Potential Impacts of Green Manure Incorporation on Soil Fertility Enhancement and Rice yield (Review)

Abstract

Green manuring is currently being emphasized as an alternative nutrient source to alleviate pressures on crop production. The review was undertaken to understand the impacts of green manure on both rice yield and soil fertility enhancement. It focused on the potential of various green manure plants such as sunn hemp, *dhaincha*, and pulses. It covers different nature of them and their potential contributions of nitrogen, carbon and other nutrients, ultimately serving as a supplement or replacement for chemical fertilizers. Quantity and quality of green manure are influencing to the decomposition and mineralization processes in the soil. Therefore, management of green manure to be efficient and synchronize crop demands is essential. Numerous studies have demonstrated that the incorporation of green manure enhances nitrogen and carbon balance in the soil while decreasing the need for chemical fertilizer applications, ensuring to improve rice yields. It was proved that only green manure application 20 ton/ha was 90% higher than any nutrient application. Then, combine application of sunn hemp and chemical nitrogen fertilizer increases rice yield 8-17% than the only chemical nitrogen fertilizer. In terms of soil fertility, not only incorporation with green manure but also with green manure and chemical fertilizer provides soil macro nutrients. By combination of green manure 20 ton/ha and chemical N fertilizer 60 kg/ha has higher yield than only double chemical N fertilizer rate of 120 kg/ha. Similarly, the synergistic effect of organic compost and green manure significantly increased the benefits of green manure alone. Furthermore, apart from providing nitrogen, a comprehensive long-term study revealed that the incorporation of green manure integrating with chemical fertilizers in paddy fields led to an increase in carbon sequestration by 3.95-4.17%. The practice of green manuring shows promising potential for positively influencing soil health, thereby contributing to the sustainability of crop yields.

Key words: green manure; nitrogen; carbon; rice yield.

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1. Introduction

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The agricultural sector faces the challenge of nitrogen loss to the environment, primarily through the emission of nitrous oxide (N_2O), which contributes significantly to global warming. Proper management of fertilizer inputs, ensuring the appropriate amount is applied throughout the growing season, is vital for both crop development and reducing N_2O emissions. Additionally, the escalating cost of fertilizers poses a financial burden on farmers. Enhancing efficiency and the judicious use of chemical fertilizers can mitigate this challenge and benefit the environment. Moreover, the percentage of organic matter in cultivated soil is a critical factor in maintaining soil health and ensuring long-term sustainability. Therefore, prioritizing practices that increase soil organic matter content is essential for sustaining agricultural productivity while safeguarding the environment.

The combination of chemical fertilizers and organic matter application can effectively mitigate nitrogen loss into the environment. Utilizing leguminous cover crops is particularly beneficial as they have the ability to fix atmospheric nitrogen, thereby reducing the fertilizer requirements for subsequent crops. Recently, alternatives such as green manure, compost, and farmyard manure have been recognized as sustainable sources of nutrients, promoting soil fertility while also reducing fertilizer costs and ensuring ecological stability. In fact, the availability of farmyard manure and compost can be limited, especially for field crops requiring substantial quantities to have enough amount to improve its soil fertility. In contrast, green manures are more readily accessible and require less labor and other resources.

Green manuring is highlighted as alternative sustainable source of nutrients for crop cultivation. Green manuring involves incorporating undecomposed or fresh organic matter either locally or from a distance (Pieters 1927) [1]. Green manures stand as a biologically sustainable and ecologically friendly option, providing dual advantage of boosting crop yield and ensuring soil fertility within sustainable agricultural approaches (Singh et al., 1991) [2]. By combining chemical fertilizer N with green manures, a sustainable and environmentally responsible agricultural system can be fostered. This integration facilitates the optimal supply of nutrients for rice cultivation while concurrently diminishing NO_3 leaching in the soil, thereby safeguarding the environment. Sunn hemp, *dhaincha,* pulses, azolla and etc. are commonly used as green manure. Various kinds of green manure plants have different adoptability and nature. The paper aims to observe the various kinds of green manure plants, their different nature and potential impacts on soil fertility and rice yields.

2.General Information of Green Manure Plants

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2.1 Sunn hemp can be adopted to soil ranging from coarse to fine textured and on infertile as well as fertile soil. It grows best on well-drained soil with pH level from 5 to 7.5. Flowering will start at the days from 65 to 90 days. Its life span is 150 days (Rotar and Joy 1983) [3]. It is prominent fiber crop due to its use as green manure and fodder.

2.2 *Dhaincha* is a quick growing succulent outstanding green manure crop. It prefers waterlogged condition. *Sesbania rostrata* has nodules on both stems and roots and it can adopt various conditions of soil and climate. It is widely recommended as green manure in many Asian countries because of its high biomass yields and flood tolerance. It is most suitable for pre-rice green manure in rainfed rice farming system (Garrity and Becker 1994) [4]. At 12 weeks old, dhaincha becomes woody and necessary to bury it about 4 to 8 weeks for decomposition before planting rice (Singh et al.,2014) [5].

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2.3 Pules such as green gram, black gram, cow pea, pigeon pea is commonly grown as green manure. Pulses contain much protein which is required for human, afterwards its residue can provide green manure. An assessment of dry matter and nitrogen yield of various kinds of pulses mentioned that cow pea produce the highest mean dry matter of 2367 kg/ha and 1.143% of N (Shah, Ahmad and Rahman 2011) [6]. Those mentioned green manure plants are harvested at the age of from 49 days to 70 days.

General description of days of harvest, biomass yield and nitrogen contribution are shown in the table 1.

Table 1. Harvesting days and potential biomass availability of different green manure plants

Sr.	Green Manure	Day to Harvest (days)	Fresh Biomass (ton/ha)	Dry Biomass (kg/ha)	N (kg/ha)	Reference

1.	Sunn hemp			5000-11500	100-200	(Ozores- Hampton 2012) [7]
	Sunn hemp	70	15 -20		75-80	(Singh et al.,2014) [5]
2.	Dhaincha (~~*sesbania*~~ *Sesbania aculeata*)	56-70	10-20		75-80	(Singh et al.,2014) [5]
	(Sesbania rostrata)	56-70	15-20		150-180	(Singh et al.,2014) [5]
	Sesbania rostrata	40-60			50-70	(Kolar et al,1993., Manguiat et al.,1992; Meelu et al.,1992) [8]
3.	Pulses (cow pea)	49		4400	95	(Singh 1984) [9]
	Pulses (cow pea)			2354	25.09	(Shah, Ahmad and Rahman 2011) [6]

Green manuring is used to be practiced in different forms such as incorporation into soil in situ before cultivating next crop, simultaneous cultivation with main crop and cut & carry from other annual or perennial leguminous trees. Regarding to crop establishment, fertilizer application is not practiced in green manure plantation. However, phosphorus application in sesbania (dhaincha) produce 4.2 ton/ha dry matter yields and 105 kg N/ha nitrogen content while 4 ton/ha of dry matter and 88 kg N/ha was obtained without Phosphorus application (Singh 1984) [9].

3. Decomposition and Mineralization Process in Soil

Incorporation of legume green manure into soil undergoes decomposition and mineralization process (Meena *et al.*, 2018) [10]. Decomposition is a biological breakdown and transformation of complex organic compounds into simpler organic and inorganic molecules (Fox et al. 1990) [11]. Those processes of green manures are affected by the types of soil, crops, crop growth stage at which it is incorporated, and prevailing climatic conditions (Meena et al., 2018) [10]. Among these, the dominant factors are the quantity and quality of green manure crops. Moreover, soil factors, which affected the decomposition and mineralization of green manure, are the soil texture, structure, soil reaction, microbial activity, and the status of soil nutrients (Dinnes et al., 2002) [12]. Decomposition and mineralization of organic matter mainly depends upon the availability of N in soil (Meena et al., 2018) [10]. Ensuring synchronization between the decomposition and nitrogen release patterns of green manure and the demands of crops is crucial for nitrogen sustainability (Kaneko et al., 2023) [13].

4. Management of Green manures

The basic principle in green manure crops, should aim at maximum succulent green matter at burial. Due to many experiments, the plowing at the flowering stage provides the best result of green manure (Singh et al., 2023) [14]. Regarding sunn hemp, the percentage of organic matter, nitrogen and other essential elements increased with the age of the plant and attained maximum at 60-75 days after sowing. Nitrogen content of the plant increases gradually up to 60 days of sowing and thereafter it declines. Thus, ploughing of the crop before or after 60 days would reduce the maximum manurial efficiency of the crop. Besides nitrogen, other inorganic constituents are also very important. In the dry mater the percentage of ash is gradually increased in the same directions as that of nitrogen. Thus, the maximum number of mineral elements is at two months stage (Srivastava and Pandit

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1968) [15]. Other organic substances such as total carbohydrate and sucrose attain maximum at 60-75 days stage. If the primary objective of green manure is to maximize nutrients input without considering the characteristics of the materials, their decomposition rate, and their availability to subsequent crops, plowing may be conducted at 90 days after sowing. However, the quantity of fertilizer constituents alone does not determine the success of green manuring. Generally, it has been reported that green manuring at 60 days after sowing yielded the best results (Sarkar et al., 2007) [16]. A study conducted over two years revealed that significant disparities in the incorporation of green manure between 50 DAS (days after sowing) and 60 DAS for sunn hemp. Various parameters including total carbon, total nitrogen, C/N ratio, nitrate N (NO_3-N), acid detergent fiber, and neutral detergent fiber resulted considerable differences. In both 2019 and 2020, sunn hemp nitrogen and acid detergent fiber yields were considerably higher at 50 DAS compared to 60 DAS. These findings underscored the crucial role of seeding and harvest timing in estimating decomposition rates (Kaneko et al., 2023) [13]. Additionally, minimum variations were observed between sunn hemp cultivars, suggesting that cultivar selection might not significantly influence decomposition outcomes (Kaneko et al., 2023) [13].

Once the decision on the appropriate age for harvesting is made, the duration required for incorporation into the soil before the main crop cultivation becomes a crucial consideration. An experiment demonstrated that burying sesbania (*dhaincha*) one day before transplanting rice resulted in significantly higher yields compared to burying it one to two weeks before rice transplantation (Beri and Meelu 1981) [17]. The other research mentioned that the waiting period between strawberry plantation and incorporation of sunn hemp was 8 days for the first time and 22 days for the second time. The research recommended that shortening the waiting period may synchronize N supply with crop uptake (Li et al/, 2020) [18].

5. Fertilizer compensation and impact on Rice yield

A field experiment in 2004-2005, rice crop reached 50% flowering stage earlier by 6-7 days due to green manure (sunn hemp) incorporation comparing to the without sunn hemp incorporation plots and only root application plots. Only roots application plot was 8.9 percent yield higher than control plots. The yield of only shoot application and whole plant application were 27.7 % and 28.75% higher than control treatment respectively (Neelima 2008) [19]. Then, the study recommended that with shoot or total incorporation and 60 kg N/ha chemical fertilizer was comparable to the rate of 180 kg N/ha (Neelima 2021) [19]. Further, incorporation of green manure 20 ton/ha (sunn hemp) without fertilizer N (inorganic Nitrogen) produce 91% greater grain yield than control (without nitrogen) on average across 3 years. Rice yield response to combination of green manure 20 ton/ha and Nitrogen fertilizer 60 ton/ha was greatest which yield 8-17% more than the combination of green manure 0 ton/ha and Nitrogen fertilizer 120 ton/ha treatment (Aulakh et al., 2000) [20]. Another study proved that rice grain yield with pretransplant incorporation of green manure 20 and 40 (sesbania) ton/ha was ranged from 5.18 to 5.81 ton/ha while the grain yield with fertilizer nitrogen 120 kg N/ha was 5.4 ton/ha (Aulakh et al., 2000). Then, the residual effect of green manure (sesbania) produces 25% higher yield of wheat crop under rice-wheat cropping system than chemical nitrogen fertilizer application which has no residue (Aulakh et al., 2000) [20].

A Research mentioned that the application of cowpea and dhaincha on a dry basis of 3.4 ton/ha and 7.2 ton/ha in dry basis respectively resulted in equal rice yield with the application of recommended dose of chemical fertilizer of N-P-K 80-25-35 kg/ha. Then, cowpea was recommended as better green manure crop than dhaincha mainly in the wet season (Bhuiyan and Zaman 1996 [43]; Selvi and Kalpana 2009 [44]; Meena 2018 [10]).

Soil organic matter and total Nitrogen in 0-15 cm layer are decreasing over the time when fertilizer N or legume green manure were added as sole and main sources in double rice cropping system. Excessive sole application of green manure exhibits a negative impact on rice yield (Dawe et al., 2003[20]; Thorup-Kristensen et al., 2012 [21]) and the optimum combination rates depends on crop species, soil type and soil fertility (Yadav et al., 2000) [22]. The combination of green manure 20 ton/ha and N 60 kg/ha has higher yield than green manure 40 ton/ha and N 60 kg/ha (Aulakh et al., 2000) [20]. Further, combined application of 20% from green manure & 80% from fertilizer nitrogen and 40% from green manure & 60% from fertilizer nitrogen were observed that increased the rice yields and soil fertility (Xie et al., 2016) [23]. The effect of different green manures on rice yield are mentioned in the table 2.

Table. 2 Effect of different green manures on rice yield and soil nitrogen balance

Green manure crops	Green matter (ton/ha)	N added (kg/ha)	Rice grain yield (ton/ha)	Increase percent over no green manure	Soil N percent with continuous with green manure
Sunn hemp	27.8	134	3.47	198	0.109
Dhaincha	21.1	133	3.62	207	0.141
Cowpea	21.0	74	3.33	180	0.101

(Shah, Ahmad & Rahman 2011) [6]

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6. Soil fertility Improvement

6.1 Nitrogen balance

Sunn hemp incorporation significantly increased soil Nitrate Nitrogen NO_3-N fluxes (by 66% to 185%) and also enhanced extractable soil NO_3-N concentration (by 20% to 94%) compared with the weedy fallow control during the first 3 weeks after incorporation (Li et al., 2021) [24]. After 4 years of experiment, application of 120 kg N/ha in both crops (rice-wheat rotation) resulted in 35 kg of residual NO_3- N/ha in 150 cm soil profile whereas only 19 kg NO_3- N/ha remained with green manure 20 ton/ha and chemical fertilizer 60 kg N/ha in rice-wheat rotation system. It was shown that integrated application of green manure and chemical fertilizer decrease the potential nitrate contamination in ground water (Aulakh et al., 2000). Incorporation of green manure 20 ton/ha added 77 to 128 kg N/ha in the aboveground material (Aulakh et al., 2000) [20]. Soil organic matter was mostly accumulated in the soil treated with green manure and rice straw. A study concluded that applying high quantities of diverse organic amendment can increase soil organic carbon content and rice yield in red paddy soil. Soil organic fraction was increased 15-58%, 16-61%, 14-50% and 12-53% by combined treatments of green manure (Chinese milk vetch) and chemical fertilizers 100% treatment when compare to only chemical fertilizer 100%. The study concluded that green manure (Chinese milk vetch) has potential to reduce 20-40% of chemical fertilizer (Li et al., 2020)[18]. A field experiments conducted to compare the summer green manure crops such as green gram, cowpea and dhaincha revealed that dhaincha produced 38.56 ton/ha and in turn led to the recycle of 180.5, 22.6, 267 N-P-K kg/ha (Pooniya et al.,2012) [25].

6.2 Carbon balance

Soil organic matter content influences on soil physical and biological properties as well as improve soil capacity to regulate ecosystem services. Soil organic matter contain 58% of soil organic carbon. Green manure contribution to soil has positive impact on increasing soil organic matter/ soil organic carbon. Kamran et al., (2021) [26]; Zhang et al., (2023) [27] found that soil organic carbon sequestration was increased by the application of green manure which significantly increase soil macro aggregation. A long-term experiment from 2008 to 2020 in Southern China mentioned that Carbon sequestration was increased 3.95-

4.17% by the application of green manure with chemical nitrogen fertilizer in paddy soil meanwhile yield was increasing compared with the application of chemical fertilizer alone (Gao et al.,2020) [28]. A meta-analysis documented that soil organic carbon in the 0-20 cm soil layer increased with the increase in rotation years at the rate of 0.0139 and 0.2211 g/kg annually in the fallow- rice and green manure- rice respectively (Gao et al.,2023) [29]. Flooding and anaerobic paddy soil reduce the decomposition rate of green matter and increase the formation of water-stable aggregate fraction, and thus increase soil carbon sequestration (Yang et al., 2014) [30]. A study mentioned that total carbon stock was increasing over 300 days in both of soil layer (0-5 cm) and (5-10 cm) from 5.81 to 8.84 ton/ha and 5.81 to 8.36 ton/ha respectively. The study was conducted to investigate the changes in stock of C and N in organic matter fraction in soil by the fertilization of sunn hemp and ammonium sulfate for coffee crop (Pereira 2018) [31].

6.3 Other Nutrients Availability

Phosphorus is one of the macro elements for crops. Researches concerned with green manure and Phosphorus availability was limited. One study mentioned that incorporation of green manure can enhance the availability of Phosphorus (Cavigelli and Thien 2003) [32]. In addition, a glasshouse study was done by using the ^{32}P – ^{33}P labeling technique to determine the relative contribution of green manure and P fertilizer to P uptake by Setaria grass (*Setaria sphacelata*). It was found that total P uptake of Setatia plant in the green manure treatment was three to four times greater than P fertilizers. It means green manure mobilize more soil P and both P with green manure and other decomposition products were involved in reduction of soil P retention capacity (Bah et al.,2007) [33]. An experiment showed that the periodical changes in available Zn and Cu contents in soil recorded highest in the treatments 50% recommended N from chemical fertilizer and 50% N through dhaincha with the simultaneous highest uptake of Zn and Cu by rice grain and straw (Sarkar et al., 2015) [34]. Regular incorporation of dhaincha green manure before rice transplanting increases rice yield and correct Fe and Mn deficiencies (Nayyar and Chhibba, 2000) [35].

6.4 Fertilizer use efficiency

Green manuring can increase the fertilizer used efficiency. It was proved that combined application of 10 ton/ha of Bokashi, 10 ton/ha of sunn hemp green manure and 50% recommended rate of chemical fertilizer provided non-significant yield of 100% recommended fertilizer rate on maize production (Yuliana, Sunarni and Islami 2015) [36]. A study mentioned that under the integration of green manure and with different rate of chemical fertilizer, soil organic matter was significantly and positively correlated with soil total nitrogen, N uptake and P uptake of wheat (Muhammad et al., 2022) [37].

6.5 Improvement of soil physical properties

Soil physical properties are contributing as important characteristics for crop productions. Green manuring application not only provide nutrients to the soil but also improve soil physical and biological properties. Incorporation of sunn hemp as green manure into the soil will release the organic acid, amino acid, sugars, vitamins and mucilage during growing as well as after decomposition (Shukla et al., 2011) [38]. These substances are capable to bind soil particles together and form better soil aggregation which in turn increases water holding capacity (MacRae and Mehuys 1985) [39]. Water holding capacities of the green manuring (rape, Chinese milk vetch and ryegrass) has increased 4.7, 13.0 and 10.3% respectively in the field of 28 years continuous cultivation of rice- rice farming system. The rest of soil physical properties including soil organic carbon improvement are mentioned in the table 3 (Yang et al., 2012) [40]. Soil organic carbon content increases the soil aggregation which in turn increase the soil structure and reduce the soil erosion (Tisdall and Oades 1982) [41].

Table 3. Different soil physical properties with different green manure treatments

Treatments	Soil Organic Carbon (g/kg)	Bulk density g/cm^3	Total Porosities (Capillary and non-capillary)
R-R-WF (rice-rice-fallow)	15.71	1.32	30.21
R-R-RP (rice-rice-rape)	16.97	1.27	38.06
R-R-MV (rice-rice-Chinese milk vetch)	16.46	1.28	38.87
R-R-RG (rice-rice-ryegrass)	16.77	1.25	40.29

(Yang et al.,2012) [40]

7. Discussion

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Various types of green manure plants offered dual advantages by both fixing nitrogen and providing green matter. Researches indicated that the use of green manure has enhanced rice yields compared to cultivation without green manure. In addition, combining green manure with chemical fertilizer yields superior results compared to sole application of green manure. The application of chemical fertilizer of 60 kg N/ha with sunn hemp incorporation provide the comparable yield of rice to the double rate of 120 kg N/ha. Likewise, large amount of dhaincha application 40 ton/ha produced 5.81 ton/ha of rice meanwhile, fertilizer nitrogen 120 kg N/ha did 5.4 ton/ha. Combination of dhaincha 20 ton/ha and chemical fertilizer 60 kg N/ha provide the yield of 6% higher than the dose of 120 kg N/ha (Aulakh et al.,2000) [20]. It means half amount of chemical fertilizer can be reduced with the substitution of green manure 20 ton/ha. The combined application of chemical fertilizer and green manure enhances soil organic matter content rather than green manure amendment only.

Some papers mentioned that the exceed amount of green manure provide negative impact on rice yield (Dawe et al., 2016 [21], Thorup et al.,2012 [42]). It was proved according to the results of combined application of 20% green manure & 80% fertilizer nitrogen exceed the rice yield than 40% of green manure & 60% fertilizer nitrogen (Xie et al., 2016). Further, the combination of green manure 20 ton/ha & N 60 kg/ha has higher yield than green manure 40 ton/ha & N 60 kg/ha (Aulakh et al., 2000) [20].

Alongside its chemical benefits, the use of green manure improves soil physical properties and stimulates biological activities. Green manure provides soil carbon; its content at 0-20 cm soil layer increased at the rate of 0.0139 and 0.2211 g/kg/yr. Especially in the paddy soil, anaerobic soil reduces the decomposition rate and increase the carbon sequestration (Yang et al., 2014) [30].

In order to have optimal biomass it is needed to consider their adaptability, access to water, sufficient growth period, and biomass production capacities and nutrient contents. Although cow pea produces relatively low amount of biomass than sunn hemp and dhaincha, it resulted in equal yields of rice and it was recommended as better green manure (Bhuiyan and Zaman 1996 [43]; Selvi and Kalpana 2009 [44]; Meena, 2018 [10]). It means carbon and nitrogen ratios are important factors as well as to biomass gained.

Key factors for optimizing nutrient supply and synchronization are number of days to harvest and incorporation days before main crop plantation. While green manuring is considered sustainable, it poses challenges in terms of time, labor, and land management, particularly in regions with three harvests per year. Seed scarcity, particularly for crops like sunn hemp, presents a significant obstacle. Despite being drought-resistant, optimal crop establishment requires sufficient moisture. Additionally, the cost of cultivating green manure can sometimes exceed that of applying chemical fertilizers. Furthermore, obtaining the required amount of green manure may prove challenging under certain conditions. Limited farmer knowledge about the diverse uses of green manure, including fodder, energy, weed and pest control, and soil conservation are still remaining as challenges.

8. Conclusion

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Green manures are socially, economically and environmentally sustainable source of nutrient application for improving and maintaining soil fertility and crop productivity. Encouraging the synchrony of crop demand and N supply increases the fertilizer efficiency at the same time. It can decrease the damage to the environment. Integrated application of green manure and chemical fertilizer keep the crop yields which can be gained with the 100% application of chemical fertilizers. Then, it can improve the soil physical properties of carbon sequestration which in turn increase the nitrogen fertilizer use efficiency and decrease the soil bulk density. It can be concluded that green manuring improves the soil health and have potential for long term sustainability.

Promoting successful green manuring requires farmers to have adequate knowledge of the optimal conditions for different green manures. In addition, other potential usages of green manure such as production of organic fertilizer by using green manure plants, seed production technologies and so on which can generate the second income for farmers should be disseminated to farmers. It is essential to introduce regionally suitable green manure varieties and promote their widespread adoption. Additionally, it is important to provide facilities for producing sufficient green manure biomass and available enough green manure seeds to overcome the challenges associated with cultivating green manure.

9. References

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