***Original Research Article***

**Study on Nutrient Provision of Sunn hemp at Various Ages on Paddy Soil**

**Abstract**

Nitrogen and carbon are essential elements for sustainable agricultural production. Green manuring provides nitrogen through decomposition while also increases soil carbon concentration. The study aimed to estimate biomass contribution of Sunn hemp at various ages and the mineralization of Sunn hemp after incorporation into paddy soil under submerged condition, focusing on synchronizing nitrogen supply with rice crop demand. Sunn hemp was harvested at different growth stages (45, 60, and 75 days) to assess its biomass and nutrient contributions, particularly nitrogen and carbon. The harvested plants were incorporated into the soil, and rice seedlings were transplanted a week later. Nitrogen mineralization was monitored over eight weeks, alongside rice plant nitrogen uptake. The study was conducted at the Department of Agricultural Research, Nay Pyi Taw, with four treatments: control (no Sunn hemp), SH45 (45 days old Sunn hemp), SH60 (60 days old Sunn hemp), and SH75 (75 days old Sunn hemp). Chemical composition analysis of Sunn hemp at different growth stages showed minimal variation, but significant differences in fresh and dry biomass. SH75 and SH60 contributed fresh biomass together with nitrogen and carbon three times higher than that of SH45. Nitrogen mineralization from different ages of Sunn hemp reached maximum within first two weeks. Consideration to mineralization percentages, SH60 and SH75 were continuously happen from 1st to 8th week, however that from SH45 was approached to 0 from the 5th week to 8th week. Meanwhile, demand of rice plants started at 3rd week and was maximum at 6th week, thereafter continued to 8th week. The synchronization of nitrogen supply from SH60 and SH75 were from 3rd week to 8th week whereas that from SH45 were from 3rd week to 5th week. Also, apparent nitrogen recovery (ANR) was the lowest in the SH45. The research highlighted the nutrient provision of Sunn hemp at different ages to rice plant under submerged paddy soil.

Key words; Sunn hemp, Biomass, Nitrogen, Carbon, Mineralization, Paddy soil

**1. Introduction**

Green manuring is one of the soil conservations practices as well as it can provide nitrogen (N) from decomposition process in the soil. Legume green manuring is alternative incorporation of organic matter into soil and it can enhance agricultural sustainability by improving nutrient retention (1), enhancing soil fertility (2). It is the practice of incorporating undecomposed fresh/dry plant materials into soil and it can offer economically attractive and ecologically sound option of reducing external inputs and improving internal resources (3). Incorporation of legume green manure into soil undergoes decomposition and mineralization process (4). The dominant factors of decomposition and mineralization are the quantity and quality of green manure crops and it mainly depends upon the availability of N in soil (4). Also, it is a kind of soil organic matter and can provide various benefits to soil physical, chemical and biological properties (5).

Sunn hemp is an excellent, rapid-growing green manure to be included in rotation with vegetable, ornamental, and other plants to add nitrogen and organic matter, to suppress weeds, and to reduce root-knot nematodes (6). It has ability to provide plant major nutrients as well as soil organic carbon. Sunn Hemp incorporation significantly increased soil NO3-N fluxes and also enhanced extractable soil NO3-N concentration compared with the weedy fallow control during the first 3 weeks after incorporation (7). Nitrogen content of the plant increased gradually up to 60 days of sowing and thereafter it declined. The percentage of ash in the dry matter was gradually increased in the same directions as that of nitrogen. Thus, mineral elements reached maximum amount at two months stage (8). Schomberg (2007) (9) mentioned that date of planting and length of growing period influenced the biomass and N content of Sunn hemp. Moreover, other organic substances such as total carbohydrate and sucrose attained maximum at 60-75 day and consideration of optimum harvesting days was reported that green manuring at 60 days after sowing was the best (10).

In a two-year study, green manure incorporation at 50 DAS differed acid detergent fiber yields to that at 60 DAS. These results suggested that the seeding and harvest time were important for decomposition estimations (11). Rice plant demands N maximum amount between the early to mid-tillering and panicle initiation stages (12). Thus, quantifying the amount of mineral N supply at a particular period was essential for synchronization with crop demand. The study was undertaken to estimate potential provision of biomass & nutrients and to investigate mineralization rate after incorporation of Sunn hemp regarding with different ages into paddy soil.

**2. Materials and Methods**

In this study, there were two experiments for estimation of biomass production from Sunn hemp at various ages and for investigation of mineralization from the incorporated these Sunn hemps with living rice plants.

**2.1 Experimental Site**

The tank-experiment (2 x 1 m2) was carried out in 15 Feb to 30 June 2024. The experiment was conducted at Water Utilization Research Section, Department of Agricultural Research, DAR (Yezin). It is situated at latitude 19.82415° or 19° 49' 27" north and longitude of 96.27597° or 96° 16' 34" east.

**2.2 Experimental Design**

There were four treatments such as control, Sunn hemp at 45 days (SH45), 60 days (SH60) and 75 days (SH75). The experiment was designed as randomized completely block with 3 replications.

**2.3 Cultivation of Sunn hemp**

The soil in all tanks were mixed to be homogenous and samples were taken and analyzed at the laboratory of Land Use Division, Department of Agriculture (DOA). Seed rate of Sunn hemp was 44.9 kg ha-1. Seed was broadcasted and other management such as irrigation were done based on requirement. Sunn hemp biomasses were separately collected at their different age by cutting plant near the soil surface. Fresh weights of biomass were recorded within 1 hour after harvest. Terminated Sunn hemp were chopped into 5 cm long pieces of residue using chopper and then incorporated into the soil at a depth of 10-15 cm (7). After Sunn hemp incorporation into soil, left the soil a week for decomposition.

**2.4 Cultivation of Rice**

Sin Thu kha (Oryza sativa. L), life span of 135 days, was cultivated in the treated tanks. Before cultivation, seeds were soaked in water for 24 hours and then incubated for 48 hours. The sprouted seeds were sown on a well-prepared seed bed using wet bed method. Then, 25 days old seedlings were transplanted one seedling per hill with the spacing of 20 cm x 15 cm. Thus, there were 60 hills in a tank.

**2.5 Physicochemical properties of experimental soil**

Composite soil samples were collected prior to the experiments and analyzed for their physicochemical characteristics as shown in the table 1.

**Table 1. Physicochemical properties of experimental soil**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Value** | **Rating** | **Methods** |
| pH | 7.53 | Slightly alkaline | 1:2.5 (water) |
| EC (mS cm-1) | 0.1 | Very low | Electrode method |
| Total N% | 0.07 | Very low | Kjeldahl digestion, distillation |
| Available P2O5 (ppm) | 51 | Very high | Olsen |
| Exchangeable K2 O (mg 100gm-1) | 7.23 | Low | Ammonium acetate extraction |
| CEC (meq 100g-1) | 20.90 | Medium | Leaching |
| Organic matter (%) | 1.96 | Low | Weight loss and ignition |
| Bulk density (g cm-3) | 1.39 |  | Disturb sample method |
| Sand % | 85.90 |  |  |
| Silt% | 9.08 |  |  |
| Clay % | 5.02 |  |  |
| Soil texture |  | Loamy Sand | Pipette method |

**2.6 Chemical composition of Sunn hemp**

Total biomass contribution of Sunn hemp was calculated as multiplication of remaining dried biomass percent and total fresh weight. Subsamples consisting of 10 -20 whole plants (depending on treatment) were randomly selected, weighted and placed in the oven at 66 °C for at least 72 hours to dry. Dry weights of subsamples were recorded to estimate the total sample dry weight. Dried samples were ground to pass a 1.0 mm sieve and then analyzed at the Laboratory (9). Nitrogen and Carbon content of Sunn hemp samples were calculated as multiplication of dry matter weight and N% and C% of sample respectively. The nutrient contents of each treatment were summarized in the table 2.

**Table 2. Nutrient contents of Sunn hemp at different ages**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatments | Total N% | Total P2O5% | Total K2O% | Carbon % | C : N | Fiber content (%) |
| SH45 | 2.73 | 0.4 | 0.28 | 51.9 | 19.01 | 18.64 |
| SH60 | 2.76 | 0.75 | 0.25 | 52.9 | 19.17 | 20.13 |
| SH75 | 2.83 | 0.4 | 0.05 | 54.9 | 19.40 | 34.50 |

**2.7 Weather Condition**

Rainfall, minimum and maximum temperature at the research location during the study was mentioned in the figure 1.

**Fig. 1. Rainfall (mm) and Minimum & Maximum Temperature (°C) during the study**

**2.8 Analysis of Rice Plant Uptake and Soil Available Nitrogen**

**2.8.1 Analysis of Rice Plant Uptake Nitrogen**

Analysis of rice plant uptake nitrogen and soil available mineral nitrogen were undertaken at the laboratory under Water Utilization Research Section, Department of Agricultural Research. Rice plant samples were weekly collected to measure nitrogen uptake until the eighth week after the recovery period. Randomly selected rice plants were cut just above the soil surface, dried at 70°C, and analyzed for total nitrogen using the Kjeldahl method.

**2.8.2 Detection of Available N (Mineral N) from Experimental Soil**

Composite soil samples were separately collected for each treatment to determine mineral N. This was done weekly from the first to the eighth week after Sunn hemp incorporation. Samples were taken from a 15 cm depth, air-dried, and sieved through a 2 mm sieve. Available nitrogen was determined using the Alkaline Permanganate Method. For the analysis, 20 grams of dried soil were weighed and placed into a 250 ml flat-bottom flask. Then, 20 ml of distilled water was added, and the mixture was left to stand for 30 minutes. Subsequently, 100 ml of KMnO4 and 100 ml of NaOH were added, and the flask was connected to a distillation apparatus. A 250 ml receiving conical flask containing 10 ml of 3% H3BO3 and three drops of a mixed indicator was simultaneously connected. The distillation process was carried out to obtain 100 ml of (NH4)3BO3 solution. Afterward, the apparatus was rinsed with a wash bottle and disconnected from the distillation setup. The conical flask was then cooled and titrated with normal H2SO4. Available nitrogen content (ppm) was calculated as following formula;

Nitrogen mineralization % was calculated as follows;

[7]

**2.8.3 Apparent N recovery (ANR)**

There are several indicators to assess the nutrient performance on crop yield. Nutrient uptake efficiency that is the proportion of nutrient added to the soil and that taken up by the plant is used [13]. The proportion of nitrogen absorbed and derived from the applied fertilizer nitrogen cannot be precisely determined. Therefore, it is referred to as the "apparent" recovery of fertilizer nitrogen [14]. Apparent N recovery is commonly used and calculated as follow;

[15]

**3. Statistical Analysis**

Experimental data were analyzed with Analysis of Variance (ANOVA) by using Statistix 8.0. Treatment means were compared using least significant difference (LSD) test at P = 0.05 level (16).

**4.Results and Discussion**

**4.1 Estimation of Biomass and Nutrient Contributions**

Measured parameters of plant heights, root length, fresh weight, dry weight, moisture content, carbon and nitrogen contents were significantly different at p<0.01 among cultivated Sunn hemps (Table 3). Minimum plant height occurred at SH45. There was no statistically difference between SH60 and SH75 for plant height, fresh weight, dry weight and N & C contribution but SH75 was numerically higher than SH60 except for fresh weight. The root length of SH45 was the shortest, 2.45 cm and 5 cm shorter than the SH60 and SH75 respectively. The weighted fresh biomass contribution of SH60 was significantly greater than that of SH45. SH60 provided fresh biomass weight 140% greater than SH45 while it was 4.6% greater than SH75. SH75 did 129.6% greater than SH45. However, dry matter contribution was the highest for the SH75 and it was 6.62% higher than SH60 and 224% higher than SH45. Although SH60 produced a higher fresh biomass than SH75, SH75 surpassed SH60 in dry biomass contribution. The reason of higher dry biomass in SH75 was related to its low moisture content (Table 3). Therefore, SH75 revealed superior dry biomass and nutrient contributions compared to SH60 and SH45.

Consequently, the nitrogen contribution of SH75 was 53.78 g tank-1, representing 236% increase over SH45 and 9.3% higher than SH60’s contribution. The N contributions of SH45, SH60 and SH75 were equivalent to the 80 kg ha-1, 245.9 kg ha-1 and 268.9 kg ha-1 respectively. Similarly, carbon contribution of SH75 was 243% higher than SH45 and 10.7% higher than SH60. The C contribution data from SH45, SH60 and SH75 were equivalent to 1520 kg ha-1, 4710 kg ha-1, 5215.5 kg ha-1 respectively. The results were similar to the research results that Sunn hemp biomass and N content increased with days after plantation (DAP) at two research location (9). Pereira (2018) (17) mentioned that carbon stock was positively changed at almost all of the evaluation times and he concluded that fertilization with Sunn hemp increased the C stock in labile and recalcitrant fractions of soil organic matter. The research finding indicated that all treatments provided the nitrogen and carbon to the soil, but in comparison, plant height, fresh weight, dry weight provisions of SH60 and SH75 were not significantly different to each other whereas SH45 consistently recorded the lowest values across all parameters.

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| **Table 3. Contributions Biomass and Nutrients at Different Ages of Sunn hemp** | | | | | | | | |
| **Treat-ments** | **Plant height (cm)** | **Root Length (cm)** | **Fresh Weigh**  **(g tank-1)** | **Dry Weight**  **(g tank-1)** | **Mois- ture**  **(%)** | **N contri-bution**  **(g tank-1)** | **C contri-bution**  **(g tank-)** |
| SH45 | 103.27b | 15.950c | 2320.0b | 586.0b | 74.7 a | 16.0b | 304.1b |
| SH60 | 139.17a | 18.400b | 5570.0a | 1782.1a | 68.0 b | 49.18a | 942.7a |
| SH75 | 145.38a | 20.950a | 5326.7a | 1900.0a | 64.33 c | 53.78a | 1043.1a |
| LSD | 14.323 | 2.2313 | 588.15 | 170.0 | 1.51 | 4.6964 | 89.615 |
| *P* value | *P* =0.01 | *P* =0.01 | *P* =0.01 | *P* =0.01 | *P* =0.01 | *P* =0.01 | *P* =0.01 |
| CV% | 8.61 | 9.75 | 10.38 | 10.81 | 3.85 | 10.75 | 10.66 |

**4.2 Rice Plant Uptake Nitrogen and Apparent Nitrogen Recovery (ANR)**

**4.2.1 Rice Plant Uptake Nitrogen**

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**Fig. 2. Plant Uptake Nitrogen (g tank-1)** **by Rice plant** **during incorporation period of 8 weeks. SH45= incorporation of Sunn hemp at the age of 45 days, SH60= incorporation of Sunn hemp at the age of 60 days, SH75= incorporation of Sunn hemp at the age of 75. Rice plant were transplanted at 1st week after incorporation and recover at the second week, afterwards, uptake was measured after the incorporation of 3rd week until 8th week**

Regarding nitrogen uptake, rice with SH75 mostly achieved the highest values across all weeks, followed by SH60 and SH45. Nitrogen uptake of rice from the soil incorporated with SH60 and SH75 steadily increased from 1st week, peaking at 6th week, after which it declined in weeks 7 and 8. These results were coincided with ANR (Figure 3). Plant uptake in the control plot was the lowest at all week. N mineralization percentage from SH45 (Figure 4) was approaching to 0 from 5th week to 8th week.

**4.2.2 Apparent Nitrogen Recovery (ANR)**

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**Fig. 3. Apparent Nitrogen Recovery % (ANR) by Rice Plant during incorporation period of 8 weeks.**

ANR is the indicator for efficient N release and uptake by plant, leading to better Nitrogen Use Efficiency (NUE). Aulakh (2000) (18) and Morris et al. (1986) (19) discussed that the value of ANR decreased by greater application of green manure to the rice field and NUE was reduced. ANR % was calculated based on rice plant uptake and N contribution from different ages of Sunn hemp within the period of incorporation of 60 days as shown in the fig. 3. It was found that apparent N recovery from SH45 was 18.94%, the highest at the 7th week throughout the incorporation period whereas SH60 and SH75 were the highest at the 6th week and the values were 33.79 and 32.06. Then, ANR values of them were decreasing to the 8th week as 26.31 and 26.85. Hu et al., (2023) (20) and Ladha et al., (2020) (21) mentioned that rice taken up 30 -50% of N inputs and improving NUE was remaining as a challenge in the rice production. In this study, ANR value were less than 50% for all treatments. It was explained that mineralization from Sunn hemp at all treatments was highest within first two weeks and decreased later on (Table 4). Fageria and Baligar, (2005) (22) explained that synchrony of N supply with crop demand could ensure adequate quantity of uptake.

**3.3 Nitrogen mineralization after Sunn hemp incorporation into soil (g tank-1)**

Except at 8th week, mineral Nitrogen at 1st to 7th week were statistically different at p<0.05 and p<0.01 respectively (table 4). Control showed the minimum amount of mineral N at every week and SH45 placed at the second. Comparing the amount of available N including (NH4-N and NO3-N), SH60 was the highest at 1st ,3rd ,4th ,6th ,7th and 8th week, followed by SH75 which was highest at the week of 2nd, 4th, 5th, 8th. According to the results, the net mineral N remained the highest in the first two week; the highest mineral N amount were produced by SH45 and SH75 at the 2st week and that of SH60 was produced at the 1st week. The research findings were consistent with the research of Aulakh (2000) (18) and Brar & Sidhu (1995) (13). In their finding, the incorporation of fresh green manure accumulated mineral N in soil during 1-2 weeks, followed by a slow decline during 2 to 3 weeks period.

Moreover, nitrogen mineralization % from Sunn hemp contribution was showed in the figure 3. N mineralization % from SH45 was very low at the week of 5th, 6th, 7th and 8th whereas, SH60 and SH75 showed some mineralization % at all weeks. According to the findings, SH45 amendment mineralized 54.99% after 14 days whereas SH60 and SH70 did 15.16% and 27.86%, respectively. These results were likely explained by the greater moisture content of SH45 (74.7%) which decompose rapidly than SH60 (68%) and SH75 (64.33%) (Table 3). On the other hand, fiber content of SH45 was the lowest (18.64%) and SH60 & SH75 contain 20.13% and 34.5% (Table 2). The fleshy portions of Sunn hemp were decomposed at first, leaving behind recalcitrant high fiber tissues that were resistant to decomposition and high level of carbon content which decomposed gradually at the later weeks (23).

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| **Table 4. N mineralization after Sunn hemp incorporation into soil (g tank-1)** | | | | | | | | |
| **Treatments** | **1st Week** | **2nd Week** | **3rd Week** | **4th Week** | **5th Week** | **6th Week** | **7th Week** | **8th Week** |
| Control | 14.77c | 8.80 c | 7.64 c | 5.31b | 6.64b | 6.64c | 8.13b | 7.64 a |
| SH45 | 17.16bc | 17.59b | 16.27ab | 7.64ab | 7.14b | 6.73c | 8.38b | 7.96 a |
| SH60 | 24.17a | 16.60b | 19.75a | 10.62a | 7.30b | 18.26a | 16.10a | 8.30 a |
| SH75 | 18.82 b | 23.41a | 12.78 b | 9.46 a | 10.79a | 16.38b | 9.63 b | 8.47 a |
| LSD | 1.17 | 0.46 | 1.71 | 1.31 | 0.531 | 0.707 | 0.648 | 0.7073 |
| CV% | 7.66 | 3.36 | 14.91 | 19.37 | 8.16 | 7.21 | 8.34 | 10.70 |
| *P* value | *P* =.01 | *P* =.01 | *P* =.01 | *P* =.05 | *P* =.01 | *P* =.01 | *P* =.01 | ns |

**Fig. 4. Nitrogen Mineralization % by Sunn hemp during incorporation period of 8 weeks SH45= incorporation of Sunn hemp at the age of 45 days, SH60= incorporation of Sunn hemp at the age of 60 days, SH75= incorporation of Sunn hemp at the age of 75, mineral N was measured after a week incorporation of Sunn hemp until 8th week**

**5. Conclusion and Recommendations**

This study estimated nutrient provision of Sunn hemp at different ages to rice plant under submerged paddy soil. For fresh biomass provision, SH60 contributed the maximum amount to paddy soil while SH75 provided the maximum amount of dry weight. Chemical composition analysis of Sunn hemp at different growth stages showed minimal variation. As fresh and dry weight production differed significantly, it leads to variations in nutrient inputs, particularly nitrogen and carbon. Under 2-month study of mineralization in submerged paddy soil, nitrogen mineralization of all treatments was the highest at the 1st and 2nd week, afterwards, it declined. N mineralization percentages of SH45 was very low from the 5th week to 8th week, while SH60 and SH75 continued relatively higher amount until 8th week. Regrading to the nitrogen input, SH60 and SH75 covered until 8th week while SH 45 as low as control from 5th week to 8th week. In addition, plant uptake was maximum at 6th week in SH60 and SH75. Considering the average N recovery percentages, the treatment of SH60 and SH75 provided all weeks and it was the maximum at 6th week. The results in this study have revealed that incorporation of Sunn hemp into paddy soil decomposed and released nitrogen rapidly and the high available nitrogen was found at the first 2 weeks, the plant’s demand was started at the 3rd week. Therefore, synchronization of the supply nitrogen and demand of crops was minimum for the first two weeks, afterwards, some synchronization occurred especially in SH60 and SH75. In conclusion, incorporation of Sunn hemp at different ages into paddy soil provided carbon and nitrogen with different proportions. By maximizing the synchronization of N supply and demand, it benefits to rice crop production. It can be suggested that the study focused on better synchronization of N supply and crop demands is still required.

**Reference**

1.Dinnes, D. L., Karlen, D. L., Jaynes, D. B., Kaspar, T. C., Hatfield, J. L., Colvin, T. S., & Cambardella, C. A. (2002). Nitrogen management strategies to reduce nitrate leaching in tile‐drained Midwestern soils. *Agronomy journal*, *94*(1), 153-171.

2.Fageria, N. K., Baligar, V. C., & Bailey, B. A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in soil science and plant analysis*, *36*(19-20), 2733-2757.

3.Sulieman, S., & Tran, L. S. P. (2014). Symbiotic nitrogen fixation in legume nodules: metabolism and regulatory mechanisms. *International Journal of Molecular Sciences*, *15*(11), 19389-19393.

4.Meena, B. L., Fagodiya, R. K., Prajapat, K., Dotaniya, M. L., Kaledhonkar, M. J., Sharma, P. C., ... & Kumar, S. (2018). Legume green manuring: an option for soil sustainability. *Legumes for soil health and sustainable management*, 387-408.

5.Lal, R. (1991). Soil structure and sustainability. *Journal of sustainable agriculture*, *1*(4), 7-92.Li, J., Zhao, X., Maltais-Landry, G., & Paudel, B. R. (2021). Dynamics of soil nitrogen availability following sunn hemp residue incorporation in organic strawberry production systems. *HortScience*, *56*(2), 138-146.

6.Rotar, P.P. and Joy, R.J. (1983) “Tropic Sun” Sunn Hemp; Crotalaria juncea L.

7.Li, J., Zhao, X., Maltais-Landry, G., & Paudel, B. R. (2021). Dynamics of soil nitrogen availability following sunn hemp residue incorporation in organic strawberry production systems. HortScience, 56(2), 138-146.

8.Srivastava, S. C., & Pandit, S. N. (1968). Relative role of sunnhemp tops and roots in contributing to the green-manuring benefits to sugarcane.

9.Schomberg, H. H., Martini, N. L., Diaz‐Perez, J. C., Phatak, S. C., Balkcom, K. S., & Bhardwaj, H. L. (2007). Potential for using sunn hemp as a source of biomass and nitrogen for the Piedmont and Coastal Plain regions of the southeastern USA. *Agronomy Journal*, *99*(6), 1448-1457.

10. Sarkar, S. K., & Ghoroi, A. K. (2007). Sunnhemp as green manure.

11. Kaneko, M., Kato, N., Hattori, I., Matsuoka, M., & Vendramini, J. M. (2023). Seeding and harvesting times and climate conditions are important for improving nitrogen and fiber contents of green manure sunn hemp. Sustainability, 15(9), 7103.

12. Sims, J. L., & Place, G. A. (1968). Growth and Nutrient Uptake of Rice at Different Growth Stages and Nitrogen Levels 1. *Agronomy Journal*, *60*(6), 692-696.

13. Barber, S. A. (1995). Soil nutrient bioavailability: a mechanistic approach. John Wiley & Sons.

14. Rao, A. C. S., Smith, J. L., Parr, J. F., & Papendick, R. I. (1992). Considerations in estimating nitrogen recovery efficiency by the difference and isotopic dilution methods. Fertilizer Research, 33, 209-217.

15. Jalpa, L., Mylavarapu, R. S., Hochmuth, G. J., Wright, A. L., & van Santen, E. (2020). Apparent recovery and efficiency of nitrogen fertilization in tomato grown on sandy soils. HortTechnology, 30(2), 204-211.

16. Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research. John wiley & sons.

17. Pereira, W. D., Martins, F. L., Santos, R. H. S., de Oliveira, T. S., & Caballero, S. S. U. (2018). Changes in the stocks of C and N in organic matter fractions in soil cropped with coffee and fertilized with sunn hemp and ammonium sulfate. Semina: Ciências Agrárias, 39(3), 999-1014.

18.Aulakh, M. S., Khera, T. S., & Doran, J. W. (2000). Yields and nitrogen dynamics in a rice–wheat system using green manure and inorganic fertilizer. Soil Science Society of America Journal, 64(5), 1867-1876.

19. Morris, R. A., Furoc, R. E., & Dizon, M. A. (1986). Rice Responses to a Short‐Duration Green Manure. II. N Recovery and Utilization 1. Agronomy Journal, 78(3), 413-416.

20. Hu, B., Wang, W., Chen, J., Liu, Y., & Chu, C. (2023). Genetic improvement toward nitrogen-use efficiency in rice: Lessons and perspectives. Molecular plant, 16(1), 64-74.

21. Ladha, J. K., Jat, M. L., Stirling, C. M., Chakraborty, D., Pradhan, P., Krupnik, T. J., ... & Gerard, B. (2020). Achieving the sustainable development goals in agriculture: The crucial role of nitrogen in cereal-based systems. Advances in agronomy, 163, 39-116.

22. Fageria, N. K., & Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. Advances in agronomy, 88, 97-185.

23. Ladha, J. K., Khind, C. S., Khera, T. S., & Bueno, C. S. (2004). Effects of residue decomposition on productivity and soil fertility in rice–wheat rotation. Soil Science Society of America Journal, 68(3), 854-864.