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Nitrogen Recoveries and Nitrogen Use Efficiencies of Organic Fertilizers with Different C/N Ratios in Maize Cultivation with Low-Fertile Soil by ^{15}N Method

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Received: 26 April 2020; Accepted: 29 June 2020; Published: 5 July 2020

Abstract: The rising cost of inorganic fertilizers, coupled with their adverse effects on soil conditions, has resulted in increasing interest in organic amendments. The objective of the present study was to evaluate the effect of organic amendments (OAs) with different C/N ratios on nitrogen use efficiency (NUE) and recovery rate, as well as on the growth and yield of *Zea mays* and soil properties. A precise pot experiment was conducted on a low-fertile, sandy-loam soil, and the dynamics of nitrogen (N) were also analyzed by the A-value method, using ^{15}N tracer. The plant height of the treatment groups decreased in the following order: inorganic fertilizer (IF) = rapeseed waste (RW) > chicken manure (CnM) > bamboo tealeaf (BTL) > cow manure (CwM) > bamboo compost (BC). Furthermore, the maize fertilized with RW only took up half of the N in IF, despite producing the same yield, which indicates that the physiological nitrogen efficiency (PUE) of RW was twice as high as that of IF. RW and CnM were regarded as valuable fertilizers that could be used to replace inorganic fertilizers. A linear relationship between the N mineralization of the OAs was obtained by an incubation test and the pot experiments, estimating the effect of OA application on the maize. Maize plants mainly absorbed N derived from fertilizers; however, for the both sources of N (fertilizer and soil), N was mainly accumulated in grains followed by the leaves, stem, and root, suggesting that studies should be conducted to improve soil N use efficiency.

Keywords: ^{15}N tracer; maize; nitrogen mineralization; organic amendment

1. Introduction

The restoration of soil fertility is now recognized as the key entry point for increasing agricultural productivity in smallholder farms [1]. In sub-Saharan Africa, soil infertility, which has resulted from continuous cultivation, rising populations, and limited fertilizer use, is considered a serious threat to agricultural productivity and has caused declining crop yields, decreasing vegetation cover, and increasing soil erosion [2]. Reductions in soil fertility remain the main biophysical cause of declining crop productivity on smallholder farms, whereas N is the main nutrient that limits cereal growth [3]. Since N is a crucial nutrient for crop production and an element that easily can be lost by many interrelated factors, both natural and cultural, it can contribute to reductions in soil fertility through leaching, soil erosion, and crop harvesting [4]. The management of N resources is important, especially in food production, as agriculture is the biggest user of anthropogenic N in the world [5]. N availability, uptake, and translocation affects basic physiological functions associated with biomass

production and grain yield [6]. The negative impacts of N due to our food production are caused by a general decrease in the nitrogen use efficiency (NUE) in most regions of the world.

NUE is defined as the weight of the grains divided by the amount of N applied to the soil and indicated how efficiently a plant is capable of capturing and using N to produce biomass or grain yield [7]. On the other hand, fertilizer NUE is governed by the major factors, which includes N uptake by the crop, N supply from soil and fertilizer, and N losses from soil–plant systems. The components of fertilizer N use efficiency are agronomic efficiency, apparent recovery efficiency, physiological efficiency, and N harvest index [8].

Maize (*Zea mays* L.), which is a highly valuable cereal crop to both man and animals, ranks in third position, following wheat and rice, in world production [9], and according to the 2000 Census of Agriculture, maize and cassava account for 50% of the value of agricultural production in many developing countries. Maize is a staple food for many African countries and in Mozambique; for example, farmers in the family sector allocate between 20% and 60% of their total land for maize production [10], contributing to the food security of the population. Its cultivation is increasing every year, in spite of its economic importance and the increase in land areas, the yield has continuously declined to as low as 1 t ha^{−1}, owing to a variety of factors, including rapidly reducing soil fertility [11] and a negligence of soil amendment practices resulting in severe nutrient depletion of soils [12]. Unless nutrients are replenished by organic or inorganic fertilizers, partially returned through crop residues, or replaced more comprehensively through traditional fallow systems that restore nutrient levels and soil organic matter, soil nutrient levels decline continuously. To sustain high crop yields in intensive crop production systems, N fertilizer is required. N management in maize production systems is one of the main concerns, since it is the most primary nutrient for the growth and development of the crop [13]. Excessive N application often reduces NUEs to 0.260 g N g^{−1} N, as reported by [14], because crop utilization of N will be limited by biotic and abiotic constraints other than N supply [15]. In contrast, low N applications may produce high NUEs but result in poor yield [16]. Sustainable sandy soil management requires practices that maintain and improve the physicochemical properties of soil while also maximizing crop yield. The use of both organic amendments (OA) and inorganic fertilizer by farmers has been reported to increase yield, sustain productivity, and improve soil physicochemical properties [17]. However, little information is available about the series of overall dynamics of N from N mineralization from OAs and soil to plant uptake. In the present study, we established a greenhouse trial, using maize as a test crop, in order to evaluate the effect of OAs available in Africa, with different C/N ratios on crop growth, yield, and soil properties, as well as to determine the dynamics of N recovery and use efficiency using a ¹⁵N tracer. Since agriculture is the main activity in many African countries, the present study findings will provide important information to the agriculture sector and for the extensionists who support local farmers.

2. Materials and Methods

The study was divided in two parts comprised of an incubation test and a pot experiment.

2.1. Incubation Experiment for N Mineralization Test for Organic Amendments

With the objective of investigating the N mineralization rates of various OAs, we evaluate a potential relationship between the N mineralization test and pot experiment and establish a model for the mineralization curve in the laboratory of Ehime University, which an incubation experiment was conducted. For this test, we used an upland soil (low fertility) collected at the Ehime University farm in Matsuyama, Ehime, air-dried, and sifted through a 2-mm mesh sieve. Initial soil pH and electrical conductivity (EC) were determined from soil–water suspensions (1:2.5 and 1:5 v/v, respectively). Soil inorganic N, including ammonium-N (NH₄⁺-N) and nitrate-N (NO₃[−]-N), was extracted with 2M KCl, and their concentrations were determined by the calorimetric methods in the indophenol blue method and the vanadium chloride nitrate reduction method. Total C and N contents were measured by the dry combustion method using an elemental analyzer (Sumigrapg NC-80 auto, Sumika,

Osaka, Japan). Available P was analyzed based on the Troug method, cations exchange capacity (CEC), and exchangeable cations by the CEC extract method [18]. OAs such as bamboo compost (BC), a mixture compost of bamboo powder and tealeaf waste at a proportion rate of 20:80 (BTL), chicken (CnM) and cow manure (CwM), and rapeseed waste (RW, The Nissin Oillio Group, Ltd.) were used in a proportion of 39 g soil:1 g OA, and soil was kept in 60% water-holding capacity. The unamended soil was used as a control treatment (NF). The characteristics of initial soil and OAs used in the experiment are shown in Table 1. All samples were replicated four times and incubated for 28 days under dark conditions at 25 °C. For the mineralization analysis, sub-samples were collected at 0, 3, 7, 14, 21, and 28 days, and NH_4^+ -N and NO_3^- -N content were analyzed using the above-mentioned method.

Table 1. Characteristics of soil and organic amendments used in the present study.

Measurements	Units	Soil	CnM	CwM	BTL	BC	RW
pH		6.88	8.10	8.53	6.73	6.40	5.93
EC	($\mu\text{S cm}^{-1}$)	162	7.97	4.53	0.363	0.463	2.67
Water content	(%)	2.26	14.6	28.6	61.8	18.8	12.6
Total carbon	(g kg^{-1})	26.7	270	321	449	446	414
Total nitrogen	(g kg^{-1})	1.13	28.6	20.7	26.1	5.48	64.3
C/N ratio		23.6	9.44	15.5	17.2	81.4	6.44
Total P	(g kg^{-1})	0.7 *	50.4	17.2	1.6	1.7	26.9
NH_4^+ -N	(g kg^{-1})	3.51	13.3	33.4	29.5	18.0	25.0
NO_3^- -N	(g kg^{-1})	17.1	49.9	106	168	2.77	23.9
CEC	(mmol _c 100 g ⁻¹ DW)	12.0	33.8	36.8	49.4	37.7	37.8
Exchangeable Ca	(mmol _c 100 g ⁻¹ DW)	16.0	-	-	-	-	-
Exchangeable Mg	(mmol _c 100 g ⁻¹ DW)	4.81	-	-	-	-	-
Exchangeable K	(mmol _c 100 g ⁻¹ DW)	0.469	-	-	-	-	-
Exchangeable Na	(mmol _c 100 g ⁻¹ DW)	0.156	-	-	-	-	-

CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste, *: Available P (g kg^{-1}) is given for the experimental soil, - not analyzed.

2.2. Plant Cultivation and Analysis of Nitrogen Dynamics by ^{15}N Tracer

The pot experiment began with seeding preparation on 12 May 2016, and transplanting time occurred after 19 days, on June 1. The plants were harvested on 17 August 2016. Using a randomized complete block design, Dent corn (*Z. mays*) was cultivated in a 1/2000 a Wagner pot (ϕ of 25.2 cm, height of 30 cm, and area of 0.05 m²), and the pots were raised 15.0 cm above the ground using blocks to avoid radiation and latent heat in a greenhouse of Ehime University. Five replicates were performed for each of the five OA treatments, which were the same as those used in the incubation test. An additional inorganic fertilizer NPK 15-15-15 (IF) treatment was added. Since we use the ^{15}N tracer method, we did not set an unamended soil (NF) treatment. Each pot in all treatments received in total 1.75 g N pot⁻¹ (35.0 g N m⁻²) applied based on the maize recommended rate of fertilizer application. N application was calculated based on the total N content of the fertilizers. To help the decomposition of the OAs, a part of amendments was mixed with soil one week before transplanting. Following OAs: CnM, CwM, BTL, BC, and RW containing 28.6, 20.7, 26.1, 5.48, and 64.3 g N kg⁻¹ (Table 1) respectively, in amounts of 30.7, 50.8, 75.2, 169, and 13.4 g pot⁻¹ (fresh weight basis) were mixed with 10 kg sandy-loam soil (sand, 79.8%; silt, 7.83%; clay, 12.4%) to supply 0.750 g N pot⁻¹ (15.0 g N m⁻²) as basal fertilization. As for the supplementary fertilization, same OAs in amounts of 20.5, 33.9, 50.2, 112, and 8.90 g pot⁻¹ to supply 0.500 g N pot⁻¹ (10.0 g N m⁻²), were applied to the surface of the pots two additional times at 3 and 5 weeks after transplanting (WAT) being the plants in an active growth stage and in between the pollination and kernel development stage, respectively. Under IF treatment, on the day of transplanting (June 1), 5.00 g NPK pot⁻¹ (dry weight basis) to supply the same amount of basal fertilization was mixed with soil and for supplementary fertilization, the same fertilizer in a 3.33 g NPK pot⁻¹ was applied under the same conditions as OAs. Any other nutrients were not supplied in all the treatments. ^{15}N tracer as $^{15}\text{NH}_4\text{Cl}$ (0.100 g N m⁻², 99.7 atom%)

was applied to all pots thoroughly using a syringe with a 20.0 cm long needle at the beginning of the cultivation and was used to quantify the N uptake by plant derived from soil and fertilizer as well as the N uptake and distribution from different plant components. From the day of transplanting up to the harvesting day, once a week, the following growth parameter data were collected: plant height, number of leaves, and chlorophyll content in the second new leaf recorded as average of 3 points measured (bottom, center and top) by SPAD 502-Plus (Konica Minolta Sensing, Inc., Osaka, Japan).

2.3. Plant and Soil Analysis, Fertilizer Nitrogen Use Efficiency, and Its Components

At maturity, each plant was harvested and divided into aboveground (AG) and belowground (BG) parts. AG plant parts were collected and divided into the main stem, leaves, and grain, while the BG plant parts comprised the roots. All samples were oven-dried at 70.0 °C for 2 days, weighed, and regarded as dry biomass. The total plant biomass was obtained by sum of the dry biomass of the AG and BG. Grain yield (GY) (g plant^{-1}) was obtained by measuring the total weight of grain per plant and number of grains (No. plant^{-1}) was estimated based on number of grains in 10.0 g and the total weight of grains. Then, maize plants sub-samples were milled for chemical analysis using a vibrating mill sampler machine. After being finely ground, they were subjected to ^{15}N analysis (ANCA-MS, Europa Scientific Ltd.) to evaluate the amount of N uptake derived from the soil and fertilizer N. We have also estimated the N uptake index as the product of plant height, leaf number, and chlorophyll content as one of the parameters that could explain the plant growth in each treatment.

2.4. Total N Uptake by Plant, Plant Uptake N Derived from Fertilizer and Soil

The amount of N uptake ($\mu\text{g pot}^{-1}$) derived from the fertilizer (N_{dff}) and soil (N_{dfs}) were estimated by the ‘A value’ method [19,20]. Total N uptake by maize (TN_{up}) was computed as the sum of concentrations of nitrogen derived from fertilizer (N_{dff}) and derived from soil (N_{dfs}) multiplied by the plant biomass.

2.5. Agronomic N Use Efficiency, Apparent N Recovery Efficiency, and Physiological Efficiency

Fertilizer NUE were estimated following the below calculations:

Agronomic NUE (ANUE) ($\text{g g}^{-1} \text{N}$) was defined as GY divided by the amount of N applied (N_a), and it was computed as:

$$ANUE (\text{g g}^{-1} \text{N}) = \text{GY}/N_a. \quad (1)$$

Apparent N recovery efficiency (ANRE) ($\text{g N g}^{-1} \text{N}$), which indicates the quantity of N uptake derived from fertilizer per unit of N applied, was calculated as:

$$ANRE (\text{g N g}^{-1} \text{N}) = N_{dff}/N_a. \quad (2)$$

Physiological N efficiency (PNE) ($\text{g g}^{-1} \text{N}$) was determined from each treatment based on the ratio of GY and TN_{up} and computed as follows:

$$PNE (\text{g g}^{-1} \text{N}) = \text{GY}/TN_{up}. \quad (3)$$

Finally, the N harvest index (NHI) was determined as the ratio of N uptake by maize grain (N_{grain}) and TN_{up} as described by Fageria [21].

Regarding soil analysis, after each plant was harvested, top 10 cm-depth soil samples were collected from all the treatments, air-dried, sifted through a 2-mm mesh sieve, and analyzed (based on dry weight) for pH, EC, $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, CEC, and exchangeable cations (Ca, Mg, K, Na), following the above-mentioned methods [18].

2.6. Statistical Analysis

Grain yield, biomass, number of grains per plant, and plant uptake N among different treatments were evaluated by an analysis of variance (ANOVA) and Tukey's HSD (honestly significant difference) test. To test whether there was a relationship between the N uptake by corn in a pot experiment and mineralized N from OAs in an incubation test, we fitted the data with a simple linear regression line, and Pearson's correlation analysis was performed to test relationship of the two parameters. The latest significant differences test was used to determine statistical significance at the probability level (P) of 0.05. All data were analyzed using "R" (version 3.3.2).

3. Results

3.1. Nitrogen Mineralization under Different Organic Amendments from the Incubation Experiment

Mineralized N during the incubation was a sum of ammonium and nitrate N in each of the sampling days. NH_4^+ -N concentration increased sharply in RW treatment within the first 7 days and reached its peak, after that, it started decreasing. Although the values were much lower, CnM showed the same tendency in which much of the NH_4^+ -N was mineralized within the first week. The remained OAs did not show increases in NH_4^+ -N compared with NF treatment, while RW showed higher mineralized N followed by CnM > CwM > BTL > BC. Almost for all of the treatments, 7 days after the incubation, when NH_4^+ -N started decreasing, NO_3^- -N started increasing with the rise of pH (data not shown). The amount of mineralized NO_3^- -N was also high under RW treatment.

3.2. Plant Growth

Plant height, chlorophyll content (SPAD value), and number of leaves over the study period were presented in Figure 1. Both plant height and number of leaves on the transplanting day and 9 WAT were compared; increased values were differently affected by the various fertilizers applied. On the day of transplanting, plant heights ranged from 33.6 to 40.0 cm and the number of leaves were about 6 leaves per plant, with no statistical difference among the treatments for each of the parameters. Nine WAT, the plants reached their maximum growth and after that did not change the values; because of that, we compared the effect of the fertilizer applied on the above-mentioned parameters during those periods. Generally, throughout the experiment, high recorded values for both parameters were found when plants were treated with IF followed by RW > CnM > BTL > CwM > BC. At 9 WAT, statistical results revealed that plant height observed the following trend: IF = RW > CnM > BTL > CwM > BC and for the number of leaves, the result revealed the following trend: IF = BC > BTL = RW = CwM > CnM. As for the chlorophyll content of all treatment groups except BC, it increased from the day of transplanting to the second WAT. The values started decreasing between the second and third WAT, and after the supplementary fertilization for each time period, the chlorophyll content increased again. However, in the BC-treated plants, the chlorophyll decreased before the first supplementary fertilization started to increase after additional fertilizer application on the surface of the soil.

3.3. Maize Grain Yield and Total Plant Biomass

Maize GY, biomass, and number of grains per plant are shown in Figure 2. We observed a clear difference on the effect of the various fertilizers applied in all parameters. High GY was recorded under IF ($45.5 \text{ g plant}^{-1}$) treated plants followed by RW ($44.9 \text{ g plant}^{-1}$) and CnM (37.1) with no statistical difference, followed by BTL ($26.5 \text{ g plant}^{-1}$) and CwM ($22.5 \text{ g plant}^{-1}$). Plants treated with BC recorded the lowest yield ($5.80 \text{ g plant}^{-1}$) (Figure 2a). Total plant biomass was high when plants received IF, followed by RW and CnM (at the same level), and then BTL and CwM (at the same level), and lower values were recorded under BC treatment (Figure 2b). The total number of grains per plant in IF treatment (501 plant^{-1}) was not statistically different from that in RW treatment (382 plant^{-1}), followed by CnM (213 plant^{-1}) and BTL (153 plant^{-1}) at the same level, CwM (123 plant^{-1}), and the lowest number was observed for the BC (20.9 plant^{-1}) groups (Figure 2c).

Figure 1. Plant height (a), SPAD value (b), and number of leaves (c) of maize plants in each treatment group from transplanting until harvesting. All values are expressed as means. IF: Inorganic fertilizer, CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste, WAT: Weeks after transplanting, SF: supplementary fertilization.

Figure 2. Total weight of grain yield in each treatment (a), Biomass of plants in each treatment (b), Number of grains per plant in each treatment (c). All values were expressed as means. IF: Inorganic fertilizer, CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste. Different lowercase letters indicate statistically significant differences ($p < 0.05$). Error bars mean standard deviations.

3.4. Maize N Dynamics on ^{15}N Tracer Method Analysis

Total N uptake by maize, N uptake by maize derived from soil and fertilizer, and the distribution of N uptake to the different maize plants components are presented in Figure 3. Much N was uptaken by maize plants under IF treatments, followed by RW > CnM > BTL > CwM > BC (Figure 3a). In all treatments, maize had a preferential uptake of N from the fertilizers rather than soil (Figure 3b), but from both sources, the acquired N was distributed as follows: grains > leaves > stems > roots (Figure 3c). The IF plants took up more of the N derived from soil than the OA-treated plants. Even applying different N sources, we observed that the N taken up by maize derived from soil during the early stages of growth accumulated in the stem, and we assume that it was then translocated to the grains at the ripening stage.

3.5. Fertilizer NUE and Its Components

Agronomic NUE, ANRE, PNE, and NHI are presented in Table 2. The results demonstrated that for ANUE, plants under IF, RW, and CnM were not statistically different, followed by BTL and CwM. BC treatment recorded the lowest value. Related with PNE, except for BC treatment, all OAs recorded high values when compared with IF treatment. RW showed the highest values ($42.8 \text{ g g}^{-1} \text{ N}$), which were statistically different from the rest of the treatments. Again, for this parameter, BC recorded the lowest values ($8.59 \text{ g g}^{-1} \text{ N}$). Remaining treatments (CnM, CwM, BTL and IF) were not statistically

different. The application of different fertilizers did not significantly affect the NHI. The maximum value in the study was 0.727 g N g^{-1} in BC, while the minimum value was 0.545 g N g^{-1} in IF.

Figure 3. Total N uptake from soil and organic amendments and distribution by maize plant (a), N uptake by maize from soil and fertilizer in different treatments (b) and distribution of N uptake by maize derived from soil and fertilizer N (c). IF: inorganic fertilizer, CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste. All values are expressed as means.

Table 2. Nitrogen use efficiency (NUE) indices among different N sources in the study period.

Treatments	Agronomic [†] N Use Efficiency ($\text{g g}^{-1} \text{ N}$)	Apparent N [‡] Recovery Efficiency ($\text{g N g}^{-1} \text{ N}$)	Physiological [§] N Efficiency ($\text{g g}^{-1} \text{ N}$)	N Harvest [#] Index (g N g)
IF	$26.0 \pm 1.20 \text{ a}$	0.883	$21.5 \pm 0.996 \text{ ab}$	0.545
CnM	$21.2 \pm 2.88 \text{ ab}$	0.341	$39.1 \pm 5.30 \text{ ab}$	0.582
CwM	$12.9 \pm 4.25 \text{ bc}$	0.209	$32.4 \pm 10.7 \text{ ab}$	0.629
BTL	$15.2 \pm 4.09 \text{ abc}$	0.294	$32.0 \pm 8.63 \text{ ab}$	0.585
BC	$3.30 \pm 2.86 \text{ c}$	0.253	$8.59 \pm 7.42 \text{ b}$	0.727
RW	$25.7 \pm 0.402 \text{ ab}$	0.393	$42.8 \pm 0.669 \text{ a}$	0.561

IF: inorganic fertilizere, CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste. All values are expressed as means. Different lowercase letters within a column indicate statistically significant differences ($P < 0.05$). [†] The ratio of maize grain yield to the total N application rate. [‡] The ratio of the total N uptake from fertilizer N and total N application in each treatment. [§] The ratio of grain yield to the total N uptake by maize. [#] The ratio of N uptake in grain yield to the total N uptake by the whole plant (above and belowground N uptake).

3.6. Relationship between the Incubation Test and Pot Experiment

The concentration of mineralized N in the incubation test and N uptake by maize plants during the cultivation period were significantly and highly correlated, $R^2 = 0.674$ (Figure 4). Furthermore, RW exhibited the highest rate of N mineralized and taken up during the incubation and pot experiments, respectively, thus demonstrating the ability to promote plant growth (Figure 1) and yield (Figure 2).

3.7. Soil Properties after Harvest

The results of the present study indicated that the fertilizer treatments significantly affected the soil's general fertility (Table 3). The application of OAs, especially manure (CnM and CwM) and BTL, tended to increase soil pH when compared to the IF treatment. The application of OA, especially CnM, also appeared to increase EC and exchangeable cations (Ca, Mg, K, and Na). With no statistically significant difference, all fertilizers affected CEC, but the application of CnM showed

higher record values compared with the other treatments (Table 3) as well as the initial soil (Table 1). RW was also revealed to be a potential soil amendment for improving general chemical properties. Therefore, both CnM and RW are suitable fertilizers to use for improving the chemical properties of the soil.

Figure 4. Relationship between the mineralized N concentration obtained by an incubation test and N uptake by corn grown in soil amended with different organic amendments. CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste.

Table 3. Chemical properties of soil after harvest.

Treatment	pH	EC	NH ₄ -N	NO ₃ -N	CEC	Exchangeable Cations			
						Ca	Mg	K	Na
		(S cm ⁻¹)	(mg kg ⁻¹)			(mmol _c 100 g ⁻¹ DW)			
IF	7.04 b	177 b	24.2 ab	20.0 a	11.5 a	18.8 b	3.58 b	0.633 b	0.305 ab
CnM	7.38 a	214 a	31.2 a	13.2 ab	14.8 a	29.0 a	5.79 a	0.998 a	0.468 a
CwM	7.46 a	162 b	27.3 a	9.11 b	12.0 a	19.3 b	3.99 b	0.629 b	0.328 ab
BTL	7.32 a	175 b	18.9 b	8.10 b	11.8 a	19.6 b	4.15 b	0.664 b	0.298 ab
BC	7.04 b	168 b	30.3 a	10.3 ab	12.2 a	19.4 b	3.85 b	0.714 ab	0.253 b
RW	7.22 ab	181 ab	26.1 ab	9.34 ab	11.8 a	19.6 b	4.72 ab	0.643 b	0.401 ab

Values are expressed as means. Different lowercase letters within a column indicate statistically significant differences ($p < 0.05$). IF: inorganic fertilizer, CnM: chicken manure, CwM: cow manure, BTL: bamboo tealeaf compost, BC: bamboo compost, RW: rapeseed waste.

4. Discussion

4.1. The Effect of Organic Amendments on Plant Growth and Yield of Maize

Zhang et al. [22] reported that poultry dropping and cattle dung increased the root growth of maize and the crop extracted soil water more efficiently for increased grain yield. Among the different sources of organic manure that have been used in crop production, poultry manure was found to be the most concentrated regarding nutrient content [23]. Hameed et al. [24] and Ayoola et al. [25] observed that the application of poultry manure improved the availability of some minerals in the soil, especially the transfer of nutrients from the root zone to the crop plant. Amujoyegbe et al. [26] reported that poultry manure increased the leaf area, total chlorophyll content, and grain yield of maize and sorghum. Furthermore, [27] observed that poultry manure mineralizes faster than other animal manure such as cattle or pig dung; hence, it releases its nutrients for plant uptake and utilization rapidly. Sharply and Smith [28] reported that poultry manure contains basic nutrients required for enhancing the growth and yield of crops. It also increases the water-soluble and exchangeable potassium and magnesium, which enhance crop yield [29]. Van Delden [30] reported an increase in leaf area with the

applications of different organic amendments. Furthermore, Board [31] concluded that an increase in leaf area has implications for light interception and dry matter production to support the plant growth and development. Our study supports the findings of the previous studies which showed that RW and CnM have a high value for improving the growth and yield of the crop. Due to their composition and low C/N ratio, it is possible to assume that the higher plant growth and consequently the yield at the same level as IF was achieved by a faster mineralization process and the easy availability of nitrogen as well as other essential nutrients required for plant development.

Hokmalipour et al. [32] reported a significant increase in chlorophyll content with increase in nitrogen concentrations. Ramesh et al. [33] reported that cereal crops yield increases with the increase of chlorophyll of leaves. In our study, the chlorophyll content of the treatment groups increased from the day of transplanting to the second week, owing to the decomposition and mineralization of the N from the OAs, and it started decreasing between the second and third weeks. Then, it was increased by the application of supplementary fertilization on the surface of the pots. However, in the BC-treated plants, the chlorophyll decreased before the first supplementary fertilization (Figure 1b), owing to the immobilization of N. Since the C/N ratio of BC was so high (approximately 81.4), N starvation occurred in the soil via microbial accumulation. However, the chlorophyll content increased with the application of supplementary fertilization, which indicates that the OA-derived N was mineralized and became available to plants. The differences in the chlorophyll content of maize leaves observed under various treatments and the higher values obtained on RW and CnM leaves could be due to the differences in nitrogen content among the fertilizers (Table 1) and the absorption and easy assimilation of nitrogen from the organic sources by plants, which in accordance with Bojović and Marković [34] is a chlorophyll constituent and is directly proportional to the photosynthetic potential of any plant.

Blumenthal et al. [35] noted that N, P, and K are taken up slowly during the seedling growth, after which they are rapidly taken up during the active vegetative growth and grain-filling stages. Nitrogen and phosphorus uptake continue until near maturity, but potassium absorption is largely completed by silking time. The major portion of the nitrogen and phosphorus taken into the early stem, leaves, and tassel are translocated into the grain, much less so with potassium.

According to Amin [36], nitrogen is the nutrient that most frequently limits yield and plays an important role in quality of crops, and it is almost deficient in most soils of Africa and most of the tropics. The addition of nitrogen fertilizer increased plant height; as well as an increase in plant height, there was also an increase in leaf number per plant, as reported by Naim et al. [37]. Amin [36] indicated that the increase in plant height with nitrogen fertilizer is due to the fact that nitrogen promotes plant growth, increases the number of internodes, and also increases the length of the internodes. The optimization of maize nutrition is essential to maintain the production of high-quality yield [38]. The different OA significantly affected the maize yield ($p < 0.05$), as follows: IF = RW = CnM > BTL > CwM > BC, (Figure 2a). The nutrient composition of manures varies with the age of the animal, feed, feeding patterns, feed conversion efficiency, water intake, management system, and sex. Those are perhaps the reasons for the wide variations in N availability among different types of animal manures [39]. The variation of yield under different organic treatments was also affected by the C/N ratio (Table 1). RW and CnM had the lowest C/N ratios (6.44 and 9.44), which indicated that the OAs N could be easily decomposed and mineralized by soil microbes, whereas the BC had the highest C/N ratio (81), which indicated that the OAs N was difficult to mineralize, resulting in low nutrient uptake, low growth, and consequently low yield. The N uptake index, which was calculated as the product of height, leaf number, and chlorophyll content, was also correlated with the C/N ratios of OAs (data not shown). Therefore, we assume that the production in the plants treated with bamboo compost and cow manure was also due to the low concentration of nutrients and high C/N ratio. These results can easily be verified by the data of mineralization of OA under incubation experiments, since the same trend of mineralization of the OA was observed in N uptake in the pot experiment. Organic amendments' mineralization under the incubation test was strongly correlated with N uptake by corn

in the pot experiment. This showed that the incubation test is an efficient method to estimate the rate of mineralized N and can be used to test many other organic fertilizers.

4.2. The Effect of Various Fertilizers on NUE, NUE Components, and N Distribution on Maize Plant

The ratio between total N uptake derived from fertilizer and the total fertilizer applied is the average ANRE of the N input. Several studies reported an ANRE of 0.30–0.35 g N g⁻¹ N in the 1990s [38] and 0.26–0.28 g N g⁻¹ N in 2001–2005 for the major cereal crops [14]. Additional studies obtained an ANRE of 0.52 g N g⁻¹ N in America and 0.68 g N g⁻¹ N in Europe [40]. The ANRE was estimated to have ranged between 0.40 and 0.68 g N g⁻¹ N during 1989–2010, averaging 0.51 [41]. Our findings showed that the ANRE for IF treatment was 0.883 g N g⁻¹ N, which was higher compared with above studies. In all the mentioned studies (including ours), the long-term application of IF to soils could contribute to soil, water, and air pollution. For example, due to high inorganic fertilizer application, ammonia and nitrous oxide emissions dominated by agricultural soils in China are the major contributions of heavy wet deposition and global warming [42]. Based on the present study findings, OAs—especially RW and CnM—were found to be useful to reduce the environmental pollution and to contribute to increasing yield. This result could also be supported by the PNE represented by grain yield/total N uptake. We observed that PNE in RW (42.8 g g⁻¹ N) was two times higher than that observed in IF (21.5 g g⁻¹ N) (Table 2), despite having the same yield (not statistically different, Figure 2a), meaning that the amount of N uptake by maize under RW to produce a similar yield as that in IF was about half of that up taken by the plants in IF treatments. This suggested that RW is a suitable and potential organic amendment to be used in the place of inorganic fertilizer.

We could observe that maize preferentially uptakes N from fertilizers and a much larger amount was taken up in IF treatment possibly because the N from inorganic fertilizers is rapidly mineralized, and in agreement with [43], inorganic fertilizer is by far the largest source of N used by plants. However, under applications of different OAs, much of the N that was uptaken by plants derived from mineralization of the respective amendments. From all sources, N mainly accumulated in grains. It was also noticed that N derived from soil was accumulated in grains; we assumed that the N taken up from soil during the early stages of growth accumulated in the stems and was then translocated to the grains at the ripening stages.

4.3. The Effect of Organic Amendments on Soil Chemical Properties

There was a significant impact on soil chemical properties with different fertilizer applications (Table 3). Soil pH is an important factor influencing the growth of most crops [44]. Soil acidity is widespread in the tropics and could be partially responsible for low maize yield in several African countries [45]. The use of organic amendments as a mean of acid soil correction has been recommended [46]. Compared with IF, due to the composition of OA, the application of chicken and cow manure tends to increase more the soil pH (7.38 and 7.46) respectively, followed by a mix of bamboo compost and tea leaves (BTL) (7.32) and rapeseed waste (RW) (7.22). This study result is in accordance with [47], which reported that chicken and cow manure application to the soil tends to increase soil pH due to their microbial decomposition and mineralization as well as hydroxyl ions released during the mineralization process. Moreover, the ability of chicken manure to increase soil pH was also attributable to the presence of basic cations, which were released upon microbial decarboxylation [48]. Furthermore, it was also in agreement with the findings of [49,50], who reported that soil pH increased after the incorporation of organic amendments by the release of NH₃ from organic N mineralization. Comparing the initial CEC of the soil (12.0 mmol_c/100 gDW) and after applying some soil amendments, the application of CnM and BC tends to increase soil CEC to 14.8 and 12.2 mmol_c 100 g⁻¹ DW, respectively (Table 3), which is due to the mineralization of the materials. These results are also related to the increasing ammonium and pH of the soil. The same results were also reported by [47], where increases in the CEC of soils treated with chicken manure were observed due to the humus contained in that amendment. A variation of CEC within the treatments

was somehow consistent with the variations in exchangeable bases and the type and effect of each OA on the soil. According to [47], therefore, the exchange capacity of the soils is attributed to the Ca^{2+} from the addition of the chicken manure. This could also explain why the pH of the soils is also relatively high.

5. Conclusions

The results of the present study indicate that the application of organic amendments, especially chicken manure and rapeseed waste, helps improve the physicochemical characteristics of soil and consequently plant growth and yield. The yield of rapeseed-fertilized maize is statistically similar to that of inorganic-fertilized plants despite the difference in N uptake, which suggests that rapeseed waste is a suitable alternative for chemical fertilizers in soil and crop management. Furthermore, the present study also demonstrates that soil-derived N mainly accumulates in grains, which strongly suggests that more studies should focus on improving the N use efficiency and N uptake by plants derived from soil in order to contribute to high yield and quality and reduce environmental problems.

Author Contributions: Conceptualization, R.A.T., H.U. and Y.T.; methodology, H.U.; software, R.A.T. and H.U.; validation, R.A.T., H.U. and Y.T.; formal analysis, R.A.T. and N.M.; investigation, R.A.T. and N.M.; resources, H.U.; data curation, R.A.T. and H.U.; writing—original draft preparation, R.A.T.; writing—review and editing, H.U. and Y.T.; visualization, R.A.T. and H.U.; supervision, H.U.; project administration, H.U.; funding acquisition, H.U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Mitsui & Co. Ltd., Japan.

Acknowledgments: The authors would like to thank Takuya Araki and Hiroyuki Yoshitomi of Ehime University for their advice on maize pest management during the experimental period as well as Jaime Afonso Macome for his assistance with data sampling and analysis.

Conflicts of Interest: The authors declare that the submitted work was carried out in the absence of any personal, professional, or financial relationships that could potentially be construed as a conflict of interest.

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