



Green Manure for Sustainable Crop Production: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AJ and KB have selected the topic for review and prepared the framework of the review paper. Author AJ compiled all the research findings and completed the review writing. The final editing and proof reading were carried out by Authors KB and Barkha. All authors read and approved the final manuscript.

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ABSTRACT

Green manuring is an economical and eco-friendly scientific approach to achieve more resilient and sustainable food production for agricultural systems. Incorporation of green manure improves soil condition by increasing soil physical, chemical and biological properties such as organic matter, availability of nitrogen, phosphorus and potassium and also improves soil structure by preventing soil erosion, increasing water holding capacity etc. Green manure acts as a natural fertilizer, releasing nutrients into the soil as it decomposes and increases the nutrient content in the soil and shows positive effect on plant growth and development. Addition of green manure crops contribute to greater fixation of atmospheric nitrogen, and when decomposed, makes the nitrogen availability in the soil, reducing the need for synthetic nitrogen fertilizers in crops. Furthermore, it has a significant impact on several plant growth and yield parameters, resulting in increased agricultural productivity and ecosystem health.

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1. INTRODUCTION

Developing sustainable and innovative approaches for improving agricultural yield and quality while lowering environmental impact is now essential due to the degradation of crop quality, quantity and the environment. So, green manure is a sustainable agricultural strategy that increases crop output while reducing environmental and health risks. It is extensively utilized in many countries because it promotes healthy crop development and productivity [1]. Green manuring is a traditional farming technique that includes adding green plant tissues to the soil. As a result, it increases soil fertility, improves biological activity, enhances soil health by nutrient mineralization, and reduces agricultural crop production costs. [2]. Furthermore, it increases organic matter and total soil nitrogen concentrations, which might enhance soil physical conditions [3]. Increasing the amount of green manure enhances natural carbon in the soil and adding nitrogen can help rice develop more effectively [4]. As a result, green manure can be beneficial in boosting soil fertility, increasing crop yield and reducing the risk of nitrogen loss [5]. It is a practical and advantageous technique to increase rice output while reducing the usage of artificial fertilizers. And also, it reduces nitrogen inputs, by the potential use of green manure in crop growth [6]. In addition to these benefits, it filters out soluble nutrients and root microorganisms, enhancing the bulk density, water conductivity, and other physical and chemical characteristics of the soil. Over time, it can increase soil porosity, water-holding capacity,

enzyme activity, organic matter, microbial biomass carbon, and soil quality [7]. As a result, the practice of green manure farming as an intercrop, main crop, or bare fallow depends on the soil and climatic conditions of the region to restore soil fertility in an ecofriendly, low-cost, sustainable manner while also increasing soil physical, chemical, and biological properties that can influence crop growth and yield.

2. MECHANISM OF GREEN MANURE ON SOIL PROPERTIES

Green manuring, a soil improvement method, has grown in importance due to the high expense of artificial fertilizers, environmental pollution threats, and the need for sustainable agricultural systems. It enhances soil characteristics, minimizes nitrate leaching risk, and reduces fertilizer requirements. However, its advantages may differ based on the soil, crop, environmental factors, and management [8]. The primary goal of a green manure crop is to improve soil and provide nutrients for future harvests. Crop growth practices that use green manure may improve economic viability while reducing agriculture's negative environmental impact, because they rely on interactions between the green manure, the environment, and management. Incorporation of green manure crops impacts on soil organic matter, nitrogen release and availability of nutrients for subsequent crops [9]. The process of green manuring adds organic matter to soils, altering their physical, chemical, and biological aspects and influencing the availability of key plant nutrients (Fig. 1).

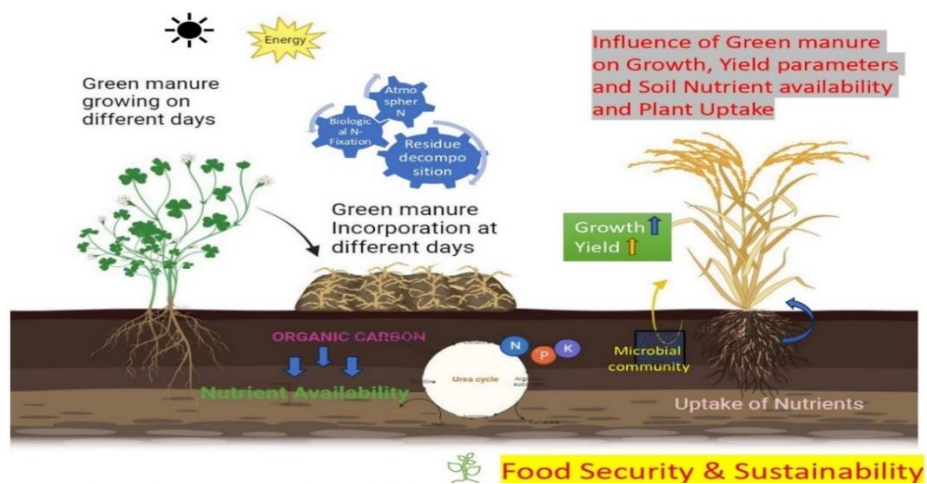


Fig. 1. Effect of green manure on crop growth, yield and soil parameters

Green manuring enhances soil physical characteristics by increasing mean weight diameter and saturation hydraulic conductivity values etc., [10,11]. It also efficiently enhances soil physical properties such as decrease in soil bulk density [12]. as well as an increase (11%) in total soil porosity and a 17 percent increase in accessible water [13]. It also, increases the water-stable aggregates and rate of infiltration and reduce the bulk density of the soil [14]. Green manure-enriched soils have a higher capacity for nitrogen mineralization. It plays a crucial role in determining how quickly the modified soils break down and subsequently starts to mineralize N [15]. Furthermore, the agronomic benefits of applying green manures act as a source of nitrogen and organic matter for wetland rice. Moreover, it has a mulching effect and aids in increasing N, K, Ca, and Mg availability. The quantities of nitrogen, phosphorus, potassium, calcium, and magnesium released from the decomposing material, the reduction in aluminium saturation, and the potential for increased nutrient accumulation as a result of less moisture stress and lower bulk density were all linked to the positive benefits of adding various types of green manure [16]. Green manure crops, both legumes and non-leguminous, can be grown in the field or supplied through vegetation and tree cuttings for the nutrient supply to crops. Rapidly growing legume-rich green manure crops have a considerable potential to seize atmospheric nitrogen and replace nitrogen fertilizer in wetland rice [17]. Furthermore, green manure crops bind nutrients and improve the effect and stability of biologically fixed nitrogen (N). In under-sowing legumes it returned up to four times as much nitrogen (N), 2.8 times as much phosphorus (P), and 2.5 times as much potassium (K) to the soil through straws and roots [18].

Green manuring also boosts nutrient sources by increasing microbial biomass compared to conventional approaches [19]. It also enhances the activity of soil enzymes by increasing microbial biomass carbon by 28% [12]. Legumes are applied to the soil's surface preserved the C supply for the soil microbial biomass and release carbon slowly for consumption of soil microorganisms [20]. The biomass of bacteria, fungus, and total microbial biomass increased by incorporation of green manuring [18]. The structure of soil and diversity of the soil microbial community are also effected by green manure incorporation [21,63,64]. In addition to

the impact on the microbial population and soil nutrients, green manure can improve soil remediation and lower greenhouse gas emissions. However, green manure application is a long-term and beneficial approach in agro-ecosystem management, as it is grown with different crop systems [22].

3. EFFECT OF GREEN MANURE ON THE GROWTH OF CROPS

Green manuring is a sustainable agriculture approach that influences plant morphological characteristics. It efficiently enhances growth parameters by providing enough nutrient levels for crop development [23]. Decomposed sesbania biomass converts inaccessible nutrients into available forms via soil microorganisms in green manure fields, which shows the impact on growth parameters compared to non-green manure fields and creates sustainable soil conditions for increased crop yield [24]. Significantly, green manure improves soil fertility and provides a chemical fertilizer substitute. Field tests evaluate its effects on soil physio-chemical characteristics and uptake of nitrogen by crops. It also boosts plant productivity for N fertilizer and increases plant availability of total organic carbon and nitrogen [25]. It generates an extensive root system, which helps in nutrient uptake, resulting in improved plant growth, a higher leaf area index, and more tillers than the conventional method (application of approved fertilizer dosages alone) [26]. Because of the increased biomass and maximum nutrient absorption in rice crops, it also shows a positive influence on plant growth attributes such as plant height, number of tillers, and dry matter accumulation [27] (Table 1). It also promotes nutrient absorption in plants and influences rice development indices such as plant height, tiller number, and leaf area index due to its residual actions compared to other methods [28].

Furthermore, green manuring-treated plots exhibit greater biomass (17.89 tons/ha) and a 7.6 percent rise in fertile tillers in wheat crops compared to non-green manuring fields, as soil moisture availability improves, which is a key component in sustainability [29]. However, they also observed that green manure serves the function of increasing enzyme activity, which makes nutrients more accessible, as well as enhancing soil texture, moisture, and other nutrients. Due to an increase in enzyme activity that releases nutrients into the crop, which

Table 1. Effect of green manure on the growth attributes of different crops

Sl.no.	Crop	Growth Parameters	Without green manure	With green Manure	Reference
1.	Rice	Plant Height	103.16 cm	107.91cm	[28]
		Tiller number	9.57	10.29	
		Leaf area Index	4.21/m ²	4.39/m ²	
2.	Wheat	Tillers/m ²	261/m ²	293/m ²	[29]
3.	Maize	Plant Height	193.2cm	222.2cm	[24]
		Cob length	15.3cm	16.2cm	
4.	Soyabean	Leaf area	96.4cm ²	126.4cm ²	[30]
		Number of Branches	8	8.3	
		Plant Height	59.2cm	60.2cm	
		Length of root	31.3cm	35.06cm	
		Collar diameter	22.49cm	24.8cm	
		Leaf number	31.6	33.2	
5.	Rice	Plant Height	49.1cm	54.3cm	[27]
		Tillers/m ²	488/m ²	423/m ²	
		Dry matter accumulation	1354 kg/ha	1651 kg/ha	
6.	Rice	Leaf Area Index	4.66/m ²	4.92/m ²	[26]
		Tillers/m ²	345/m ²	383/m ²	

influence on crop growth attributes such as plant height, number of branches, collar diameter, length of root, number of leaves, and leaf area than other control plots in the cropping system [30].

4. EFFECT OF GREEN MANURE ON YIELD PARAMETERS OF CROPS

Crops grown by green manuring have the potential to reduce their dependence on artificial fertilizers, especially the need for nitrogen inputs. Green manure incorporation reduces fertilizer use and improves soil health by reducing microbial loss, which has a favourable effect on panicle length, number of filled grains/panicle and test weight. It functions as a natural fertilizer, supplementing the soil with critical nutrients while improving nutrient absorption and overall production [28,26]. Because the incorporation of green manure has a higher biomass and shows an impact on grain and straw yield [29]. Furthermore, it increases soil microbial activity, which causes nutrient release and absorption from the enzymatic process, plant metabolic process, nutrient translocation and efficient transportation of synthates to boost haulm and crop production [31] (Table 2).

Although applying green manure had the twin benefits of enhancing soil quality and fertility, it also maintained high yields by partially meeting crop nutrient requirements [27]. However, in comparison to control treatments, greater growth

and dry matter buildup by green manure yields higher grain and straw yields. However, due to greater biomass buildup than in the absence of a green manuring field, green manuring of leguminous crops boosts the performance of grain and straw output as well as maximum productive tillers [32]. Green manure offers sufficient nutrients, resulting in improved development of crop and production [30].

5. EFFECT OF GREEN MANURE ON NUTRIENT AVAILABILITY AND UPTAKE OF CROPS

The incorporation of green manure increases the concentration and availability of soil nutrients, resulting in crop absorption of nitrogen and phosphorus compared to areas without green manure [24]. Rice grains absorb nitrogen and phosphorus at much higher rates when green manure is applied because it exhibits a variety of reduction mechanisms and modifies the pH of the soil in a way that facilitates nutrient uptake by the crop [32]. Beyond preserving the soil's long-term fertility, it is also crucial for achieving higher yields and profits. In addition, reintroducing the green manure into the soil results in a linear increase in organic carbon maximizes nutrient absorption, and transforms many soils from potential sources of atmospheric CO₂ into sinks (carbon sequestration). It also inhibits the thermal oxidation of organic materials on the soil surface and decreases soil loss [33].

Table 2. Effect of green manure on yield attributing characteristics of different crops

Sl. no.	Crop	Yield Parameters	Without green manure	With green Manure	Reference
1	Wheat	Grain yield	3789 kg/ha	4300 kg/ha	[29]
		Straw yield	6584 kg/ha	7514 kg/ha	
2	Rice	Grain yield	5026 kg/ha	5590 kg/ha	[32]
		Straw yield	6565 kg/ha	7109 kg/ha	
3	Rice	Grain yield	40.88 q/ha	48.89 q/ha	[28]
		Straw yield	59.86 q/ha	70.41 q/ha	
		Number of panicle/m ²	189.81	206.44	
		Panicle length (cm)	19.81	21.72	
		No. of filled grains/panicle	78.28	82.21	
		Test weight (g)	28.84	30.55	
4	Soyabean	Grain yield	2.83q/ha	3.02q/ha	[30]
		1000 Seed weight	160.4	170.6	
		No. of pods/plant	49.3pods	59pods	
5	Rice	Grain Yield	4794 kg/ha	5589 kg/ha	[27]
		Straw Yield	5517 kg/ha	6391 kg/ha	
6	Rice	Panicle length (cm)	21	23	[26]
		Number of grains per panicle	95	113	
		1000 grain weight	22 g	23 g	
		Grain yield	3.63 q/ha	4.33 q/ha	
		Straw yield	5.05 q/ha	5.99 q/ha	
7	Safflower	Number of pods per plant	34.25	34.33	[31]
		Grain yield	874.69 kg/ha	876.03	
		Haulm yield	873.24 kg/ha	kg/ha	
		Harvest Index	49.28 %	884.32	
				kg/ha 49.60 %	

While applying synthetic fertilizers alone reduces soil nutrient availability and results in poor plant nutrient absorption, whereas green manure in a rice-based cropping system improves soil nitrogen availability [27]. Similarly, when compared to other treatment techniques, green manure improves the physical and chemical characteristics of the soil, increases the amount of organic carbon in the soil, and increases the amount of nutrients that are accessible (N, P, and K) [26] (Table 3 and 4). Furthermore, green manure has improved biological qualities, as evidenced by increased bacterial population, residual, and enzymatic activities in comparison to other applications [34].

6. EFFECT OF GREEN MANURE ON SUSTAINABILITY

Sustainable agriculture and green manuring are interconnected to maintain long-term production and environmental integrity. Green manuring, an ancient technique, uses organic matter to increase crop yields and soil fertility. It enhances water retention, reduces artificial fertilizer use, and reduces climate change effects and also

boosts soil nutrients and crop quality [35,36,37,38]. Soil fertility and production can be reduced by frequent cultivation and cropping due to organic matter loss and aggregate disintegration. Farmers can use the green manuring as a traditional practice to boost soil fertility, limit weed development, enhance soil structure, and avoid erosion and it is a low-cost way to maintain soil fertility and decrease inorganic fertiliser expenses [39,40,41]. So, by green manure application, it retains lost humus, can improve soil health, nitrogen availability, and microbe development [42]. Crop production also benefited from green manuring, enhances soil qualities, lowers the need for fertiliser N, and lessens the chance of nitrate leaching. Its effects, however, differ according to crop, soil, climate, and management. It is a practical means of boosting agricultural yields and soil fertility [43,44,45].

Furthermore, overuse of nitrogen fertilizer in agriculture is causing environmental damage, with reactive forms of nitrogen increasing to around 120% in the atmosphere, intensive agriculture, including repeated tillage, high-

Table 3. Effect of green manure on uptake of plant nutrients by different crops

S.no.	Crop	Nutrients uptake	Without green manure	With green manure	Reference
1	Maize	Nitrogen	1.37 %	1.61 %	[24]
		Phosphorus	0.37 %	0.59 %	
		Potassium	1.25 %	1.46 %	
2	Rice	Nitrogen	103.7 kg/ha	138 kg/ha	[27]
		Phosphorus	15.1 kg/ha	21.4 kg/ha	
		Potassium	151.1 kg/ha	209.3 kg/ha	
3	Cotton	Nitrogen	40.7 kg/ha	44.6 kg/ha	[33]
		Phosphorus	5.6 kg/ha	5.8 kg/ha	
		Potassium	24.2 kg/ha	24.9 kg/ha	
4	Rice	Nitrogen	64.5 kg/ha	72.4 kg/ha	[32]
		Phosphorus	17.63 kg/ha	20.76kg/ha	
		Potassium	16.96 kg/ha	19.96kg/ha	
5.	Rice	Nitrogen	72.16 kg/ha	87.60 kg/ha	[26]
		Phosphorus	24.55 kg/ha	31.67 kg/ha	
		Potassium	80.60 kg/ha	94.20 kg/ha	

Table 4. Effect of green manure on nutrient availability of soil on different crops

Sl.no.	Crop	Nutrient Availability	Without green manure	With green Manure	Reference
1	Rice	Nitrogen	175kg/ha	230kg/ha	[24]
		Phosphorus	59kg/ha	73kg/ha	
		Potassium	263kg/ha	318kg/ha	
2	Cotton	Nitrogen	172 kg/ha	194 kg/ha	[33]
		Phosphorus	20.9 kg/ha	18.3 kg/ha	
		Potassium	523 kg/ha	590 kg/ha	
3	Rice	Nitrogen	220.3 kg/ha	254.0 kg/ha	[26]
		Phosphorus	21.2 kg/ha	25.8 kg/ha	
		Potassium	153.0 kg/ha	159.0 kg/ha	

analysis fertilizers, and burning agricultural residue, has led to soil organic carbon decline, impaired soil health, decreased biodiversity, and increased demand for essential plant nutrients. Improving soil organic matter (SOM) and nitrogen levels can reduce environmental damage caused by overuse of nitrogen fertilizers. This necessitates a rethinking of biological nitrogen fixation (BNF) and the use of green manuring with legumes can improve soil organic carbon (SOC), nutrient availability, and under cover green manure also increase moisture content, soil properties, and improves yields [46,47,48]. This technique lessens the demand for synthetic fertilisers and lessens its negative effects on the environment. In addition to mitigating climate change, green manuring enhances soil structure, water retention, erosion reduction, microbial diversity, nutrient cycling, and carbon sequestration [49,50,51]. However, an environmentally friendly method of increasing soil fertility and crop development by fast-

growing, legume-rich plants that improve soil and boost crop yields without damaging the environment. In addition, green manuring decreases insect and disease issues, inhibits weed growth, and produces more food for animals [52].

Although food is self-sufficient in many nations, soil deterioration and depletion are caused by ongoing cropping and soil cultivation. Toxicants released by the breakdown of chemical fertilisers endanger the food chain. There are concerns regarding the sustainability of soil due to the decrease in organic nutrient source such as green manure. Green manuring is an inexpensive, efficient technique that protects soil fertility and reduces the need for inorganic fertilisers. By providing nitrogen and organic matter, it increases soil fertility and enhance both soil fertility and structure [53]. Technological advancements have benefited agriculture by overcoming limits, but they have also resulted in

issues such as a lower C/N ratio, less microbial diversity, and less organic matter per unit area. Therefore, adding green manure (GM) to the soil improves the organic matter, mobilises phosphorus, and enhances the sources of nitrogen [54,55,56]. Furthermore, green manure methods provide ecological benefits, particularly in tropical environments, as they increase nitrogen fixation and nutrient cycling [57,58,59]. For sustainable agricultural systems to improve lives and crop yields, green manuring is essential. It improves the carbon-to-nitrogen ratio, microbial biomass, organic matter, structure, fertility, and nutrient content of soil and boost fertiliser efficiency [60,61,62]. Green manure maintains soil health, preserves the biodiversity and has great potential for sustainable crop production.

7. CONCLUSION

Green manure is a sustainable farming method that has several environmental and agronomic benefits. It is proven to be an effective way to increase crop productivity while reducing the environmental impact of intensive agriculture techniques. It restores soil fertility and increases production potential and sustainability in agricultural systems. Therefore, it is concluded that the incorporation of green manure improves the physical, chemical, and biological properties of the soil. These improvements have an advantageous effect on crop growth and development and ultimately contribute to ensuring long-term sustainable agricultural production for farming communities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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