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Integrating biological and organic nutrient sources for enhanced productivity and soil sustainability in maize-wheat cropping system review

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Abstract
Crop and soil conservation practices have a considerable impact on soil development, agro-ecosystem performance, and the long-term sustainability of agricultural systems. Among the main factors limiting crop production, nutrient availability is second only to water. Maintaining consistent rice yields has become increasingly challenging, especially in areas where maize-wheat productivity declines despite the use of recommended nutrient management strategies. Combining organic nutrient sources with bio-fertilizers offers a promising approach to improve and sustain rice productivity. However, chemical fertilizers remain essential, contributing roughly 50% to the increase in food grain output—an important aspect given our country's growing population.

Effective nutrient management can boost crop yields, increase farm profitability, and reduce nutrient losses. Organic fertilizers improve the soil's physical and biological qualities, but they are poor in nutrient concentration, necessitating higher volumes for successful plant development. In contrast, bio-fertilizers improve the soil's physical, chemical, and biological attributes, which are crucial for better crop yields. Inorganic fertilizers provide essential nutrients in readily available forms, leading to quick results. However, their continuous use without supplementation can cause soil degradation, increased acidity, and environmental problems.

An INM approach (Integrated Nutrient Management) combining inorganic, organic, and biological sources- provides a cost-effective and more sustainable solution for preserving soil health and productivity while reducing environmental harm. Organic manure, either alone or in combination with bio-fertilizers, has been found to considerably boost nitrogen, phosphorous, potassium, and sulphur absorption in rice.The greatest improvements in soil health and microbial activity were seen with organic nitrogen sources, either alone or combined with bio-fertilizers. A 50:50 ratio of organic to chemical fertilizers resulted in better nutrient availability (NPK) and higher rice yields compared to using 100% chemical fertilizers, while also lowering chemical inputs and promoting sustainability. This review highlights a comprehensive nutrient management strategy that boosts crop productivity and nutrient use efficiency sustainably.

Keywords: Organic, biofertilizers, soil health, maize, wheat, productivity

Introduction
In the North-Western region of India, the ongoing practice of repeatedly cultivating rice and wheat has a detrimental impact on agricultural production by causing the loss of natural resources and a decrease in soil fertility. As a result, in order to maintain soil quality and assure long-term yield, crop rotations must be implemented. Implementing alternative cropping systems and soil management techniques could prove advantageous in enhancing soil fertility and promoting environmental well-being. It has been determined that growing maize and wheat together is a good way to diversify crops and a good substitute for the existing wheat and rice cropping system (Dhaliwal *et al.*, 2021). The maize-wheat cropping system is the most significant among various maize-based systems, ranking first overall and third after rice-wheat and rice-rice systems. It encompasses an area of 1.8 million hectares, contributing approximately 3% to India's food grain production (Sudhakar *et al.*, 2019).

Maize (*Zea mays* L.), sometimes known as the "queen of cereals" due to its high genetic production potential in contrast to other cereals, is one of India's principal cereal crops. Maize can be grown in a variety of agroclimatic conditions, soil types, and cropping sequences. In India, maize accounts for 3% of worldwide production and is ranked as the world's fifth-largest producer of maize behind the US, China, Brazil, & Mexico. It has become a crucial commodity for food, nutritional security, and the agriculture trade. It is cultivated on nearly 197 Mha area with production of 1148 Mt and productivity of 5823.8 kg ha^{-1}. All over the world contributes 37% to the global grain production (FAO STAT, 2022). India produced 33.62 million tonnes of maize in an area of 10.04 Mha in 2021-22. In India, currently, maize is primarily utilized for producing poultry feed and extracting starch. It supplies essential raw ingredients for a variety of enterprises, including biofuel, as well as food, animal feed, and fodder. In India, the *Kharif* season accounts for about 75% of maize production, with the remaining 25% occurring throughout the spring/summer and *Rabi* seasons. During the *Rabi* season, maize is cultivated with assured irrigation; however, during the *Kharif* season, it is mainly grown under rainfed conditions. For the development of all growth phases, it needs more N and P than other essential elements. Essential nutrient components should be supplied in sufficient amounts to maintain soil fertility and generate high yields. It has been demonstrated that integrating organic and inorganic fertilizers to apply plant nutrients in a balanced manner improves soil fertility and maize production (Sudhakar *et al.*, 2019).

Wheat (*Triticum aestivum* L.) is the world's single most important cereal crop that has been considered an integral component of the food security system of several countries. More than 35% of the world's population depends on it as their primary source of nutrition. It is India's second primary cereal crop, behind rice. In India, the area under wheat is 30.47 Mha with a total wheat production of 106.84 Mt in 2021-22 (agricoop.nic.in). Uttar Pradesh, Punjab, Haryana, and Madhya Pradesh are the top four wheat-producing states, constituting about 70%of the total wheat cultivation in India (Ministry of Agriculture and Farmers Welfare, 2020- 21).

Organic matter (SOM) dynamics are significant in natural ecosystems and extensive agriculture. In high-fertilization intensive agricultural systems, the various organic components could act as a temporary nutrition reserve. If this reservoir is managed properly, it should be possible to employ soil and fertilizer nutrients efficiently (Paul, 1984) [97]. It's critical to keep soil organic carbon (SOC) levels high for several reasons. First and foremost, enhancing soil quality requires SOC. It increases nutrient availability, enhances water retention capacity, stimulates soil organism activity, encourages soil aggregation, and finally boosts soil productivity and fertility (Karlene *et al.*, 1997), so assuring an agroecosystem's long-term viability. In addition to improving carbon absorption in soils for agriculture and functioning as a sink for atmospheric carbon dioxide (CO2), soil may help decrease the global increase in greenhouse gas concentrations (Young, 2003). Adopting optimum management methods, that include conservation agriculture, fertiliser and biosolids or organic amendments application, crop rotation, and enhanced residue management, can boost the retention of carbon in soils used for agriculture and turn soil into a significant sink for atmospheric carbon (Lal, 2003) [38]. Among these methods, it is well known that applying mineral fertilizers and manures in a balanced manner helps maintain and raise the levels of SOC in agricultural soils (Rudrappa *et al.*, 2006).

Multiple long-term fertilizer experiments conducted around the world have demonstrated that balanced fertilization with mineral fertilizers and composted manure can maintain high crop yields, improve the state of soil nutrients, and accumulate large amounts of residue which can be added back to the soil to raise SOC concentration (Holeplass *et al.*, 2004). Soil organic carbon, the primary component of soil organic matter, is a significant indication of the quality of the soil, sustainable farming, and the fertility of the soil (Yuan *et al.*, 2021). The stability of different components of soil organic carbon varies due to variations in turnover time and physicochemical properties. Labile fractions of soil organic carbon are less because the pool depletes more quickly than non-labile pools (Paul *et al.*, 2000) [98]. Since microbial activity changes the highly recalcitrant or passive pool of SOC very slowly, it is rarely a reliable predictor of soil quality. In comparison to green manure, FYM adds more to the passive pool of C (Majumdar *et al.*, 2008). To identify even the smallest changes in the SOC, it is useful to fractionate the SOC into active and passive pools (Mandal *et al.*, 2013) [41]. The active soil organic carbon fraction is the primary source of energy for soil microorganisms that can influence crop nutrient availability and enhance soil chemical and physical properties. (Xing *et al.*, 2019).

The use of organic or inorganic fertilizer alone can have both beneficial and negative impacts on soil health, nutrient availability, and plant development. Organic sources are naturally occurring nutrient sources that can improve soil's biological and physicochemical and qualities while also increasing output& productivity. Vermicompost and well-decomposed FYM are added to the soil to boost its physical properties and act as a binding agent in addition to providing plants with nutrition.

Organic manure is the principal source of organic matter in the soil. Numerous soil ecosystem functions, such as soil structure creation, nutrient cycling, carbon sequestration, water retention, and microorganism energy supply, depend heavily on soil organic matter (Lakaria *et al.*, 2011). The biggest disadvantage of using organic sources for the nutrients is that they may not contain significant quantities of plant nutrients, as they are just soil amendments. As a result, adding organic matter to soil by itself cannot fully replace inorganic fertilizer, and vice versa; rather, their functions are complementary. Therefore, in order to replenish soil nutrients and sustain crop productivity, it appears as though applying chemical fertilizers and organic manure at the same time is the best course of action.

Combining inorganic, organic, and biofertilizers is being marketed as a strategy known as integrated nutrition management. As a result of nutrient supplies, biofertilizer maybe essential in this situation toincrease crop yields (Kader *et al.*, 2002). Considering the significance of biofertilizers, Azotobacter is a significant contributor. The rhizosphere of a large number of crops, including rice, sorghum, wheat, maize, sugarcane, potatoes, cotton, tomatoes, brinjal, and cabbage, is the habitat of the adaptable free-living nitrogen-fixing bacterium Azotobacter. It fixes 10–20 kg N ha-1 during the cropping season (Jadhav *et al.*, 1987). Significant amounts of physiologically active substances, including vitamins, pantothenic acid, nicotinic acid, heteroauxins, biotin, gibberellins, & others, are produced & secreted by Azotobacter in addition to fixing nitrogen. (Rao, 1986). The excretion of ammonia in the rhizosphere in the presence of root exudates, which aids in modifying the plants' intake of nutrients, is another significant aspect of Azotobacter's association with crop development (Narula and Gupta, 1986). Incorporating *Azotobacter* into intercropping involving cereals and pulses establishes a synergistic relationship, optimizing nutrient utilization and fostering a balanced ecosystem. Cereals assume a crucial role by providing structural support to pulses, mitigating the risk of lodging, while pulses reciprocate by contributing nitrogen to the soil, enhancing overall fertility. This cyclic collaboration not only enhances soil health but also promotes resource efficiency and resilience, adapting to changing agricultural conditions. As intercropping emerges as an effective and sustainable system for maize and soybean cultivation, it proves to be more efficient even under limited resources (Ren *et al.*, 2017). The symbiosis of legumes with maize further enriches the soil, converting minerals into organic forms accessible for crop absorption, significantly decreasing the need for nitrogen fertilization (Li *et al.*, 2013). The advantageous characteristics extend to runoff reduction, exemplified by maize-cowpea intercropping, effectively concealing the soil surface and protecting against soil depletion (Kariag, 2004). Moreover, the ability of legumes to fix atmospheric nitrogen provides a cost-effective alternative for maintaining soil fertility (Phiri *et al.*, 2013). Intercropping non-fixing and N-fixing crops consistently results in higher production and yields than monocropping (Seran and Brintha, 2010) [92].

Humans have traditionally used well-decomposed Farm Yard Manure (FYM) to boost crop output, microbial activity, soil fertility, soil organic matter, and structure for sustainable agriculture (Blair *et al.*, 2006; Kundu *et al.*, 2007) [36]. However, a good mix of both inorganic & organic fertilizers is more beneficial to crops' growth, development, and yield than either one alone (Budaruddin *et al.*, 1999; Hossain *et al.*, 2002; Manna *et al.*, 2005). In a maize-wheat cropping system, balancing N, P, and K fertiliser applications with FYM was the most successful technique for increasing crop output (Brar *et al.*, 2015) [96].

Improved soil physical conditions and a rise in SOC may have resulted in higher maize and wheat harvests, as well as enhanced nutrient absorption (Brar *et al.*, 2015) [96]. When organic material and inorganic fertilisers are used simultaneously, the system becomes more productive and the soil remains healthy for a longer period of time. In intensive agricultural systems, the application of organic manure combined with the appropriate fertiliser rate increased nitrogen turnover in the soil plant system (Metkari and Dhok, 2011).

Soil supplemented with half of the recommended chemical fertilizers and enhanced manures. Compared to applying manures alone in maize-rice crop rotation, there was a notable improvement in agricultural output, soil mineral N, and organic carbon pools. Using manures in conjunction with beneficial microbes could be a practical and environmentally friendly way to recycle different farm wastes and raise the amount of carbon in different soil components (Velmurugan and Swarnam, 2021).

Soil organic matter includes fine plant roots, humus, charcoal, living microbial biomass, and particulate organics. Through a variety of enzymatic processes produced by the soil biota, SOM is also a dynamic storage of nutrients that cycle to plant-available forms. This is somewhat linked to plant requirement by releasing labile carbon from roots, which stimulates soil biological activity (Paterson, 2003) [94]. The mineralization of SOM represents a gross flux to the atmosphere ten times larger than that of burning fossil fuels, making it the greatest C stock in the majority of terrestrial ecosystems (Amundson, 2001) [93].

Concerns have been expressed regarding the interactions of soil organic carbon stocks and the possible role of soil in the prolonged accumulation and storage of atmospheric CO2 (Srinivasarao *et al.*, 2012) [95]. Cropland can reach a significant level of SOC through practices such as conservation tillage, integrated management of soil fertility, effective crop rotations, and the application of appropriate amounts of organic compost & inorganic fertilizers (Srinivasarao *et al.*, 2012; Bhattacharyya *et al.*, 2011; Wright and Hons, 2005) [95]. Including legumes in crop rotations is a highly effective method to achieve these benefits. Even with a 25% reduction in nitrogen application, incorporating pulses can still contribute nitrogen through biological nitrogen fixation (BNF) and improve carbon sequestration in the soil, resulting in a comparable output to the suggested methods (Tripathi *et al.*, 2021). When Inorganic and organic N fertilizers were administered simultaneously in a maize-wheat cropping system, the quantity of soil organic matter increased along with the type and amount of soil microorganisms, all of which enhanced soil fertility (Yang *et al.*, 2020) [88]. The distribution of SMBN, SMBC, and mineralizable C, as well as the depth of SOC, is significantly impacted by the long-term use of both Inorganic and organic fertilizers. The active and passive pools of C and N in the surface soil were preserved through using the balancing fertiliser NPK alone or in conjunction with FYM (Kaur *et al.*, 2008). The continuous use of fertilizer N alone has redued soil organic carbon, according to long-term fertilizer tests conducted in India's acid Alfisols under the maize-wheat cropping system (Sharma *et al.*, 1998). A balanced application of inorganic fertilizer either maintained or raised the SOC over the baseline values, per many long-term field studies. Land management strategies such as cropping frequency (Campbell *et al.*, 1995), reduced tillage, fertilizer and manure application all have an impact on SOM gains and losses (Sommerfeldt *et al.*, 1988).

Influenceonsoil quality

The terms "soil quality" and "soil health," which are used interchangeably (Harris and Bezdicek 1994) [26], refer to a soil's ability to support biological production, encourage plant growth, preserve environmental quality, and support animal health within ecosystem bounds (Doran and Parkin 1994). The impact of management approaches is shown by a variety of chemical, physical, biochemical and biological, parameters that affect soil quality (Elliott *et al.* 1994). The chemical, physical, and biological properties of the soil have been adversely affected, and the ecosystem has been deteriorated by intensive farming and continuous pesticide use. Santos, Monteiro e Araujo (2008). Furthermore, the growing cost of agrochemicals has exacerbated the financial instability of marginal and small farmers (Tensingh 2017) [79]. Organic and biological sources of nutrition are crucial in addressing these issues by banning the use of artificial agrochemicals. Chand, Anwar, and Patra (2006) [13] state that organic inputs such as FYM (Farmyard manure) give the soil microflora energy to increase the organic carbon content and microbial biomass carbon, which are considered indicators of soil health. A key component of organic farming, FYM has long been one of the primary methods for reclaiming soil losses. Furthermore, the growing cost of agrochemicals has exacerbated the financial instability of marginal and small farmers (Tensingh 2017) [79]. Organic and biological sources of nutrition are crucial in addressing these issues by banning the use of artificial agrochemicals.

Chand, Anwar, and Patra (2006) [13] state that organic inputs like FYM (Farmyard Manure) give the soil microflora energy to increase the organic carbon content and microbial biomass carbon, which are considered indicators of soil health. FYM, a fundamental component of organic farming, has long been one of the most effective strategies for recuperating soil loss (Howard 2000) [28]. By supplementing the soil with organic materials. Unlike synthetic agrochemicals, organic manures enhance soil quality by making nutrients more accessible to plants and boosting their potential to stimulate development (Birkhofer *et al.* 2008) [12]. Developing a future organic agricultural system requires maximizing and promoting soil health because it helps retain nutrients and encourages soil aggregation, which increases water infiltration & reduces erosion. Research experiences have demonstrated that the application of synthetic agrochemicals cannot restore the fertility or health of soils; thus, a portion of the biological products that the soil produces must be returned to the soil (Tensingh 2017) [79].

Plant growth relies heavily on soil health management to ensure long-term fertility, stability, and productivity. Gangware et al (2017) [22]. Conventional agriculture has produced major changes to agricultural soils, including changed micro-ecological niches, reduced beneficial microbial diversity, and decreasing soil fertility. This is a result of conventional agriculture's heavy reliance on agri-inputs, including chemical pesticides and fertilizers, to boost output. To reduce the adverse effects of agrochemicals and satisfy the expanding population's food demands, a sustainable solution is essential (Singh *et al.* 2019) [76]. Utilizing organic methods, such as supplementing soil with compost and farmyard manure, can reduce soil deterioration brought on by excessive use of synthetic agrochemicals and a lack of recyclable materials. Organic farming may increase crop yield and soil quality by altering soil parameters over time. After four years, organic and low-input farming approaches increased the reserve pool of stored nutrients, soluble phosphorus, exchangeable potassium, pH, nutrient/water utilisation efficiency, and EC level stability (Clark *et al.* 1998; Gaur, Nilkantan, and Dargan 2002) [16, 24]. Furthermore, Rupela (2007) [58] showed that plant biomass is the only input required to increase soil organic matter. Apart from providing nutrients to crops and improving soil structure in arid areas, organic manures also enhance seed germination, increase the soil's capacity to hold water, and create the perfect microclimate for the development of a diverse range of beneficial rhizospheric microorganisms (Sharma, 1991; Reddy Suresh, 2010) [57, 65].

Improving the condition of the soil is crucial for maintaining crop productivity and ecological integrity because soils offer a multitude of ecosystem services. While organic farming concentrates on feeding the soil, which in turn cares for crop plants, the contemporary farming system concentrates on feeding the crop plants (Alvares *et al.* 1999; Alam and Wani Shafiq 2003) [2, 3]. The only way to achieve sustainable agriculture is through the ecological transformation of today's "unproductive" & "waste" in the commercial framework of modern agriculture into productive (Shiva 1992) [69]. The decomposition of biological material increases the quantity of nutrients available to plants by releasing macro and micronutrients into the soil solution (Minhas and Sood 1994) [46]. The breakdown of soil organic material limits its potential to provide nutrients in rice-wheat cropping systems, especially on soils with a significant initial organic matter content (Yadav, Dwivedi, and Pandey 2000) [87]. Organic farming increased the soil's physicochemical qualities within the ecosystem, the amount of organic matter in the soil, and the labile form of nutrients (Subbiah and Kumaraswamy, 2000) [77]. According to Bhattacharaya and Barman (2018) [10], compost and renewable energy might be produced by adding carbonaceous materials, including straw, wood, bark, sawdust, and maize cobs. These materials reduced the water content due to N immobilization, and when the C:N ratio was high, they also had a detrimental impact on crop yields (Zhou *et al.* 2019) [90].

Bacteria, nematodes, protozoa, and arthropods are more common in organic soils than in traditional soils (Wu, Ingham, and Hu 2002) [83]. Because compost is made up of bacteria, actinomycetes, and fungus, a new supply of labile carbon not only enriches the rhizosphere but also promotes potentially helpful microbes (Balasubramanian and Rangaswami 1972; Gaur *et al.* 1973) [7]. Compost is also essential for managing plant nematodes and reducing pesticide effects by limiting their breakdown and movement through soil via sorption, the most significant interaction between organic matter and pesticides (Prasad, Mishra, and Gaur 1972; Gaur 1975) [53]. The labile form of carbon in compost boosted the activity of heterotrophic bacteria and fungi, as well as soil enzymatic activity, which is responsible for converting limiting nutrients into usable forms (Alvares *et al.* 1999) [3]. Unlike chemical farming, organic farming delivers high-quality products while enhancing soil fertility, structure, biological activity, carbon sequestration, and soil organic matter (SOM) content. Characterising the physical, chemical, and biological health of the soil in relation to long-term organic farming is critical for regulating nutrient and water use efficiency for optimal soil health and plant growth.

Influence on yield

Several researches have been conducted to investigate the productivity yield difference between conventional and organic farming. A meta-analysis by Ponisio *et al.* (2015) [51] observed that deficits in organic management, particularly in weed, insect, and disease control, phosphorus uptake in extremely acidic and alkaline soils, and nitrogen availability and usage are the variables that restrict productivity in organic crop rotations. Considering that organic crop yields are around 19.2% lower than conventional yields, organic farms were urged to adopt mixed cropping and a high degree of crop sequence variability to increase productivity per unit of land. These techniques are based on strategies that mimic natural systems and have been used for thousands of years. Since they have been demonstrated to improve soil health, reduce insect pressure, and foster biodiversity, they may raise yields while safeguarding the environment (Aulakh and Ravisankar 2017) [4]. Limited availability to nutrients from organic manures, a lack of options for soil enrichment, and insufficient management of pests, diseases, and weeds are believed to be the main reasons for lower productivity in organic farming systems. Because of crop needs and the unregulated nitrogen-releasing process, organic nitrogen is not very efficient in this system (Kirchmann *et al.* 2008) [30].

Raising the amount of organic matter in the soil is known to boost crop yields; Sharma and Mitra (1990) [64] discovered that employing organic materials enhanced the output of straw and rice grain. In a cropping system using linseed (*Linum usitatissimum* L.) and maize (*Zea mays* L.), the use of chemical fertilizers resulted in the maximum linseed seed output, whereas the application of chicken manure generated the best grain yield in maize (Ramesh *et al.*, 2008) [55]. Similar to FYM, Ranganathan and Selvaseelan (1997) [56] discovered that, in comparison to NPK fertilizer, applying composted rice straw and leftover mushrooms increased rice grain yields by 20%.

Grain and straw yields following FYM treatment at 7.5 t ha-1 were significantly greater than those from unfertilized regions, according Singh *et al.* (1998) [72]. Scented rice cultivated with the recommended inorganic fertilizers yielded a 20.1% higher grain yield when the optimal organic source combination of green manuring 5 tha-1 + FYM 10 t ha-1 was used (Kumari *et* *al.* 2010) [35]. Grain yields were enhanced when dhaincha (*Sesbania aculeata* L.) was utilized in organic rice and chickpea production (Singh, Prasad, and Sinha 2001) [73]. Unstable yields of potato tubers under organic farming were documented by Kler and Walia (2004) [82]. Baishya, Kumar, and Ghosh (2010) [6] found that Meghalaya produced more potato tubers with chemical fertilizers than with organic ones.

Yadav *et al.* (2002) [86] found that throughout the first four years of their study, organic farming produced less wheat and rice than conventional farming on average. Most of the crops that organic growers produce have yield levels that are typically lower than those of conventional systems (Aulakh *et al.* 2009) [5].

The main explanation for the lower sustainable yield indices in grains grown organically was the wheat crop's unexpected output (Hazra *et al.* 2014). Forster *et al.* (2013) [20, 27] evaluated a long field study carried out in tropical Madhya Pradesh in central India. Cotton-soybean-wheat crop rotation's economic performance under conventional, organic, and biodynamic management was contrasted. They found that while organic farming systems achieved significantly higher gross margins in the second year of crop rotation due to similar yields but lower variable production costs, conventional farming systems, on average, achieved significantly higher gross margins in the first year of crop rotation for all crops.

Applying 188 kg N ha-1+ cow dung + Azotobacter generated the highest plant height (53.74 cm), number of spikelets (8.93), grains per spike (15.10), and spike length (6.31 cm), whereas the control group produced the least amount (Kader *et al.*, 2002). In Ladakh, Jammu and Kashmir, Ram and Mir (2006) found that the application of FYM 10 t + 120 kg N ha-1 considerably improved the wheat growth indices, including plant height (96.6 cm), effective tillers/m row length (104.6), and number of grains per spike (48.9). This was equivalent to applying FYM 15 t + 100 kg N ha-1 and was the lowest in the control.

In a field experiment with wheat in Udaipur on sandy clay loam calcareous soil, Verma *et al.* (2006) [81] discovered that the growth characteristics manifested themselves best in the treatment that applied organic matter in the form of FYM 10 t ha-1 in addition to 100% NPK, which was similar to 150% NPK. Singh *et al.* (2007) [74] discovered that the combined application of 50 kg N ha-1 and Azospirillum or Azotobacter increased spike length, plant height, test weight, grain weight spike-1, wheat yield and tillers m-2.

Sharma *et al.* (2007), seed inoculation of Azotobacter above control resulted in a considerable increase in spikes m^{-1}, grain, plant height, and straw yields of wheat by 7.86, 10.18, 9.05, 19.76, and 18.22%, respectively. Additionally, he reported that during harvest, plant height was much higher by 28.71 percent when 150 kg N ha^{-1} + 10 t FYM ha^{-1} + Azotobacter were added to the control. Singh *et al.* (2008) at CAZRI, Jodhpur discovered that when compared to 100% RDF, FYM @ 15 t ha-1, and control, the application of FYM at 7.5 t ha-1 + 50% RDF + bio fertiliser resulted in improved effective tillers m-2, plant height, grains per spike, 1,000 seed weight, and wheat yield.

In an experiment to examine the effects of Azotobacter seed inoculation & varying nitrogen fertilizer levels on wheat growth and yield, Soleimanzadeh and Gooshchi (2013) found that inoculated plants exhibited significantly higher plant height, grains per ear, and biological yield compared to non-inoculated plants. As the N level rose over the 75% N indicated for non-inoculated plants, ear length, plant height, number of grains per ear, biological yield, and yield of grain all increased. Grain yield might be increased by using 50% N Azotobacter, which performed adequately.

In comparison to crops planted solely, Alla *et al.* (2014) observed that the cowpea-maize intercropping method considerably enhanced plant height, the number of ears per plant, the number of rows per ear, 100-grain weight, and maize straw output. Yadav *et al.* (2017), different nutrient levels applied by fertilizers alone and in combination with FYM and bio-fertilizers had a substantial impact on wheat plant height. Under 50% RDF + 50% N-FYM + PSB and minimum management, the maximum plant height (93.2 cm), effective tillers (92.6 m^{-1}), and grain per ear (61.6) were observed.

Singh and Sukul (2019) [76] reported that the combination of 100% RDF and 100% vermicompost had the greatest effect on raising plant height, increasing the number of cobs per plant, and increasing the number of grains per cob in maize. The application of 75% NPK + FYM 5 t + vermicompost 2.5 t ha^{-1}. Singh (2019) [76] reported that among other nutrient management techniques, resulted in more tillers/m (87.8), taller plants (90.6 cm), grains/spike (38.6), spike length (9.0 cm), and test weight (45.8 g) of wheat.

It was reported that applying 25% RDF + FYM @ 18 t ha-1 to wheat resulted in maximum plant heights of 14.35 and 85.79 cm at 30 and 90 DAS, respectively, as well as tiller plant-1 (6.17), ear plant-1 (5.97), ear length (10.25 cm), grain spike-1 (55.70), and test weight (38.95 g), according to Choudhary *et al.* (2022).

Kumar and Niwas (2022) conducted tests in order to investigate the different characteristics of wheat growth that were impacted by organic and inorganic fertilisers and reported that significantly higher plant height, Plant population, dry matter output, number of effective tillers, number of tillers, leaf area index, days to flowering, ear length, spike count, grain count per ear and spikelets per ear, were recorded with an application of 100% NPK + FYM 5 t ha-1 + vermicompost 5 t ha-1.

Yadav *et al.* (2022) conducted one-year study in maize demonstrated that applying 100% RDF + FYM @ 15 t/ha resulted in the highest plant height (183.82 cm), cob length (19.76 cm), cobs per plant (1.40), and grains per cob (684.19), whereas using 75% RDF + FYM at 15 t/ha produced the lowest. Shah *et al.* (2023) [61], reported that applying 10 t ha-1 of organic manure under 100% field capacity in 2018 and 2019 resulted in the highest plant heights (229.7 and 235.5 cm), grain rows per cob (19.70 and 20.47), cob lengths (21.93 and 22.47 cm), number of grains per cob (835.3 and 875.9) and number of grains per row (41.33 and 42.80). However, the recommendation for chemical fertilizer treatment (120:100:80) showed the lowest amount.FYM increases soil fertility and rice productivity because it contains both organic and mineral nitrogen (Mandal, Dutta, and Umdar 2017) [41]. Applying 10 t vermicompost ha^{-1} and 10 t FYM ha^{-1} to sugarcane was just as successful as applying N-150 kg, P- 60 kg, and K-60 kg ha^{-1} from inorganic fertilizers. It also significantly raised the soil's organic carbon content (Singh *et al.* 2007) [74]. Jat and Ahlawat (2006) reported that the application of vermicompost enhanced the cropping system's total uptake of nitrogen and phosphorus, bacterial count, dry fodder yield of subsequent maize, grain yield, dry matter accumulation, and grain protein content in chickpeas, as well as soil nitrogen and phosphorus.Growth, quality, and yield metrics are significantly impacted by the use of organic manures, such as chicken manure, cow dung, neem cake and mustard cake.

Sharma *et al.* (2001) [62] reported that when compared to using 50% NPK from organic sources found that using inorganic fertilizers (NPK) in conjunction with organic inputs like FYM and green manure of dhaincha in a 75:25 ratio produced noticeably higher straw and grain yields for both crops.

Satyanarayana *et al.* (2002) reported that applying 10 tons of farmyard manure per hectare rise in yield of rice grain by 25% when compared to the control group that did not receive farmyard manure. This beneficial effect proved true for a number of measures, such as 1000-grain weight, filled grains per panicle, tiller number, and straw production. Farmyard waste and inorganic fertilizer treatments showed significant interactions. Interestingly, increasing rates of inorganic fertilizer application did not increase the positive impacts of FYM. The use of Ten tons of farmyard manure per hectare and inorganic fertilizer at a rate of 120:60:45 kg NPK per hectare, respectively, produced the highest yield of rice grain. The main factors contributing to this increase in grain output were improved nutrient uptake, more filled grains per panicle, a higher 1000-grain weight and a higher number of tillers. Sharma *et al.* (2002) studied that application of FYM 10 t ha^{-1} in conjunction with inorganic fertilizer resulted in a noticeably higher grain yield and straw yields than other treatments.

Kader *et al.* (2002) from Bangladesh in wheat found that the maximum wheat yield (168 kg N ha-1 + cow manure + Azotobacter) compared to the least yield in the control. The application of 240 kg N ha-1, Azotobacter, 192 kg N ha^{-1} + Azotobacter, 168 kg N ha^{-1} + cow dung, and 168 kg N ha-1 + cow dung + Azotobacter, respectively, enhanced the grain yields by 62, 18, 72, 68, and 84%. Similarresults was also reported in the straw yields. According to Panwar (2008), applying 25% N through FYM + 75% N, P2O5, and K2O through chemical fertilizers to maize produced a noticeably highest yield of grain (3.95 t/ha), followed by applying 50% N through FYM + 50% N, P_2O_5, and K_2O through chemical fertilizers (3.84 t/ha). The control had the lowest grain yield (1.27 t/ha). Rasool *et al.* (2008) found that in a maize-wheat rotation, the FYM @ 20 Mg ha^{-1} treated plot produced the maximum straw and grain yield of both maize (5.50 and 12.6 Mg ha^{-1}) and wheat (4.58 and 7.80 Mg ha^{-1}), followed by the NPK (100:50:50) treated plot. The control plot growth the lowest grain and straw yield of both crops.

For eight consecutive cropping seasons (1999-2003), Singh *et al.* (2008) studied the impact of FYM, vermicompost, green manuring, rice residue inclusion, and NPK fertiliser on soil fertility and long-term productivity in a rice-wheat cropping system on an Inceptisol. When rice and wheat were planted after daincha-situ green manuring or the application of FYM 10 t ha-1 or vermicompost 5 t ha-1 together with 75% NPK each year using chemical fertiliser in the *Kharif* season, yields for both crops increased considerably. The usage of FYM 7.5 t ha-1 + 50% RDF + bio fertiliser yielded more wheat than 100% RDF, FYM 15 t ha-1, and control (Singh *et al.* 2008).

Kumar and Singh (2010) conducted a long-term experiment on integrated nutrient management using rice-wheat cropping systems to assess the direct and residual impacts of green manures on crops with and without FYM. The maximum rice and wheat grain and straw yields were achieved with the application of 100% NPK + FYM 5 t ha-1. Shanwad *et al.* (2010) discovered that applying FYM @ 7.5 t ha-1 + 100% RDF resulted in a significantly higher maize yield (6348 kg ha-1), which was comparable to using vermicompost @ 2.5 t ha-1 + 100% RDF (6093 kg ha-1).

Iranian researchers Soleimanzadeh and Gooshchi (2013) found that a two-year study with 100% indicated N with Azotobacter inoculation produced the maximum grain production (6.8 t ha^{-1}), and 25% recommended N without Azotobacter treatment produced the least yield of grains (5.4 t ha^{-1}). Sharma (2015) showed that a significant improvement in wheat production was achieved by applying both inorganic and organic fertilizers at the same time. The treatment that comprised 50% FYM and 50% NPK had the maximum grain yield, measuring 32.61 q ha^{-1}. The treatment with 75% NPK + 25% FYM came next. The control treatment had the least wheat yield, 14.42 q ha^{-1}.

Meena *et al.* (2018) [44] found that the application of FYM 5 t ha^{-1} in conjunction with 100% NPK produced grain, stover, and biological yield of maize that was significantly greater than the other treatments and comparable to 100% NPK + lime. Yadav *et al.* (2017), 50% RDF + 50% N- FYM + PSB produced the highest wheat grain yield (41.9 q ha^{-1}) and straw yield (60.7 q ha^{-1}), while the control produced the lowest grain and straw yield (17.9 and 26.5 q ha^{-1}, respectively). Additionally, Dhiman *et al.* (2019) observed that 100% NPK + FYM @ 5 t ha-1 produced the best yield of wheat grain and straw (30.34 and 53.22 q ha-1, respectively), whereas 100% N produced the lowest yield.

Priyanka *et al.* (2019) found that adding 100% NPK + FYM 10 t ha-1 considerably boosted the grain and stover yields of both crops compared to the control in a maize-wheat cropping system. Their greatest yields under 100% NPK + FYM 10 t ha-1 were 4033 and 4053 kg ha-1 for maize grain and 5290 and 5320 kg ha-1 for stover, 4939 and 5107 kg ha-1 for wheat grain, and 7217 and 7270 kg ha-1 for straw in 2014–15 and 2015–16, respectively. In theirexperiment to examine the impact of integrated nutrient management on the maize-wheat cropping system, Bharti *et al.* (2022) found that the control group's grain and straw yields were the lowest at 9.01 and 20.42 q ha^{-1}, respectively, and the greatest at 46.29 and 70.53 q ha-1 with 50%N (FYM) + 50% RDF. According to Yadav *et al.* (2022), applying 100% RDF + FYM @ 15 t ha^{-1} and then 75% RDF + FYM @ 15 t ha^{-1} produced the highest grain yield (76.12 q ha^{-1}) and straw yield (100.94 q ha^{-1}) of the maize crop, while applying 75% RDF produced the lowest grain yield (65.65 q ha^{-1}) and straw yield (96.35 q ha^{-1}).In a rice-rice cropping system experiment, Paramesh *et al.* (2023) demonstrated that application of chemical fertilizer and farmyard manure together produced significantly higher rice yield than other treatments.

Effect on produce quality

Biological, sensory, technical, nutritional, and ethical qualities of produce are all encompassed in the general phrase "food quality." It is well recognized that various facets of agriculture, whether conventional, integrated, or organic, influence the production, quality, and environmental health (Water, air, soil, ecological balances, etc.). There is still debate over the relative significance of conventional and organic farming in terms of nutritional quality, despite the fact that a great deal of study has been done to determine the various effects of agricultural practices on crop yields.

Two schools of thought advocating the maximum nutritional qualities of organic produce compared to its conventionally produced equivalents emerged as a result of the organic management system's prohibition or restriction of the use of agrochemicals. First off, under traditional management approaches, nitrogenous fertilizers' quick and simple absorption speeds up plant growth and development, which reduces the formation of secondary metabolites like flavonoids and phenolics. Second, when plants are stressed by not using pesticides, they activate their natural defense mechanism, which ultimately leads to increased creation of apologetic substances (Faller and Fialho 2009) [19]. Organic agricultural produce is safer, hygienic, more nutrient-dense, and a viable substitute even at premium prices to produce grown using various agrochemicals under conventional methods because it is free of chemical fertilisers, pesticides, and other synthetic inputs, as well as the hazardous chemical residues that result from them. However, there is still disagreement and uncertainty about the relative nutritional value of conventional vs organic vegetables (Gastoł, Domagała-´Swiatkiewicz, and Krosniak 2009) [21]. The type of fertilizer used as a source of nitrogen has an impact on the quantity and quality of protein. Protein synthesis is improved, and carbohydrate biosynthesis is decreased when nitrogen is more bioavailable to plants. However, proteins' nutritional value is limited because they incorporate fewer essential amino acids in response to greater nitrogen levels (Worthington 2001). As reviewed by However, several studies find that organically grown cereal grains have higher levels of important amino acids, suggesting that cultivation practices have an impact on quality of protein (Madder *et al.* 2007). Benbrook *et al.* (2008) and Madder *et al.* (2007) [9] conducted comparative studies on cereal quality and found that simple availability of nitrogen using standard methods led to higher grain protein and amino acid content. Zorb *et al.* (2009) [91] conducted research that examined the effects of two conventional and two organic cultivation methods on the accumulation of metabolites (lipids, carbohydrates, and protein) in mature wheat grains and developing ears. They found differences in the metabolism and metabolite supply to developing ears in relation to cultivation practices, but these differences were negligible in comparison to the metabolite content of mature grains, indicating a change in nutrient accumulation and homeostasis at the last stage of seed set.

The availability of additional fertilizer during the ear-developing period, which mostly affects the grain protein content, is one important distinction between the traditional management system and the organic management system, according to Wieser and Seilmeier (1998). In addition, Baran´ski *et al.* (2014) conducted a meta-analysis of compositional variations in relation to cultivation methods and discovered a detrimental relationship between organic management and the amount of nitrogen, protein, and amino acids contained in produce, and a positive correlation with lower N inputs used in organic farming.

Exploring the possibilities of organicmaize and wheat production: Among the new possibilities inmaize production, Kumar *et al.* (2007) found that applying vermicompost at 2.5 t ha-1 resulted in a higher grain yield (53.05 q ha^{-1}) compared to the control (38.32 q ha^{-1}). This was comparable to applying FYM at 10 t ha^{-1} (51.83 q ha^{-1}), incorporating green leaf manure at 5 t ha^{-1} (48.19 q ha^{-1}) and poultry manure at 1 t ha-1 (49.94 q ha-1). In wheat, Channabasanagowda *et al.* (2008) recorded a significantly highest yield of grain (30.43 q ha^{-1}) using poultry manure at 2.45 t ha^{-1} + vermicompost at 3.8 t ha^{-1}. Rice and wheat output rose considerably in plots that included farmyard trash, green manure, and biofertilizer (Kumar *et al.* 2015) [31] because organic manures have greater stomatal conductance, leaf N status, and leaf area index. In comparison to treatments treated with standard fertilizer (SF; 204-252 kg N ha-1 yr-1) or light fertilizer (LF; 102-126 kg N ha-1 yr-1), Kato *et al.* (2011) found that biomass output was greater in treatments with a high rate of organic manure (OM; 80 t ha-1 yr-1). The grain yield for both cultivars was equivalent in SF (6.6-8.5 t ha-1) and considerably greater in OM (6.6-8.9 t ha-1) than in LF (3.5-6.6 t ha-1). Higher FYM levels applied over a short period of time significantly improved the soil's characteristics and water availability while increasing the absorption of nutrients by maize plants, according to Masood *et al.* (2014).

Accordingly, Achieng *et al.* (2010) assessed whether FYM and inorganic fertilizers affected maize yield. For the FYM, the same parameters as for the earlier inorganic treatments were used: grain, stover, height, number of cobs, 100 seed weight, and plant population. Sudhakar *et al.* (2019) found that pressmud vermicompost outperformed the other organic treatments in terms of plant height, number of grains per cob, test weight, and maize grain yield (205.93 cm, 320, 24.56 g, and 6549 kg ha^{-1}, respectively).

Conclusion

In conclusion, this review paper emphasizes that the Indian subcontinent's rice crop can be made more sustainable through a combined nutrient management system, which combines biological and organic nutrition sources. Compared to inorganic fertilizers, organic fertilizers offer more long-term advantages. Although organic fertilizer enhances a soil's physical, biological, and chemical characteristics, plants might not be able to get the nutrients as easily. Nevertheless, biological fertilizer also enhanced the physico-chemical and biological characteristics of the soil biota, which increased production. Pollution of the environment, soil acidity, and soil degradation can result from the overuse of inorganic fertilizers in agriculture. Utilizing both biological materials and organic fertilizers, the integrated soil fertility management approach, which reduces the input of inorganic fertilizers, is an alternate strategy for managing soil fertility sustainably and economically. Applying biological and organic fertilizers together increases soil fertility, increases crop output in maize and wheat systems, and lessen the environmental impact of inorganic fertilizers.

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