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Influence of Various Composted Organic Amendments and their Rates of Application on Nitrogen Mineralization and Soil Productivity Using Chinese Cabbage (*Brassica rapa* L. var. *Chinensis*) as an Indicator Crop

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Citation: Suruban, C.; Kader, M.A.; Solaiman, Z.M. Influence of Various Composted Organic Amendments and their Rates of Application on Nitrogen Mineralization and Soil Productivity Using Chinese Cabbage (*Brassica rapa* L. var. *Chinensis*) as an Indicator Crop. *Agriculture* **2022**, *12*, 201. https://doi.org/10.3390/agriculture12020201

Academic Editor: Xinhua Yin

Received: 18 December 2021
Accepted: 27 January 2022
Published: 31 January 2022

Abstract: There is a diversity of locally available nitrogen (N)-rich organic materials in Samoa. However, none of them was evaluated for their N supplying capacity after composting in Samoan Inceptisols for vegetable cultivation. Thus, N-releasing capacity of five composted organic amendments (OAs) namely macuna, gliricidia, erythrina, lawn grass and giant taro, and their two application rates (10 and 20 t ha^{-1}) were assessed through a laboratory incubation and a crop response study using Chinese cabbage as a test crop. Among the OAs, composted mucuna was characterized by a higher total N (2.91%), organic C (63.6%) and NO_3^-N content (341 mg N kg^{-1}). A significant difference in N mineralization was observed among the OAs as well as application rates. The highest N mineralization was recorded in composted mucuna followed by gliricidia, erythrina, lawn grass, and giant taro. A crop response study also showed a similar trend. Mucuna treatment had the highest biomass yield and N uptake followed by gliricidia, erythrina, lawn grass, and giant taro. Leguminous composted OAs @ 20 t ha^{-1} performed substantially better in all the plant growth and yield parameters, and N uptake compared to 10 t ha^{-1} that was not the case for non-leguminous OAs. Thus, non-leguminous OAs should be applied at 10 t ha^{-1}. All the composted leguminous OAs showed promising results while mucuna was the best in both the application rates. Therefore, mucuna can be promoted to supply N for crop cultivation in Samoa, other Pacific Islands and tropical countries where N fertilizer is costly and not easily available.

Keywords: Chinese cabbage; organic amendments; compost; nitrogen mineralization; soil productivity; biomass yield

1. Introduction

In South Pacific Island countries (SPIc), including Samoa, most farmers follow the traditional shifting cultivation system and are not applying fertilizer [1]. This is because chemical fertilizers are very costly for being imported from abroad and transportation costs are much higher due to the remoteness and isolation of these island countries. However, with the increasing demand for food production and declining soil fertility over time, soil health and fertility management have become a growing need for the SPIc's. Considering the traditional farming system and high cost of imported chemical fertilizers, organic sources of nutrients are the best alternatives to inorganic fertilizers for sustainable soil management and agricultural development in SPIc's [2]. Besides, the inability of most resource-poor farmers to afford inorganic fertilizer has made the organic amendment a viable alternative source for soil fertility replenishment [3,4]. Accordingly, some of the SPIc's governments, including Samoa, initiated programs to promote the application of organic fertilizer. With such awareness throughout the initiative programs of the Samoan government, farmers have been showing greater interest in following organic practices in crop production. However, composting of available organic biomass is not practiced before application and farms in Samoa instead use fresh organics as mulch. Thus, it takes a long time to release the nutrients from those mulched organics. In most cases, nutrients are immobilized depending on the bio-chemical composition of added biomass [5]. One of the problems identified for crop N nutrition management prompted farmers to use costly inorganic fertilizers.

Composting is a low-cost natural way of recycling and stabilizing organic matter under thermophilic temperature that forms a pathogen-free substrate, beneficial to crops [6–8]. Low-income farmers found it more advantageous to them. Composting was found to be a promising practice that brought organic materials to a certain stage by narrowing down its C: N ratio where nutrients are easily accessible to plants [9]. Partey et al. [10] and Dinesh et al. [11], had consolidated that biomass needs to decompose for making N available to crops. Thus, composting locally available organic amendments (OAs) is essential for a healthy and sustainable agro-ecosystem.

Nitrogen is the most limiting nutrient in many crop production areas in the tropics [12,13] and its efficient use is vital for the economic sustainability of cropping systems is paramount [14,15]. Better understanding of N mineralization of inherent soil organic matter (SOM) and OAs is vital for proper crop N management. Nitrogen mineralization is a biological process that highly depends on the soil microbial activities [5,16], and the quantity and quality of inherent SOM and/or exogenous organic amendments [17]. The soil inorganic exchangeable ions (NH_4^+-N and NO_3^--N) that are produced through N mineralization are mainly influenced by treatments, time, and application rates [18]. The amount of mineralized N released for crop uptake also depends upon the biochemical composition of organic matter [18–20]. All those factors make the N-supplying capacities of OAs very complex, requiring an adequate understanding. However, in most literature, those issues were not addressed in a holistic approach. Therefore, N suppling capacities of OAs are either underestimated or overestimated resulting in poor crop performance. In most cases, it is overlooked due to the time-consuming process of N mineralization study. However, some quickly and routinely measured parameters of OAs e.g., organic carbon, total N and C:N ratio might be used as a proxy of laboratory incubation for estimating the N mineralization capacity of OAs if it is appropriately calibrated for specific soil and climate [18–20]. Proper understanding and estimating of N supplying capacity of a locally available wide range of OAs in Samoa will help farmers to attain food security and maintain soil health and the environment. However, no research has been done yet on N mineralization potential and N dynamics of OAs that are available in Samoa. From this viewpoint, a laboratory incubation study and a pot experiment were conducted using five local composted organic amendments that are abundant in Samoa, namely erythrina (*Erythrina* spp.), gliricidia (*Gliricidia sepium*), mucuna (*Mucuna pruriens*), giant taro (*Alocasia macrorrhizos*) and the lawn grasses. Chinese cabbage (*Brassica rapa.* L. var. *Chinensis*), also known as pak choy or bok choy, is used as an indicator crop as it is a very quickly grown and N-responsive leafy vegetable [21]. It is the most important and popular vegetable in human nutrition in east, north-east and south-east Asia, while China is responsible for 30–40% of its production volume [22]. The consumption of Chinese cabbage in Europe, North America and the Pacific has increased owing to its relatively mild favor [23]. It has become increasingly popular due to numerous cultivar choices, fast maturity, high productivity, wide adaptability and its potential use for winter production in high tunnels in a subtropical climate [24]. It is also a very popular vegetable in the Pacific Island countries including Samoa. The objectives of this research are to (*i*) compare the N mineralization capacity of composted OAs in Samoan Inceptisols, and (*ii*) evaluate the interaction effects of OAs and their application rates in soil on growth, physiological and yield parameters of and N uptake by Chinese cabbage (*Brassica rapa. L.* var. *Chinensis*). Moreover, this study may identify suitable OA(s) and its application rate that can be used by Samoan farmers.

2. Materials and Methods

2.1. Site and Soil

The incubation experiment was conducted in the laboratory, whilst the pot experiment was conducted in the screen house at the Alafua Campus, University of South Pacific (USP), Samoa, from May to October 2017. The experimental area is characterized by having a tropical climate with a yearly mean temperature and rainfall of 29 °C and 3500 mm, respectively [25]. Surface soil (0–20 cm depth) was collected from an arable field belonging to the USP Alafua Campus Agriculture Experimental Field (13.56 S, 171.70 W). Soils were sieved through a 2 mm sieve and air-dried at room temperature (28 °C) to a moisture content of less than 50% water-filled pore space for an incubation study and pot trial [26]. A portion of soil samples was further air-dried to constant weight for physicochemical analysis. Soil texture was determined using the hydrometer method [27]. Total N and available phosphorus in soil were determined by the semi-micro Kjeldahl method [28] and Olsen et al., [29] method, respectively. Exchangeable bases such as (Ca^{2+}, Mg^{2+} and K^{+}) were measured by the NH_4OAc method following Daly et al., [30]. DTPA extractable traces (Fe, Mn, Cu, Zn) were detected using the Lindsay and Norvell [31] method. The measurements in the extract were made using atomic absorption spectroscopy (PerkinElmer, Waltham, MA, USA). Soil organic carbon was analysed by using the Walkley and Black [32] method. Finally, soil pH was measured in 1:5 soil: water suspension with the help of a pH meter. This soil is classified as Typic Humitropept, fine, oxidic isohyperthemic [33]. Characteristically, the soil had a clay loam texture, 3.34% organic carbon, 0.32% total nitrogen, 12.1 mg kg^{-1} available P and 0.46 cmol kg^{-1} exchangeable K (Table 1).

Table 1. The soil chemical and physical properties used for the experiments.

Soil Composition	Values
Total Nitrogen (%)	0.32
Organic Carbon (%)	3.34
Olsen phosphorus (mg kg^{-1})	12.1
Ex. Potassium (cmol kg^{-1})	0.46
Ex. Calcium (cmol kg^{-1})	6.40
Ex. Magnesium (cmol kg^{-1})	3.0
Available Iron (mg kg^{-1})	60.0
Available Manganese (mg kg^{-1})	87.0
Available Copper (mg kg^{-1})	4.0
Available Zinc (mg kg^{-1})	4.3
pH (water)	5.30
Electrical Conductivity (sm^{-1})	78.
Sand (%)	31
Silt (%)	39
Clay (%)	30
Texture class	Clay loam
USDA Soil Classification	Typic Humitripept

2.2. Collection of Organics and Composting

Prior to the experiment, the organic biomass was composted following the Indore method of composting in the screen house at the USP Alafua Campus, Samoa. Five locally available fresh organic amendments namely erythrina (*Erythrina* spp.), gliricidia (*Gliricidia* *sepium*), mucuna (*Mucuna pruriens*), giant taro (*Alocasia macrorrhizos*), and the lawn grasses were collected from their primary sources at two distinct stages (the old and the young amendments). They were shredded into small pieces (around 1~2 cm) using a grinding machine and five composted windrows were built. Each windrow consisted of each amendment placed in layers (10 cm thick organic amendments and 2 cm thick soil layers) until each of the windrows reached 1 m height and 3 m width. Water was added by weighing to each windrow based on the moisture content. The composting process was undertaken for 2 months.

2.3. Incubation Experiment Setup

The incubation study was carried out under a controlled environment using a laboratory incubator (Thermoline Scientific, Waltham, MA, USA) with a constant temperature of 28 °C (average temperature of Samoa) for 42 days. The aforementioned five organic amendments with two rates of application (10 and 20 t ha^{-1}) along with a control (11 treatments) were arranged in three blocks (replicates) with four (4) sampling dates. In total, 132 small plastic polythene bags weighing 2 g (10.5 cm height, 7 cm diameter with a volume of 384.65 cm^3) were filled with 200 g soil and 1.5 g (10 t ha^{-1}) or 3.0 g (20 t ha^{-1}) different composted organic amendments based on the treatment. In total, there were 12 (three replicates × four dates) polythene bags for each treatment. The soil sampling was done every fortnightly to analyse NH_4^+-N and NO_3^--N contents using a destructive sampling method where 33 polythene bags were removed (samples). Soil moisture content was brought to 50% water-filled pore space and maintained throughout the incubation period by reweighing the polythene bags with the addition of demineralized water by using a hand sprayer every week.

2.4. Nitrogen Mineralization

Both the NH_4^+-N and NO_3^--N were extracted from soil by using 2 M KCl solution at a ratio of 1:10 followed by determination with steam distillation method [34]. An amount of 10 g well mixed moist soil was transferred into small plastic bottles (~150 mL) and extracted with 100 mL 2 M KCl by shaking for 1 h on an electrical shaker followed by filtration through a Whatman 42 filters paper. An accurately pipetted 20 mL aliquot was transferred into a digestive tube, added with approximately 0.2 g of MgO powder and distilled using a distillation unit (VELP SCIENTIFICA UDK 129, 10400399) for 3 min with boric acid. Then it was titrated with 0.0025 M of H_2SO_4 and determined the NH_4^+-N content. In determining the nitrate -N (NO_3^--N), all the procedures were followed as it was done for NH_4^+-N but after 3 min of distillation with MgO, the same solution containing supernatant with MgO, about 0.2 g Devarda's alloy was added and distilled for another 3 minutes. The clear solutions were titrated with 0.0025 M of H_2SO_4 and NO_3^--N content of the treatments was determined.

2.5. Screen House Pot Experiment

The same soil and treatments that were used for the incubation study were used for the pot experiment. Soils (10 kg) were placed into a 40 BP (black polythene) bag and were incorporated with different composted organic amendments at a rate of 10 t ha^{-1} and 20 t ha^{-1} as per treatment. The amendments were incorporated at a 10–15 cm depth in potted soils except for control. All the pots were watered to maintain their field capacity and incubated for 2 weeks prior to the transplanting of seedlings. All 11 treatments were laid out in a randomized complete block design with three replications and three sampling dates [14, 28, 42 days after transplanting (DAT)]. Thus, each treatment had nine pots (three × three) and in total 99 pots were subjected to destructive sampling in reference to the three harvesting days at two weeks interval. Treatments were randomly allocated in each replication, including the control. Two weeks old Chinese cabbage (*Brassica rapa* L. var. *Chinensis*) seedlings were transplanted into the pot and irrigated daily with around 400 mL water pot^{-1}, both in the morning and afternoon to ensure field capacity was maintained. Weeding was done every 3 days (debris still kept in the polythene bags when uprooted to avoid the export of nutrients from the experimental units) to avoid competition between crops and weeds. Number of leaves was recorded by counting, plant height was determined with a 60 cm ruler from the soil surface to the tip of the tallest leaf, and the average chlorophyll content (SPAD reading) was recorded using a chlorophyll meter (SPAD-502 Plus,Konica Minolta, Tokyo, Japan) a day before each plant sampling. Uprooted plant samples' roots were washed with tap water to remove the soils debris, followed by rinsed with deionized water and dried using tissue paper. The fresh weights of the samples were recorded within a few minutes using an analytical weighing balance (SHIMADZU UW 2200H, Kyoto, Japan). The leaf area was determined using a Portable Leaf Area Meter (YMJ-B). Then, the leaf area index (LAI) was calculated based on the number of plants in a square meter by applying a total green leaf area [35]. The samples were then packed into an A4 envelope and placed in the oven at 65 °C for 96 h. The dried samples were grounded using a grinding machine and sieved through a 1 mm sieve and 0.5 g of samples were analysed for total N using the Kjeldahl method.

2.6. Statistical Analyses

N mineralization rates were estimated by fitting a zero-order kinetic model: $N(t) = N0 + kt$, where t is the time (in a day), $N(t)$ is the amount of mineral N (NH_4^+-N + NO_3^--N), $N0$ is the initial amount of mineral N (NH_4^+-N + NO_3^--N) in mg N kg^{-1} soil, and k is the mineralization rate (mg kg^{-1} soil day^{-1}) as adopted by Kader et al. [36,37]. Two-way analysis of variance (ANOVA) (compost source x compost rate) was performed with the least significant difference (LSD) post-hoc test for all the N mineralization and plant growth parameters. The level of probability was fixed at 5%. The Pearson correlation was calculated between the mineralization rates and the other plant parameters. The correlation coefficient was determined using the Pearson correlation (r) matrix. All the collected data were subjected to statistical analysis using IBM SPSS version 22 (Chicago, IL, USA).

3. Results

3.1. Composted Organic Amendments Characterization

All the studied characteristics of the composted OAs were significantly different ($p < 0.05$) (Table 2). The highest amount of total N was found in mucuna compost followed by erythrina, glirichida, lawn grasses, and giant taro compost. However, the total N content in erythrina and glirichida compost was statistically identical and superior to the total N content of lawn grasses and giant taro compost. Total N content in lawn grasses and giant taro compost was also statistically similar. NH_4^+ and NO_3^--N contents followed a more or less similar trend (both accounted for 1.1–1.6% of total N) measured the highest (statistically) in macuna compost. In contrast, the highest amount of P and K were found in giant taro compost. A large amount of NO_3^--N was observed in all the composted OAs that varied from 93.20 to 341.10 mgNkg^1 compost accounting 63–90% of mineral N. Giant taro compost has the widest C: N ratio followed by (≥) lawn grass > mucuna ≥ glirichida ≥ erythrina.

Table 2. Characteristics of composts used in both experiments

Organic Amendments	**Chemical Composition**							
	Moisture Content (%)	**N_{Total} (%)**	**C_{Total} (%)**	**C/N (-)**	**Total P (%)**	**Total K (%)**	**NH_4^+-N (mg N kg^{-1})**	**NO_3^--N (mg N kg^{-1})**
Erythrina	25.57 ± 0.52 **c**	1.87 ± 0.09 **b**	38.37 ± 0.11 **b**	20.51 ± 0.90 **b**	0.33 ± 0.01 **ab**	0.21 ± 0.05 **c**	30.76 ± 8.78 **d**	263.70 ± 8.77 **b**
Gliricidia	18.40 ± 0.70 **d**	2.01 ± 0.04 **b**	42.05 ± 0.61 **b**	20.92 ± 0.67 **b**	0.33 ± 0.01 **ab**	0.16 ± 0.06 **d**	69.14 ± 6.20 **a**	218.95 ± 6.26 **c**

Mucuna	31.70 ± 0.26 **ab**	2.91 ± 0.04 **a**	63.59 ± 4.29 **a**	21.85 ± 1.21 **b**	0.20 ± 0.06 **b**	0.25 ± 0.15 **b**	41.49 ± 2.32 **abc**	341.10 ± 16.23 **a**
Lawn grasses	30.41 ± 0.96 **b**	1.33 ± 0.25 **c**	33.04 ± 0.43 **c**	24.84 ± 1.66 **a**	0.40 ± 0.00 **a**	0.03 ± 0.15 **e**	36.51 ± 6.99 **abc**	100.19 ± 2.33 **d**
Giant taro	33.14 ± 0.31 **a**	1.02 ± 0.07 **c**	26.65 ± 0.06 **d**	25.81 ± 1.27 **a**	0.39 ± 0.00 **a**	0.34 ± 0.33 **a**	55.92 ± 2.28 **ab**	93.20 ± 15.98 **e**
Level of significance	**	**	**	**	**	**	**	**

Data are means of three replicates and ± is the standard error. Means with the same letter are not significantly different at $p < 0.05$. ** Significant at $p < 0.01$, * Significant at $p < 0.05$.

3.2. Nitrogen Mineralization

There was a significant difference in both NH_4^+-N and NO_3^--N contents among the treatments throughout the incubation period (*$p < 0.01$*). NH_4^+-N (mg N kg^{-1} soil) contents were gradually decreased in all the amendment treatments with the advancement of incubation time (Figure S1). In contrast, NO_3^--N contents were linearly increased over time of incubation (Figure S2). Nitrogen mineralization (NH_4^+-N + NO_3^--N) increased linearly over time as did NO_3^--N evolution in all the treatments (Figure 1) as the evolution of NO_3^--N was much faster than the decline of NH_4^+-N. NH_4^+-N dominated at the beginning of incubation while NO_3^--N dominated at the latter stage in all the OAs treatments under both application rates. In the case of 10 t ha^{-1} OAs, N mineralization during 42 days incubation was in favour of mucuna with the highest of 75.70 mg N kg^{-1} soil accounting for 1.93% of total N (amended N + soil inherent N) followed by gliricidia, erythrina, lawn grass, giant taro and control with 64.97, 52.17, 42.50 and 27.30 mg N kg^{-1} soil accounting for 1.73%, 1.63%, 1.05%, 1.27% and 0.68% of total N, respectively (Figure 1A,B). In case of 20 t ha^{-1} OAs, absolute N mineralization (mg N kg^{-1}) also followed the same trend as 10 t ha^{-1} OAs (Figure 1C,D).

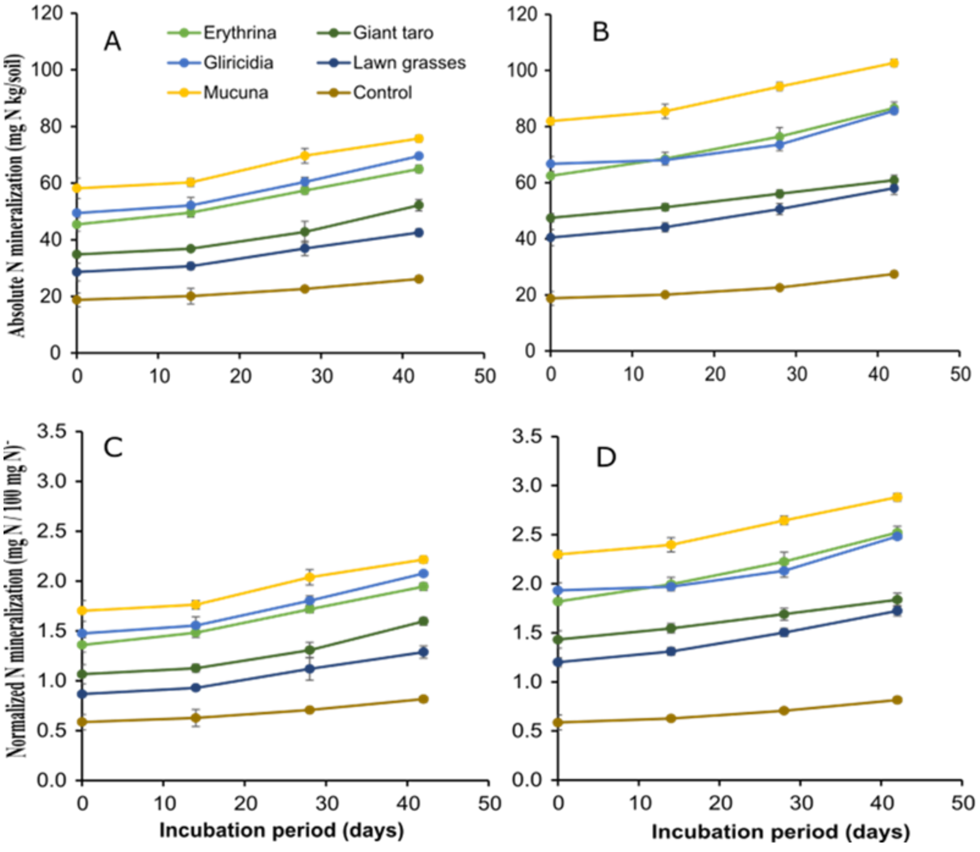

Figure 1. Absolute (mg kg^{-1} soil) (**A**,**B**) and relative (mg N 100 mg^{-1}N) N mineralization (**C**,**D**) from organic amended @ 10 (**A**,**C**) and 20 t ha^{-1} (**B**,**D**) during 42 days of incubation study (mean ± standard error).

N mineralization rates also significantly differed among the OAs treatments. Again, mucuna topped the N mineralization rates (0.70 mg N kg^{-1} soil day^{-1} for 10 t ha^{-1} application rate) likewise for absolute N mineralization. However, it was statistically identical to gliricidia, erythrina but superior to lawn grass, giant taro, and control (Table 3). The N mineralization rate @ 20 t ha^{-1} application also followed the same statistical order as 10 t ha^{-1} application rate. It again favours mucuna followed by gliricidia, erythrina, lawn grass, giant taro, and the control with 0.72, 0.59, 0.57, 0.48, 0.35, and 0.04 mg N kg^{-1} soil day^{-1}, respectively. Difference in N mineralization rate between applications rates was not statistically different except for giant taro compost amendment. N released from different OAs (except inherent SOM) under 10 t ha^{-1} application rate was calculated as 30.4, 41.5, 33.6, 16.8, and 15.4 mg N kg^{-1} composted erythrina, gliricidia, mucuna, lawn grass and giant taro, respectively, accounting for 22%, 22%, 19%, 23%, and 16% of total N (Table 3). Under 20 t ha^{-1} application rate, it was calculated as 50.0, 67.7, 49.3, 23.2 and 19.1 mg N kg^{-1} compost accounting for 21%, 20%, 19%, 19% and 13% of total N. N released from 20 t ha^{-1} application rate for all OAs was statistically superior to 10 t ha^{-1} application rate.

Table 3. Interaction effects of organic amendments with two application rates (10 and 20 t ha^{-1}) on N mineralization rate (*k*) (mg N kg^{-1} soil day^{-1}) (28 °C), net N mineralization and % of total N released from the different organic amendments during the 42-day incubation study.

Organic Amendments	***k* (mg N kg^{-1} Soil Day^{-1})**	**N Released from Compost during Growing Season (6 weeks)**	
		(mg N kg^{-1} compost)	% of total compost N
10 t ha^{-1}			
Erythrina	0.51 ± 0.05 **ab**	30.42 ± 3.97 **d**	21.69
Gliricidia	0.64 ± 0.02 **ab**	33.55 ± 4.42 **d**	22.26
Mucuna	0.70 ± 0.05 **a**	41.54 ± 4.13 **c**	19.03
Lawn grass	0.45 ± 0.01 **b**	18.83 ± 3.92 **f**	23.46
Giant taro	0.35 ± 0.04 **c**	15.44 ± 3.07 **g**	15.95
20 t ha^{-1}			
Erythrina	0.57 ± 0.11 **ab**	50.00 ± 0.11 **b**	21.43
Gliricidia	0.59 ± 0.04 **ab**	49.26 ± 3.89 **b**	19.61
Mucuna	0.72 ± 0.09 **a**	67.67 ± 3.91 **a**	18.61
Lawn grass	0.48 ± 0.05 **b**	23.17 ± 2.51 **e**	18.93
Giant taro	0.41 ± 0.04 **c**	19.10 ± 3.17 **f**	12.76
Control	0.21 ± 0.04 **d**	NA	NA
Level of significance	*	**	NS

Data are means of three replicates and ± is the standard error. Within columns, means with similar lowercase letters are not significantly different at $p < 0.05$. NA = not analysed, NS = not significant, ** Significant at $p < 0.01$, * Significant at $p < 0.05$.

3.3. Interaction Effect of OAs on Plant Growth Parameters

A significant interaction effect (OAs x application rates) was observed in leaf number (count) recorded at 14 ($p < 0.05$), 28 ($p < 0.05$) and 42 ($p < 0.01$) DAT. Mucuna compost showed the best performance throughout DATs in both rates of application rates. The mucuna treatment had the highest leaf numbers of 14.7 and 19.0 at 10 and 20 t ha^{-1} respectively at the last harvest (42 DAT) (Figure 2). Giant taro compost did not influence the leaf number at a higher application rate.

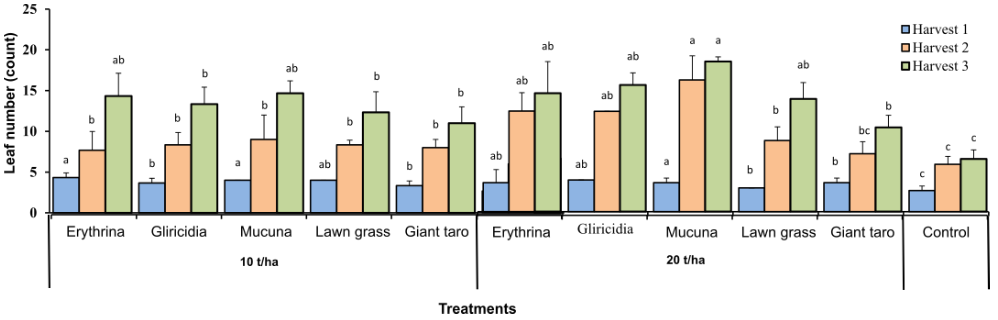

Figure 2. Interaction effect of organic amendments and their application rates (10 and 20 t ha^{-1}) on leaf number (count) of Chinese cabbage (*B. rapa cv. Chinensis)* harvested at 14, 28 and 42 days after transplantation. Treatments having different lowercase letters are significantly different from each other at $p < 0.05$.

Plant height (cm) of Chinese cabbage was not influenced by compost application rates ($p > 0.05$) at 14 DAT but significantly influenced by OAs treatment ($p < 0.05$) and interaction (OAs x application rates) ($p < 0.05$). Compost application rates ($p > 0.05$), OAs treatment ($p < 0.05$) and interaction (OAs x application rates) ($p < 0.05$) significantly influenced the plant height at 28 and 42 DAT (Figure 3). Plant height in response to treatments amended with 20 t ha^{-1} application rates was higher than 10 t ha^{-1} and the control. Again, mucuna compost was the best treatment with the highest plant height (cm) recorded at 42 DAT with an average of 20.67 and 38.33 cm followed by gliricidia (25.7 and 32.7 cm), erythrina (21.0 and 37.7 cm), lawn grass (23.3 and 27.0 cm), giant taro (19.7 and 24.7 cm) at 10 and 20 t ha^{-1}, respectively, and the least was in control (26.33 cm) (Figure 3). Second harvest had a substantially higher plant height compared to the first harvest but slightly higher from the third harvest contrastingly at higher application rate (20 t ha^{-1}) (Figure 3).

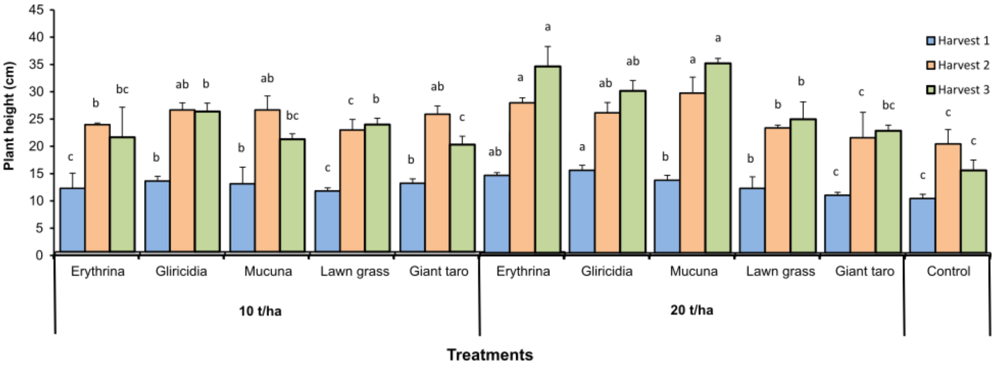

Figure 3. Interaction effect of organic amendments and their application rates (10 and 20 t ha^{-1}) on plant height (cm) of Chinese cabbage (*B. rapa cv. Chinensis)* harvested at 14, 28 and 42 days after transplantation. Treatments having different lowercase letters are significantly different from each other at $p < 0.05$.

There was a significant increase ($p < 0.05$) in LAI (m^2 m^{-2}) in response to the interactions of OAs treatments and application rates (Table 4). The treatment combinations with 20 t ha^{-1} had a higher LAI compared to 10 t ha^{-1}. Among the treatments, mucuna exhibited the highest LAI throughout the experimental duration with 1.84 (m^2 m^{-2}) at 10 t ha^{-1} and 1.65 (m^2 m^{-2}) at 20 t ha^{-1} during the first harvest and then it was increased to 6.46 (m^2 m^{-2}) at 10 t ha^{-1} and 6.62 (m^2 m^{-2}) at 20 t ha^{-1} during the third harvest followed by gliricidia, erythrina, lawn grass, giant taro and the control.

It was noticed that as the harvesting days' increased all the aforementioned parameters also increased. The composted treatments had a higher leaf number, plant height and LAI compared to the control (Figure 2). It was observed that the leguminous treatments on both rates at each harvesting time were performed better than the non-leguminous treatments and the control.

Table 4. Interaction effect of organic amendments with two application rates (10 and 20 t ha^{-1}) at three harvesting times (14, 28 and 42 DAT) on means leaf area index (m^2 m^{-2}) (± standard deviation) of Chinese cabbage.

Organic Amendments	**1st Harvest (m^2 m^{-2})**	**2nd Harvest (m^{2}m^{-2})**	**3rd Harvest (m^{2}m^{-2})**
10 t ha^{-1}			
Erythrina	2.13 ± 0.5 **a**	3.71 ± 0.2 **c**	4.45 ± 0.5 **c**
Gliricidia	1.68 ± 0.4 **b**	5.06 ± 0.5 **bc**	5.86 ± 1.1 **b**
Mucuna	1.84 ± 0.3 **ab**	5.41 ± 0.3 **a**	6.46 ± 1.9 **a**
Lawn grass	1.56 ± 0.4 **b**	3.98 ± 1.7 **b**	4.25 ± 0.5 **c**
Giant taro	1.35 ± 0.7 **bc**	3.31 ± 0.9 **c**	3.86 ± 0.2 **c**
20 t ha^{-1}			
Erythrina	1.86 ± 0.5 **ab**	4.35 ± 0.2 **b**	5.37 ± 0.1 **b**
Gliricidia	1.72 ± 0.2 **b**	5.47 ± 0.9 **a**	5.94 ± 1.3 **b**
Mucuna	1.67 ± 0.7 **b**	5.89 ± 2.2 **a**	6.62 ± 0.5 **a**
Lawn grass	1.02 ± 0.1 **c**	4.04 ± 1.1 **b**	4.20 ± 0.2 **c**
Giant taro	1.42 ± 0.3 **bc**	3.29 ± 0.3 **c**	4.96 ± 0.3 **c**
Control	0.41 ± 0.3 **d**	1.17 ± 0.6 **d**	1.90 ± 0.8 **d**
Level of significance	*	**	**

Data are means of three replicates and ± is the standard error. Treatments indicated with different letters are statistically different. Within columns, means with similar lowercase letters are not significantly different at $p < 0.05$.

3.4. Interaction Effects of Organic Amendments (OAs) on Leaves' Chlorophyll Content

Chlorophyll content (SPAD) of the leaves were significantly influenced by the OAs treatments ($p < 0.05$) and the interaction between OAs treatments and application rates, but not influenced by application rates in all three sampling occasions (Table 5). At the first harvest (14 DAT), there was a slight variation in chlorophyll content among the OAs treatments and eventually the variation became wider in second and third harvest (28- 42 DAT). Among all the treatments, leguminous treatments had a higher chlorophyll content compared to the non- leguminous treatments and the control. Of these, mucuna appeared to be the best OAs with higher chlorophyll content throughout both application rates. At 42 DAT; mucuna treatment had the highest leaf chlorophyll content having SPAD values of 44.3 and 45.1 followed by erythrina with 44.9 and 40.3, gliricidia with 39.3 and 40.2, lawn grass with 38.9 and 39.8, giant taro with 35.1 and 35.7 in 10 and 20 t ha^{-1}, respectively. The lowest SPAD value was recorded from control with 30.9 (Table 5). Leaf chlorophyll content was increased with the advancement of plant growth.

Table 5. Interaction effect of organic amendments with two application rates (10 and 20 t ha^{-1}) at three harvesting times (14, 28, and 42 DAT) on leaf chlorophyll content (SPAD) (± standard deviation) of Chinese cabbage.

Organic Amendments	**1st Harvest**	**2nd Harvest**	**3rd Harvest**
10 t ha^{-1}			
Erythrina	32.0 ± 0.7 **a**	35.4 ± 4.3 **ab**	44.9 ± 6.9 **a**
Gliricidia	32.7 ± 3.3 **a**	36.6 ± 3.1 **ab**	39.3 ± 1.4 **b**
Mucuna	32.6 ± 2.1 **a**	39.8 ± 4.7 **a**	44.1 ± 2.9 **a**
Lawn grass	30.8 ± 1.6 **a**	37.0 ± 6.2 **ab**	39.8 ± 2.9 **b**
Giant taro	31.9 ± 0.6 **a**	37.8 ± 7.1 **ab**	35.1 ± 2.6 **b**
20 t ha^{-1}			

Erythrina	32.8 ± 2.6 **a**	39.1 ± 4.6 **ab**	40.3 ± 3.1 **b**
Gliricidia	30.4 ± 2.1 **a**	36.0 ± 3.0 **ab**	40.7 ± 5.7 **b**
Mucuna	31.4 ± 3.7 **a**	40.4 ± 7.0 **a**	45.1 ± 5.1 **a**
Lawn grass	33.6 ± 2.6 **a**	36.2 ± 3.5 **ab**	38.8 ± 3.1 **b**
Giant taro	30.1 ± 2.1 **a**	30.0 ± 3.4 **b**	32.7 ± 2.4 **bc**
Control	23.9 ± 2.6 **b**	31.2 ± 5.5 **c**	30.9 ± 3.1 **c**
Level of significance	**	**	**

Data are means of three replicates and ± is the standard error. Treatments indicated with different letters are statistically different. Within columns, means with similar lowercase letters are not significantly different at $p < 0.05$.

3.5. Interaction Effects on Yield Parameters

ANOVA showed that there was a significant ($p < 0.05$) difference between OAs treatments and application rates on the fresh and dry biomass yield of cabbage (roots, leaf, and stalk). The interaction effect of OAs and application rates was also significant on both fresh and dry biomass yield of chinses cabbage ($p < 0.05$) (Figures 4 and 5A,B). The treatments dosed with 20 t ha^{-1} were significantly ($p < 0.05$) higher than the 10 t ha^{-1} and highly significant compared to the control (0 t ha^{-1}). There was a small variation in fresh weight among treatments and the control at first harvest, however, the variation became wider at the second and third harvests (Figure 4). Throughout the harvesting time, mucuna had the highest average fresh weight with 193.8 and 224.2 g followed by gliricidia with 136.8 and 182.9 g, erythrina with 128.3 and 157.8 g, lawn grass with 83.2 and 90.9 g, giant taro with 50.6 and 58.7 g at 10 and 20 t ha^{-1} respectively and the least was from the control (36.7 g) at the final harvest.

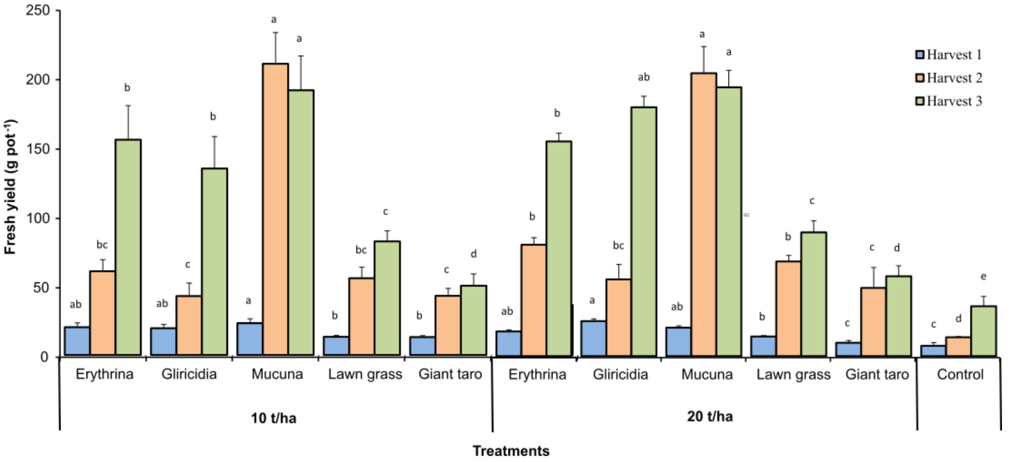

Figure 4. Interaction effect of organic amendments and their application rates (10 and 20 t ha^{-1}) on total fresh weight (g pot^{-1}) of Chinese cabbage harvested at 14, 28 and 42 days after transplantation. Treatments having different lowercase letters are significantly different from each other at $p < 0.05$.

There was also a similar trend with the dry biomass yield. The highest dry weight biomass at 42 DAT was again recorded in mucuna treatments at both rates of application followed by gliricidia, erythrina, lawn grass, giant taro and the least was in control (Figure 5A,B).

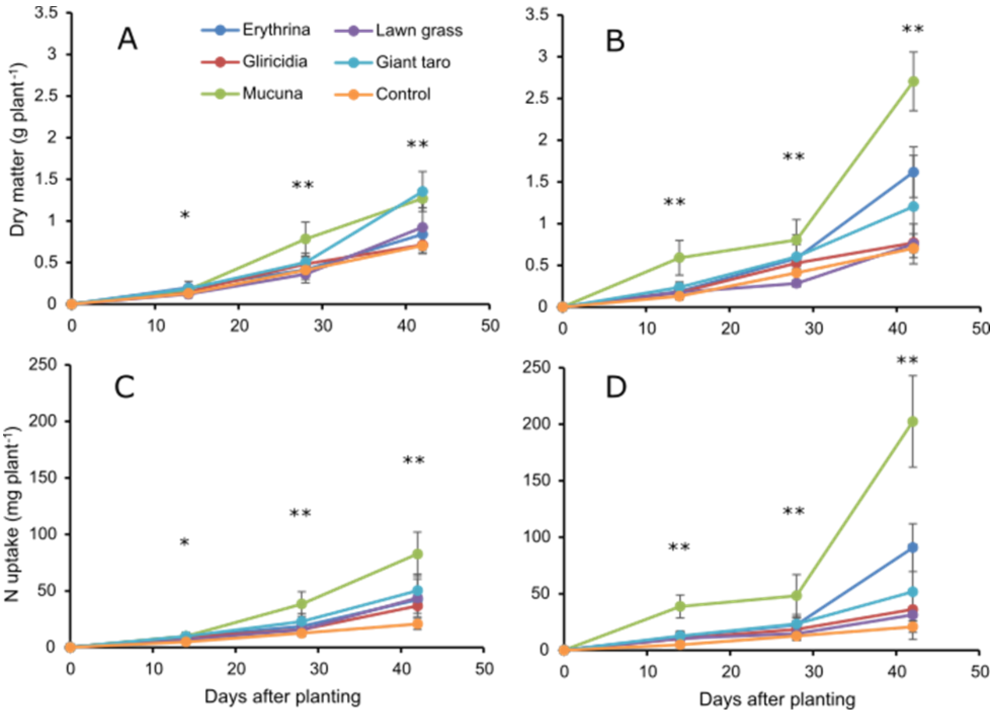

Figure 5. Dry matter accumulation (g $plant^{-1}$) (**A**,**B**) and total N uptake (mg N $plant^{-1}$) (**C**,**D**) in Chinese cabbage over time as influenced by different organic amendments applied with 10 (**A**,**C**) and 20 t ha^{-1} (**B**,**D**) (*, ** indicate significant at the 0.05 and 0.01 probability levels, respectively; vertical bars represent standard deviation).

3.6. Total N Uptake by Chinese Cabbage

Nitrogen uptake of the growing plant increased constantly in all the treatments with the advancement of plant growth and it was always higher in treatments amended with 20 t ha^{-1} OAs compared to 10 t ha^{-1} OAs (Figure 5C,D). Nitrogen concentration in all treatments gradually decreased with the advancement of plant growth. Total N uptake of all the treatments followed the same inclination as the growth parameters of the test crop. Among all the harvesting dates under both application rates, higher N uptake was recorded in mucuna amended treatments followed by gliricidia, erythrina, giant taro, lawn grass and control.

3.7. Correlation between Nutrient Content and N Mineralization of Composted OAs and the Plant Parameters, and N Uptake

Among the nutrients concentration of OAs, N mineralization rate was positively correlated with total N and NO_3^--N ($p < 0.05$) and negatively correlated with p ($p < 0.05$) (Table 6). On the other hand, no significant correlation was observed between N mineralization rate and organic carbon, C: N ratio, total P, total K and NH_4^+-N of different composted OAs.

Table 6. Pearson correlation coefficient between N mineralization rates (k, (mg N kg^{-1} day^{-1}) and the nutrient content of composted organic amendments.

Nutrient Content of OAs	Mineralization Rates (*k*) (mg N kg^{-1} Day^{-1})
Total nitrogen (%)	0.904 **
Total carbon (%)	0.764
Phosphorus (%)	−0.884 **
Potassium (%)	0.396
Ammonium –N (mg N kg^{-1} soil)	0.272

Nitrate –N (mg N kg^{-1} soil)	0.884 **
C/N	−0.506

** Correlation is significant at $p < 0.01$ (2 tailed).

There was a significant correlation between the total N and NO_3^--N content of the composted OAs with the plant parameters except for the dry biomass yield. They all were showed a positive correlation between each other however P content of the composted OAs found to be negatively correlated with leaf number ($p < 0.05$), fresh biomass yield ($p < 0.05$) and N uptake ($p < 0.01$) (Table 7). There was no significant relationship between any plant parameters, K and NH_4^+-N content of the composted OAs. N mineralization rates (k, mg N kg^{-1} day^{-1}) were positively correlated with crop growth and yield parameters in both application rates (Table 7).

Table 7. Pearson correlation coefficient between nutrient content and N mineralization of composted organic amendments and plant growth parameters and N uptake at final harvest.

Plant Growth Parameters	**OAs Nutrient Content**					**N Mineralization Rates (mg N kg^{-1} Day^{-1})**	
	N_{total} (%)	P (%)	K (%)	NH_4^+-N (mg N kg^{-1} soil)	NO_3^--N (mg N kg^{-1} soil)	10 tha^{-1}	20 tha^{-1}
Leaf number (count)	0.992 **	−0.953 *	−0.022	−0.115	0.908 *	0.914 *	0.895 *
Plant height (cm)	0.879 *	−0.781	−0.026	0.008	0.922 *	0.906 *	0.889 *
Chlorophyll content (nmolcm^{-2})	0.900 *	−0.820	−0.231	−0.468	0.885 *	0.913 *	0.922 *
Fresh biomass yield (g pot^{-1})	0.983 **	−0.982 **	0.096	−0.198	0.921 *	0.904 *	0.960 **
Dry biomass yield (g pot^{-1})	0.819	−0.738	−0.376	−0.164	0.624	0.908 *	0.965 **
LAI (m^2/m^2)	0.953 *	−0.899 *	0.063	0.190	0.886 *	0.918 *	0.892 *
Total N uptake (mg N pot^{-1})	0.994 **	−0.981 **	0.088	−0.102	0.924 *	0.912 *	0.903 *

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level.

4. Discussions

4.1. Nitrogen Mineralization

The availability of N is mostly low in agro-ecosystems and the main source of N for crops and microbes becomes available through soil organic matter mineralization [16,36]. Exogenous organic matter is also important, similar to inherent soil organic matter, in supplying N to crop however, it depends on both its quality and quantity [17]. High-quality organic matter is that with a low C: N ratio and with sufficient N to sustain microbe and crop growth [16,17]. Thus, it is always better to use the composted biomass than the fresh biomass as the composting process narrows down the C: N ratio as well as reduces the bulk volume [8]. This study also observed that the composting processes narrowed down the C: N ratio between 20 and 26 in all the OA treatments (Table 1). The rates and patterns of N mineralization during decomposition are known to be affected by the C: N ratio and the initial concentrations of N, lignin, and soluble polyphenols of the plant materials [38]. Among the OAs, mucuna had characterized by the highest total N content. It is similar to Clover having the ability to fix atmospheric N and take up N from soil [39,40].

Much higher NH_4^+-N concentration in all the OAs treatments with both application rates at the initial stage of mineralization is likely due to mineralization of the organic components of the amendment at rates greater than nitrification which can convert it to NO_3^--N in the later stage [41]. After the second sampling (day 14), NH_4^+-N was constantly decreased till the end of the incubation period indicating that NH_4^+-N was quickly nitrified [42,43]. Thus, NO_3^--N was increased exponentially after second sampling. This rapid decrease in NH_4^+-N and increase in NO_3^--N in soils showed that nitrification proceeded rapidly in these soils and that the incubation proceeds under complete aerobic conditions [43,44]. Surprisingly, the results showed that composted OAs released 10–25% of their total N within 42 days of incubation which seems much higher. This might be due to the positive priming effect of inherent SOM due to OAs. Addition of OAs stimulates the mineralization processes of the intrinsic as well as exogenous soil organic nitrogen [45].

Zero-order N mineralization rates (*k*) also followed the same order as absolute N mineralization but N mineralization rates were slightly higher under higher application rates. This is logical as higher application rate provides more N to the system. Correlation studies showed a significant correlation between N mineralization rate and total N (%) and NO_3^--N contents of the OAs. These results were in line with the previous findings [45–47]. Hence, this strong correlation between the total N and NO_3^--N contents and the N mineralization rate represent the complex mineralization process that is influenced by different parameters and not only the residual added nitrogen [47]. From the calculated correlation between N mineralization rates and total N, it coincides with the finding of Widowati et al. [47] who reported that N content of OAs may still be the best factor predicted difference in N mineralization behaviour.

The zero-order mineralization rates (*k*) found for the Samoan volcanic originated Inceptisol (0.21 mg N kg^{-1} soil day^{-1} in control soil; 0.35–0.72 mg N kg^{-1} soil day^{-1} in OAs amended soil) was higher than other studies reported in the literature. For example, upland volcanic and non-volcanic soils from Japan had N mineralization rates of 0.152 and 0.120 $week^{-1}$ respectively [48] and volcanic and non-volcanic soils from Indonesia had 0.095–0.202 and 0.076–0.137 mg N kg^{-1} soil day^{-1}, respectively [47]. The difference in N mineralization rates for the soil in this study compared with the previous studies might be due to firstly, they used a first-order kinetic model, however, a zero-order kinetic model was used in this study. Secondly, the incubation temperature maintained in this study was much higher (28 °C; average yearly temperature of Samoa). Thirdly, the total N content of the studied soil was much higher than those of the previously studied soils.

4.2. Interaction Effects of Organic Amendments (OAs) on Crop Growth Parameters

The OA treatments produced taller plants than the control. This could be due to the additional nutrients involved in respiration, energy storage, and rapid shoot growth [49]. Furthermore, higher plant height could be attributed to microbial activities involved in the rhizosphere assisting in the processes of N mineralization which root-released available substrates increased microbial growth and stimulate N demand for mineralized N for plant uptake [50,51]. Blay et al. [52] reported that the application of OAs to the soil supply the plant nutrients for increased plant height. Initially, slow plant growth and shorter plant height in all treatments might be due to the slow mineralization of OAs at the beginning. However, over time, increased N mineralization leads to increased plant height at second and third harvests. The higher the application rates of OAs except for lawn grass and giant taro composts, the higher the plant height as higher application rate supplied more plant nutrients in the soil for the roots to access [51,53,54].

There was a significant increase in the leaf number in response to the treatments following a similar trend to plant height throughout the experiment. As stated, the nitrification process in the initial stage was slow and eventually it increased, and this was seen in the leaf number development over time. It was confirmed that the speed of leaf differentiation and the growth of leaves are affected by nitrogen supply [55]. The treatments with high N content had a higher leaf number, hence, the treatments with a high application of N perform better and with that, mucuna amended with 20 t ha^{-1} had the highest leaf number [53].

Interestingly, at the first harvest, there was a slight variation among the treatments and this could be the reason that the organic amendments were nitrified to produce available NO_3^--N for plant uptake to develop chlorophyll for photosynthesis [56]. Photosynthesis is a vital process and N plays an important role in this process as it is a major component of chlorophyll. Limited supply or deficiency in N will drastically impact photosynthesis, and consequently the crop performance. Based on the results, chlorophyll contents increased as the crop aged, leading to an increase in the plant biomass. There was a significant increase in chlorophyll content (SPAD) in response to the treatment combination effects. Higher chlorophyll contents have implied higher crop N uptake. A significant increase in chlorophyll content in mucuna compost-amended plants is logical as mucuna compost had higher N content and N mineralization. The chlorophyll content of the mucuna treatment combinations were all above 35 SPAD value. According to Ahmad et al. [57], a SPAD reading above 35 indicated N was sufficient and, in contrast, SPAD below 30 indicated that there was severe N deficiency. No organic amendment treatments had a SPAD reading below 30 except the control. A low SPAD reading in lawn grass and giant taro compost at 20 t application rate indicate that N availability was low in these two treatments. This might be due to immobilization of N at high application rate as the C:N ratio of both the compost was higher close to 25. Low SPAD reading mostly close to 30 at the first sampling in all the OAs treatments again suggested that N mineralization was slow at the initial stage of crop growth. N insufficiency and low SPAD reading could be also attributed due to leaching losses of mineralized N but this was not the case in this study [58].

4.3. Interaction Effects of Organic Amendments (OAs) on Yield Parameters

The crop fresh biomass and dry biomass yield (g pot^{-1}) improved significantly with the application of the organic amendments. Amended treatments had a higher fresh biomass yield than the control and this was because of supplementary nutrients added by the organic amendments. The added organic amendment increased the supply of plant nutrients, particularly N, in the soil for the roots to access through the mineralization process to increase the yield [54,59]. The higher N mineralization rate may eventually lead to higher soil N availability for root uptake due to faster turnover of microbes [60,61]. These results agree with Van Averbeke et al. [62] and Lee et al. [63] who reported that N from OAs application increases the yield of Chinese cabbage. Fresh yield of Chinese cabbage was increased from 6.6 g (control) to 80.8 g per pot in compost-biochar mixed (@ 80:20) treatment [63]. Bonanomi et al. [64], confirmed the N in organic amended soil with high C quality coupled with high N content (e.g., meat powder, fish meal and alfalfa litter) promoted N supplying capacity similar to inorganic N fertilizers.

Organic amendments with higher N content produced better yield [49,65]. Mucuna treatments were dominant throughout the experiments compared to the other treatments and the control. It had the highest fresh biomass yield because of the higher N content of the composted OA and higher N release during mineralization [40,49,66]. Incubation results showed that mucuna treatment with both the application rates (10 and 20 t ha^{-1}) released the highest amount of mineral N among all the OAs treatments. The treatment amended with higher rates of application of OAs had higher yield (fresh weight) compared to the treatments dosed with lesser rates of or no OAs except lawn grass and giant taro composts due to the supply of more nutrients [67]. This is also supported by Choi et al. [68] who reported that the N uptake by Chinese cabbage significantly increased with increasing OAs application rates ranging from 0–600 (0, 200, 400 and 600) mg N kg^{-1} soil. Organic amendment application did not show any significant effect on the uptake efficiency of inorganic-N by Chinese cabbage during the first 30 days. It significantly ($p < 0.05$) increased inorganic-N uptake efficiency, total-N uptake and dry matter yield at the end of the 60-day growth period.

4.4. Total N Uptake by the Chinese Cabbage

Initially, there was a slight increase in N uptake in OAs treatments because of the lower mineralization in the rhizosphere where the microbes need to take up inorganic nitrogen at a certain proportion before more can be mineralized and released to the roots

[69]. They further stated that N uptake increase continuously due to microbial breakdown of macromolecular organic N into smaller molecular weight, more generally usable organic N compounds. Kuzyakov and Xu [61] stated that the absence of new C input and continuous consumption of C by the microorganisms leads to increase in N immobilization in microbial biomass. The consequence is N is unavailable for plant uptake [70]. That might be the case observed in lawn grass and giant taro compost amendments particularly at higher application rates. Considering these short utilization periods and the turnover time of rhizosphere microorganisms ranging from days to weeks, most N is not fully utilized [69,71]. These were observed in the second and third sampling dates with treatments amended with higher rates of the application having a higher N uptake compared to lower rates particularly with leguminous OAs treatments. The sufficient N levels in soil promote higher N uptake resulting in enhanced chlorophyll formation. Higher chlorophyll formation increased photosynthesis and protein synthesis and finally the general productivity of the crop [54,72]. Total N uptake increased drastically with the composted legume treatments over composted non- leguminous OAs treatments. This is logical as composted legumes had higher total N, narrow C:N ratio and higher N mineralization than composted non-legumes. Among the composted legume OAs treatments, mucuna on both application rates took up a higher amount of N. This was in line with Silva-Galicia et al. [40] who reported that mucuna contributed to the higher N content in subsequent maize crops. Weil and Brady [54] confirmed that increased application rates of mucuna increased growth parameters, physiological parameters and N uptake. All of these parameters were mainly influenced by the total N uptake by the plant.

4.5. Correlation between Nutrient Content, N Mineralization of Composted OAs, the Plant Parameters and N Uptake

The positive correlation between the total N and NO_3^--N content of OAs with the plant growth parameters signified that they have a mutual relationship. Zhang et al. [73] found similar results showing a stronger correlation between soil NO_3^--N and plant N concentration than the total N and plant N concentrations. Furthermore, mobile nutrients in soil solutions, such as NO_3^--N, do not develop strong depletion zones around roots; their concentration decreases extremely rapidly due to root uptake [74]. By contrast, NH_4^+-N develops strong depletion zones around roots because it is not very mobile [75] and, as a result, there was no correlation between NH_4^+-N contents and plant growth parameters.

From both application rates, all the treatment combinations had a significant correlation between N mineralization rate and total N of OAs as well as plant N uptake. Thus, the cumulative N mineralization and plant N uptake can be predicted quite closely by linear regression using total N content of OAs as predictor [76] particularly for leguminous OAs. This type of relationship was first reported for crop residues by [77]. Interestingly, the rate constant, k (day^{-1}), did not alter much between the rates but among the OAs tested. Fertility levels of OAs, particularly total N content, was responsible for these differences in mineralization rate.

5. Conclusions

Composted mucuna was found to be superior to the other four locally available organic amendments in Samoa in releasing N to soil. It was also indicated by the growth, physiological and yield parameters of Chinese cabbage. Mineral-N release as a function of time from the five locally-made compost during incubation study followed the same trend corresponding to their nutrient content particularly total N content. Lab incubation and pot trials showed that mucuna had released a higher amount of mineral-N than other OAs treatment combinations. The application of leguminous composted OAs performed better over non-leguminous ones and the control. A higher rate of application performed better than the lower application rate for leguminous OAs. Therefore, *Macuna pruriens* compost might be promoted for use by Samoan farmers to supply N to their soil for crop production.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/agriculture12020201/s1, Figure S1: The evolution of NH_4^+ –N (mg kg^{-1} soil) from amended @ 10 t/ha (left) and 20 t/ha (right) during 42 days of incubation study (mean ± standard error). Figure S2: The evolution of NO_3^- –N (mg kg^{-1} soil) from amended @ 10 t/ha (left) and 20 t/ha (right) during 42 days of incubation study (mean ± standard error)

Author Contributions: Conceptualization, C.S. and M.A.K.; Methodology, C.S. and M.A.K.; Investigation, C.S.; Data curation, C.S. and M.A.K.; formal analysis, C.S., M.A.K. and Z.M.S., Visualization, C.S. and M.A.K.; Writing-original draft preparation, C.S.; Writing-review and editing, M.A.K., Z.M.S.; Supervision, M.A.K.; Fund acquisition, Z.M.S. All authors have read and agreed to the published version of the manuscript**.**

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable

Data Availability Statement: The data are available from the corresponding author upon reasonable request.

Acknowledgments: C. Suruban wishes to acknowledge European Commission for providing him a Building University Links for Action (BULA) scholarship for conducting this research.

Conflicts of Interest: One of the co-authors of this manuscript is Guest Editor of a special issue of Agriculture.

References

1. Pierre-Louis, R.C.; Kader, M.A.; Desai, M.N.; Jhon, E.H. Potentiality of Vermicomposting in the South Pacific Island Countries: A review. *Agriculture* **2021**, *11*, 876. https://doi.org/10.3390/agriculture11090876.
2. Ghosh, S.; Ow, L.F.; Wilson, B. Influence of biochar and compost on soil properties and tree growth in a tropical urban environment. *Int. J. Environ. Sci. Technol.* **2015**, *12*, 1303–1310.
3. Makumba, W.; Akinnifesi, F.K.; Janssen, B.; Oenema, O. Long-term impact of a Gliricidia- maize intercropping system on carbon sequestration in southern Malawi. *Agric. Ecosyst. Environ.* **2007**, *118*, 237–243.
4. Ferdous, Z.; Zulfiqar, F.; Datta, A.; Hasan, A.K.; Sarker, A. Potential and challenges of organic agriculture in Bangladesh: A review. *J. Crop Improv.* **2021**, *35*, 403–426. https://doi.org/10.1080/15427528.2020.1824951.
5. Manojlovic, N.T.; Vasiljevic, P.J.; Gritsanapan, W.; Supabphol, R.; Manojlovic, I. Phytochemical and antioxidant studies of Laurera benguelensis growing in Thailand. *Biol. Res.* **2010**, *43*, 169–176.
6. Bueno, P.; Tapias, R.; López, F.; Díaz, M. Optimizing composting parameters for nitrogen conservation in composting. *Bioresour. Technol.* **2008**, *99*, 5069–5077.
7. Gurtler, J.B.; Doyle, M.P.; Erickson, M.C.; Jiang, X.; Millner, P.; Sharma, M. Composting to inactivate foodborne pathogens for crop soil application: A review. *J. Food Prot.* **2018**, *81*, 1821–1837.
8. Somerville, P.D.; Farrell, C.; May, P.B.; Livesley, S.J. Biochar and compost equally improve urban soil physical and biological properties and tree growth, with no added benefit in combination. *Sci. Total Environ.* **2020**, *706*, 135736.
9. Palaniveloo, K.; Amran, M.A.; Norhashim, N.A.; Mohamad-Fauzi, N.; Peng-Hui, F.; Hui-Wen, L.; Kai-Lin, Y.; Jiale, L.; Chian-Yee, M.G.; Jing-Yi, L.; et al. Food Waste Composting and Microbial Community Structure Profiling. *Processes* **2020**, *8*, 723. https://doi.org/10.3390/pr8060723.
10. Partey, S.T.; Thevathasan, N.V.; Zougmoré, R.B.; Preziosi, R.F. Improving maize production through nitrogen supply from ten rarely-used organic resources in Ghana. *Agrofor. Syst.* **2018**, *92*, 375–387.
11. Dinesh, R.; Suryanarayana, M.A.; Nair, A.K.; Chaudhuri, S.G. Leguminous cover crop effects on nitrogen mineralization rates and kinetics in soils. *J. Agron. Crop Sci.* **2011**, *187*,161–166.
12. LeBauer, D.S.; Treseder, K.K. Nitrogen limitation of net primary productivity in terrestrial ecosystems is globally distributed. *Ecology* **2008**, *89*, 371–379.
13. Wright, S.J. Plant responses to nutrient addition experiments conducted in tropical forests. *Ecol. Monogr.* **2019**, *89*, e01382.
14. Fageria, N.; Baligar, V. Enhancing nitrogen use efficiency in crop plants. *Adv. Agron.* **2005**, *88*, 97–185.
15. Xing, Y.; Jiang, W.; He, X.; Fiaz, S.; Ahmad, S.; Lei, X.; Wang, W.; Wang, Y.; Wang, X. A review of nitrogen translocation and nitrogen-use efficiency. *J. Plant Nutr.* **2019**, *42*, 2624–2641.
16. Masunga, R.H.; Uzokwe, V.N.; Mlay, P.D.; Odeh, I.; Singh, A.; Buchan, D.; De Neve, S. Nitrogen mineralization dynamics of different valuable organic amendments commonly used in agriculture. *Appl. Soil Ecol.* **2016**, *101*,185–193.
17. Córdova, S.C.; Olk, D.C.; Dietzel, R.N.; Mueller, K.E.; Archontouilis, S.V.; Castellano, M.J. Plant litter quality affects the accumulation rate, composition, and stability of mineral-associated soil organic matter. *Soil Biol. Biochem.* **2018**, *125*, 115–124.

18. Azim, K.; Soudi, B.; Boukhari, S.; Perissol, C.; Roussos, S.; Alami, I.T. Composting parameters and compost quality: A literature review. *Org. Agric.* **2018**, *8*, 141–158.
19. Calderon, F.J.; McCarty, G.W.; Reeves, J.B. Analysis of manure and soil nitrogen mineralization during incubation. *Biol. Fertil. Soils.* **2005**, *41*, 328–336.
20. Mohanty, M.; Reddy, K.S.; Probert, M.; Dalal, R.C.; Rao, A.S.; Menzies, N. Modelling N mineralization from green manure and farmyard manure from a laboratory incubation study. *Ecol. Modell.* **2011**, *222*, 719–726.
21. Meschede, C.A.C.; Abdalla, M.A.; Mühling, K.H. Sulfur but not nitrogen supply increases the ITC/Nitrile ratio in Pak Choi (*Brassica rapa subsp. Chinensis* (L.) Hanelt). *J. Appl. Bot. Food Qual.* **2020**, *93*, 95–104.
22. Zhu, B.; Yang, J.; Zhu, Z.J. Variation in glucosinolates in pak choi cultivars and various organs at different stages of vegetative growth during the harvest period. *J. Zhejiang Univ. Sci.* **2013**, *14*, 309–317. https://doi.org/10.1631/jzus.B1200213.
23. Kim, M.J.; Chiu, Y.-C.; Kim, N.K.; Park, H.M.; Lee, C.H.; Juvik, J.A.; Ku, K.-M. Cultivar-specifc changes in primary and secondary metabolites in Pak Choi (*Brassica Rapa*, *Chinensis* Group) by methyl jasmonate. *Int. J. Mol. Sci.* **2017**, *18*, 1004. https://doi.org/10.3390/ijms18051004.
24. Li, T.; Lalk, G.T.; Zhang, Q.; Xing, Z.; Bi, G. Winter Production of Asian Leafy Greens in High Tunnels Using Biodegradable Mulches. *Horticulturae* **2021**, *7*, 454.
25. Siose, T.K.; Kader, M.A.; Tulin, A.B. Determination of limiting nutrient to Sweetpotato (*Ipomoea batatas* (L.) growth on Samoa Oxisol using a Nutrient Omission Technique. *Ann. Trop. Res.* **2017**, *39*, 106–119.
26. De Neve, S.; Hofman, G. Quantifying soil water effects on nitrogen mineralization from soil organic matter and from fresh crop residues. *Biol. Fertil. Soils.* **2002**, *35*, 379–386.
27. Bouyoucos, G.J. Hydrometer method improved for making particle size analysis of soils. *Agron. J.* **1962**, *54*, 464–465.
28. Blackmore, L.C.; Searle, P.L.; Daly, B.K. *Methods for Chemical Analysis of Soil*; New Zealand Soil Bureau, Department of Scientific and Industrial Research: Lower Hutt, New Zealand, 1987; p. 103.
29. Olsen, S.R.; Cole, C.V.; Watanabe, F.N.; Dean, L.A. *Estimation of Available Phospherous in Soils by Extraction with Sodium Bicarbonate*; USDA Department Circular: Washington, DC, USA, 1954.
30. Daly, B.K.; Manu, V.; Halavatau, S.M. Soil and Plant Analysis Methods for Use at Agriculture Research Station. In *New Zealand Soil Bureau Laboratory Report*; New Zealand Soil Bureau: Vaini, Tonga, 1984.
31. Lindsay, W.L.; Norwell, W.A. Development of A DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* **1978**, *42*, 421–428.
32. Walkley, A.; Black, I.A. An Examination of the Degtjareff method for determining organic matter and propose modification of chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38.
33. Morrison, R.; Prasad, R.A.; Asghar, M. *Taxonomy of Some Western Samoa Benchmark Soils*; Institute of Natural Resources, University of the South Pacific: Suva, Fiji, 1986.
34. Bremner, J.; Keeney, D.R. Steam distillation methods for determination of ammonium, nitrate and nitrite. *Anal. Chim. Acta* **1965**, *32*, 485–495.
35. Hamad, A.A.A.; Xu, J.; Wei, Q.; Hamoud, Y.A.; Shaghaleh, H.; Wang, K.; Hameed, F.; Xu, L. Effect of different irrigation and nitrogen management options on growth, yield and water use efficiency of Chinese cabbage in greenhouse cultivation. *Pak. J. Agric. Sci.* **2021**, *58*, 341–356.
36. Kader, M.A.; Sleutel, S.; Begum, S.A.; Moslehuddin, A.Z.M.; De Neve, S. Nitrogen mineralization in sub-tropical paddy soils in relation to soil mineralogy, management, pH, carbon, nitrogen and iron contents. *Eur. J. Soil Sci.* **2013**, *64*, 47–57.
37. Kader, M.A.; Yeasmin, S.; Solaiman, Z.M.; De Neve, S.; Sleutel, S. Response of hydrolytic enzyme activities and N mineralization to fertilizer and organic matter application in two long-term subtropical paddy field experiments. *Eur. J. Soil Biol.* **2017**, *80*, 27–34.
38. Omari, R.A.; Aung, H.P.; Mudan, H.; Yokoyama, T.; Onwona-Agyeman, S.; Oikawa, Y.; Fujii, Y.; Bellingrath-Kimura, S.D. Influence of different plant materials in combination with chicken manure on soil carbon and nitrogen contents and vegetable yield. *Pedosphere* **2016**, *26*, 510–521.
39. Seneviratne, G. Litter quality and nitrogen release in tropical agriculture: A synthesis. *Biol. Fertil. Soils* **2000**, *31*, 60–64.
40. Silva-Galicia, A.; Álvarez-Espino, R.; Sosa-Montes, E.; Ceccon, E. Fertilisation schemes based on organic amendments; decomposition and nutrient contribution of traditionally used species in an indigenous region of southern Mexico. *Biol. Agric. Hortic.* **2020**, *37*, 55–70.
41. Ge, X.; Deng, S.; Zhu, L.; Li, Y.; Jia, Z.; Tian, Y.; Tang, L. Response of nitrogen mineralization dynamics and biochemical properties to litter amendments to soils of a poplar plantation. *J. For. Res.* **2018**, *29*, 915–924.
42. Widowati, L.R.; De Neve, S.; Setyorini, D.; Kasno, A.; Sipahutar, I.A. Nitrogen balances and nitrogen use efficiency of intensive vegetable rotations in South East Asian tropical Andisols. *Nutr. Cycling Agroecosyst.* **2011**, *91*, 131–143.
43. De Neve, S.; Hofman, G. Modelling N mineralization of vegetable crop residues during laboratory incubations. *Soil Biol. Biochem.* **1996**, *28*, 1451–1457.
44. De Neve, S.; Sáez, S.G.; Daguilar, B.C.; Sleutel, S.; Hofman, G. Manipulating N mineralization from high N crop residues using on-and off-farm organic materials. *Soil Biol. Biochem.* **2004**, *36*,127–134.
45. Sigurnjak, I.; De Waele, J.; Michels, E.; Tack, F.; Meers, E.; De Neve, S. Nitrogen release and mineralization potential of derivatives from nutrient recovery processes as substitutes for fossil fuel-based nitrogen fertilizers. *Soil Use Manag.* **2017**, *33*, 437–446.

46. Constantinides, M.; Fownes, J. Nitrogen minerlization from leaves and litter of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biol. Biochem.* **1994**, *26*, 49–55.
47. Widowati, L.R.; Sleutel, S.; Setyorini, D.; De Neve, S. Nitrogen mineralisation from amended and unamended intensively managed tropical andisols and inceptisols. *Soil Res.* **2012**, *50*, 136–144.
48. Sano, S.; Yanai, J.; Kosaki, T. Relationships between labile organic matter and nitrogen mineralization in Japanese agricultural soils with reference to land use and soil type. *Soil Sci. Plant Nutr.* **2006**, *52*, 49–60.
49. Poku, P.A.; Agyarko, K.; Dapaah, H.; Dawuda, M. Influence of Mucuna pruriens Green Manure, NPK and Chicken Manure Amendments on Soil Physico–Chemical Properties and Growth and Yield of Carrot (*Daucus carota* L.). *J. Agric. Sustain.* **2014**, *5*, 26–44.
50. Zhao, F.; Zou, G.; Shan, Y.; Ding, Z.; Dai, M.; He, Z. Coconut shell derived biochar to enhance water spinach (Ipomoea aquatica Forsk) growth and decrease nitrogen loss under tropical conditions. *Sci. Rep.* **2019**, *9*, 1–8.
51. Zhu, B.; Gutknecht, J.L.; Herman, D.J.; Keck, D.C.; Firestone, M.K.; Cheng, W. Rhizosphere priming effects on soil carbon and nitrogen mineralization. *Soil Biol. Bioch.* **2014**, *76*, 183–192.
52. Blay, E.; Danquah, E.; Ofosu-Anim, J.; Ntumy, J. Effect of poultry manure and/or inorganic fertilizer on the yield of shallot [*Allium cepa* var. *aggregatum* (G. Don)]. *Adv. Hortic. Sci.* **2002**, *16*, 13–16.
53. Poinkar, M.; Shembekar, R.; Neha, C.; Nisha, B.; Archana, K.; Kishor, D. Effect of organic manure and biofertilizers on growth and yield of turmeric (*Curcuma longa* L.). *J. Soils Crops* **2006**, *16*, 417–420.
54. Weil, R.R.; Brady, N.C. *The Nature and Properties of Soils*, 15th ed.; Prentice Hall: Hoboken, NJ, USA, 2017.
55. Qiu, X.; Wang, Y.; Hu, G.; Wang, Q.; Zhang, X.; Dong, Y. Effect of different fertilization modes on physiological characteristics, yield and quality of Chinese cabbage. *J. Plant Nutr.* **2013**, *36*, 948–962.
56. Jasso-Chaverria, C.; Hochmuth, G.; Hochmuth, R.; Sargent, S. Fruit yield, size, and color responses of two greenhouse cucumber types to nitrogen fertilization in perlite soilless culture. *HortTechnology* **2005**, *15*, 565–571.
57. Ahmad, A.A.; Fares, A.; Hue, N.V. Nitrate dynamic in a tropical mollisol amended with organic manures, planted with sweet corn, and monitored with SPAD readings. *Commun. Soil Sci. Plant Anal.* **2012**, 43, 2274–2288.
58. Maseko, I.; Beletse, Y.G.; Nogemane, N.; du Plooy, C.P.; Musimwa, T.R.; Mabhaudhi, T. Productivity of non-heading Chinese cabbage (*Brassica rapa* subsp. *chinensis*) under different agronomic management factors. *S. Afr. J. Plant Soil* **2017**, *34*, 275–282.
59. Siose, T.K.; Guinto, D.F.; Kader, M.A. Organic Amendments Increased Sweetpotato (*Ipomoea batata* L.) Yield in Calcareous Sandy Soil of Samoa. *S. Pac. J. Nat. Appl. Sci.* **2018**, *36*, 36–45.
60. Frank, D.A.; Groffman, P.M. Plant rhizospheric N processes: What we don't know and why we should care. *Ecology* **2009**, *90,*1512–1519.
61. Kuzyakov, Y.; Xu, X. Competition between roots and microorganisms for nitrogen: Mechanisms and ecological relevance. *New Phytol.* **2013**, *198*, 656–669.
62. Van Averbeke, W.; Juma, K.; Tshikalange, T. Yield response of African leafy vegetables to nitrogen, phosphorus and potassium: The case of *Brassica rapa* L. subsp. *chinensis* and *Solanum retroflexum* Dun. *Water SA* **2007**, *33*, 355–362.
63. Lee, J.H.; Luyima, D.; Lee, J.Y.; Kim, S.J.; Son, M.K.; Yoon, C.W.; Choi, Y.J.; Choi, H.Y.; Shinogi, Y.; Park, K.W. Effects of two biochar–based organic amendments on soil chemical properties and productivity of selected vegetables. *J. Fac. Agric. Kyushu Univ.* **2019**, 64, 39–46.
64. Bonanomi, G.; Sarker, T.C.; Zotti, M.; Cesarano, G.; Allevato, E.; Mazzoleni, S. Predicting nitrogen mineralization from organic amendments: Beyond C/N ratio by ^{13}C-CPMAS NMR approach. *Plant Soil* **2019**, *441*,129–146.
65. Luo, G.; Li, L.; Friman, V.P.; Guo, J.; Guo, S.; Shen, Q.; Ling, N. Organic amendments increase crop yields by improving microbe-mediated soil functioning of agroecosystems: A meta-analysis. *Soil Biol. Biochem.* **2018**, *124*, 105–115.
66. Anand, S. Developing a Taro (*Colocasia esculenta*) Production System Based on Genotype and Fallow System for Economic and Environmental Sustainability under Local Conditions in Samoa. PhD Thesis, The University of the South Pacific, Suva, Fiji, 2016.
67. Agyarko, K.; Kwakye, P.; Bonsu, M.; Osei, B.; Frimpong, K. The effect of organic soil amendments on root-knot nematodes, soil nutrients and growth of carrot. *J. Agron.* **2006**, *5*, 641–646.
68. Choi, W.J.; Ro, H.M.; Chang, S.X. Recovery of fertilizer-derived inorganic-^{15}N in a vegetable field soil as affected by application of an organic amendment. *Plant Soil* **2004**, *263*, 191–201.
69. Schimel, J.P.; Bennett, J. Nitrogen mineralization: Challenges of a changing paradigm. *Ecology* **2004**, *85*, 591–602.
70. Musyoka, M.W.; Adamtey, N.; Bünemann, E.K.; Muriuki, A.W.; Karanja, E.N.; Mucheru-Muna, M.; Fiaboe, K.K.; Cadisch, G. Nitrogen release and synchrony in organic and conventional farming systems of the Central Highlands of Kenya. *Nutr. Cycl. Agroecosyst*. **2019**, *113*, 283–305.
71. Blagodatskaya, E.; Yuyukina, T.; Blagodatsky, S.; Kuzyakov, Y. Turnover of soil organic matter and of microbial biomass under C_3–C_4 vegetation change: Consideration of ^{13}C fractionation and preferential substrate utilization. *Soil Biol. Biochem.* **2011**, *43*, 159–166.
72. Moriwaki, T.; Falcioni, R.; Tanaka, F.A.O.; Cardoso, K.A.K.; Souza, L.; Benedito, E.; Nanni, M.R.; Bonato, C.M.; Antunes, W.C. Nitrogen-improved photosynthesis quantum yield is driven by increased thylakoid density, enhancing green light absorption. *Plant Sci.* **2019**, *278*, 1–11.
73. Zhang, J.; Wei, Q.; Xiong, S.; Shi, L.; Ma, X.; Du, P.; Guo, J. A spectral parameter for the estimation of soil total nitrogen and nitrate nitrogen of winter wheat growth period. *Soil Use Manag.* **2021**, *37*, 698–711. https://doi.org/10.1111/sum.12639.

74. Lynch, J.P. Root phenotypes for improved nutrient capture: An underexploited opportunity for global agriculture. *New Phytol.* **2019**, *223*, 548–564.
75. Orcutt, D.M. *The Physiology of Plants under Stress: Soil and Biotic Factors*; John Wiley & Sons: Hoboken, NJ, USA, 2000.
76. Ahmad, A.; Hue, N.; Radovich, T. Nitrogen release patterns of some locally made composts and their effects on the growth of Chinese cabbage (*Brassica rapa*, *Chinensis* group) when used as soil amendments. *Compost Sci. Util.* **2014**, *22*, 199–206.
77. Vigil, M.; Kissel, D. Equations for estimating the amount of nitrogen mineralized from crop residues. *Soil Sci. Soc. Am. J.* **1991**, *55*, 757–761.