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Residual Management of Sunnhemp (*Crotalaria juncea*) Varieties in Releasing Soil Nutrients and Their Impact on Succeeding Rice Crop

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ABSTRACT

Background: Legume is an essential alternative approach in the organic agricultural system to produce ecologically safe nitrogen (N), while restoring soil health in an appropriate mode to supply nutrients for subsequent crops. The experimental study was conducted in the *summer* (March) 2024 at Tamil Nadu rice research institute, Aduthurai, Tamil Nadu to study the residual effect of Sunnhemp varieties either alone or incorporation along with rice stubbles and their impact on nutrient availability of soil, soil organic carbon and yield attributes of succeeding rice in sunnhemp-rice cropping system.

Methods: The field trial was set up in a split-plot design with fivefold replication during the *summer* of 2024, with the main plot consisting of two Sunnhemp varieties (V_1 - ADT 1, V_2 - CO 1) and the subplot comprising of Rice residues (W_1 - Without residues, W_2 - With residues). The treated Sunnhemp varieties were ADT 1 and CO 1; the succeeding rice variety was ADT 57.

Result: The results indicated that there was a significant difference between the two varieties in terms of nutrient release pattern. The residual effect of Sunnhemp variety (ADT 1) with residues (V_1W_2) contributed sustained release of nitrogen (143.4 kg/ha), phosphorus (22.9 kg/ha) and potassium (56.4 kg/ha). The increase in soil organic carbon from the initial level was also 0.036% throughout the crop growth, which has greatly influenced the growth and yield attributes and eventually resulted in the highest grain and straw yield of the succeeding rice crop.

Key words: Alternative approach, Legume, Residual effect, Soil organic carbon, Sustained release.

INTRODUCTION

Sunnhemp is a tropical to subtropical crop known for its versatile nature with profitable value for farmers because of its numerous characteristics, such as high biomass, fibre crop, weed suppressive, insect and pathogen resistance and mainly cultivated as a green manure crop (Maheshwari *et al.*, 2020). Green manuring is an ideal approach for minimizing synthetic nitrogen input and reactive nitrogen losses to the environment, which helps accomplish the dual targets of green agricultural development and food security (Liang *et al.*, 2022; Bala and Patel, 2023). It helps to improve the physical conditions of soil by building up soil organic matter, increasing the water holding capacity and hydraulic conductivity of soil (Zhou *et al.*, 2020). Sunnhemp reportedly has a higher decomposition rate during the first few weeks of incorporation due to the sugars and phenols of low molecular weight. It had a better residual quality, which released more than 50% of nitrogen in its first 2-3 weeks of incorporation. Upon plant substance degradation, sunnhemp releases nutrients that will be available to the succeeding crop (Surucu *et al.*, 2014). Sunn hemp produces 5050-11235 kg/ha of dry biomass with 2.85% N in plant residues, providing 100-200 kg/ha of total available nitrogen to the succeeding crop (Xie *et al.*, 2023). Simulated N budgets showed that green manure diminishes 20-40% of the conventional N fertilizer input (Liang *et al.*, 2022).

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Li *et al.* (2024) reported that incorporating 20 t/ha green manure alone increases rice yield by 90% compared to without any nutrient application. Different sunnhemp varieties vary in their ability to decompose and mineralize nutrients, especially nitrogen, when used as a green manure crop (Stallings *et al.*, 2017). The potential of sunnhemp varieties with differential growth habits, biomass accumulation, C:N ratio and nutrient content will significantly influence the biological nitrogen fixation, leading to different nutrient release patterns to the succeeding crops (Naumann *et al.*, 2025). ADT 1, the Sunnhemp variety was released during 2023 a green manure crop, which is highly suitable for irrigated and rainfed ecosystems of Tamil Nadu with average biomass yield of 20.79 t/ha and could be incorporated in the soil within 45-60 DAS (Pushpa *et al.*, 2023).

In addition, including residues along with green manure would synergistically affect decomposition and significantly increase organic matter, allowing the succeeding crop to better uptake nutrients. Returning rice stubble to the soil after harvest with green manure incorporation resulted in long-term soil fertility and sustainability (Guopeng *et al.*, 2020). Sowing Sunnhemp seeds in crop residues will be crucial for balancing the C:N ratio, accelerating decomposition, enhancing mineralization in the long term, resulting in prolonged nutrient release to the succeeding crops (Mangaravite *et al.*, 2023). It can increase the organic carbon content, available nitrogen, phosphorus and potassium in soils, preventing nutrient loss and organic carbon loss and improving nutrient availability. It also leads to temporary nitrogen immobilization due to a high C:N ratio, around 60-100:1. The study hypothesizes that incorporating sunnhemp varieties with and without crop residues affects the nutrient supply to the soil and yield performance of the following rice crop. The objective of the current study is to assess the effect of sunnhemp varieties and residual management on soil organic carbon, nutrient supply in soil and yield of the rice crop. This paper examines the replacement of chemical inputs to achieve environmental sustainability by improving soil fertility and protecting natural resources.

MATERIALS AND METHODS

A field trial was superintended during the *summer* of 2024 at Tamil Nadu rice research institute, Aduthurai in Thanjavur District, where the investigated field soil exhibits a clayey texture. The experiment was conducted in a split-plot design with fivefold replication. Two Sunnhemp varieties (V_1 - ADT 1, V_2 - CO 1) were assigned in the main plot; the subplot consists of Rice residues (W_1 - Without residues, W_2 - With residues). The sunnhemp varieties involved in this treatment were ADT 1 and CO 1. Both are 120-day duration crops. The succeeding rice variety was ADT 57, a short-duration (115-120 days) crop. The crops were also free from major pest and disease incidence in all growth stages. Other chemical inputs, like fertilizers and pesticides, were completely avoided. Sunnhemp seeds of both varieties were sown in the field without stubble (A clear field without any crop residues) and with stubble (a previously harvested rice field left with residues). Sunnhemp varieties with and without crop residues were incorporated 48 days after sowing and the succeeding rice crop was transplanted 7-10 days after incorporation. The soil samples were collected at 15 cm soil depth at initial, before incorporation, 30 DAI (Days After Incorporation), 60 DAI, 90 DAI and 120 DAI. The varietal characteristics of sunnhemp is given in the Table 1.

RESULTS AND DISCUSSION

Nitrogen mineralization pattern

The data on nitrogen mineralization of Sunnhemp varieties incorporated with and without crop residues showed that the co-incorporation of the ADT 1 variety with rice residue (V_1W_2) (143.4 kg/ha) has released a higher amount of nitrogen (Table 2) in a sustained manner throughout the crop growth as shown in (Fig 1). Generally, crop residues like rice or wheat residues have high cellulose and low nitrogen content and a high C: N ratio, which results in nitrogen immobilization. In contrast, leguminous sunnhemp has a high nitrogen concentration and a low C: N ratio, which results in high carbon and nitrogen mineralization. In combination, rice residues reduced leaching, enhanced nitrogen availability throughout the crop period, which synchronizes the nitrogen release with the crop demand. The reports were similar to Zhou *et al.* (2020). Because of the high C: N ratio in rice stubbles, it exhibited temporary nitrogen immobilization during the 30 DAI period due to the microbial immobilization of nitrogen; high lignin and cellulose content in rice residue have temporarily immobilized the nitrogen and the same was happened for CO 1 also while incorporated with rice residues (Garzon *et al.*, 2022, Jopir *et al.*, 2024). Sunnhemp varieties (ADT 1 and CO 1) without residue, *i.e.*, (V_1W_1, V_2W_1), had a better decomposition rate during the time (30 DAI) and nitrogen release was also rapid during that period due to a low C: N ratio. During 60, 90 and 120 days after incorporation, the nitrogen release rate decreased. Li *et al.* (2021) demonstrated that after two weeks of incorporation of sunnhemp had the highest net nitrogen mineralization rate over the 8-week incubation study. In V_2W_1, the rate of nitrogen availability started decreasing and contributed the lowest nitrogen of 103.7 kg/ha.

Table 1: Varietal characteristics of sunnhemp.

Varieties	Green biomass (t/ha)	Dry biomass (t/ha)	Nitrogen content (%)	C:N ratio
ADT 1	20.7	5.2	1.70	14: 1
CO 1	18.6	3.5	1.68	15: 1

Phosphorus availability in soil

The data on the phosphorus availability due to the residual incorporation of sunnhemp varieties is given in Table 2. Incorporation of the ADT 1 variety with the residue (V_1W_2) resulted in a higher phosphorus availability (22.9 kg/ha) as compared to CO 1. Combining sunnhemp with rice residues has increased the soil's organic matter, improved soil structure and enhanced mineralization, resulting in reduced P fixation. Particularly, rice residues might contribute organic phosphorus and their decomposition significantly increased phosphorus availability throughout the incubation period (Mahey *et al.*, 2024). The least phosphorus availability among all other treatments resulted in the CO 1 incorporation without residue (V_2W_1) (15.0 kg/ha). Lower organic matter and the phosphorus released in the soil are primarily obtained from the inherited biomass of green manure alone, so it has been comparatively lower. Phosphorus availability pattern throughout the incubation period is shown in Fig 2.

Potassium availability in soil

The data on incorporating sunnhemp varieties alone and with/without rice residues in Table 2 showed that co-

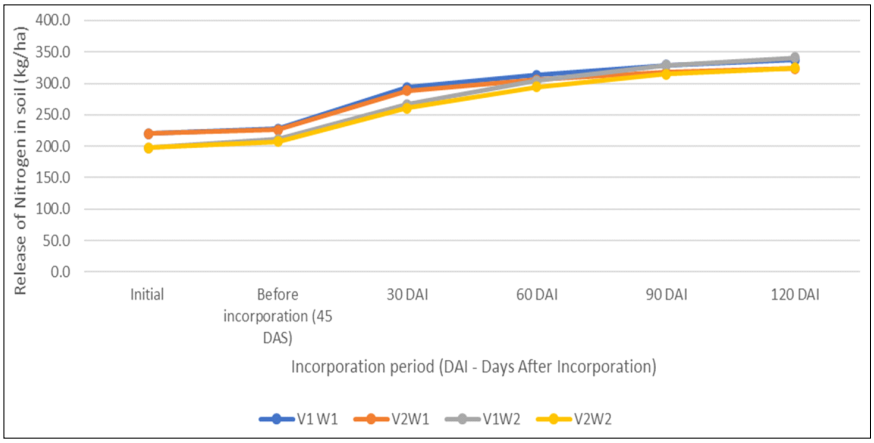


Fig 1: Effect of residual management of sunnhemp varieties on nitrogen release in the soil.

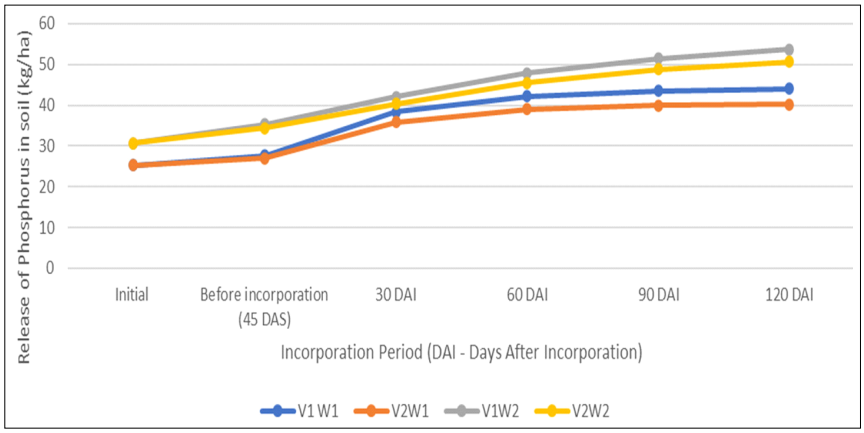


Fig 2: Effect of residual management of sunnhemp varieties on phosphorus release into the soil.

Table 2: Status of levels of Initial (Before sowing sunnhemp seeds), final (120 DAI) and total release (From initial to final) of organic carbon, nitrogen, phosphorus and potassium into the soil.

Treatments	OC %			Nitrogen (kg/ha)			Phosphorus (kg/ha)			Potassium (kg/ha)		
	Initial	Final	Total release	Initial	Final	Total release	Initial	Final	Total release	Initial	Final	Total release
V_1W_1	0.319	0.339	0.020	220.3	337.2	116.9	25.3	44.1	18.8	110.7	152.2	41.5
V_2W_1	0.319	0.335	0.016	220.3	324.0	103.7	25.3	40.3	15.0	110.7	147.3	36.6
V_1W_2	0.311	0.347	0.036	197.5	340.9	143.4	30.8	53.7	22.9	112.2	168.6	56.4
V_2W_2	0.311	0.339	0.028	197.5	324.1	126.6	30.8	50.7	19.9	112.2	160.7	48.5

incorporation of ADT 1 with rice residue (V_1W_2) contributed the highest potassium availability of 56.4 kg/ha. Increased biomass added significant organic matter, resulting in improved soil aggregation and structure, leading to better aeration and infiltration in soil that acts as a reservoir of potassium. Those residues might stimulate microbial activity, resulting in higher release of potassium (Bargali *et al.*, 2024). Among all the treatments, CO 1 incorporation without rice residue (V_2W_1) resulted in the soil's lowest potassium availability of 36.6 kg/ha. The pattern of potassium availability after incorporation for all the treatments is shown in Fig 3.

Soil organic carbon levels

The data on availability of soil organic carbon through incorporation of sunnhemp varieties alone or with residues in Table 2 showed that among all the residual management practices, the highest organic carbon (0.036%) was achieved by incorporating the ADT 1 with rice residues (V_1W_2). The increased biomass added through integrated incorporation of green manure and rice reduces, then increases nutrient availability, particularly nitrogen and phosphorus, adds more organic matter into the soil throughout the incubation period and enhances the soil organic level (Adekiya *et al.*, 2023). The lowest soil organic carbon of 0.016% has resulted from CO 1 incorporation without rice residues (V_2W_1). Lower nutrient availability and biomass resulted in the lowest addition of organic carbon into the soil. The availability of soil organic carbon at different stages of incorporation is shown in Fig 4.

Yield of the succeeding rice crop

The results of sunnhemp incorporation alone and its integration with rice residues Table 3 indicated that the residual effect of ADT 1 along with rice residue (V_1W_2) has achieved the highest grain and straw yield of 5100 kg/ha and 9160 kg/ha. Increased biomass accumulation, microbial activity, organic matter in the soil and increased soil organic carbon level enhanced the nutrient availability to the rice crop, resulting in increased plant height, leaf area index, dry matter accumulation, leading to produce more productive tillers/hill, increased number of panicles/ hills, which significantly increased the grain and straw yield. (Jat *et al.*, 2024; Baheliya *et al.*, 2025). Vice versa, the lowest grain and straw yield was obtained in V_2W_1 among all treatments. Lowest biomass accumulation, soil organic

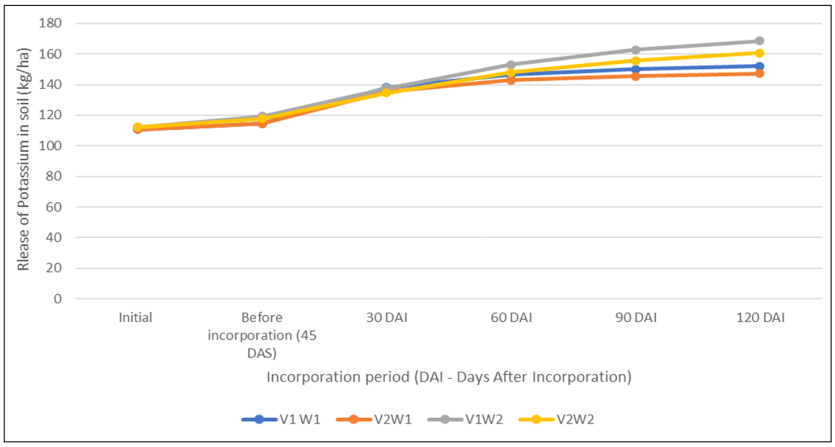


Fig 3: Effect of residual management of sunnhemp varieties on potassium release in the soil.

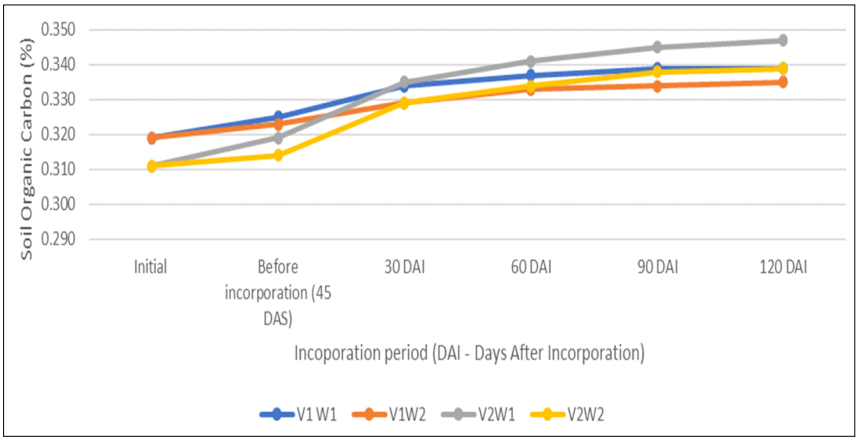


Fig 4: Effect of residual management of sunnhemp varieties on soil organic carbon for the succeeding rice crop.

Table 3: Effect of Residual management of sunnhemp varieties on the grain and straw yield of succeeding rice crop.

Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)		
	W_1	W_2	Mean	W_1	W_2	Mean
V_1	4750	5100	4925	8550	9160	8855
V_2	4670	4910	4790	8370	8720	8545
Mean	4710	5005	4857.5	8460	8940	8700
	V	W	V × W	V	W	V × W
SE. d	49.82	53.54	75.72	61.40	108.90	154.01
C. D	128.40	126.02	178.22	137.70	256.29	362.45

carbon, decreased nutrient availability, leading to lowest plant height, leaf area index, dry matter accumulation, resulted in less productive tillers/hill causing decreased grain and straw yield of succeeding rice crop (Dhara, 2024).

CONCLUSION

Legumes as a green manure play a vital role in the replacement/ substitution of chemical fertilizers with improved nutrient use efficiency. Integrated incorporation of green manure with rice residue had better results in terms of improving soil health by improving soil properties like soil structure, water holding capacity, microbial biomass accumulation, increased organic matter, increased organic carbon level, enhanced soil nutrient availability by increasing the nitrogen, phosphorus and potassium levels in the soil, maintained the C:N ratio through controlling the release of nutrients to the succeeding rice crop in a sustained manner, long-term nutrient stability by avoiding leaching losses. The recently released sunnhemp variety ADT 1 was compared with CO 1 for its nutrient release pattern and its impact on the succeeding rice crop. ADT 1 produced higher biomass than CO 1; better nutrient release pattern and soil NPK contents differed significantly from CO 1. Similarly, incorporation of ADT 1 varieties with crop residues produced higher rice yield as a succeeding crop. The impact of the mixture of CO 1 with rice residue resulted in the highest nitrogen availability (109. Kg/ha), though temporary immobilization of nitrogen occurs at 30 DAI because of the high C: N ratio of rice residue, increased release of phosphorus (20.9 kg/ha) and potassium (62.4 kg/ha) in the soil. As a result, the grain and straw yields of 5100 kg/ha and 9160 were obtained in V_2W_2. Sunnhemp incorporation alone also influences the soil characteristics, but the integrated mixture of green manure and crop residues in the soil had better performance, notably aiming to have long-term sustainability of soil health.

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Conflict of interest

All authors declared that there is no conflict of interest.

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