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RESEARCH ARTICLE

DECOMPOSITION AND NITROGEN MINERALIZATION OF *Gliricidia sepium* LEAF GREEN MANURE UNDER DIVERSE NUTRIENT MANAGEMENT STRATEGIES IN IRRIGATED LOWLAND RICE CROPPING SYSTEMS IN SRI LANKA

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Abstract

The utilization of green manure has become an essential strategy for enhancing soil fertility and substituting synthetic fertilizers. The decomposition and release of nutrients through mineralization processes are influenced by soil microbial activity, which in turn depends on the nutrient management practices employed. depending on nutrient management approaches. The study aimed to investigate the decomposition and N mineralization of *Gliricidia sepium* leaf green manure in an irrigated lowland rice ecosystem under different nutrient management systems (NMS), for a duration of eight weeks. Litterbags were placed at two soil depths, namely the topsoil, and subsoil, within three NMS; 100% Department of Agriculture (DOA) recommended inorganic fertilizer application (CNM), 50% of DOA recommended inorganic fertilizer combined with the organic fertilizer application (INM), and 100% organic fertilizer application (ONM). The treatments were arranged in a randomized complete block design and litterbags were retrieved weekly to determine dry mass, total N content, and total organic carbon content remaining in the leaves. The rate of decomposition and nutrient release was estimated using an exponential decay equation and analysis of variance was carried out using the repeated measures MIXED model. A consistent biphasic pattern of decomposition and mineralization was observed across all NMS treatments and soil depths, characterized by an initial rapid phase followed by a slower phase. However, significant differences ($p<0.05$) were observed among the treatments. The ONM treatment combined with topsoil placement exhibited a shorter time for 50% and 80% reduction in biomass and nitrogen content. Approximately 80% of the nitrogen content was released into the soil solution within 4-5 weeks of green manure incorporation, regardless of the nutrient management system employed. These findings suggest that with proper application rates and appropriate depth of placement, *Gliricidia sepium* green manure can effectively replace a significant portion of mineral nitrogen fertilizer, thereby enhancing nutrient use efficiency in lowland rice-based systems.

Keywords: Conventional nutrient management systems, Decomposition, Green manure, Lowland rice ecosystem, Mineralization

INTRODUCTION

Agricultural sustainability relies on good soil management and the sustenance of soil organic matter at desired levels. One way of achieving this is through the ex-situ application of organic inputs, such as green manure. The incorporation of plant residues has proven to improve the status of the soil by releasing organic matter (Martínez-García *et al.* 2021) which is capable of reducing bulk density, building up structure, improving the holding capacities of nutrients and water, and boosting biological activity (Murphy 2014; Bünemann *et al.* 2018; Barrios *et al.* 2018; Asigbaase *et al.* 2021). Thus, the addition of plant residues and organic matter is essential in maintaining the beneficial physical, chemi-

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cal, and biological properties of soil required for improving soil fertility and overall soil health. Returning organic matter is a major strategy for returning nutrients back to the soil, thereby playing a significant role in nutrient recycling (Bhattarai and Bhatta 2020). Moreover, maximizing nutrient release, such as N from plant residues is useful in reducing or possibly eliminating the application of fertilizer in crop cultivations (Martínez-García *et al.* 2021).

Decomposition can be defined as the biological disintegration of dead organic materials whereby the mineralization of complex organic compounds into simple inorganic forms takes place (Saha *et al.* 2016; Bhattarai and Bhatta 2020). Hence, decomposition and mineralization are responsible for releasing organically bound nutrients to inorganic elements that are readily available for plant uptake (Lupwayi *et al.* 2004).

The pattern of nutrient release and the temporal availability of each such nutrient element are determined by the kinetics of decomposition processes. The decomposition process is influenced by multiple factors. The physicochemical environment in which decomposition occurs, the size and composition of the microbial community, and the quality of organic matter are these determinants (Swift *et al.* 1979; Martínez-García *et al.* 2021).

The changes in a microbial community can significantly alter the rates of decomposition and N mineralization from the same litter (Martínez -García *et al.* 2021). The way of managing major agricultural inputs, *i.e.*, conventional, or organic, affects the diversity and abundance of microbial decomposers as well as the physical and chemical properties of the decomposing environment. The carbon loss from decomposing organic matter has shown different patterns depending on different nutrient management systems, irrespective of litter quality (Martínez -García *et al.* 2021). A previous study has revealed that the average monthly mass loss of leaf litter was more than two times higher, and the time required for 50% and 90% decomposition was lower in organic farms compared to conventional (Asigbaase *et al.* 2021).

The rate of decomposition in leguminous litter is directly related to the initial N concentration. Similarly, N concentration alters the balance between N release and immobilization in the litter biomass (Parton *et al.* 2007; Hobbie 2015, Martínez-García *et al.* 2021). Studies have discovered that litter with relatively higher N concentrations is readily decomposed undergoing a greater mass loss at the initial stages owing to its succulent nature (Cornwell *et al.* 2008; Hobbie 2015, Martínez -García *et al.* 2021). On the contrary, with materials rich in lignin, decomposition and N mineralization rates can be negatively related to initial litter N content (Karberg *et al.* 2008). Nevertheless, the nutrient dynamics in lowland rice cultivation, where anaerobic conditions are dominant, decomposition processes can significantly differ from upland fields characterized by aerobic decomposition (Nishimura *et al.* 2008; Dung *et al.* 2022).

Legume leaves are a potential alternative to mineral N fertilizers in crop production systems (Zaharah and Bah 1999) and the incorporation of nutrient-rich leguminous green leaves is a proven substitute for mineral N fertilizer (Martínez-García *et al.* 2021). With judicious application, mineral fertilizer requirements can be either substituted or eliminated and further can contribute to enhancing the sustainability of cropping systems (Fontes *et al.* 2014; Costa *et al.* 2017; Asigbaase *et al.* 2021). In order to optimize the benefits of plant residues on soil quality improvement and to increase the amount of nutrients available for crop growth over time, it is vital to synchronize nutrient release with the pattern of nutrient uptake by the plant, minimizing the nutrient losses due to leaching, runoff, and erosion (Shi 2013; Chanda *et al.* 2021). Hence, in the utilization of green leaf manure as a fertilizer substitute, understanding the rate and patterns of release of nutrients through decomposition and mineralization is necessary.

Regardless of the underlying mechanisms, measurements of organic matter decomposition and mineralization employ standard techniques to gather information on rates and patterns of decomposition in different ecosystems. Litterbag studies where fresh leaf litter is enclosed in mesh bags, placed on the ground, and collected at periodic intervals for measurement of the mass remaining, provides an effective approach to estimating decomposition rates in the field over various time scales and under different conditions. A similar technique was employed in the present experiment.

In this study, it was hypothesized that differences in nutrient management systems in lowland rice ecosystems can differentially affect the rate of decomposition of C and mineralization of N from *Gliricidia sepium* litter. Furthermore, the study was conducted with the general objective of studying the decomposition and N mineralization of *G. sepium* green leaf manure in contrasting nutrient management systems (NMS) in a lowland irrigated rice ecosystem. The specific objectives were to explore the dynamics of the biomass decomposition pattern of *G. sepium* green leaf manure and to quantify the amount of nutrients decomposed from it in diverse NMS in a lowland irrigated rice ecosystem.

MATERIALS AND METHODS

The study was conducted in the research field of the Faculty of Agriculture, Rajarata University of Sri Lanka located at Puliyankulama in the Anuradhapura district of Sri Lanka in the 2020/2021 *Maha* season. The experimental site belongs to the agro-ecological region of DL1b situated within 8°25'18.12" of latitude and 80°24'9.37" of longitude. The experiment consisted of three nutrient management systems (NMS); conventional nutrient management (CNM), integrated nutrient management (INM), and organic nutrient management (ONM). These nutrient management systems have been maintained in the field for a period of two years prior to the commencement of the study.

In the CNM, 100% of the requirement of N, P, and K were supplied through inorganic fertilizers Urea, Triple Super Phosphate (TSP), and Muriate of Potash (MOP) respectively based on the recommendation by the Department of Agriculture (DOA), Sri Lanka (Department of Agriculture, Sri Lanka 2013). In the INM, both inorganic and organic fertilizers were applied. By applying Urea, 50% of the N was supplied and N equivalent to 25% of the recommendation was provided from organic fertilizers (Table 01). Only organic fertilizer applications were carried out in the ONM system to fulfil 50% of the N recommendation by DOA. Due to the difficulties in estimating the nutrient losses in organic nutrient management systems, the study was conducted based on the assumption that there is no loss in N supplied through organic fertilizer. Since the percentage loss of N when urea is applied to rice cultivation is about 50% (Filler *et al*. 1986; Dharmakeerthi and Thenabadu 1996), irrespective of the nutrient source, the total amount of nitrogen applied at the beginning of the experiment was equal in all three nutrient management systems. However, in the integrated and organic systems, P and K rates were not standardized and the quantities of these nutrients supplied were dependent on the quality of fertilizers used to supply N. The organic fertilizer applied to the field was compost with a known nutrient composition which was prepared by incorporating buffalo manure, poultry manure, *G. sepium* leaves, and sunn hemp (*Crotalaria juncea*).

Decomposition and nutrient release dynamics were studied using the litterbag approach for a period of 08 weeks. Fresh *G. sepium* leaves were filled up into 25 cm × 25 cm nylon netting litterbags with 2 mm mesh size at a rate of 600 g m^{-2} (6000 kg ha^{-1}) on a fresh basis (37.5 g per litterbag). A similar sample was oven dried at 70 °C for initial leaf chemical analyses. The treatments were established in a randomized complete block design having four replicates with a plot size of 15 cm × 6 cm. Litterbags were placed in 14-day-old lowland rice lands under the three different nutrient management systems in two soil depths, namely, topsoil (S_1); 0-15 cm, and subsoil (S_2); 15-30 cm. Sixteen litterbags were buried at a single depth in each system. Two bags from each depth were retrieved weekly throughout the experimental period. The collected samples were gently and briefly washed under slowly running tap water and rinsed with distilled water. Samples were oven dried

Table 1: Sources and rates of fertilizer application and content of nutrients in nutrient management systems

Recommended Rates (DOA)		**Source**	**Quantity of Fertilizer (kg ha^{-1})**
Inorganic	N	Urea (N = 46%)	225
	P	TSP (P_2O_5 = 43.7%)	55
	K	MOP (K_2O_5 =60)	60

Rate used as treatments in the experiment

	Nutrient	Inorganic Nutrients (kg ha^{-1})	Organic Nutrients (kg ha^{-1})
Conventional Nutrient Management System (CNM)	N	103.5	-
	P	10.5	-
	K	29.8	-
Integrated Nutrient Management System (INM)	N	51.8	25.9
	P	5.23	0.65
	K	14.9	52.5
Organic Nutrient Management System (ONM)	N	-	51.8
	P	-	0.65
	K	-	52.5

for 48 hours at 70 °C and dry weight was measured (Naik *et al.* 2018).

The Total N content of each sample was analyzed using the Kjeldahl procedure (Bremner and Mulvaney 1982), and the total organic matter percentage was estimated by the loss on ignition method (Blume *et al*. 1990; Schumacher 2002) which was used in the calculation of total organic carbon (TOC) using the conversion factor 1.72 (Nelson and Sommers 1996; Schumacher 2002).

The percentage of litter decomposed at each time t, R_t was calculated as follows.

$$R_t\,(\%) = \frac{M_t}{M_i} \times 100 \quad \text{.........…..........Eqn 01}$$

Where M_t = the dry weight of the decomposed leaf litter at sampling time t and Mi = the initial dry weight of the leaf sample (Asigbaase *et al.* 2021).

The percentage of N and C loss were calculated using the initial and final litter mass and the respective N concentration.

$$N/C\ Loss\,(\%) = \frac{(N_i \times M_i) - (N_f \times M_f)}{(N_i \times M_i)} \times 100$$

…………………………………………..Eqn 02

N_i and N_f are the initial and final N or C concentrations respectively; and M_i and Mf are the initial and final dry weights of the sample (Handa *et al*. 2014; Martínez-García *et al*. 2021).

The litter decomposition and, N and TOC release rates were estimated by fitting the percentage mass of litter, N, and TOC remaining respectively to a negative exponential decay equation using SigmaPlot (15.0) software.

The following model was used.

$$m = Ae^{-kt} \quad \text{……………………..Eqn 03}$$

Where m is the percentage of initial dry mass, N or TOC remaining at time t, A is a constant and k is the coefficient of the rate of decay per week and t is the time in weeks (Asigbaase *et al*. 2021).

The time required for 50% (t_{50}) and 80% (t_{80}) decomposition of leaf litter and nutrients were computed accordingly.

The remaining leaf mass, N, and TOC remaining in each nutrient system over time were analyzed to identify the impact of different nutrient management strategies for decomposition and mineralization at the two soil depths. Statistical analysis was performed using the SAS computer program version 9.0. Analysis of variance (ANOVA) was carried out using the repeated measures MIXED model. The means were separated using the least significant difference (LSD) method at a 5% probability level.

Sigmaplot (15.0) and OriginPro 2022 were used in graphical illustrations of the results.

RESULTS AND DISCUSSION

Weather Conditions

Weekly temperature and rainfall variation during the study period of December 2020 to January 2021 is shown in Figure 1. The mean rainfall and temperature during the study period were 39.2 mm per week and 26.04 °C respectively.

Rate of Decomposition

The decomposition of leaf litter expressed as the loss of dry mass followed a similar pattern in both depths under all three NMS (Figure 2). The rate of decomposition illustrated a rapid initial decomposition and a slower rate of mass loss during the latter stages. At the first sampling week i.e., the first week of incorporation of leaf litter into the soil, approximately 33–44% of the dry mass was lost irrespective of the management system, while at the end of the study period, the mass remaining ranged between 26–33% of the initial dry mass.

The NMS by depth by time interaction on decomposition was not significant ($p<0.05$) (Table 2). However, the dry mass loss of topsoil and subsoil was significant ($p<0.05$), in which the topsoil recorded a higher loss. The decomposition of the three NMS was significantly different ($p<0.05$). The highest mass loss was recorded in ONM, followed by INM and CNM (Table 2). The weekly mass loss was significant ($p<0.05$), irrespective of the depth of placement and nutrient management system.

The rate of decomposition per week (*k*) was the highest in the ONM system, while contrasting two depths, the topsoil layer recorded the highest in the same. The weekly rate of decomposition in ONM was higher than INM by 16.6% and 7.9% in the top and subsoil layers respectively. The lowest rate of decomposition was recorded in the subsoil layer of

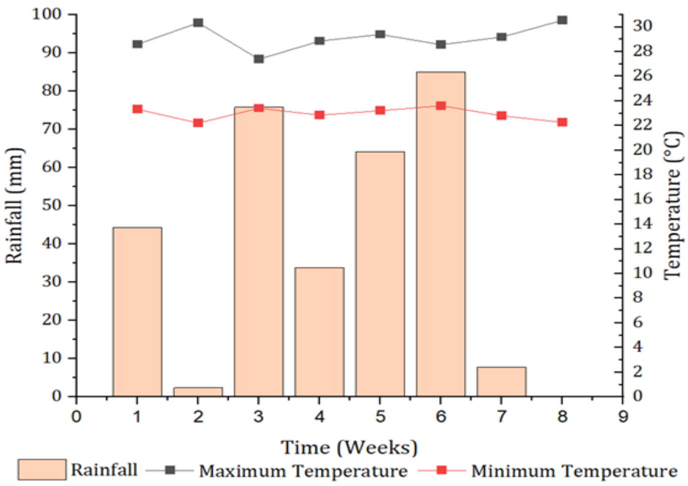

Figure 1: Weekly cumulative rainfall and, the weekly mean maximum and minimum temperature in *Puliyankulama, Anuradhapura* from December 2020 – January 2021

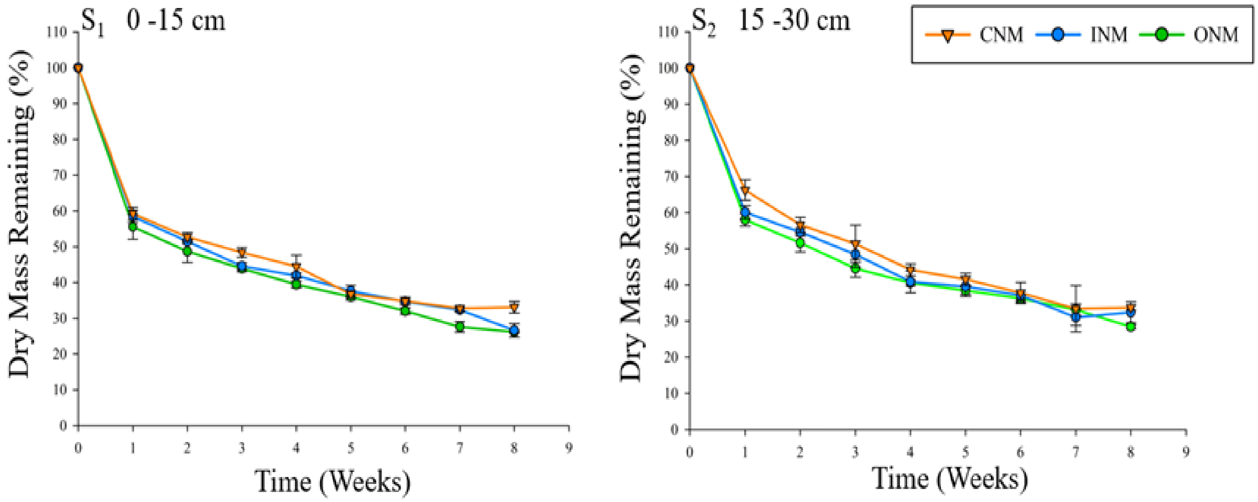

Figure 2: Decomposition of *Gliricidia sepium* in topsoil (S_1) and subsoil (S_2) soil layers under different nutrient management systems; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

CNM and it was quantitatively 7.94% lower than the highest ONM in the same layer. The time taken for 50% and 80% decomposition of total added biomass was the lower ONM system. Within the ONM system, the decomposition of surface-placed litter was quicker (Table 2).

Loss of TOC

The pattern of loss of TOC from leaf matter under NMSs in both top and subsoil displayed a similar outcome to dry mass loss. A loss of 44 – 48% TOC was observed within the first week of the study and then the loss was observed at a slower rate. The interaction between depth and time for TOC loss under NMS was significant ($p<0.05$) (Table 3). The highest amount of OC was released in the topsoil layer of ONM, where the loss was nearly 62% of the initial amount. The lowest TOC loss of 56% was recorded in the subsurface soil layer of CNM. The rate of TOC loss per week (k) in ONM at the topsoil layer was the highest compared to the rest. Within a period

Table 2: The coefficient of rate of decomposition per week (*k*) ($week^{-1}$), and time taken for 50% and 80% of dry mass loss under different nutrient management systems; ONM – organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

	k	R^2	t_{50} (weeks)	t_{80} (weeks)
Topsoil (0-15 cm)				
ONM	0.183	0.83	2.81	7.81
INM	0.169	0.82	3.09	8.80
CNM	0.157	0.82	3.32	9.17
Subsoil (15-30 cm)				
ONM	0.163	0.82	3.14	8.76
INM	0.158	0.84	3.34	9.15
CNM	0.151	0.88	3.67	9.73

Table 3: Effect of the nutrient management system and depth on the rate of decomposition and N mineralization of *Gliricidia sepium*

	Nutrient Management System (NMS)			**Depth**		**NMS * Depth**					
						Topsoil			**Subsoil**		
(%)	ONM	INM	CNM	Topsoil	Subsoil	ONM	INM	CNM	ONM	INM	CNM
Dry Mass	38.87^{c}	40.77^{b}	42.86^{a}	39.60^{b}	42.02^{a}	37.42^{c}	39.76^{b}	41.74^{ab}	40.36^{b}	41.80^{ab}	44.01^{a}
N	24.20^{c}	26.44^{b}	27.77^{a}	24.39^{b}	27.91^{a}	22.03^{d}	24.72^{c}	26.64^{b}	26.59^{b}	28.28^{a}	28.94^{a}
TOC	45.12^{c}	47.61^{b}	48.96^{a}	46.43^{b}	47.99^{a}	44.01^{f}	45.70^{d}	48.66^{b}	46.24^{b}	48.51^{c}	49.27^{a}

P values	Dry Mass	N	TOC
NMS	<.0001	<.0001	<.0001
Depth	0.0003	<.0001	<.0001
Time	<.0001	<.0001	<.0001
NMS * Depth	0.7668	0.0005	<.0001
NMS * Time	0.9474	<.0001	<.0001
Depth * Time	0.8135	0.0002	<.0001
NMS * Depth * Time	0.7731	<.0001	<.0001

Means values followed by the same letter are not significantly different at p<0.05
ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System, TOC – Total Organic Carbon

of 3.72 weeks, 50% of TOC was lost to the system. In contrast, the 80% loss of TOC took a longer duration than the loss of dry mass (Table 4).

The loss of TOC in the ONM system was 23% and 14% greater than that of the CNM at topsoil and subsoil respectively. The TOC loss rates were similar in the topsoil layer of INM and the subsoil layer of ONM, while similar rates were also recorded in both depths of CNM (Table 4).

N Mineralization

The N mineralization trends in both depths and three nutrient management systems were similar (Figure 4). The initial loss of N was rapid and decreased over time. During the rapid phase, N release ranged between 46–57%. With the decreasing rate, during 8 weeks of study, only 86–91% was lost. The three-way ($p<0.05$) interaction between NMS, depth, and time significantly affected the N loss (Table 3). The remaining N content of the surface layer of soil in ONM was the lowest compared to all NMS at two depths (Table 5). The N remaining was similar in the topsoil

Table 4: The coefficient of rate of TOC loss per week (*k*) (week^{-1}), and time taken for 50% and 80% of dry mass loss under different nutrient management systems; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

	k	R^2	t_{50} (Weeks)	t_{80} (Weeks)
Topsoil (0 – 15 cm)				
ONM	0.116	0.61	3.72	11.65
INM	0.105	0.61	4.22	12.94
CNM	0.094	0.57	4.70	14.45
Subsoil (15 – 30 cm)				
ONM	0.105	0.60	4.14	12.84
INM	0.097	0.60	4.60	14.05
CNM	0.092	0.60	4.82	14.69

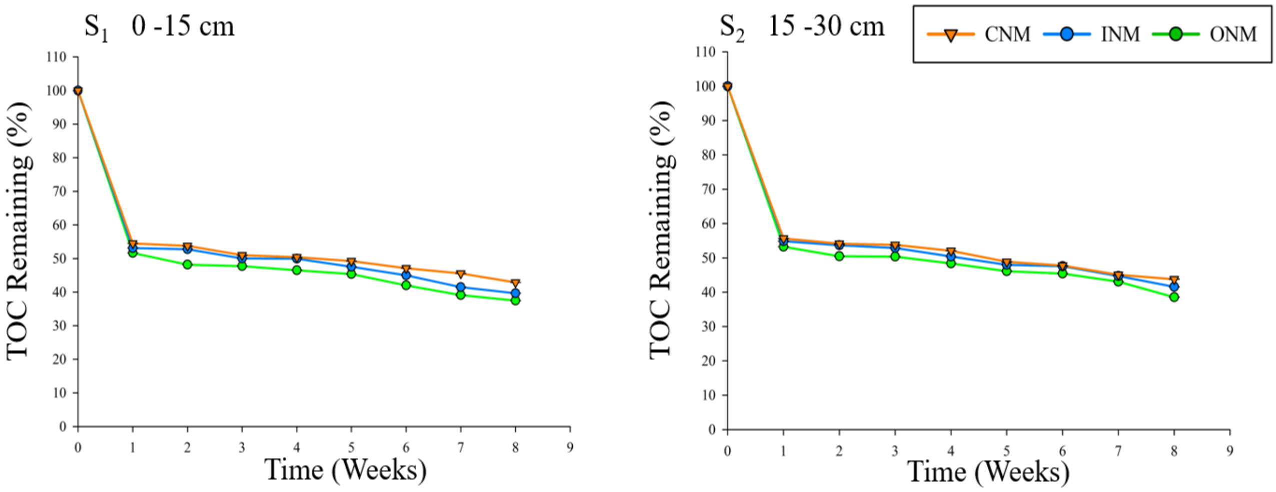

Figure 3: The loss of TOC in *Gliricidia sepium* in topsoil (S_1) and subsoil (S_2) soil layers under different nutrient management systems; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

layer of CNM and the subsoil later of ONM, while a comparatively higher remaining N was recorded in subsoil INM and CNM systems.

The N release in the surface soil layer of ONM was approximately 20–21% higher than the respective soil layer of INM and CNM. The highest rate of N release was recorded from the ONM system, where the remaining N was reacted to 50% and 80% of N in a relatively shorter time (Table 5).

The application of *G. sepium* leaf litter at a rate of 6000 kg ha^{-1} could deliver 57.58 kg of N ha-1. Approximately 26–33 kg of N ha^{-1} from total N was released within the first week of application across all NMSs. Thereafter, the balance N was released at a slower rate till the end of the study duration of eight weeks (Figure 5).

Generally, N loss in the three systems ranged between 49–53 kg. In accordance with the nutrient release pattern, the highest amount of

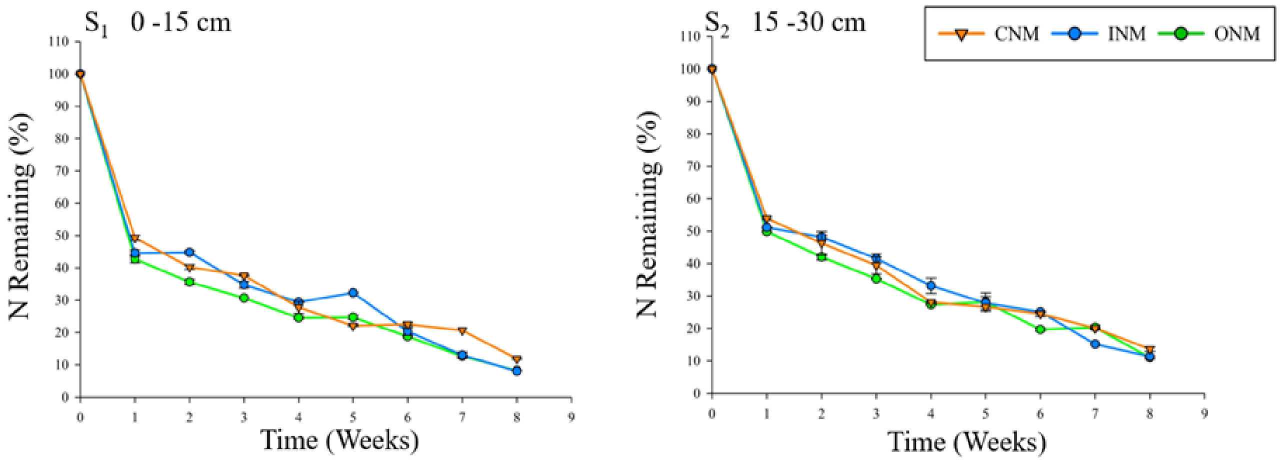

Figure 4: N mineralization of *Gliricidia sepium* in the topsoil (S_1) and subsoil (S_2) soil layers under different nutrient management conditions; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

Table 5: The coefficient of the rate of N release per week (*k*) (week^{-1}), and time taken for 50% and 80% of N loss under different nutrient management systems; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

	k	**R^2**	**t_{50} (Weeks)**	**t_{80} (Weeks)**
Topsoil (0 – 15 cm)				
ONM	0.344	0.87	1.59	4.25
INM	0.285	0.86	1.90	5.12
CNM	0.287	0.88	1.92	5.11
Subsoil (15 – 30 cm)				
ONM	0.285	0.89	1.94	5.16
INM	0.258	0.91	2.19	5.74
CNM	0.264	0.91	2.15	5.62

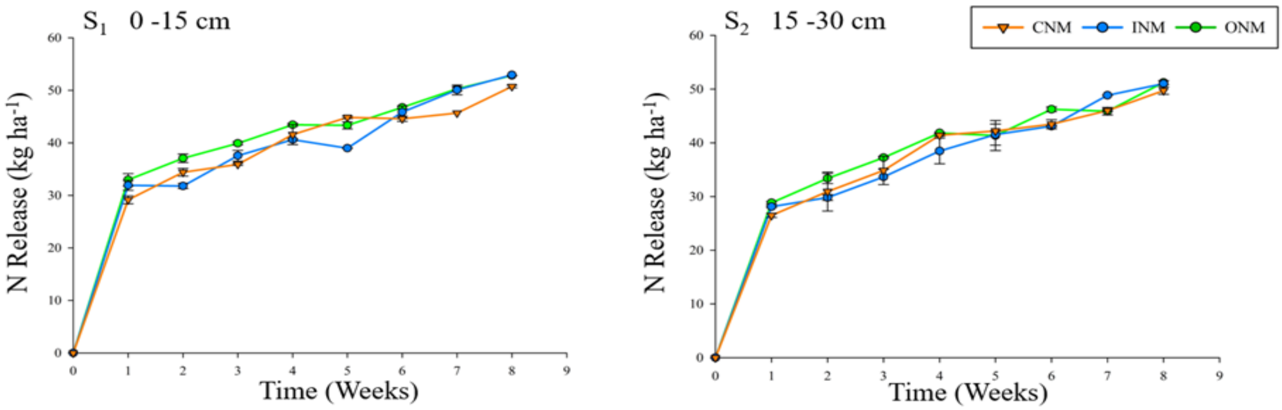

Figure 5: Cumulative N released by *Gliricidia sepium* in the surface and subsurface soil layers under different nutrient management conditions; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

N was released by the ONM in topsoil at the end of the experimental period (Table 6).

Litter decomposition in an agro ecosystem is a key process that delivers nutrient elements back into a system after being taken up (Naik *et al*. 2018). The decomposition process primarily depends on climatic and edaphic conditions (Berg and McClaugherty 2014, Bhattarai and Bhatta 2020). The microbial processes linked to litter decomposition are sensitive to soil qualities, and further, the nutrient status of the soil is also a key aspect that determines the rate of decomposition (Asigbaase *et al*. 2021). The rate of litter decomposition in a tropical context is an accelerated process. The warm temperature and amount of rainfall determine the time of litter retention in an agroecosystem (Pando-Moreno *et al.* 2018) even if there are attempts to maintain reasonable organic matter content soils. Hence, maintaining desirable organic carbon amounts in tropical soils is challenging in intensively cultivated lands and has resulted in a search for methods that ensure sustainability. The application of green manure to cultivated lands during land preparation or during crop growth is one of the commonly used solutions by farmers in tropical regions (Tzec-Gamboa *et al.* 2023). The *ex-situ* application of *G. sepium* is one of the popular green manures in these regions.

Decomposition and Nutrient Release

During the study period, the mass loss and nutrient release from *G. sepium* followed a pattern of negative exponential decay irrespective of the NMS and depths. The rates of decomposition and nutrient release were high during initial sampling weeks; at an accelerated rate during the first three to four weeks, and later the rates gradually decreased towards the end of the experiment. A similar pattern was reported in several other studies involving the decomposition of plant matter under varying climatic and soil conditions (Majumder *et al.* 2010; Triadiati *et al.* 2011; Hayashi *et al*. 2012; Kaba 2017; Mohammed *et al.* 2019; Asigbaase *et al*. 2021).

Accordingly, two distinct phases can be identified in mass loss and nutrient release, a rapid

Table 6: N release by weight (kg ha^{-1}) at the end of the study under different nutrient management conditions; ONM – Organic Nutrient Management System, INM – Integrated Nutrient Management System, CNM – Conventional Nutrient Management System

	CNM	INM	ONM
Topsoil (0 -15 cm)	50.7	53.0	52.8
Subsoil (15 -30 cm)	49.7	51.0	51.2

initial phase, and a following slow phase. This biphasic decomposition can be explained in terms of underlying physical and microbial processes and disparities of compounds undergoing decomposition (Prescott 2005; Akoto 2022). The accelerated loss of mass is attributed to the breaking down of readily soluble compounds and non-lignified carbohydrates including water-soluble starch, proteins, and sugars (Issac and Nair 2005; Kumar 2008; Dawoe *et al*. 2010; Triadiati *et al*. 2011; Asigbaase *et al.* 2021). Simple breakdown of these tissues aided by the warm and moist nature of growing conditions results in a rapid rate of decomposition and nutrient release. Released N, especially, is expected to be diluted or leached from the immediate surrounding of the decomposition site. During the latter slow phase, the decomposition of the recalcitrant fraction; lignified carbohydrates, and aromatic compounds dominates (Swift *et al.* 1979; Zaharah and Bah 1999). The decomposition of *G. sepium* followed a 7 -day rapid phase in a study by (Zaharah *et al*. 1998) in tropical conditions, which is analogous to this study. The dry mass loss of 33-44% observed during the first week of the study, was below the 56% mass loss observed during the study by (Zaharah *et al*. 1998) during the first 10 days of decomposition. The two studies are similar by resulting in more than 60% of the biomass in 40 days and little change thereafter.

The decomposition of organic matter differs in aerobic and anaerobic soil; the rate being faster in aerobic. Inundating the root zone transforms an aerobic environment into an anaerobic or near-anaerobic creating an environment where oxygen is absent or limiting (Patrick and Mahapatra 1968; Fageria *et al.* 2011). Hence, the lowland systems are contrastingly distinctive to uplands, where aerobic conditions are prevailing. Thus, the accumulation of organic matter compared to upland systems occurs in submerged soil due to incomplete and inefficient decomposition under anaerobic conditions (White and Reddy 2001; Sahrawat 2004; Sahrawat 2010). Future, the recovery efficiency of N is lower in lowland rice compared to upland crops (De Datta 1981; De Datta 1986; Sahrawat 2010).

Impact of Nutrient Management Systems

The study hypothesized that the rate of decomposition and N mineralization from *G. sepium* litter is different in NMS in lowland rice fields. The hypothesis was further supported by possible differences in microbial populations as a response to different NMS. Microorganisms are crucial for the decomposition process and the primary source of energy for these organisms is organic matter (Kumar 2008; Asigbaase *et al*. 2021). Microbial growth and activities are higher in ONM with higher availability of carbon added with organic sources. The C and N composition of organic matter in the system determines the rate of the decomposition process, and systems with added mineral fertilizers might deliver differential rates of decomposition. Synthetic agrochemicals *i.e.*, mineral salts and biocides possibly alter the microbial diversity, abundance, and population resulting in relatively lower rates of decomposition (Domínguez et al. 2014; Barrios *et al*. 2015; Lori *et al*. 2017; Asigbaase *et al*. 2021) in INM and CNM. In contrast, the abundance of essential minerals through mineral salts can accelerate the decomposition process, due to the availability of N at the initial activation mineralization process. Yet, the decomposition in CNM can be slower due to weather and edaphic reasons; as an example, organic matter can resist decomposition under alternative wetting and drying. The observation during this study was more similar to the former, as the ONM resulted in higher decomposition and mineralization rates, while the time taken for 50% and 80% reduction of biomass and N were modelled to be several days earlier than INM and CNM.

Contrasting Depths of Placement

The decomposition and nutrient-releasing rates of litter bags placed on topsoil (0–15 cm) were higher than the subsoil (15–30 cm) placement. The retention time of green manure added can also be varied considerably with the placement of soil depth. The coefficients of decomposition and nutrient release rates of the two depths were not contrastingly different during the study; yet certain quantitative differences were observed (Tables 2 and 5). The observations made by Berset (2008) on the decomposition of *G. sepium* placed on the surface and subsurface soil are consistent with the findings of this study. Findings of several other studies are in line with these where higher decay and nutrient release of leaf materials occur when applied to the topsoil layer than buried (Read *et al*. 198l; Zaharah and Bah 1999). In a rice-based system, the slower decomposition in subsoil can be attributed to low oxygen diffusion to deeper soil layers due to inundation. This results in stratification, forming very distinctive conditions for chemical reactions and microbial processes. The top layer becomes an aerobic layer where oxygen is abundant and the underneath layers are anaerobic with no oxygen (Fageria *et al.* 2011). The anaerobic conditions and reduced conditions result in slower oxidation status of organic matter in deeper layers. The difference was not pronounced in this study. Despite being lowland cultivation, the crop was not maintained strictly under inundated conditions due limitation of irrigation water supply and changes in precipitation, especially during the initial weeks of the study (Figure 1). The field might have been under field capacity rather than being saturated allowing the slower soil layers to return to higher oxidation status to deliver relatively higher decomposition rates than conventional lowland. The N release might be facilitated at the surface due to the precipitation affecting the leaf material directly and leading to the initial release of easily decomposable substances like amino sugars, nucleic acids, and proteins. With changing water status of top and subsoils, thus fluctuation of oxidative status might have generated the same redox conditions even in subsoil led aerobic microbes to thrive to deliver approximately similar N releasing rates. Generally, in soil, at different depths, the microbial diversities and activities are distinct (Agnelli *et al.* 2004; Tian *et al.* 2017) and distinct substrate utilization patterns are observed (Tian *et al*. 2017). The microbial population in upper soil layers generally utilizes more easily decomposable carbohydrates and carboxylic acids favoring C mineralization and delivering higher decomposition rates. The utilization of N-containing substrates by microbes in the subsoil is relatively higher, which creates an N-limited condition with microbial immobilization. The C mineralization and net N mineralization are subsequently low in subsoil (Tian *et al*. 2017). Furthermore, several models dealing with the turnover of organic matter in subsoils stated higher stability of C in deeper soil layers (Jenkinson and Coleman 2008; Berset 2008). These imply that the decomposition rate and nutrient release decline with depth, explaining the highest release at the surface observed during the study can be generalized to similar agro ecosystems.

The release or accumulation of nutrients is determined by mineralization, leaching, consumption, or transformation by soil biota (Issac and Nair 2005; Naik *et al*. 2018). The mineralization process is generally initiated with the accumulation of microbial biomass that demands a nutrient from soil solution leading to a temporary decline of elements such as N and P. Hence, an increase of the N percentage remaining in leaf materials was observable, which was a result of microbial N immobilization (Berset 2008). Accelerated mass loss from leaf litter is dependent on the N content of the material. *G. sepium* leaf green manure carries a relatively high N footprint, thus reflected carbon mineralization and N immobilization might be characterized by the quality of microorganism populations in different systems. Based on the pattern of N release (Figure 4), an immobilization was observed in the 5th week in the topsoil of ONM, the 2nd and 5th weeks in the topsoil of INM, and, the 3rd and 6th weeks in the topsoil of CNM. In the topsoil, immobilization was observed in ONM in the 5th and 7th weeks. Changing the chemical composition of leaf matter from easily digestible to more lignified, dynamic of soil decomposer microorganisms is possible, and active soil decomposer group in each NMS in each soil layer might vary, thus the ratio of immobilized and excreted nutrients varies (Ekschmitt *et al*. 2008; Berset 2008).

Synchronizing with Crop Demand

These findings derived an important insight for synchronizing the nutrient release for *G. sepium* leaf green manure with crop nutrient requirements in lowland rice cultivation.

Lowland rice requires a guaranteed N supply from early vegetative growth to early reproductive growth (Table 7). The synchrony between the external application and soil supply is essential. Through the *G. sepium* leaf green manure addition, the percentages of N release measured in this study did not deliver the entire nitrogen requirement of the rice crop (Table 7). Generally, 30 % to 50 % of applied N is recovered by crops. The retention time of N in soil solution enhances the recovery and uptake. Nitrogen is partly lost through leaching, denitrification, and ammonia volatilization in an agricultural ecosystem (Sanchez *et al*. 1989; Berset 2008). Nitrogen added through green manure is advantageous as the release can be synchronized with crop demand to a certain degree.

Assuming no net N loss from applied *G. sepium* leaf green manure during this study, 49.7 to 53 kg N ha^{-1} were released across all three NMS in both depths. N supplementation irrespective of NMS ranged between 41 to 43 kg N ha^{-1} during the first 04 weeks. Theoretically, the *ex-situ* application could deliver the required N to match the crop requirement during the early stages of the life cycle. However, with time, the amount of N released decreases with the reduction of leaf inherent N content as the decomposition process progresses. Approximately, 80% of the N from *G. sepium* leaf green manure was released at 4–5 weeks after application leaving lignified low N containing less decomposable matter behind. The concentration of lignin increases as the decomposition proceeds (Zaharah *et al*. 1998), resulting in a slow rate of decomposition and a low level of mineralization of N (Kayuki and Wartman 2001; Naik *et al*. 2018). Hence, to guarantee adequate N in the soil, reapplication of *G. sepium* after 4–5 weeks of initial application, at the same rate of application, matching the requirements in each NMS with rice crop can be practiced. Generally, for a continuous supply of N to an annual crop in a tropical agro ecosystem, frequent incorporation of green manure is essential. The results of the study also suggest that inputs of *G. sepium* leaf green manure can effectively be used even by simply applying it to the topsoil (0 – 15 cm).

Finally, it should be noted that application rates, frequency, and placement depth are key determinants of returns from *G. sepium* green manure applied to rice fields in the dry zone of Sri Lanka.

CONCLUSIONS

The decomposition and nutrient release of *G. sepium* leaf green manure followed a biphasic pattern with a 50% reduction within approximately 2-3 weeks for both dry matter and N. Higher rates of decomposition, the release of TOC, and N mineralization were observed in the ONM compared to INM and CNM and in S_1 than S_2. Incorporation of *G. sepium* leaf green manure at appropriate rates and frequency with correct placement may deliver N at a higher use efficiency.

Table 7: N release by weight (kg ha^{-1}) at the end of the study under different nutrient management conditions

Age of Rice (weeks)	Corresponding Week of the Experiment (weeks)	N Recommendation (kg ha^{-1})	Availability of N through green manure assuming no losses (kg ha^{-1})
02	00	23.0	
04	02		30.0 -37.0
06	04	34.5	6.0-10.0
08	06	29.9	5.0-3.0
09	07	16.1	6.0-1.0

Leaf N = 4.42% *Rate of Application = 6000 kg ha^{-1}*

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AUTHOR CONTRIBUTION
USH collected and analyzed data, and drafted the manuscript; WMDMW collected and analyzed data; LMR supervised the work and reviewed the manuscript; WCPE designed the research, supervised the work, drafted, and reviewed the manuscript.

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