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Understanding Potential Impact of Green Manuring on Crop and Soil: A Comprehensive Review

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ABSTRACT: Green manuring plays a pivotal role in sustainable agricultural systems by optimizing crop yields and improving the livelihoods of farming communities. Various studies have emphasized the positive impact of green manuring in enhancing the soil organic matter, soil's structure, fertility, and nutrient content, microbial biomass, water holding capacity and balancing the soil's carbon-to-nitrogen (C:N) ratio. The incorporation of green manure crops also enhances fertilizer use efficiency. The growing challenges in agriculture, such as climate change, degrading soil fertility, extreme weather events, and environmental pollution resulting from the excessive use of chemical fertilizers, Hence, the integrated application of both green manuring and fertilizers represents the optimal combination for achieving higher yields. Many farmers are incorporating green manuring into their practices. This is done to mitigate soil erosion, enhance soil structure, Suppress Weeds growth, and, most significantly, boost soil fertility. However, the inclusion of green manure crops in the existing cropping system does come with certain challenges, including issues such as insufficient availability of high-quality seeds of desired species to the farmers, managing performance variability in green manure crops, and addressing challenges related to their establishment and incorporation. The biggest challenges farmers face while doing green manuring is choosing the right green manure crop with respect to the succeeding crop along with its adaptability to their particular climate. The aim of this article is to provide a comprehensive overview of recent advancements in green manuring practices, considering both the potential advantages and limitations of this approach in annual crop production and the maintenance of soil health and fertility.

Keywords: Green Manuring, NPK content, Soil fertility, Biomass, Limitations, Profitability, Future Prospects.

INTRODUCTION

Green manuring is a technique used in farming and agriculture that involves the incorporation of certain cover crops, commonly leguminous plants, into the soil (Arasan *et al*., 2022). These crops are grown specifically to improve soil fertility and overall plant and soil health. The primary purpose of green manure is to increase the nitrogen supply for succeeding crops through biological nitrogen fixation. This practice has gained significant attention and adoption due to the rapid increase in the price of inorganic fertilizers and reduced soil fertility caused by the imbalanced use of these fertilizers. Green manuring plays a crucial role in enhancing soil fertility by providing a sustainable and natural source of nitrogen. One major benefit obtained from green manures is the addition of organic matter to the soil (Yu, 2011). This organic matter increases the food supply for macro and microorganisms in the soil, leading to increased biodiversity. The increased biodiversity in the soil, in turn, has positive effects on disease control. The presence of diverse microorganisms in the soil helps to suppress harmful pathogens and pests, reducing the risk of diseases and promoting healthier plant growth. Furthermore, the use of green manures and other organic practices effectively increases the organic matter content of soil, improves soil-water relationships, and enhances nutrient availability in the soil (Mavi and Singh 2007). This improvement in soil structure and nutrient availability ultimately leads to increased crop productivity and yield.

In addition to improving soil fertility, green manure crops also offer several other benefits. These include protecting the soil from erosion, enhancing soil properties such as structure and water-holding capacity, and providing an energy source for soil microbes. Furthermore, green manure crops can also contribute to the control of soil borne pathogens through various mechanisms (Ortiz *et al.*, 2015). For example, the incorporation of green manures into the soil can alter the composition and activity of the indigenous soil microbial community, which can lead to suppression of plant-parasitic nematodes and the production of phytochemicals that are toxic to pathogens (Yu, 2011). Green manure crops play a vital role in improving soil fertility and overall plant and soil health (Deketelaere *et al*., 2020). The primary purpose of green manure crops is to increase the nitrogen supply for succeeding crops through biological nitrogen fixation (Irin and Biswas 2021). Green manuring crops are beneficial for increasing nitrogen uptake by plants and improving fodder yield. Green manuring crops provide multiple benefits in enhancing soil fertility and crop productivity (Nelson *et al.,* 2010). These benefits include increased organic matter content, improved soil structure, enhanced nutrient availability, reduced erosion, and disease suppression. The use of green manure crops in agriculture has become increasingly important as a means to enhance soil fertility and promote sustainable crop production Overall, the addition of green manuring crops to agricultural practices is crucial for maintaining and enhancing soil fertility (Chandrasoorian *et al.,* 2020).

Green manure crops, such as Sesbania aculeate and cluster beans, have been found to increase soil organic matter content, nutrient availability and soil fertility by improving the physical, chemical, and biological properties of the soil (Li *et al.,* 2021). Furthermore, incorporation of agricultural manure and green manure with mineral fertilizers in crop patterns has been shown to increase yields. The use of green manure crops can also help mitigate the limitations of inorganic fertilizers, such as scarcity, high cost, nutrient imbalance, and soil acidity (Isah *et al.,* 2014). Green manure crops offer a low-cost opportunity for maintaining soil fertility by supplying nutrients during decomposition with slow release, which can be better timed with plant uptake while reducing nutrient losses. In addition to enhancing soil fertility and nutrient availability, green manure crops also contribute to sustainable agriculture practices by reducing erosion and suppressing diseases (Ansa and Wiro 2020). Green manuring is a field operation that involves in-situ raising and incorporation of legume crops in the soil to supply nitrogen through biological nitrogen fixation (Kaur *et al.,* 2019). Additionally, the use of green manure crops also promotes bio-diversity and helps in weed control by providing competition against unwanted plant species. Overall, the adoption of green manuring crops is a crucial step towards enhancing soil fertility and overall plant and soil health. The integration of agricultural manure and green manure in combination with mineral fertilizers has been proven to significantly increase crop yields, indicating the potential of these biofertilizers to promote sustainable agriculture and enhance crop productivity (Lorraine *et al.,* 2015).

IMPORTANCE AND NEED OF GREEN MANURE CROPS

Green manure crops have significant importance in agricultural production (Golub *et al.,* 2021). They are a valuable management practice that improves soil fertility and quality. In addition, green manure crops provide a sustainable source of nitrogen, an essential nutrient for crop growth. Furthermore, green manure crops play a crucial role in preventing the leaching of soluble nutrients from the soil and inhibiting weed growth. They also help in increasing the organic matter content of the soil, improving soil-water relationships, and enhancing nutrient availability. By incorporating green manure crops into crop rotation systems, farmers can effectively replenish soil nutrients and maintain soil health without relying heavily on synthetic fertilizer (Ambrosano *et al.,* 2018). They also contribute to the improvement of soil physical properties, such as structure, aeration, and water storage capacity. Moreover, the use of green manure crops is economically viable, environmentally sustainable, and socially acceptable in sustainable agricultural systems (Javanmard *et al.,* 2022). Green manure crops are necessary for stabilizing yields in dry seasons. Green manure crops are crucial for preventing the leaching of soluble nutrients from the soil, checking weed growth, improving soil fertility and quality, and providing a sustainable source of nitrogen for crops (Hoque *et al.,* 2017).

In addition, they contribute to enhancing soil physical properties and promoting sustainable agricultural practices. Overall, the use of green manure crops is essential for maintaining soil health, optimizing crop productivity, and ensuring sustainable agricultural systems. Furthermore, the incorporation of green manure crops into agricultural systems helps increase the organic matter content of the soil, improve water retention capacity, and enhance the availability of nitrogen in the soil (Isah *et al*., 2014). In conclusion, green manure crops play a vital role in enhancing soil fertility, preventing nutrient leaching and weed growth, providing a sustainable source of nitrogen for crop growth, and promoting overall soil health and sustainable agriculture (Javanmard *et al.,* 2022).

BENEFITS OF GREEN MANURE CROPS

Green manuring refers to the practice of incorporating plant biomass into the soil as a means to improve soil health and fertility (Ferreira *et al.,* 2022). Some of the benefits of green manuring in crop production include: - Increased organic matter: Green manures add organic matter to the soil, which improves soil structure, moisture retention, and nutrient availability. Nutrient enrichment: Green manures, especially legumes, have the ability to fix atmospheric nitrogen into the soil, thereby increasing the nutrient content available to the crops (Javanmard *et al.,* 2022). Improved soil fertility: Green manures release nutrients slowly over time, providing a steady supply of essential elements for crop growth. (Isah *et al*., 2014)- Weed suppression: Green manures can help suppress weed growth by competing for resources such as light, water, and nutrients.- Reduced soil erosion: Green manures cover the soil surface, protecting it from erosion caused by wind and water.- Enhanced soil microbial activity: Green manures provide a food source for soil microorganisms, stimulating their growth and activity.- Environmental sustainability: Green manuring is a more environmentally friendly alternative to the use of agrochemicals and pesticides, as it reduces reliance on synthetic inputs and promotes natural processes in the soil . - Increased soil water holding capacity: Green manures improve the soil's ability to retain moisture, reducing the need for irrigation and improving drought resilience.- Enhanced soil aeration: Green manures can improve the porosity and structure of the soil, allowing for better air circulation and reducing the risk of waterlogging and soil compaction.- Disease suppression: Green manures can have allelopathic effects, where they release chemicals that inhibit the growth of disease-causing organisms in the soil, reducing the risk of crop diseases (Woźniak *et al*., 2018).- Improved crop yield: The combination of increased organic matter, nutrient enrichment, and enhanced soil fertility can lead to higher crop productivity and yield. These crops can help mitigate the adverse effects of climate change by sequestering carbon dioxide from the atmosphere and reducing greenhouse gas emissions (Fabunmi *et al*., 2012).The addition of organic matter through green manure crops provides a food supply for macro and microorganisms in the soil, leading to increased biodiversity. This increased biodiversity supports the activity of beneficial microorganisms and macroorganisms in the soil, contributing to a healthier and more resilient ecosystem (Auld *et al.,* 1982). Green manure crops are particularly beneficial in less intensive cropping systems such as organic agriculture, where they have been shown to enhance yields and contribute to yield stability (Knapp & Heijden 2018). In these ways these crops indirectly help in reducing runoff and increasing infiltration into the soil. These soils must be used on the degraded soils as to reduce the impact of soil erosion (Bhayal *et al.* ,2018). Green manure crops also reduce the residual effect of various chemical fertilizers and pesticides which in turn reduces soil compaction, make it more arable (Billah *et al.,* 2022).

Table 1: Nutrient content of green manure crop and weeds on dry basis.

Sr. No.	Plant	Botanical name	Nutrient content (%) on air dry basis		
			N	P	K
	Green manure crop				
1.	Sunnhemp	*Crotolaria juncea*	2.30	0.50	1.80
2.	Dhaincha	*Sesbania aculata*	3.50	0.60	1.20
3.	Sesbania	*Sesbania speciosa*	2.71	0.53	2.21
4.	Cowpea	*Vigna sinensis*	1.70	0.28	1.25
5.	Mungbean	*Vigna radiate*	2.21	0.26	1.26
	Green leaf manure				
6.	Gliricidia	*Gliricidia sepium*	2.76	0.28	4.60
7.	Pongamia	*Pongamia pinnata*	3.31	0.44	2.39
8.	Neem	*Azadiracta indica*	2.83	0.28	0.35
9.	Gulmohar	*Delonix regia*	2.76	0.46	0.50
10.	Peltophorum	*Peltophorum ferrugenum*	2.63	0.37	0.50
	Weeds				
11.	Parthenium	*Parthenium hysterophorus*	2.68	0.68	1.45
12.	Water hyacinth	*Eichhornia crassipes*	3.01	0.90	0.15
13.	Trianthema	*Trianthema partulacastrum*	0.64	0.43	1.30
14.	Ipomoea	*Ipomoea*	2.01	0.33	0.40
15.	Calotropis	*Calotropis gigantean*	2.06	0.54	0.31
16.	Cassia	*Cassia fistula*	1.60	0.24	0.20

Source: Dubey *et al*. (2015)

Altogether, the green manuring in crop production provides both direct and indirect benefits to the plant, soil and environment. In crop production its effect includes increased organic matter and nutrient enrichment, improved soil fertility, weed suppression, reduced soil erosion, enhanced Soil organic matter and nutrient availability: Green manure crops contribute to the organic matter in the soil, improving its structure and fertility (Irin and Biswas 2021). These benefits ultimately lead to improved crop yield and overall sustainability in agricultural systems. Overall, incorporating green manures into crop production can improve soil health, decrease reliance on synthetic inputs, reduce erosion and weed growth, enhance water holding capacity, and suppress diseases (Kaur *et al.,* 2019). Overall, there are many advantages to using green manuring in crop production, including better soil physical, chemical, and biological qualities; less compaction and increased soil porosity; improved microbial activity; improved nutrient cycling; and improved crop health (Pandey and Srivastava 2021). Additional advantages of green manuring for crop production include better weed control, less soil erosion, better soil aeration, and higher crop yields (Moraes *et al.,* 2019). These crops help in nutrient mineralization and reduce the percentage of immobilization of various nutrients in the soil (Dinesh and Dubey 1998). Altogether green manuring practice must be promoted to increase the long term sustainability of agriculture without impairing its present production level.

INCORPORATION OF GREEN MANURE CROPS

Several methods can be used to incorporate green manure crops into the field. These methods include plowing, harrowing, discing or tilling the green manure crop into the soil. The green manure crops, once tilled into the soil, enrich the soil fertility as they decompose, spur plant growth and upgrade nutrient availability due to increased soil enzyme activities (Asghar and Kataoka 2021). However, the timing of incorporation is the key as it can influence nutrient uptake, help suppress weed growth, and enhance soil quality through the subsequent decomposition process (Sharifi *et al*., 2016, Kaur *et al.*, 2019; Brito *et al.*, 2019).

Additionally, some farmers may choose to use specialized equipment such as flail mowers or roller-crimpers. These tools mechanically terminate and incorporate the green manure crop, resulting in a more uniform distribution throughout the field. The incorporation of green manure can also help control the occurrence of insects and plant diseases, contributing to a healthier crop yield (Pandey and Srivastava 2021). Yet, these methods of incorporation are not without their drawbacks; they bring challenges such as the cost of establishment, management, and integration of green manure that may potentially outweigh its direct economic benefits to farmers.

In addition to enhancing soil quality, the incorporation of green manure during tillage time has also been documented to inhibit weed growth through allopathic or shading effects, thus providing a natural method for managing weed populations in agricultural fields. By incorporating green manure crops into the field, farmers can improve soil fertility, increase organic matter content, and reduce nutrient leaching. Overall, the incorporation of green manure crops into the field offers numerous benefits including reduced fertilizer requirements, improved soil quality, and potential marketing opportunities for organic products (Asghar and Kataoka 2021).

Furthermore, the incorporation of green manure crops can also improve soil structure and water retention, leading to better moisture management and reduced soil erosion. In conclusion, incorporating green manure crops into the field through methods such as plowing or using specialized equipment provides multiple benefits including improved soil fertility, reduced weed growth, and enhanced crop yield due to accelerated soil enzyme activities (Kaur *et al.*, 2019). All things considered, incorporation must be completed prior to flowering in order to reap the full benefits of these crops and prevent their needless reproductive expansion.

EFFECT OF GREEN MANURING ON CROP YIELD

Green manuring has the potential to enhance soil physical, chemical, and biological characteristics, resulting in improved crop yields in subsequent crops. Green manuring, particularly with legumes, has a notable beneficial effect on grain yield by improving soil organic matter and providing increased nutrients to the growing crops. The utilization of synthetic nitrogen in combination with green manure enhances nitrogen use efficiency (NUE) even further. The effect of green manuring on yield of different subsequent crops, as observed in field experiments conducted by several researchers presented in Table 3. The below tables give a quick overview of selecting the right green manure crop while anticipating its advantages in the succeeding crop.

CONSTRAINTS IN ADOPTING GREEN MANURING

Green manuring, despite its numerous benefits, is subject to certain constraints that can limit its effectiveness. Some of these constraints include: The increasing nutrient demands of modern high-yield cultivars, which have led to a surge in the use of inorganic fertilizers at the expense of organic materials such as green manure (Sumon *et al.,* 2018). This can lead to a decline in the use of green manure and its potential benefits for soil health and fertility.

Table 2: Green manure crops suitable for different agro-climatic zones.

Sr. No.	Plant	Botanical name	Nutrient content (%) on air dry basis		
			N	P	K
	Green manure crop				
1.	Sunnhemp	*Crotolaria juncea*	2.30	0.50	1.80
2.	Dhaincha	*Sesbania aculata*	3.50	0.60	1.20
3.	Sesbania	*Sesbania speciosa*	2.71	0.53	2.21
4.	Cowpea	*Vigna sinensis*	1.70	0.28	1.25
5.	Mungbean	*Vigna radiata*	2.21	0.26	1.26
	Green leaf manure				
6.	Gliricidia	*Gliricidia sepium*	2.76	0.28	4.60
7.	Pongamia	*Pongamia pinnata*	3.31	0.44	2.39
8.	Neem	*Azadiracta indica*	2.83	0.28	0.35
9.	Gulmohar	*Delonix regia*	2.76	0.46	0.50
10.	Peltophorum	*Peltophorum ferrugenum*	2.63	0.37	0.50
	Weeds				
11.	Parthenium	*Parthenium hysterophorus*	2.68	0.68	1.45
12.	Water hyacinth	*Eichhornia crassipes*	3.01	0.90	0.15
13.	Trianthema	*Trianthema partulacastrum*	0.64	0.43	1.30
14.	Ipomoea	*Ipomoea*	2.01	0.33	0.40
15.	Calotropis	*Calotropis gigantean*	2.06	0.54	0.31
16.	Cassia	*Cassia fistula*	1.60	0.24	0.20

Source: Meena *et al.* (2018); Das *et al*. (2020)

Table 3: Percentage increase in crop yield by adopting green manure practice.

Crop	Green Manure Crop	Increase in yield (%)	References
Maize	Sunnhemp	26.4%	Pasha *et al.* (2019)
	Red clover	6%	Kanatas *et al.* (2020)
safflower	Sunnhemp	29%	Yogesh and Hiremath *et al.* (2020)
	Green gram	19%	
	Cowpea	42%	
Rice	Sunnhemp	58%- 112%	Islam *et al.* (2019)
	Dhaincha	68%-117%	
	Sunnhemp	59%	Irin *et al.* (2021)
	Mung bean	14.8%	
	Black gram	35.5%	
	Cowpea	53.5%	
	Dhaincha	7.8%	Ahmed *et al.* (2020)
wheat	Dhaincha	23%	Gautam *et al.* (2021)
	Sunnhemp	31%	
	Cowpea	19%	
	Black gram	39.5%	
	Mung bean	30%	
	Cowpea	13.5%	Sajjad *et al.* (2019)
Sugarcane	Dhaincha	12%-22%	Yadav and Yaduvanshi (2001)
	Cowpea	10%	White *et al.* (2020)

Other constraints include limited availability of suitable green manure crops that can effectively improve soil properties and nutrient content. Additionally, the timing and integration of green manuring into the cropping system can be challenging, as it requires careful planning and coordination to ensure optimal results. Furthermore, the adoption of green manuring practices may also be limited by financial constraints, as the cost of acquiring and managing green manure crops can be high, especially for small-scale farmers with limited resources. Furthermore, the lack of knowledge and awareness about the benefits and techniques of green manuring can also hinder its adoption and implementation by farmers. The cost of implementing green manuring can also pose a significant obstacle, particularly for small-scale farmers with limited resources, thereby creating another barrier to widespread adoption. The lack of awareness among farmers about the long-term benefits and cost-effectiveness of green manuring can also pose a constraint on its wider adoption (Sarmento *et al.,* 2019; Arasan *et al.,* 2022).

While green manuring has many potential benefits for soil health and crop yields, it is important to recognize and address these constraints in order to ensure its successful implementation and widespread adoption. Some additional constraints to consider include the availability of suitable land for green manuring, as well as potential conflicts with existing cropping systems. Furthermore, the use of chemical fertilizers and herbicides may also deter farmers from adopting green manuring practices. Another constraint in green manuring is the time required for the decomposition of organic materials, as it can delay the planting of subsequent crops. In brief, the hurdles in adopting green manuring include the increasing use of inorganic fertilizers, limited availability of suitable green manure crops, challenges in timing and integration, financial constraints, lack of knowledge and awareness, cost of implementation, availability of suitable land, conflicts with existing cropping systems, use of chemical fertilizers and herbicides, and time constraints for decomposition (Adigbo *et al.,* 2013).

The other constraints in green manuring include the costs involved in establishing legumes and managing green manure, lack of sufficient seeds of appropriate green manure legumes, high variability in green manure performance, high price of land and labor, relatively low price of mineral fertilizer, potential conflicts with existing cropping systems, and the time required for decomposition of organic materials (Boyette *et al.,* 2014).

FUTURE PROSPECTS OF GREEN MANURING

Despite the drawbacks associated with green manuring, there is still potential for its future utilization and improvement. Research and development efforts can focus on optimizing green manure management practices, such as identifying the most appropriate timing for incorporation and improving nutrient release patterns. Additionally, advancements in technology and precision agriculture can help farmer better coordinate green manure practices with their overall farming schedule. This can include using remote sensing and data analytics to monitor soil health and nutrient levels, making it easier to determine when and where green manuring would be most beneficial. Furthermore, there is a growing demand for sustainable and organic farming practices, which may increase the use of green manuring in the future. Despite the disadvantages of green manuring, it is important to note that there are potential economic and environmental advantages associated with its use.

Overall, while green manuring has its drawbacks and limitations, it remains a viable option for improving soil health and nutrient availability in agricultural systems (Bai *et al*., 2017). Green manuring may require additional labor and resources, such as seeds and water, to establish and maintain the cover crop. Additionally, green manuring may not provide immediate benefits and farmers may need to wait for the cover crop to decompose and release nutrients into the soil. However, with proper management and consideration of these factors, green manuring can contribute to sustainable agricultural practices and provide long-term benefits for soil health, nutrient availability, and crop productivity (Goulart *et al*., 2022).

While there are some limitations and potential drawbacks associated with green manuring, the benefits it can bring to agricultural systems should not be overlooked. Overall, the disadvantages of green manuring include potential increased labor and resource requirements, delayed benefits and the need for proper management. Despite the disadvantages of green manuring, it is important to note that there are potential economic and environmental advantages associated with its use.

CONCLUSIONS

Green manuring crops play a crucial role in enhancing soil fertility and overall plant and soil health. The significance of this soil improvement practice has been on the rise in recent years. As the cost of inorganic fertilizers continues to rise and their imbalanced use leads to reduced soil fertility, the adoption of green manuring has become an essential practice for enhancing soil fertility and ensuring sustainable crop production. Green manuring helps conserve soil moisture and improves the soil's ability to retain water by enhancing its physico-chemical properties and increasing soil organic matter, leading to enhanced water use efficiency (WUE). Green manuring not only enhances soil quality but also leguminous green manure crops play a crucial role in nitrogen fixation, thereby increasing fertilizer use efficiency and facilitating integrated nutrient management. Furthermore, it aids in the control of pest insects, diseases, and weeds in subsequent crops. It may be concluded that green manuring stands as one of several viable alternatives to attain the desired ecological and agronomic sustainability, ultimately contributing to increased agricultural yields.

FUTURE SCOPE

Farmers may combine green manure crops with other manures, such as vermicompost and farm yard manure, to safeguard their output without the use of chemical fertilizers in response to the growing demand for organic food.

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Conflict Of Interest. None.

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