Review Article

Green manure for sustainable crop production: A Review

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. However, incorporation of green manure can be a greater opportunity to farming communities for long-term sustainable agricultural production.

Comment [AH1]: This statement shouldn't start with 'however' since it doesn't negate the above statements.

Key words: *Green manure; sustainability; soil fertility; growth; organic matter; nutrients; yield.*

Comment [AH2]: Write the first letter of each phrase in capital letter, and separate the phrases with commas.

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. Incorporationof green manure crops impacts on soil organic matter, nitrogen release and availability of nutrients for subsequentcrops [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**). 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 propertiessuchas 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 infiltrationand 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 aluminiumsaturation, 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 nitrogenand replace nitrogen fertilizer in wetland rice [17]. Furthermore, green manure crops bind nutrients and improve the effect and stability of biologically fixed nitrogen (N). Inunder-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 biomassand release carbon slowly for consumption of soilmicroorganisms[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 effectedbygreen manure incorporation [21]. 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].

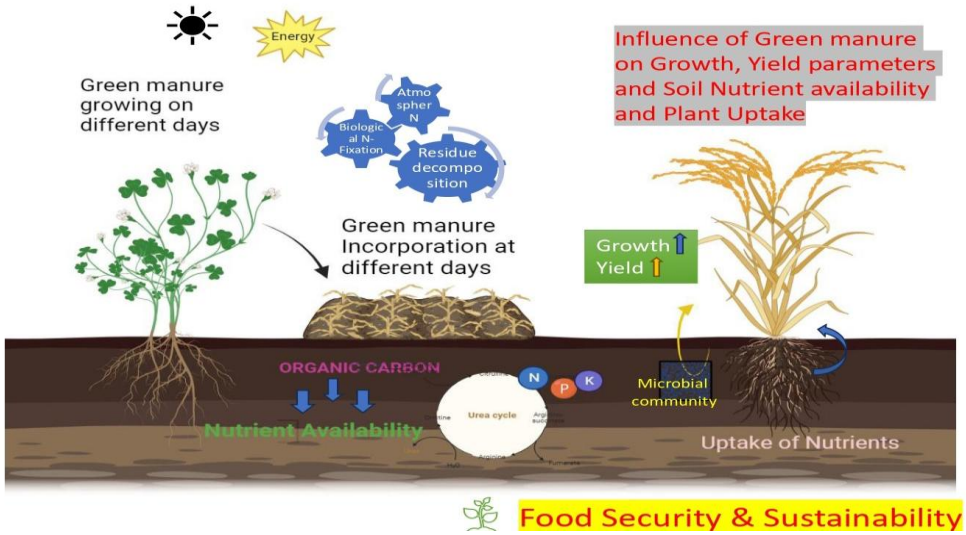

Fig.1. Effect of green manure on crop growth, yield and soil parameters

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] [**Table1**]. 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 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].

Sl.no.	Crop	GrowthParameters	Without green manure	With green Manure	Reference
1.	Rice	Plant Height Tiller number Leaf areaIndex	103.16 cm 9.57 4.21/m^2	107.91cm 10.29 4.39/m^2	[28]
2.	Wheat	Tillers/m^2	261/m^2	293/m^2	[29]
3.	Maize	Plant Height Cob length	193.2cm 15.3cm	222.2cm 16.2cm	[24]
4.	Soyabean	Leaf area Number of Branches Plant Height Length of root Collar diameter Leaf number	96.4cm^2 8 59.2cm 31.3cm 22.49cm 31.6	126.4cm^2 8.3 60.2cm 35.06cm 24.8cm 33.2	[30]
5.	Rice	Plant Height Tillers/m^2	49.1cm 488/m^2	54.3cm 423/m^2	[27]

		Dry matter accumulation	1354 kg/ha	1651 kg/ha	
6.	Rice	Leaf Area Index Tillers/m^2	4.66/m^2 345/m^2	4.92/m^2 383/m^2	[26]

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

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].

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 Straw yield	3789 kg/ha 6584 kg/ha	4300 kg/ha 7514 kg/ha	[29]
2	Rice	Grain yield Straw yield	5026 kg/ha 6565 kg/ha	5590 kg/ha 7109 kg/ha	[32]
3	Rice	Grain yield Straw yield Number of panicle/m^2 Panicle length (cm) No. of filled grains/panicle Test weight (g)	40.88 q/ha 59.86 q/ha 189.81 19.81 78.28 28.84	48.89 q/ha 70.41 q/ha 206.44 21.72 82.21 30.55	[28]
4	Soyabean	Grain yield 1000 Seed weight No. of pods/plant	2.83q/ha 160.4 49.3pods	3.02q/ha 170.6 59pods	[30]
5	Rice	Grain Yield Straw Yield	4794 kg/ha 5517 kg/ha	5589 kg/ha 6391 kg/ha	[27]
6	Rice	Panicle length Number of grains per panicle 1000 grain weight Grain yield Straw yield	21 95 22 g 3.63 q/ha 5.05 q/ha	23 113 23 g 4.33 q/ha 5.99 q/ha	[26]
7	Safflower	Number of pods per plant Grain yield Haulm yield Harvest Index	34.25 874.69 kg/ha 873.24 kg/ha 49.28 %	34.33 876.03 kg/ha 884.32 kg/ha 49.60 %	[31]

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 CO_2 into sinks (carbon sequestration). It also inhibits the thermal oxidation of organic materials on the soil surface and decreases soil loss [33]. 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].

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 Phosphorus Potassium	1.37 % 0.37 % 1.25 %	1.61 % 0.59 % 1.46 %	[24]
2	Rice	Nitrogen Phosphorus Potassium	103.7 kg/ha 15.1 kg/ha 151.1 kg/ha	138 kg/ha 21.4 kg/ha 209.3 kg/ha	[27]
3	Cotton	Nitrogen Phosphorus Potassium	40.7 kg/ha 5.6 kg/ha 24.2 kg/ha	44.6 kg/ha 5.8 kg/ha 24.9 kg/ha	[33]
4	Rice	Nitrogen Phosphorus Potassium	64.5 kg/ha 17.63 kg/ha 16.96 kg/ha	72.4 kg/ha 20.76kg/ha 19.96kg/ha	[32]
5.	Rice	Nitrogen Phosphorus Potassium	72.16 kg/ha 24.55 kg/ha 80.60 kg/ha	87.60 kg/ha 31.67 kg/ha 94.20 kg/ha	[26]

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 Phosphorus Potassium	175kg/ha 59kg/ha 263kg/ha	230kg/ha 73kg/ha 318kg/ha	[24]
2	Cotton	Nitrogen Phosphorus Potassium	172 kg/ha 20.9 kg/ha 523 kg/ha	194 kg/ha 18.3 kg/ha 590 kg/ha	[33]
3	Rice	Nitrogen Phosphorus Potassium	220.3 kg/ha 21.2 kg/ha 153.0 kg/ha	254.0 kg/ha 25.8 kg/ha 159.0 kg/ha	[26]

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,overuseof 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-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 legumescan 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.

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. Furthermore, green manure has residual effects that boost soil organic carbon, total nitrogen, and soil extractable nitrogen, all of which help to improve soil fertility, nutrient availability and increase the uptake of nutrients in the crop. However, the incorporation of green manure improves soil's physical, chemical, and biological properties. These improvements have an advantageous effect on crop growth and development and ultimately assure long-term, sustainable agricultural production forfarming communities.

REFERENCES

Comment [AH3]: Follow the correct format of writing references. It should also be consistent.

1. Valizadeh N, Jalilian S, Hallaj, Z. Encouraging adoption of green manure technology to produce clean rice product. *Sci Rep* **13**, 8690 (2023).

2. Asghar W, Kataoka R. (2022). Green manure incorporation accelerates enzyme activity, plant growth, and changes in the fungal community of soil. Arch Microbiology .**204**:7.

3. Mandal U.K, Singh G, Victor U.S, Sharma K.L. (2003). Green manuring: its effect on soil properties and crop growth under rice–wheat cropping system. *European Journal of Agronomy*.19:2.225-237.

4. Cassman K, Datta S, Amarante S, Liboon S, Samson M, Dizon, M. (1996). Long-term comparison of the agronomic efficiency and residual benefits of organic and inorganic nitrogen sources for tropical lowland rice. Experimental Agriculture, 32(4), 427-444. https://doi.org/10.1017/s0014479700003793

5. Hu A, Huang R, Liu G, Huang D, Huan H. Effects of Green Manure Combined with Phosphate Fertilizer on Movement of Soil Organic Carbon Fractions in Tropical Sown Pasture. Agronomy. 2022; 12(5):1101.

6. Irin I, Biswas P.K, Ullah M, & Roy T.S. (2020). Effect of in situ green manuring crops and chemical fertilizer on yield of T. Aman rice and mustard.Asian Journal of Crop, Soil Science and Plant Nutrition. 2. 68-79.

7. Lei B, Wang J, Yao H. Ecological and Environmental Benefits of Planting Green Manure in Paddy Fields. *Agriculture*. 2022; 12(2):223.

8. Fageria N. K. (2007). Green Manuring in Crop Production. *Journal of Plant Nutrition*, *30*(5), 691–719. https://doi.org/10.1080/01904160701289529.

9. Cherr C.M, Scholberg J.M.S. and McSorley R. (2006), Green Manure Approaches to Crop Production: A Synthesis. Agron. J., 98: 302-319. https://doi.org/10.2134/agronj2005.0035.

10. Mandal U. K, Singh G, Victor U. S, Sharma K.L. (2003). Green manuring: its effect on soil properties and crop growth under rice–wheat cropping system. **European Journal of Agronomy**. 19 (2), 225-237. https://doi.org/10.1016/S1161-0301(02)00037-0.

11. Puget P and Drinkwater L.E. (2001). Short-Term Dynamics of Root- and Shoot-Derived Carbon from a Leguminous Green Manure. **Soil Science Society of America Journal**. 65: 771-779.

12. Ma, Dengke & Yin, Lina & Ju, Wenliang & Li, Xiankun & Liu, Xiaoxiao & Deng, Xi-Ping & Shiwen, Wang. (2021). Meta-analysis of green manure effects on soil properties and crop yield in northern China. Field Crops Research. 266. 108146. 10.1016/j.fcr.2021.108146.

13. Sultani, M.I., Gill, M.A., Anwar, M.M. *et al.* Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. *Int. J. Environ. Sci. Technol.* **4**, 109–118 (2007). https://doi.org/10.1007/BF03325968

14. Boparai, B. S., Singh, Y., & Sharma, B. D. (1992). Effect of green manuring with *sesbania aculeata* on physical properties of soil and on growth of wheat in rice-wheat and maize-wheat cropping systems in a semiarid region of India. *Arid Soil Research and Rehabilitation*, *6*(2), 135–143. https://doi.org/10.1080/15324989209381306.

15. Dinesh R. and Dubey R.P. (1998), Nitrogen Mineralization Rates and Kinetics in Soils Freshly Amended with Green Manures. Journal of Agronomy and Crop Science, 181: 49-53. https://doi.org/10.1111/j.1439-037X.1998.tb00397.x

16. .Wade M.K. and Sanchez P.A. (1983). Mulching and Green Manure Applications for Continuous Crop Production in the Amazon Basin‡. Agron. J., 75: 39-45. https://doi.org/10.2134/agronj1983.00021962007500010010x.

17. Talgre L, Lauringson E, Roostalu H, Astover A, Makke A. (2012). Green manure as a nutrient source for succeeding crops. Plant Soil Environ., 58: 275-281.

18. Elfstrand S, Hedlund K, Mårtensson A. (2007). Soil enzyme activities, microbial community composition and function after 47 years of continuous green manuring. Applied Soil Ecology.35:3.610-621.

19. Lei B, Wang J, Yao H. (2022). Ecological and Environmental Benefits of Planting Green Manure in Paddy Fields. *Agriculture*. 12(2):223.

20. Carvalho, N. S, Oliveira, A. N. B. B, Cala A, M. M, Neto, V. P. C., De Sousa, R. S, Dos Santos, V. M., & de Araujo, A. S. F. (2015). Short-term effect of different green manure on soil chemical and biological properties. *African Journal of Agricultural Research*, *10*(43), 4076-4081.

21. Ablimit, R, Li, W, Zhang, J, Gao, H, Zhao, Y, Cheng, M, Meng, X, An, L, & Chen, Y. (2022). Altering microbial community for improving soil properties and agricultural sustainability during a 10-year maize-green manure intercropping in Northwest China. *Journal of environmental management*, *321*, 115859. https://doi.org/10.1016/j.jenvman.2022.115859.

22. Raheem, A, Zhang, J, Huang, J, Jiang, Y, Siddik, M.A, Deng, A, Gao, J., & Zhang, W. (2019). Greenhouse gas emissions from a rice-rice-green manure cropping system in South China. *Geoderma*.

23. Meng X, Li Y, Zhang Y, & Yao H. (2019). Green manure application improves rice growth and urea nitrogen use efficiency assessed using ^{15}N labeling. *Soil Science and Plant Nutrition*, *65*(5), 511–518. https://doi.org/10.1080/00380768.2019.1635872

24. Rani Y, S, Jamuna P, Triveni U, Patro T.S. S. K., and Anuradha N. (2022). Effect of in situ incorporation of legume green manure crops on nutrient bioavailability, 4794 5517 productivity and uptake of maize*, Journal of Plant Nutrition*. 45:7, 1004-1016.

25. Song S, Li L, Yin Q. and Nie L. (2022). Effect of in situ incorporation of three types of green manure on soil quality, grain yield and 2-acety-1-pyrrolline content in tropical region. *Crop and Environment*, **1**(3):189- 197.

26. Karmakar S, Prakash S, Kumar R, Agrawal B.K, Prasad D, Kumar R. (2011). Effect of green manuring and biofertilizers on rice production. *Oryza.*48:4,339-342.

27. Puli M.R, Prasad P.R.K, Babu P.R, Jayalakshmi M, Burla S.R. (2016). Effect of organic and inorganic sources of nutrients on rice crop. *Oryza.*53:2, 151- 159.

28. Parmar S.K, Thanki J.D, Gudadhe N.N, Pisal R, Naik J. (2020). Effect of different green manures on growth and yield of kharif rice under Integrated nutrient management. Journal of Pharmacognosy and phytochemistry.6: 128-130.

29. Sajjad Md. R, Suhani A, Rafique R, Hussain T, Naseem W, Bibi R, Malik S.N. (2018). Green Manuring for Moisture Conservation and Wheat Yield Improvement in Rainfed Agriculture. *Journal of Natural Sciences Research*. 8(9):2224-3186.

30. Egbe E.A, Soupi N.M.S, Awo M.E, Besong G.A. (2022). Effects of Green Manure and Inorganic Fertilizers on the Growth, Yield and Yield Components of Soybean (*Glycine max* (L.) Merr.) in the Mount Cameroon Region. *American Journal of Plant Sciences*. 13:702-721.

31. Goddumarri C.K, Reddy, U.V.B, Babu P.V.R, Kavitha P. (2022). Effect of Different Green Manuring Crops and Fertilizer Doses on Growth and Yield of Chickpea (Cicer arietinum L.) at Scarce Rainfall Zone of Andhra Pradesh, India. *International Journal of Environment and Climate Change*. 12(11): 744-750.

32. Mrudhula K.A, Rao. Ch. P, Venkateshwarlu B, Prasad P.R.K, Rani. Y.A. (2020). Yield and Nutrient Uptake of Rice Crop as Influenced by Green Manures and Phosphorus Levels*. Indian Journal of Pure and Applied Bio sciences.* **8**(5):115-123.

33. Praharaj C. S, Sankaranarayanan. K, Khader. S. E. S. A, Gopalakrishnan N. (2009). Sustaining cotton productivity and soil fertility through in situ management of green manure and crop residues in semi-arid irrigated condition of Tamil Nadu. *Indian Journal of Agronomy.***54**(4): 415-422.

34. Alagappan S, Venkitaswamy R, Mariappan G. (2017). Impact of different sources of organic manures in comparison with RDF and INM on growth, yield, system productivity, nutrient status and economics in rice- green gram cropping system. *Agric. Update,* 12(TECHSEAR-1): 145-153.

35. Patra, Abhik & Singh, R P & Kundu, M. & Kumar, Gagan & Malkani, Pankaj & Singh, Bhushan & Choudhury, Saurav & Mukherjee, Sayon. (2023). Green Manuring: A Sustainable Approach for Soil Health Improvement.

36. Kumar, R, Mahajan, G, Srivastava, S, & Sinha, A. (2014). Green manuring: a boon for sustainable agriculture and pest management–a review. Agricultural Reviews, 35(3), 196-206.

37. Tejada, M, Gonzalez, J. L, García-Martínez, A. M., & Parrado, J. (2008). Effects of different green manures on soil biological properties and maize yield. Bioresource Technology, 99(6), 1758-1767.

38. Dubey, L, Dubey, M, & Jain, P. (2015). Role of green manuring in organic farming. Plant Archives, 15(1), 23-26.

39. Singh D, Devi K. B, Ashoka P, Bahadur R, Kumar N, Devi O. R, &Shahni Y. S. (2023). Green Manure: Aspects and its Role in Sustainable Agriculture. *International JournalofEnvironmentandClimateChange*, *13*(11),39–45. https://doi.org/10.9734/ijecc/2023/v13i113142.

40. Mishra BB, Nayak KC. Organic Farming for Sustainable Agriculture. Orissa Review. 2004;42-45.

41. Kumar R, Mahajan G, Srivastava S, Sinha A. Green manuring: A boon for sustainable agriculture and pest management – A review. Agric. Review. 2014;35:196-206.

42. Kaur, Dr. (2015). Importance of Green Manuring in Sustainable Agriculture. popular kheti. 3. 8-12.

43. Chishi, Hillel. (2021). GREEN MANURING: An option to increase Soil Fertility and Crop Production ABSTRACT.

44. Florentin MA, Penalva M, Calegari A, Derpsch A. Green manure/ cover cropsand crop rotation in conservation agriculture on small farms, FAO, IntegratedCrop Management, 2011; 12:97.

45. Pandey DK, Pandey R, Mishra RP, Kumar S, Kumar N. Collection of Dhaincha(Sesbenia spp.) variability in Uttar Pradesh, Biodiversity and Agriculture(Souvenir), Uttar Pradesh Biodiversity Board,Lucknow,2008,48-51. https://www.researchgate.net/publication/351264674_GREEN_MANURING_An_option_to_increase_Soil_Fertility_and_Crop_Production_ABSTRACT [accessed Apr 30 2024].

46. Meena B.L, Fagodiya R.K, Prajapat K, Dotaniya M.L, Kaledhonkar M.J, Sharma, P.C, Meena, R.S, Mitran, T, & Kumar, S. (2018). Legume Green Manuring: An Option for Soil Sustainability.

47. Bah AR, Zaharah AR, Hussin A (2006) Phosphorus uptake from green manures and phosphate fertilizers applied in an acid tropical soil. Commun Soil Sci Plant Anal 37:2077–2093.

48. Becker M, Ladha JK, Ali M (1995) Green manure technology: potential, usage, and limitations. A case study for lowland rice. Plant Soil 174:181–194.

49. Prajapati, Sunil & Dayal, Parmeswar& Kumar, Vipin & Gairola, Ananya. (2023). Green Manuring: A Sustainable Path to Improve Soil Health and Fertility.

50. Das, K, Biswakarma, N., Zhiipao, R., Kumar, A., Ghasal, P. C., and Pooniya, V. 2020. Significance and management of green manures. Soil Health 197-217.

51. Ghosh, R.L.M., Ghate, M.B. and Subrahmanyam, T. 1960. Rice in India. ICAR New Delhi-12. 7. Savithri, P., Poongothai, S., Joseph, B and Vennila, R.K. 1999. Non-

conventional sources of micronutrients for sustainable soil health and yield of rice-green gram cropping system. Oryza, 36 (3): 219-222.

52. Kailash Walia,R.K.Agarwal and Bhardwaj S.K. 2018.Evaluation of Air pollution tolerances index and Anticipated Performances Index of plant and their role in development of green belt along national highway22. *Int.J.Curr.Microbiol.App.Sci.*8(3):2509-2513.doi: https://doi.org/10.20546/ijcmas.2019.803.297

53. Tanveer, A. & Ali, Hafiz Haider & Ikram, Nabeel. (2019). Green Manuring for Soil Health and Sustainable Production of Agronomic Crops. 10.1007/978-981-32-9783-8_20.

54. Kumar, Sanjeev & Saluja, Samiksha & Sukul, Premasis. (2020). Green Manuring and Its Role in Soil Health Management. 10.1007/978-3-030-44364-1_13.

55. Adekiya AO, Agbede TM, Aboyeji CM, Dunsin O, Ugbe JO (2019) Green manures and NPKfertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra(Abelmoschus esculentus (L.) Moench). J Saudi Soc Agric Sci 18:218–223

56. Agbede TM (2018) Effect of green manure application on cassava (Manihot esculenta Crantz)growth, yield quantity and quality in degraded alfisols. Pertanika J Trop Agric Sci 41(4):1757–1777 https://www.researchgate.net/publication/341661224_Green_Manuring_and_Its_Role_in_Soil_Health_Management

57. Kumar, S, Samiksha, Sukul, P. (2020). Green Manuring and Its Role in Soil Health Management. In: Giri, B., Varma, A. (eds) Soil Health. Soil Biology, vol 59. Springer, Cham. https://doi.org/10.1007/978-3-030-44364-1_13

58. Adekiya AO, Agbede TM, Aboyeji CM, Dunsin O, Ugbe JO (2019) Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). J Saudi Soc Agric Sci 18:218–223.

59. Baig MB, Zia MS (2006) Rehabilitation of problem soils through environmental friendly technologies-II: role of sesbania (*Sesbania aculeata*) and gypsum. Agric Trop Subtrop 39:1

60. Verma, Neelendra Singh & Yadav, Deepika & Chouhan, Monika & Bhagat, Charu &Kochale, Priya. (2023). Understanding Potential Impact of Green Manuring on Crop and Soil: A Comprehensive Review. 15. 832-839.

61. Ahmed P, Nath R. K. and Sarma R. (2020). Cultivation of green manuring crops for improving soil health and increasing yield of rice in Tinsukia district of Assam. A case study. Journal of Pharmacognosy and Phytochemistry, 9(2), 655-657.

62. Bhayal D, KhaddarV, Bhayal L., Yadav T, Bangar K. and Singh, B. (2018). Effect of sunhemp green manuring and intercropping on soil properties. International Journal of Current Microbiology and Applied Sciences, 7(12), 371-384.