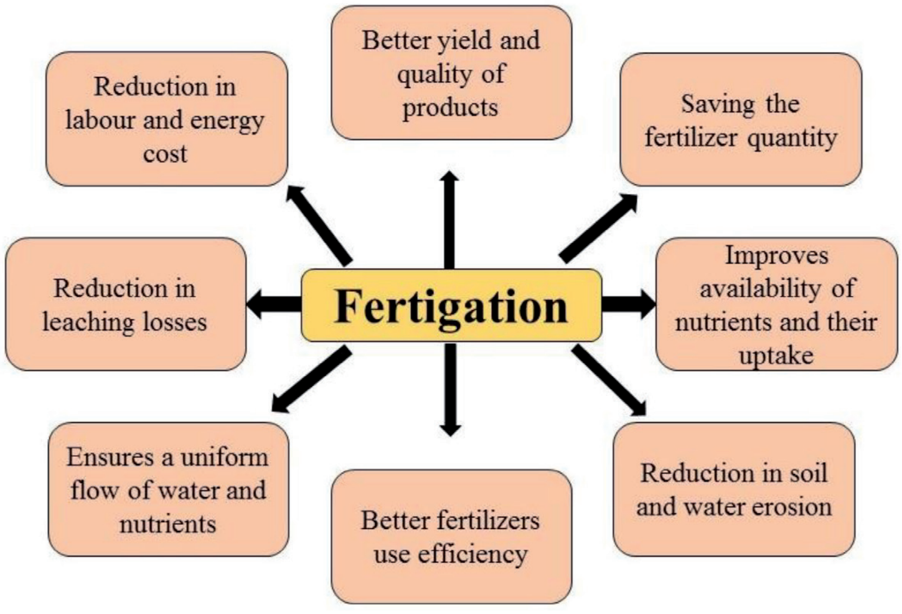

Figure 6.
Advantages of fertigation technique in agriculture.

plant tissue. It is also used in fertigation, sprinkler, or drip irrigation systems to increase yield and to improve the quality of fruits and vegetable crops. These fertilizers should meet certain criteria such as 100% solubility, high purity, low salt index, (EC = 0.9–1.2), pH acidic (5.5 to 6.5), and no inert matter, free from sodium and chloride, driven by R&D, suitable for fertigation and foliar application, higher nutrient use efficiency, etc. These fertilizers are mostly the combination of N, P, K, Ca, Mg, S, and micronutrients with different ratios developed to suit the type of crop, quality of water, soil fertility, and climatic conditions [50]. The Fertilizer Control Order (FCO) approved water-soluble fertilizers and their nutrient composition is presented in **Table 3**.

2.8 Biofertilizers

Biofertilizers are the source of microbial inoculants prepared in a controlled laboratory condition that acts as a substituent for chemical fertilizer and helps to achieve sustainable agriculture [51] boosting farm productivity [52]. Several studies indicated the use of biofertilizers in agriculture enhanced crop yields at greater levels. Usage of biofertilizers such as *Azotobacter*, *Azospirillum, Rhizobium* for N, and phosphate solubilizing bacteria (PSB) for P, vesicular-arbuscular micorhizae (VAM) for other nutrients availability in crop cultivation helps in improving crop yields and quality. Soil inoculation with *Azotobacter*, *Azospirillum,* and PSB produced maximum crop yields by 5–10% over farmers' practice [53]. In another study under jute, the yield was increased by 19% due to biofertilization over RDF, rice by 8% and green gram by 12%. Rao [53] studied the effect of BF on nutrient recovery. The study revealed that NPK recovery increased from 62.0% to 74.0% in recommended fertilizers + BF treatment. Combining soil test based fertilizer recommendation with organics and biofertilizers under maize cultivation considerably enhanced the recovery of N from 18–66%, P from 9–36%, K from 33–88%, and S from 17–34% [54] (**Table 4**). ICAR is also promoting the development of biofertilizers consisting of *Azospirillum lipoferum*, *Azotobacter chroococcum* and plant growth promoting *Rhizobacteria* (PGPR Mix I). But in India, the current supply position is very low (<100, 000 t), as the total anticipated biofertilizers demand is 1 Mt. [53].

Product (grade)	Nutrient composition (%)						
	N	P	K	S	Ca	Mg	Zn
NPK (13–40-13)	13	40	13				
NPK (18–18-18)	18	18	18				
NPK (13–5-26)	13	5	26				
NPK (6–12-36)	6	12	36				
NPK (20–20-20)	20	20	20				
NPK (19–19-19)	19	19	19				
NPK (12–30-15)	12	30	15				
NPK (12–32-14)	12	32	14				
Potassium nitrate (13–0-45)	13	0	45				
Mono potassium phosphate (0–52-34)	0	52	34				
Calcium nitrate	15.5				18.8		
Potassium magnesium sulphate			22	20		18	
Mono ammonium phosphate (12–61-0)	12	61	0				
Urea phosphate (17–44-0)	17	44	0				
Urea phosphate with SOP (18–18-18)	18	18	18	6.1			
NPK Zn (7.6–23.5-7.6-3.5)	17.6	23.5	7.6				3.5

Table 3.
FCO approved 100% water-soluble fertilizers (Source: [50]).

Treatment	Nutrient (%)			
	N	P	K	S
Soil test based fertilizer	18	9	33	17
Soil test based fertilizer + Organics	59	30	80	26
Soil test based fertilizer + Organics + Bio fertilizers	66	36	88	34

Table 4.
Apparent recovery of nutrients as affected by different treatments under maize cultivation (Source: [54]).

2.9 Nano fertilizers

Regular synthetic fertilizers are highly vulnerable to the losses such as leaching, volatilization, percolation, etc. which ultimately results in low NUE which is below 30%. "Nano fertilizers" are prepared by extracting the nutrients from different parts of the plant through chemical, physical, mechanical, or biological methods using nanotechnology. Nanotechnology has a long-term impact on agriculture and food production as the usage of these fertilizers in farming improves crop growth, yield, and quality parameters while increasing the nutrient use efficiency (NUE), and reducing the wastage and cost of cultivation. A significant higher selenium uptake was observed in the plots where nano-sized particles were applied [55]. Nano-fertilizers in agriculture enhanced nutrient uptake and crop productivity [56, 57]. The percent yield increased in different crops due to the addition of Nano-fertilizers illustrated in the table below (**Table 5**).

2.10 Customized fertilizers

Customized fertilizers (CF) are multi-nutrient (macro-N, P, K, secondary-Ca, Mg, S, and micro nutrient-Zn, Cu, B, Fe, Mn, etc.) produced from both inorganic

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Nano fertilizer	Crops	% Yield increased
Aqueous solution on nano iron	Cereals	8–17
Nano silver + allicin	Cereals	4–8.5
Nano fertilizer + urea	Rice	10.2
Nano-encapsulated phosphorous	Vegetables	12.0–19.7
Rare earth oxides nanoparticles	Vegetables	7–45
Nano chitosan-NPK fertilizers	Wheat	14.6
Nano chitosan	Tomato	20.0
Nano powder of cotton seed and ammonium fertilizer	Sweet potato	16
Nanoparticles of ZnO	Cucumber	6.3

Table 5.
% yield increased by the application of nano fertilizer in different crop production (Source: [56]).

and organic sources, manufactured through a systematic process of granulation designed to facilitate the availability of a complete range of nutrients to the plant growth during its growth stages [58]. It has various advantages besides soil health enhancement and maximum crop yields (**Figure 7**). On the basis of nutrient uptake, total soil fertility status, crop nutrient requirement, and fertilizer nutrient to be applied and its use efficiency, grades of the CF are prepared [59]. Different forms of CF available across various geographical areas of India presented in **Table 6**.

2.11 Sensors based technologies for irrigation and fertilization

A new approach of collecting real soil moisture using sensors offers real potential for reliably monitoring the status of soil water in croplands [60]. The use of sensor technology for an automatic irrigation system is highly economical

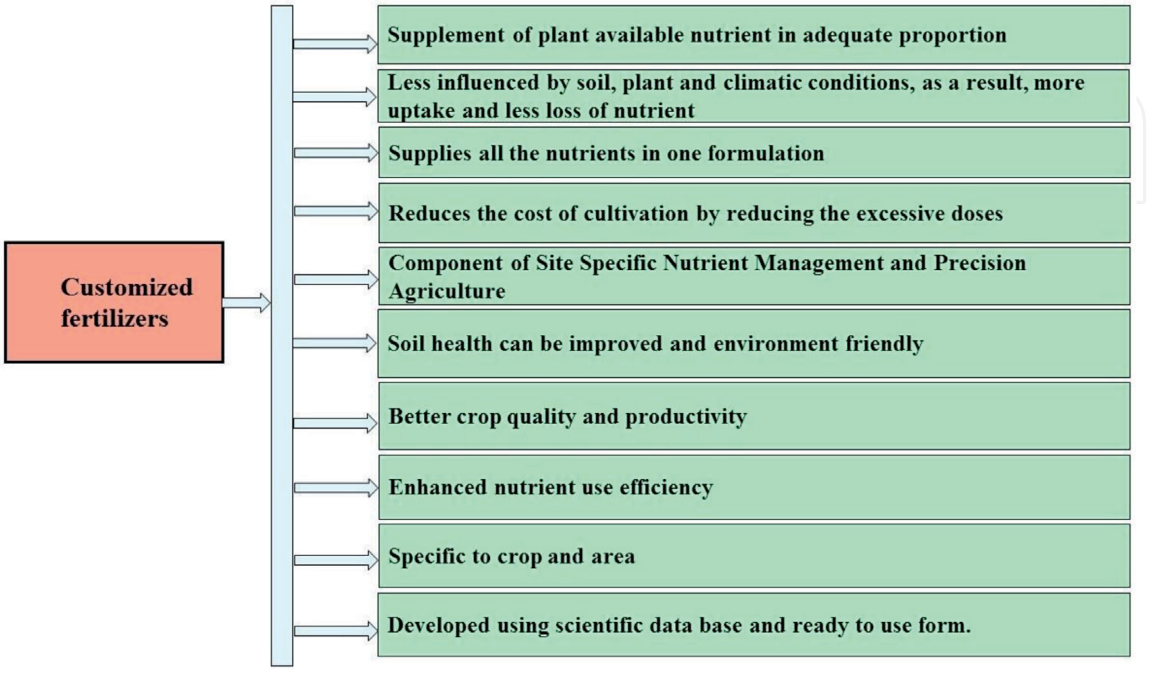

Figure 7.
Advantages of using customized fertilizers in agriculture.

Crops	Formulations (N:P:K:S:Zn:B)/ N:P:K: Zn/ N:P:K:S:Mg:Zn:B:Fe/ N:P:K:S:Zn:B)	Geography
Rice	8:15:15:0.5:0.15:0	GB Nagar, Ghaziabad, Rampur, Shahjahanpur, Mainpuri and US Bagar
Wheat	10:18:25:3:0.5:0	Muzaffarnagar, Barielly, Bijnore, Hathras, Pilibhit, Mathura, Meerut and Etah
Maize	14:27:10:4:0.5	Karimnagar, Warangal and Ranga Reddy
Potato	8:16:24:6:0.5:0.15	Agra, Aligarh, Budaun, Bulandshahar and Baghpath
Sugarcane	7:20:18:6:0.5:0	Moradabad, KR Nagar, Farukhabad and Ferozabad
Groundnut	15:15:15:9:0.5:0.2	Andhra Pradesh
Grape, Cotton, Onion, Banana, Tomato, Gourds & Leafy and Vegetable	15:15:15:5:2:0.5:0:0.2	Nasik, Dhule, Jalgaon, Pune, Ahmednagar and Aurangabad

Table 6.
Customized Fertilizer Formulations available for different crops in India (Source: [57]).

as it aids in the provision of optimum use of water, saving money, electricity, and time of the farm. Many researchers reported significant water saving through this technology [61]. The use of sensors with drip and sprinkler irrigation systems can effectively improve the water application efficiency up to 80–90% as compared to the surface irrigation method (40–45%) [62]. In Egypt, potato yields were increased and a loss of 2 billion pounds was recovered in a year through the wireless sensor network technology [63]. Sensors in the prediction of crop nitrogen requirements are also practically significant in agricultural production and environmental safety. Usage of an optical sensor-based algorithm that employs yield prediction and N responsiveness by location can enhance the crop yields and minimize the environmental contamination caused by the application of excessive N fertilizers [64].

2.12 Vertical farming with hydroponics and aeroponics

Vertical farming is a type of indoor farming where the crop grows in multiple levels on a vertical axis which results in maximum production and efficiency per square foot [65]. It is a potential option to achieve sustainability in the agricultural system. By replacing traditional farms with vertical farming techniques, society would be protected both economically and environmentally. It reduces the amount of resources needed and also decreases agriculture's carbon footprint. Hydroponics/aquaponics are nothing but the produced plants in a nutrient-enriched solution in the presence or absence of a growing medium [66]. This system reduces labor, water, and soil efficiently. This system is more sustainable and profitable in food generation; is the future of alternative agriculture [67]. Aeroponics is a subcategory of hydroponics that suspends the roots in the air, thus there is around 95% saving of water than traditional systems [66]. Cultivation of these hydroponics and aeroponics in vertical farming under a controlled environment makes more profitable yields as there will be no damages to the plant by the external factors. By implementing vertical farms in communities, the cost of food would decrease, the economy could thrive, transportation costs are cut dramatically, and therefore so are food prices, create employment and increase educational opportunities. Further, people would be able to become economically and nutritionally stable as it makes a huge impact on both food insecurity and poverty.

3. Programs and policies executed by GOI for sustainable agriculture

The convergence of various policy programs has been initiated by the GOI to ensure the effective utilization of existing resources are briefly discussed here. The National Mission of Sustainable Agriculture (NMSA) under the National Action Plan on Climate Change (NAPCC) was launched in 2010 in order to encourage the judicious management of existing resources. The Paramparagat Krishi Vikas Yojana (PKVY) mission was executed in conjunction with the Indian Council of Agricultural Research (ICAR) and state governments of India to extensively leverage adaptation of climate-smart practices and technologies. In 2015, GOI has launched the Soil Health Card (SHC) scheme to protect the soil health for future agriculture with the main objective of analyzing soil samples of farmers' fields and recommending fertilizers accordingly. Additionally, Neem-Coated Urea (NCU) was introduced to the farmers of India for a slow supplement of nitrogen (N0 by reducing the N losses and excess addition of urea fertilizers. Programs such as the National Project on Organic Farming (NPOF) and National Agroforestry Policy (NAP) was introduced in 2004 and 2014 respectively to encourage the farmers with more profit and ecosystem service through supplements of plant nutrients in the form of organic amendments, improvement of soil carbon storage, and soil protection from erosion loss. States like Andhra Pradesh, Himachal Pradesh, Sikkim, etc. have already adopted and promoted organic farming practices on a wider scale. "Sikkim" state recognized as an "*Organic State*" of India. A "4 per 1000/4 per mille" initiative launched by France in 2015 as a part of the Global Climate Action Plan (GCAA) adopted by the United Nations Framework Convention on Climate Change (UNFCCC) at a conference of the parties (COP) 22 also recognized the importance of SOC in achieving sustainability in agriculture system. It considered the technologies such as agroforestry, conservation agriculture system intensification (CASI), and landscape management to improve SOC.

4. Conclusion and way forward

The post-Green Revolution period witnessed a drastic change in environmental conditions and the status of existing natural resources. A gradual decline in soil fertility has occurred by the non-judicious management of chemical fertilizers that further exacerbated by the progressively decreasing usage of organic amendments. Added to this, abysmally low NUE of applied fertilizers impacted agricultural productivity and sustainability to a great extent. Supplement of plant nutrients in balanced proportion is important; at least in such a way that the critical growth stages of the crop meet the required amount of nutrients results in achieving maximum crop yields that satisfy the growing population. Hence, these constitute a vital component of sustainable food production. Further, agricultural intensification is in critical need of improvements in the flow of plant nutrients to the crops from the soil through efficient nutrient uptake. Improved technologies involved effective nutrient management strategies are the need of the hour to accomplish the targeted food grain production while balancing the stability of the agriculture system, farmers' income, and feed the over-exploiting population of the country.

- Creating awareness among the farmers regarding fertilizer management, nutrient flows, and use efficiencies are essential.
- Strengthening the database on nutrient recommendations specific to soil type, cropping system, and climatic regions is crucial to manage soil productivity.
- Efficient modern technologies are critical in order to ensure the food security of the country.
- Evaluation of technology should be based on locally available resources.
- Identifying policy interventions needed to promote soil management practices that help in achieving maximum crop yields and nutrient use efficiency.
- Developing site-specific holistic land management practices to sustain production rates.
- Implementing a protocol for payment to farmers for strengthening of ecosystem services generated through adoption of sustainable agriculture.
- Bringing sustainability into the agricultural ecosystem needs to be meaningful and result-oriented.

Conflict of interest

The authors declare no conflict of interest.

Abbreviations

%	Percentage
B	Boron
C	Carbon
Ca	Calcium
CASI	Conservation agriculture system intensification
CF	Customized fertilizers
COP	conference of the parties
Cu	Copper
FCO	Fertilizer Control Order
Fe	Iron
GCAP	Global Climate Action Plan
GFSI	Global Food Security Index
GM	Green manure
GOI	Government of India
GR	Green revolution
GVA	Gross value added
ha	Hectare
ICAR	Indian Council of Agricultural Research
INM	Integrated Nutrient Management
K	Potassium
Kg	Kilo gram
Mg	Magnesium

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Mn	Manganese
Mt.	Million tons
N	Nitrogen
N_2	Atmospheric Nitrogen
NAP	National Agroforestry Policy
NAPCC	National Action Plan on Climate Change
NCU	Neem-Coated Urea
NMSA	National Mission of Sustainable Agriculture
NPOF	National Project on Organic Farming
NUE	Nutrient Use Efficiency
P	Phosphorus
PKVY	Paramparagat Krishi Vikas Yojana
PSB	Phosphate solubilizing bacteria
S	Sulphur
SHC	Soil Health Card
SOC	Soil organic carbon
SYI	Sustainability yield index
t	Tons
UNFCCC	United Nations Framework Convention on Climate Change
yr.	Year
Zn	Zinc

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