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Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

Communications in Soil Science and Plant Analysis

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713597241>

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To cite this Article Shu, Yung-Yu and Chung, Ren-Shih(2006) 'Rice Growth and Nutrient Accumulation as Affected by Different Composts', Communications in Soil Science and Plant Analysis, 37: 7, 1139 — 1156

To link to this Article: DOI: 10.1080/00103620600588470

URL: <http://dx.doi.org/10.1080/00103620600588470>

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Rice Growth and Nutrient Accumulation as Affected by Different Composts

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Abstract: This study evaluated the effects of four different kinds of compost: pea–rice hull compost (PRC), cattle dung–tea compost (CTC), hog dung–rice hull compost (HDR), and hog dung–sawdust compost (HDS). These types of compost differ in nitrogen composition and in the dry matter yield and nutrient accumulation [nitrogen (N), phosphorus (P), potassium (K)], of rice plants. The rice (*Oryza sativa* L.) plants were planted in an Oxisol soil. Plants were cultivated in pots, which contained 3 kg of soil, mixed with the four different composts (PRC, 404 g; CTC, 395 g; HDR, and HDS, 450 g) and chemical fertilizer (CHEM) (N:P₂O₅:K₂O = 120:96:72). The residual effect was studied after the crop was harvested. All treatments were replicated four times, with a randomized complete block design. The nutrient concentrations in the root, leaf sheath, leaf blade, stalk, and grain were analyzed at different growth stages. After the first crop, the dry matter yield and the amount of N, P, and K absorbed from the CTC or HDS treatments were higher than those of the other treatments, at the most active tillering stage. The growth and nutrient accumulation of rice plants given the PRC treatment were higher than those given the CHEM treatment at the heading stage or the HDR treatment at the maturity stage. In the second crop, the dry matter yield from the PRC, CTC, and HDR treatments was higher than from the other treatments. The nutrient accumulation of the rice plants

Received 17 September 2004, Accepted 28 September 2005

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was positively correlated with the dry matter yield. The residual effect of the HDS compost was the least among all four composts.

Keywords: Nutrient accumulation, compost, chemical fertilizer, rice plants

INTRODUCTION

Annually, the amount of agricultural waste produced in Taiwan is enormous. The effect of using agricultural waste composts to fertilize agricultural land has been positive from the perspective of a recycling economy and because of their valuable characteristics and ingredients (Bangar et al. 1989; Chang 1995; Clark et al. 1998; Eneji, Yamamoto, and Honna 2001). Baziramakenga and Simard (2001) and Mohammad (1999) reported that organic materials contained many essential elements at low concentrations, which were slowly released upon decomposition. Manure is used mainly as a source of nitrogen (N) and phosphorus (P) (Materechera and Salagae 2002). The soil pH, organic carbon, and available P and potassium (K) concentrations of soils increased with the application of compost. Application of manure enhanced rice nutrient accumulation and dry matter yield (Eneji, Yamamoto, and Honna 2001; Marchesini et al. 1988).

Taiwan is located in a subtropical zone. The Oxisol soil, one of the main soil types on this island, is a vast area (Leung 1971). Oxisol soil has lost most of the bases such as K, calcium (Ca), and magnesium (Mg) and contains a high concentration of aluminum oxide (Chen 1979; Leung 1971; Shieh and Wang 1989). Oxisol soil is strongly acidic and sticky, contains low levels of organic matter, and has a low availability of plant nutrients; therefore, the Oxisol soil is classified as an infertile and low productivity soil, not suitable for crop growth (Chen 1979; Gregan, Hirth, and Conyers 1989; Lee 1982). Higher crop productivity could be reached through appropriate fertilization and cultivation management in Oxisol soil (Tsai, Huang, and Huang 1990). Kumar, Ghosh, and Bhat (1999) also indicated that using organic matter would be beneficial in acid laterite soils, which are generally deficient in organic matter and nutrients.

Under submerged conditions, organic fertilizer, applied to rice plants, must undergo anaerobic decomposition; little information is available on nutrient-release patterns from different organic fertilizers and the effects on rice growth and nutrient accumulation (Kumar, Ghosh, and Bhat 1999). The total input of N, P, and K should be close to optimal to ensure sufficient nutrient supply for high yields (Regmi et al. 2002). Manures vary widely in their characteristics. The types and amounts of available nutrients excreted by animals are influenced by, among other factors, the type of animal, the animals' diets, the watering regime, and the conditions under which the manure is stored and handled (Materechera and Salagae 2002). The objective of this study was to determine the effects of the application of high rates of different composts on

rice growth and the nutrient accumulation at different stages of rice growth, in order to evaluate the residual effect of compost treatment.

MATERIALS AND METHODS

Experimental Site and Soil

The experiment was conducted at the National Taiwan University, Taipei, Taiwan, during the first crop-growing season of 1997 (from March to July) and the second crop-growing season (from August to December). The soil used for the study was an Oxisol (Kaniperox) soil from the Taiwan Tea Experiment Station. The soil had a pH in water (1:1) of 4.65; electric conductivity of saturation extraction of 0.12 dS m^{-1} , cation exchange capacity of $11.0 \text{ cmol kg}^{-1}$, organic matter of 11.7 g kg^{-1} , total N of 0.7 g kg^{-1} , Bray-1 P of 6.9 mg kg^{-1} , exchangeable K of 64.6 mg kg^{-1} , exchangeable Ca of 83.5 mg kg^{-1} , exchangeable Mg of 13.4 mg kg^{-1} , available Fe of 23.9 mg kg^{-1} , available Mn of 41.1 mg kg^{-1} , available Cu of 0.9 mg kg^{-1} , and available Zn of 2.1 mg kg^{-1} . The soil had a clay texture.

Experimental Design

The soil was air dried and passed through a 1 cm sieve. Each pot contained 3 kg of soil. Four different kinds of compost were used: pea-rice hull compost (PRC, a compost made from pea seedling residue and rice hull); cattle dung-tea compost (CTC, a compost made from cattle dung and tea residue); hog dung-rice hull compost (HDR, a compost made from hog dung and rice hull); and hog dung-sawdust compost (HDS, a compost made from hog dung and sawdust). Some selected chemical properties of these composts are shown in Table 1. The dry composts were sieved to pass through a 10-mesh sieve. Six different soil treatments included the four compost-treated plots, one treated with a chemical fertilizer, and one with no fertilizer (designated control) (CT). For the first crop, the application rate of HDS was 150 g kg^{-1} soil, and the other organic fertilizers were applied based on the same amount of N. Therefore, 3 kg of soil were thoroughly mixed with 404 g PRC, 395 g CTC, 378 g HDR, and 450 g HDS. The application rate for the chemical fertilizer-treated plot was N (as urea) 0.7 g pot^{-1} (half as basal dressing, applied the day before transplanting, and half applied 50 days after transplanting), P [as $\text{Ca}(\text{H}_2\text{PO}_4)_2$] 0.25 g pot^{-1} , and K (as KCl) 0.35 g pot^{-1} (applied as basal dressing), respectively. For the second crop, no further compost was applied to the compost-treated soils; however, the same amount of N and P fertilizers used for the first crop were applied to the chemical fertilizer-treated soil. All treatments were replicated four times with a randomized complete block design. The

Table 1. Chemical properties of the four composts

Item	Compost			
	PRC ^a	CTC	HDR	HDS
Organic matter (g kg ⁻¹)	800	830	810	600
N (g kg ⁻¹)	24.5	26.0	29.0	22.1
NH ₄ -N (g kg ⁻¹)	1.65	0.11	1.80	0.24
NO ₃ -N (g kg ⁻¹)	0.20	0.70	0.82	9.05
P ₂ O ₅ (g kg ⁻¹)	6.0	26.2	34.2	22.0
K ₂ O (g kg ⁻¹)	11.1	17.2	5.1	15.2
Ca (g kg ⁻¹)	17.4	26.1	38.1	66.4
Mg (g kg ⁻¹)	1.8	5.2	4.9	5.0
Fe (mg kg ⁻¹)	1150	4100	4550	7400
Mn (mg kg ⁻¹)	132	697	307	1015
Cu (mg kg ⁻¹)	5.0	28	166	101
Zn (mg kg ⁻¹)	26	313	585	224

^aPRC: pea–rice hull compost; CTC: cattle dung–tea compost; HDR: hog dung–rice hull compost; HDS: hog dung–sawdust compost.

soil was flooded a day before transplanting. Two rice seedlings were planted in each pot and thinned to one after 2 weeks.

Plant Sampling and Analysis

Rice plants were sampled at the most active tillering stage (60 days after transplanting), the heading stage (90 days after transplanting), and the maturity stage (120 days after transplanting). The whole plant was sampled and separated into root, leaf sheath, leaf blade, stalk, and grain (if present) and oven dried to a constant weight, at 65°C, to determine the dry matter (DM) yield. The dried samples were ground through a 40-mesh screen and analyzed for total N, P, and K concentrations. Total N was digested by a Kjeldahl method (Bremner and Mulvaney 1982). Phosphorus and K were determined using an inductively coupled plasma atomic emission spectrometer (Model GBC Integra XMP, Melbourne, Australia) after digesting of samples with H₂SO₄–H₂O₂. Nutrient accumulation was calculated as the product of the concentration in the different organs of the rice plant and the amount of their DM.

Incubation Study

Each 100 mL plastic pot was filled with 50 g of air-dried soil. The soil and compost (6.7 g PRC, 6.6 g CTC, 6.3 g HDR, and 7.5 g HDS) were thoroughly mixed. The study consisted of six treatments including the four compost

treatments, a chemical fertilizer ($N-P-K = 0.23-0.08-0.12 \text{ g kg}^{-1}$) treatment, and a control. Water was added to each beaker, and flooding was maintained at 1 to 2 cm. The beakers were covered with aluminum foil and incubated at 25°C for 112 days. Water was added to ensure a constant water content during the incubation period. The soil was sampled after 0, 7, 14, 21, 28, 35, 49, 70, 91, and 112 days of incubation, and the exchangeable $\text{NH}_4\text{-N}$ and Mehlich-3 extractable P and K were measured (Mehlich 1984). All treatments were replicated three times, with a complete randomized design. Exchangeable $\text{NH}_4\text{-N}$ was extracted with 25 mL of 2 M KCl solution and determined colorimetrically (Kempers and Zweers 1986). Mehlich-3 extractable P and K were determined by ICP.

Data Analysis

The data were statistically analyzed by Statistical Analytical Systems (SAS/SAAT 1987). A probability level $P \leq 0.05$ was considered significant, and mean separation was by the Duncan's Multiple Range Test (Eneji, Yamamoto, and Honna 2001).

RESULTS

Dry Matter Yield

The effects (first crop) and residual effects (second crop) of the various treatments on the DM yield of rice plants are shown in Table 2. At the most active tillering stage of the first crop, the DM yield of the CTC or HDS treatment was significantly higher than that of the CHEM treatment, and the growth of the CT treatment was almost negligible. The DM yield of the PRC, HDR, or CT treatment was lower than that of the CHEM treatment. However, no significant difference in DM yield occurred among the PRC, HDR, and CT treatments. At the heading stage, there was a large increase in DM yield of the PRC treatment, and the DM yield of the PRC, CTC, or HDS treatment was higher than that of the CHEM treatment. The DM yield of the CT treatment was the lowest among all the treatments. At the maturity stage, the DM yield of the grain was not calculated, because the grain had been damaged by birds, making it impossible to measure the induced rice yield. The DM straw yield of the CT treatment was the lowest, but the PRC treatment was the highest among all of the treatments.

For the second crop, the DM yield of the CT treatment was the lowest among all of the treatments, at all growth stages, with its growth being small enough to be considered negligible. At the most active tillering stage, the DM yield of the PRC, CTC, or HDR treatment was higher than that of the CHEM treatment. There was no significant difference in the DM yield between the HDS and CHEM treatments.

Table 2. Effect and residual effect of various treatments on yield of rice plant dry matter

Treatment ^a	Most ats., ^b whole ^c	Stage of growth					
		Heading stage			Maturity stage		
		Grain	Straw	Whole	Grain	Straw	Whole
First crop, mg plant ⁻¹							
PRC	2 d ^d	1 c	65 ab	66 ab	ND ^e	97 a	ND
CTC	19 a	7 a	70 a	77 a	ND	70 b	ND
HDR	1 d	0 c	27 c	27 c	ND	56 b	ND
HDS	16 b	5 b	74 a	78 a	ND	66 b	ND
CHEM	8 c	3 b	47 bc	50 bc	ND	66 b	ND
CT	1 d	0 c	3 d	3 d	ND	3 c	ND
Second crop, mg plant ⁻¹							
PRC	28 a	4 a	53 a	57 a	44 a	43 a	87 a
CTC	20 b	3 b	31 b	34 b	20 c	25 c	45 c
HDR	20 b	4 a	46 a	50 a	30 b	31 b	61 b
HDS	13 c	2 c	18 c	20 c	13 d	16 d	28 e
CHEM	12 c	2 bc	23 bc	25 bc	15 d	23 c	38 d
CT	1 d	0 d	1 d	1 d	0 e	1 e	2 f

^aPRC: pea–rice hull compost; CTC: cattle dung–tea compost; HDR: hog dung–rice hull compost; HDS: hog dung–sawdust compost; CHEM: chemical fertilizer; CT: no addition.

^bThe most active tillering stage.

^cThe dry weight of the whole plant.

^dMeans in a column followed by the same letter are not significantly different at $P \leq 0.05$, based on Duncan's multiple range test.

^eND: No determination.

At the heading stage, the DM yield of the PRC, CTC, and HDR treatment was higher than that of the CHEM treatment. The DM yield of the HDS treatment was lower than that of the CHEM treatment, however. At the maturity stage, the DM yield of the PRC, CTC, or HDR treatment was significantly higher than that of the CHEM treatment. Again, the DM yield of the HDS treatment was lower than that of the CHEM treatment. About half of the total DM yield accumulated was in the grain, except for the CT treatment, where the grain made up only 23% of total DM yield.

Nitrogen Accumulation

The effects and residual effects of the various treatments on the N accumulation of rice plants are shown in Table 3. For the first crop, the amount of N accumulation of the CT treatment was the lowest among all the treatments, at all growth stages. At the most active tillering stage, the N accumulation of the CTC and HDS treatments was significantly higher than that of the CHEM treatment. However, the N accumulation of the PRC or HDR treatment was low, and significantly lower, than that of the CHEM treatment. At the heading stage, the amount of N accumulation of the PRC treatment was the highest among all the treatments. There was no significant difference in N accumulation among the CTC, HDR, HDS, and CHEM treatments. There was a large increase in N accumulation from the most active tillering stage to the heading stage in treatments of PRC and HDR. A very small amount of N was absorbed with the CT treatment. At the maturity stage, the amount of N in the straw after PRC treatment was the highest among all the treatments.

For the second crop, the amount of N accumulation of the CT treatment was the lowest among all the treatments, at all growth stages. The residual effect of the PRC compost on N accumulation was the largest, and the effect of the HDS compost was the smallest. At the most active tillering stage, the amount of N accumulation of the PRC treatment was the highest among all treatments. The amount of N accumulation of the CTC and HDS treatments was lower than that of the CHEM treatment. There was no significant difference in the amount of N accumulation between the HDR or CHEM treatment. At the heading stage, the amount of N accumulation of the PRC or HDR treatment was significantly higher than that of the CHEM treatment. However, the amount of N accumulation of the CTC or HDS treatment was significantly lower than that of the CHEM treatment. From the most active tillering stage to the heading stage, only small amounts of N accumulation were measured in rice plants after PRC, CTC, or HDS treatment. At the maturity stage, the amount of N accumulation of the various compost-treated plots was in this order: PRC > HDR > CTC > HDS. This was also the order of the residual effect of the composts on N availability. The amount of N accumulation of the CTC and HDS treatments was significantly lower than that of the CHEM treatment. About 33 to 67% of N was accumulated in

Table 3. Effect and residual effect of various treatments on the N accumulation of rice plants

Treatment ^a	Most ats., ^b whole ^c	Stage of growth					
		Heading stage			Maturity stage		
		Grain	Straw	Whole	Grain	Straw	Whole
First crop, mg plant ⁻¹							
PRC	72 c ^d	11 c	1154 a	1165 a	ND ^e	911 a	ND
CTC	396 a	72 a	592 b	664 b	ND	444 c	ND
HDR	20 c	4 c	603 b	607 b	ND	745 b	ND
HDS	353 a	50 b	635 b	685 b	ND	417 c	ND
CHEM	235 b	39 b	444 b	483 b	ND	407 c	ND
CT	19 c	2 c	22 c	24 c	ND	19 d	ND
Second crop, mg plant ⁻¹							
PRC	550 a	48 a	542 a	590 a	454 a	223 a	677 a
CTC	246 c	28 b	237 c	265 c	206 c	117 c	323 d
HDR	372 b	45 a	469 a	514 a	330 b	181 b	511 b
HDS	170 d	17 b	158 d	175 d	126 d	76 d	202 e
CHEM	338 b	23 b	382 b	406 b	225 c	223 a	448 c
CT	11 e	1 c	11 e	12 e	7 e	14 e	21 f

^aSame as in Table 2.^bThe most active tillering stage.^cThe N accumulation of the whole plant.^dMeans in a column followed by the same letter are not significantly different at $P \leq 0.05$, based on Duncan's multiple range test.^eND: No determination.

the grain at the maturity stage. The residual effects of the different composts on the amount of N translocated into the grain were significantly different.

Phosphorus Accumulation

The effects and residual effects of the various treatments on the P accumulation of rice plants are shown in Table 4. For the first crop, there were great differences in P accumulation among the various treatments. At the most active tillering stage, the amount of P accumulation by the CTC or HDS treatment was significantly higher than that of the other treatments. However, there was a significant difference in P accumulation between the CTC and HDS treatments. The amount of P accumulation of the CT treatment, the lowest among all the treatments, was negligible. There was no significant difference in P accumulation among the PRC, HDR, and CT treatments. At the heading stage, there was a large increase in P accumulation for various treatments. However, the amount of P accumulation of the CT treatment was still low, when compared to the most active tillering stage. The amount of P absorbed by the CTC, HDS, or PRC treatment was higher than that of the HDR or CHEM treatment. At the maturity stage, the amount of P in the straw of the CT treatment was the smallest, and in the PRC, CTC, or HDR treatment it was significantly higher than in the HDS or CHEM treatment.

For the second crop, the amount of P accumulation of the CT treatment was negligible, the lowest of all the treatments, at all growth stages. At the most active tillering stage, the amount of P accumulation of the PRC, CTC, and HDR treatments was significantly higher than those of the CHEM and HDS treatments. There was no significant difference in the amount of P accumulation between the HDS and CHEM treatments. At the heading stage, the amount of P accumulation of the HDR treatment was significantly higher than that of the other treatments; the amount of P accumulation from the most active tillering stage to the heading stage doubled. At the maturity stage, the amount of P accumulation of the PRC treatment was significantly higher than that of the other treatments. The P accumulation in the HDS or CHEM treatment was only one third that of the PRC treatment. Most of the P (56–87%) was accumulated in the grain. There was a considerable amount of P absorbed from the heading to maturity stages in the PRC and CTC treatments. However, almost no P was absorbed from the heading to maturity stages in the HDR treatment.

Potassium Accumulation

The effects and residual effects of the various treatments on the K accumulation of rice plants are shown in Table 5. At the most active tillering stage of the first crop, the amount of K accumulation of the CTC treatment was the highest and those of the HDR and CT treatments the lowest. However, there was no

Table 4. Effect and residual effect of various treatments on the P accumulation of rice plants

Treatment ^a	Stage of growth						
	Most ats., ^b whole ^c	Heading stage			Maturity stage		
		Grain	Straw	Whole	Grain	Straw	Whole
First crop, mg plant ⁻¹							
PRC	4 d ^d	2 d	99 ab	100 ab	ND ^e	110 a	ND
CTC	51 a	21 a	148 a	169 a	ND	113 a	ND
HDR	1 d	1 d	62 bc	63 bc	ND	107 a	ND
HDS	40 b	11 b	102 ab	113 a	ND	51 b	ND
CHEM	11 c	6 c	41 cd	48 c	ND	37 b	ND
CT	1 d	0 d	2 d	3 d	ND	2 c	ND
Second crop, mg plant ⁻¹							
PRC	39 a	7 a	71 b	78 b	112 a	17 b	129 a
CTC	40 a	4 b	56 c	60 c	63 c	17 b	80 c
HDR	45 a	7 a	89 a	96 a	83 b	22 a	105 b
HDS	25 b	3 b	34 d	36 d	36 d	12 c	48 d
CHEM	18 b	3 b	29 d	31 d	29 d	15 bc	44 d
CT	0 c	0 c	0 e	1 e	1 e	0 d	1 e

^aSame as in Table 2.^bThe most active tillering stage.^cThe P accumulation of the whole plant.^dMeans in a column followed by the same letter are not significantly different at $P \leq 0.05$, based on Duncan's multiple range test.^eND: No determination.

Table 5. Effect and residual effect of various treatments on the K accumulation of rice plants

Treatment ^a	Most ats., ^b whole ^c	Stage of growth					
		Heading stage			Maturity stage		
		Grain	Straw	Whole	Grain	Straw	Whole
First crop, mg plant ⁻¹							
PRC	71 d ^d	6 c	1467 a	1473 a	ND ^e	1695 a	ND
CTC	566 a	41 a	975 b	1016 b	ND	828 b	ND
HDR	16 d	3 c	563 c	566 c	ND	794 b	ND
HDS	474 b	33 a	1044 b	1077 ab	ND	837 b	ND
CHEM	183 c	21 b	390 cd	411 cd	ND	411 c	ND
CT	19 d	1 c	30 d	31 d	ND	31 d	ND
Second crop, mg plant ⁻¹							
PRC	715 a	32 a	1003 a	1035 a	176 a	623 a	800 a
CTC	417 b	18 b	498 c	516 c	92 c	316 c	408 c
HDR	376 b	29 a	645 b	674 b	115 b	365 b	479 b
HDS	281 c	12 b	321 d	333 d	60 d	200 d	260 d
CHEM	136 d	13 b	171 e	183 e	38 d	116 e	154 e
CT	8 e	0 c	12 f	12 f	1 e	11 f	12 f

^aSame as in Table 2.^bThe most active tillering stage.^cThe K accumulation of the whole plant.^dMeans in a column followed by the same letter are not significantly different at $P \leq 0.05$, based on Duncan's multiple range test.^eND: No determination.

significant difference in K accumulation among the PRC, HDR, and CT treatments at this stage. The amount of K accumulation of the CHEM treatment was significantly lower than those of the CTC and HDS treatments. At the heading stage, the amount of K accumulation of the four compost treatments was higher than those of the CHEM and CT treatments. The increase in K accumulation of the CT treatment from the most active tillering stage to the heading stage was small, compared to the other treatments. At the maturity stage, the amount of K accumulated in the straw of the PRC treatment was the highest among all the treatments. The amount of K accumulated in the straw of the CHEM treatment was lower than that of the compost-treated plants.

For the second crop, the K accumulation of the CT treatment was negligible and was the lowest among all the treatments at all growth stages. At the most active tillering stage, the amount of K accumulation of the compost-treated plants was significantly higher than that of the CHEM treatment. There was also a significant difference in the amount of K accumulation among compost-treated plants. The K accumulation of the PRC treatment was the highest. Most of the K was accumulated in the straw. However, the effects of the treatments on the amount of K accumulation at the heading and maturity stages were the same as at the most active tillering stage. There was a large increase in K accumulation from the most active tillering stage to the heading stage, except for the CT treatment. About 25% of K was translocated into the grain.

Concentrations of N, P, and K Released during Incubation under Flooding

The effects of different composts on the ammonium nitrogen, and the Mehlich-3 extractable P and K, during incubation, are shown in Table 6. The $\text{NH}_4\text{-N}$ concentration of the PRC, HDR, or CHEM treatment was higher than that of the other treatments for the whole incubation period. The Mehlich-3 extractable P of the HDR or HDS treatment was higher than those of the other treatments, in the whole incubation period. The Mehlich-3 extractable P of the CHEM and CT treatment was low. The Mehlich-3 extractable K of the four compost-treated treatments was higher than those of the CHEM and CT treatments. The Mehlich-3 extractable K of the HDS treatment was the highest, and that of the HDR treatment was the lowest among the four compost-treated samples.

DISCUSSION

At the most active tillering stage of the first crop, the DM yield and nutrient accumulation from the PRC and HDR treatments were low. This result may be due to the higher content of the easily mineralized N in the composts

Table 6. Changes in ammonium nitrogen, available phosphorus, and potassium concentrations of the soil during incubation

Treatment ^a	Days after incubation									
	0	7	14	21	28	35	49	70	91	112
Ammonium nitrogen (mg kg ⁻¹)										
PRC	100 a ^b	145 a	139 a	107 b	136 a	128 a	100 b	49 ab	43 b	34 b
CTC	32 c	73 c	81 d	69 d	61 c	64 c	57 d	31 b	19 cd	17 c
HDR	104 a	137 a	111 c	81 cd	79 b	87 b	78 c	42 b	45 b	36 b
HDS	19 d	39 d	59 e	84 cd	72 bc	46 c	45 d	33 b	16 d	18 c
CHEM	56 b	111 b	127 b	135 a	121 a	129 a	130 a	74 a	92 a	73 a
CT	20 d	32 d	55 e	85 c	70 bc	60 c	49 d	37 b	31 bc	35 b
Mehlich-3 extractable phosphorus (mg kg ⁻¹)										
PRC	94 b	22 c	17 c	14 c	104 c	73 b	5 b	19 b	79 c	81 c
CTC	151 a	15 d	19 bc	17 cd	61 cd	66 b	5 b	17 b	96 c	51 cd
HDR	110 b	30 b	31 b	21 b	206 b	127 b	13 b	37 b	201 b	148 b
HDS	110 b	50 a	198 a	203 a	501 a	439 a	411 a	357 a	294 a	229 a
CHEM	31 c	6 e	15 c	10 d	44 cd	43 b	11 b	25 b	37 c	24 d
CT	15 d	3 e	17 c	14 d	38 d	24 b	16 b	19 b	25 c	21 d
Mehlich-3 extractable potassium (mg kg ⁻¹)										
PRC	638 c	577 c	632 c	581 c	760 b	689 b	655 b	667 b	598 b	594 b
CTC	792 b	764 b	789 b	756 b	800 b	732 b	704 b	680 b	600 b	613 b
HDR	285 d	244 d	265 d	248 d	337 c	303 c	278 c	287 c	193 c	223 c
HDS	1000 a	959 a	1023 a	1054 a	997 a	916 a	977 a	964 a	832 a	780 a
CHEM	170 e	144 e	165 e	151 e	174 d	171 d	174 d	177 d	149 d	146 d
CT	123 f	107 e	119 f	109 e	115 d	114 d	102 e	120 d	105 e	104 d

^aSame as in Table 2.^bMeans in a column followed by the same letter are not significantly different at $P \leq 0.05$, based on Duncan's multiple range test.

and the resulting higher $\text{NH}_4\text{-N}$ concentrations in the soil after application of the compost (Table 6). Therefore, the poor early growth of these compost-treated rice plants was probably due to the higher soil $\text{NH}_4\text{-N}$ concentration, this being the toxic ingredient inhibiting the growth and nutrient accumulation (Chung et al. 2000; Eneji, Yamamoto, and Honna 2001; Hagin, Olsen, and Shaviv 1990; Tiquia, Tam, and Hodgkiss 1996). The poor growth of the CT treatment was due to low availability of N and P (Table 6). The significantly lower growth of rice plants receiving the CHEM treatment, compared to the CTC and HDS treatments, can be attributed to the low availability of P; this result is because the higher fixation capacity of Oxisol is attributed to low availability of P (Adediran et al. 1998; Chung and Liang 1993).

At the heading stage of the first crop, the DM yield and nutrient accumulation of the PRC treatment were higher than for the plants receiving the CHEM treatment. This result was not the case in the HDR treatment. The high Mehlich-3 extractable K (Table 6) of the PRC treatment probably results in alleviation of $\text{NH}_4\text{-N}$ toxicity (Guohua, Wolf, and Kafkafi 2002; Scherer, Mackown, and Leggett 1984). Potassium activates plant enzymes functioning in ammonium assimilation and thus prevents accumulation of toxic concentrations of ammonium in the plants (Hagin, Olsen, and Shaviv 1990). There was a large increase in DM yield and the amount of N accumulation of the PRC treatment, from the most active tillering stage to the heading stage (Tables 2 and 3). It has been suggested that the availability of N in PRC is greater than in other composts; that is, there are higher levels of N in PRC mineralized residue than in that of other composts (Wong 1998). At the maturity stage of the first crop, the DM yield and the amount of nutrients in the straw of the HDR treatment were higher than those of the CHEM treatment. This was probably due to the rice plant having a larger root system than that of the former stages, which allowed it to assimilate more ammonium into nontoxic amides and amino acids (Mills and Jones 1979).

There was a great residual effect in the PRC, CTC, and HDR treatments; therefore, the DM yield of the PRC, CTC, and HDR treatments was higher than that of the other treatments at all growth stages, even though all of the compost treatments applied the same amount of N. The residual effect of the HDS compost was the least among all four composts. This result suggests that most of the nutrients in the HDS were released during the first crop and that the residual nitrogen was mineralized at a relatively slow rate from material with relatively high lignin content (Becker et al. 1994).

There were great differences in the effects of growth and nutrient accumulation among the various compost-treated rice plants. These results indicate that the effect of compost on the DM yield and nutrient accumulation depend on chemical composition. The nutrients in the chemical fertilizer were readily available, but the nutrients in the various composts were released slowly (Ghoshal and Singh 1995; Kumazawa 1984). Nutrients supplied by the chemical fertilizer were sufficient to support the early growth of the rice plants; however, the incubation study showed that $\text{NH}_4\text{-N}$ concentration

was high in the soils receiving CHEM treatment (Table 6). High concentrations of $\text{NH}_4\text{-N}$, the hydrolytic product of urea, might be the toxic ingredient inhibiting growth and N accumulation (Chung et al. 2000). At the maturity stage of the first crop, the DM yields and the amount of nutrients accumulated in the straw of the plants receiving the four compost treatments were higher than those receiving the CHEM treatment. This result indicates that the nutrients added from the chemical fertilizer were depleted after applications of 100 d, whereas the compost continued to provide nutrients over a longer period (Tester 1989). For the second crop, included in this study, the application of chemical fertilizer had very little residual effect on the succeeding crop (Mohammad 1999). The DM yield and nutrient accumulation of the CT treatment were negligible, measuring lowest among all the treatments, in all growth stages of both the first and second crops. This means that Oxisol soil is almost incapable of supplying any nutrients for rice plant growth. Eneji, Yamamoto, and Honna (2001) reported that application of manure enhanced rice nutrient accumulation and DM yield.

The Mehlich-3 extractable P of the CHEM and CT treatments was low (Table 6). This was because the tested soil was an Oxisol, containing high acidity and high levels of iron and aluminum oxides with high P-fixing capacity (Adediran et al. 1998). The applied P was fixed in nonlabile forms, which could not be absorbed by the plants (Dias et al. 2000); therefore, even with a supply of superphosphate, the amount of P absorbed by rice plants receiving the CHEM treatment was low. The P accumulation of compost-treated plants was higher than for those receiving the CHEM treatment. Chung and Wu (1997) and Hue (1991) indicated that organic matter increased the availability of soil phosphate. The activity of organic matter in making soil phosphate available has been attributed to the ability of certain metabolic products, of microbiological decomposition, to form stable complex molecules with the iron and aluminum responsible for phosphate fixation in acid soils. The Mehlich-3 extractable K from the four compost treatments was higher than that from the CHEM and CT treatments (Table 6). Singh et al. (1995) suggested that the increase in the exchangeable K content of the soil was expected because of the large supply of total K from manure. An application of urea showed no appreciable effect on the available K content of the soil.

At the maturity stage of the second crop, grain composed about 23–50% of the DM (Table 2). About 33–67% of N had accumulated in the grain (Table 3), as had 56–87% of P (Table 4). This result might be due to the P remobilization from mature and senescent tissues to actively growing sinks (Smith, Jackson, and Vanden Berg 1990). Snapp and Lynch (1996) also indicated that the P was remobilized from bean leaves and stems to the grain. At the maturity stage of the second crop, 27–46% of K was accumulated in the stalk (data not shown). Yoshida (1981) indicated that the rice leaf sheath functions as a storage organ for K, where only 20% of the absorbed potassium is translocated to the panicles; the rest remains in the vegetative parts at maturity.

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