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Impact of ^{15}N-labeled rice straw and rice straw compost application on N mineralization and N uptake by rice

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Abstract

Incorporation of plant residues in soil affects N and C content and dynamics. This study determined the effects of short-term alternative rice (*Oryza sativa* L.) residue management on N mineralization and uptake by rice. Pot and laboratory incubation experiments were established by incorporating ^{15}N-labeled rice straw and rice straw compost in paddy soil. The ^{15}N recovered by rice averaged 16.6%; most of this recovered ^{15}N-fertilizer was cycled through soil pools and only small amounts originated from labeled rice residues. At harvest, denitrification rate of rice straw and rice straw compost was 27.2% and 38.5%, respectively in the pot experiment, while residual N in soil ranged from 56.2% and 55.1%, respectively. The incubation study showed that about 22-26% of N from ^{15}N-labeled rice straw was mineralized over a period of 105 days. Recovery of residual ^{15}N-fertilizer appears to contribute little to total inorganic N. The results showed that rice residues exerted a small and short-term positive effect on N mineralization and N uptake.

Keywords: Soil N pool; N uptake; ^{15}N-labeled rice residues; Nitrogen recovery

Introduction

Effective management of post harvest rice straw is perhaps the biggest challenge facing intensive rice production in Egypt. Rice residues contain large quantities of silica and burning is the most cost-effective and the predominant method of disposal in areas under combined harvesting (Samra et al., 2003). However, disposal of rice residues by burning is often criticized for accelerating losses of soil organic matter and nutrients, increasing C emissions, causing intense air pollution, and reducing soil microbial activity (Ebid et al., 2008; Kumar and Goh, 2000). Substantial quantities of greenhouse gases are generated by burning of rice straw in Egypt, contributing to the greenhouse effect, in addition to posing serious health hazards, evident from increased in respiratory and eye problems among the local population (Grace et al., 2003). It has been observed that incorporation of rice residues in soil causes lower yields in the following crop due to N immobilization, a problem that is attributable to the slow rates of residue decomposition (Ghoneim et al., 2008; Beri et al., 1995). Other potential problems associated with residue incorporation include accumulation of phenolic acids in soil and increased CH_4 emissions under flooded conditions (Grace et al., 2003). Compared with the traditional method of wet incorporation shortly before planting of the next rice crop, the potential benefits of shallow incorporation shortly after crop harvest include accelerated aerobic decomposition of crop residues (about 50% of the C within 30-40 days), leading to increased N availability (Witt et al., 2000). While burning of crop residues must be avoided at all costs for environmental reasons, farmers will probably incorporate crop residues only if legislation forces them to, or if there is a clear yield increase that cannot achieved through the application of additional fertilizer. Nitrogen from crop residues and soil N mineralization potential are usually not taken into consideration when fertilizer applications are made. Decomposing crop residues may release significant amounts of N and influence the availability of N by affecting mineralization–immobilization processes in the soil (Bijay-Singh et al., 2001; Hood et al., 2000). The quantity of N derived from crop residues by a succeeding crop is highly variable and depends largely on residue characteristics and the synchronization between N release and crop N uptake.

Few studies have investigated how time of incorporation and starter-N application influence crop residue decomposition, nutrient release, and crop yields. Since no single residue management practice is superior under all conditions, information on rice residue decomposition dynamics is essential for developing effective management strategies. The objective of this study was to investigate the shot-term effect of rice straw and rice straw compost incorporation in soil on N mineralization and N uptake using ^{15}N-labeled rice straw.

Materials and methods

Preparation of ^{15}N-labeled rice straw and compost

Rice cultivar (Sakha 104) was grown in perlite under flooded conditions and fertilized five times during cultivation season with a nutrient solution containing $^{15}NH_4Cl$ (10.5 ^{15}N atom%) as the N source. At maturity, the aboveground portions were harvested and the grains separated from the straw. It was established that ^{15}N enrichment of the straw was 8.45 ^{15}N atom%. The straw was then chopped into 5.0cm long pieces and used for the study. Rice straw compost (Table 1) was made from ^{15}N-labeled (8.50 ^{15}N atom%) straw harvested in a previous year. The straw was chopped into 5.0 cm long pieces, piled, and periodically moistened with water for a period of about 3 months.

Table 1. Some chemical properties of ^{15}N-labeled rice straw and rice straw compost.

Amendment	Total C ($g\ g^{-1}$ DW)	Total N ($g\ g^{-1}$ DW)	C/N ratio
Rice straw	0.366	0.008	45.2
Rice straw compost	0.335	0.015	22.1

DW: dry weight

Pot experiment

Soil properties and fertilizers

A pot experiment was carried out under greenhouse conditions in 2005-2006 at the Ehime University Farm, Japan, (33° 57' N, 132° 47' E) at an elevation of 20m above sea level. Topsoil (0-10) from a lowland paddy soil (Eutric Fluvisols; FAO/UNESCO classification) was collected, air-dried, and sieved to pass through a 2-mm mesh. Soil characteristics were; sand, 58.46 %; silt, 28.04 %; clay, 13.49 %; pH (H_2O), 6.8; EC, 0.37 dS m^{-1}; total C, 1.46%; total N, 0.15%; C/N ratio, 9.7; available P, 1.897 g kg^{-1}; exchangeable K, 624 mg kg^{-1}; Ca, 1.44 g kg^{-1}; Mg, 341 mg kg^{-1}; NH_4^+–N, 2.00 mg kg^{-1}; CEC, 9.50 cmol (+) kg^{-1}, dried soil basis. Pots with a surface area of 0.02 m^2 were filled with 2.75 kg of air-dried soil. Three fertility treatments with seven replications were set up in a completely randomized design as follows: (a) labeled rice straw (b) rice straw compost and (c), no amendment (without rice residue) as control. The rice residue was mixed into the soil at the rate shown in Table 2. Further, phosphorus (P_2O_5) and potassium (KCl) were applied at the rate of 0.12 and 0.07 g pot^{-1}, respectively to the soil just before transplanting. On June10, the pots were flooded with tap water before transplanting 3 seedlings per pot of 4 week-old rice (*Oryza sativa* L. cv. 'Sakha 102'). The rice plants were harvested on October, 2 by cutting above the soil surface. They were thoroughly washed, first under running tap water and finally with distilled water to remove soil particles and plant debris. The plants were then dried at 70 ± 2°C to a constant weight, weighed and then ground with an electric mill to a fine powder in preparation for chemical analysis. The soil in experimental pots was homogenized and samples oven dried at 70°C for 3 days. The dried sub-sample was finely ground and used to measure N and ^{15}N. Total N content and ^{15}N abundance in soil and plant samples was determined by automatic combustion in tin (Sn) capsules and analyzed using a stable isotope mass spectrometer (ANCA–SL; Europa Scientific Co. Ltd.,). Denitrification associated with the incorporation of rice residue was estimated by the following equation:

$$D = 100 - (P + I)$$

Where *D* denotes denitrification; *P* denotes total rice uptake and *I* is the residual N remaining in soil including immobilized and assimilated fractions. Due to the nature of the pots used, it was assumed that no N was lost through leaching.

Table 2. Application rate of rice straw and rice straw compost used in the study.

Rice residue	Applied N (g FW pot^{-1})	Applied N (g DW pot^{-1})	$N^{\#}$ (mg N pot^{-1})
Rice straw	7.50	6.40	54.2
Rice straw compost	15.0	3.05	54.2

#; corresponds to 20.2 mg N kg^{-1} dried soil, FW; fresh weight basis, DW; dry weight basis.

Calculations of N dynamics

Atom% ^{15}N excess was calculated from the difference between the ^{15}N atom percent in the plant, and natural abundance in the atmosphere (0.366 %). The atom% of ^{15}N was recalculated by subtraction from that of the labeled rice residue sample to which no amendment was added.

Ndfr = atom% excess of plant sample / atom% excess of rice residues (1)

Where Ndfr; amount of N derived from rice residues

Ndfs = total N uptake-Ndfr (2)

Where Ndfs; amount of N derived from soil

$\%^{15}Nrr$ = 100 x Ndfr / amount of ^{15}N applied (3)

Where $\%^{15}Nrr$ represents derived N (%)

Incubation experiment

Using the same soil and ^{15}N-labeled rice straw and rice straw compost, an incubation experiment was also carried out to determine changes in soil NH_4^+–N and NO_3^-–N in a controlled environment. Soil was air-dried, ground, and sieved through a 2-mm mesh. Plastic cups (350mL) were filled with 200 g soil and the ^{15}N-labeled rice straw and rice straw compost (ground to 2-3 cm size) mixed into the soil at the rate of 0.50 g DW cup^{-1} and 1.28 g DW cup^{-1}, respectively, corresponding to 20.2 mg N $kg^{-}1$ dried soil. Control soil (without rice residue added) was similarly prepared with each treatment replicated five times. Subsequently, distilled water that amounted to 60% of the water-holding capacity of the soil was added, and incubated at 25 ±1^{o}C for 105d. Soil water content in the cups was maintained by adding water when needed. Soil sub-samples from the individual cups were collected at 35, 70 and 105 days after application the organic residues. Inorganic N (NH_4^+-N and NO_3^--N) in wet soil were determined in 2.0 *M* KCl extracts by microKjeldahl steam distillation (Bremner, 1960). The N uptake derived from rice residues (Ndfr) and from soil (Ndfs) to inorganic N was calculated as follows:

Ndfr = NH_4^+–N x NH_4^+–N atom% excess + NO_3^-–N x NO_3^-–N atom% excess / atom% excess of rice residues. (5)

Statistical analysis

Data was subjected to analysis of variance (ANOVA) and treatment means separated using the Fisher protected least significant difference (LSD) method.

Results and discussion

Rice straw compost accounted for the highest dry weight in rice though there were no significant differences between treatments (Table 3). Rice N derived from residue varied between treatments with rice straw treatment accounting for the highest uptake relative to the control. The percentage of ^{15}N recovered from rice straw, and rice straw compost was 16.5 and 6.60%, respectively (Table 3). There was no significant difference in soil derived N between treatments. The results show that rice residue application resulted in low amounts of available N. The low N availability from rice residues is largely due to the rapid immobilization of N by microbial activity (Ghoneim et al., 2006; Ghoneim et al., 2008). Available N derived from rice residues has also been shown to be involved in other soil process such as nitrification and denitrification (Asagi et al., 2007; Ebid et al., 2007).

Table 3. Dry matter, N uptake and N derived from rice straw, rice straw compost and soil.

Treatment	DW (g pot^{-1})	Ndfr$^{\alpha}$ (mg pot^{-1})	Ndfs* (mg pot^{-1})	^{15}Nrr %	^{15}Ndfr %	Total N (mg pot^{-1})
Non-amendment	48.2	-	382.3	-	-	382.3
Rice straw	55.3	8.59	402.3	16.5	2.13	410.9
Rice straw compost	50.3	3.68	400.2	6.6	0.92	403.9
F value	NS	**	NS	**	**	NS

DW: dry weight; *Ndfs, N derived from soil; $^{\alpha}$Ndfr, N derived from rice residues; %Nrr, % recovery by rice and %Ndfr, % Ndfr to total N. (**Significant; at P = 0.01; NS; not significant at P = 0.05).

Table 4. Changes of soil NH_4^+–N and NO_3^-–N amended with rice residues at different time of incubation.

	Amendment	Time of incubation (days)		
		35	70	105
Non-amendment		144.1	190.2	171.8
Rice straw		135.0	124.3	112.8
Total inorganic N	Rice straw compost	138.8	162.0	162.4
(mg kg^{-1})	LSD/ *F* value	NS	21	37
Non-amendment		-	-	-
Rice straw		5.44	4.77	3.85
Ndfr	Rice straw compost	1.62	1.89	1.70
(mg kg^{-1})	LSD/ *F* value	*	*	*
Non-amendment		144.1	190.2	171.8
Rice straw		129.6	119.5	108.2
Ndfr	Rice straw compost	137.2	160.2	155.8
(mg kg^{-1})	LSD/ *F* value	NS	19	30
Non-amendment		-	-	-
Rice straw		25.6	22.3	15.6
Nrr	Rice straw compost	8.70	9.66	9.10
(%)	LSD/ *F* value	*	*	*
Non-amendment		-	-	-
Rice straw		4.03	3.84	3.41
Ndfr %	Rice straw compost	1.17	1.17	1.05
(%)	LSD/ *F* value	*	*	*

NS, not significant at P>0.05; Ndfs, inorganic N derived from soil; Ndfr, inorganic N derived from rice residue; Nrr%, percentage of Ndfr to amount of ^{15}N applied; Ndfr%, percentage of Ndfr to inorganic N (*Significant at P=0.05).

However, the effects of N immobilization were reduced when rice straw was used. Percentage of N derived from rice residues as a fraction of total N uptake ranged from 0.92 to 2.13% with N recovery (%Ndfr) being higher in rice straw than in rice straw compost (Table 3). The contribution of organic matter derived N to total N uptake varies during the growing season depending on the time at which fertilizer N is applied, and the amount of available fertilizer N (Ghoneim et al., 2008; Hood et al., 2000). Added N interaction (ANI) is used to describe any decrease or increase in mineralization of native soil N after organic matter application. Table 4 shows that there was increased ANI at 70 and 105 days after incubation following application of rice straw compost, with the opposite being observed for rice straw. Immobilization of N resulted in ANI changes via pool substitution of native soil N and ^{15}N after organic matter application (Witt et al., 2000). In addition, denitrification could contribute to an increase in ANI under the flooded conditions associated with rice cultivation. Thus, the competition between plant roots and microorganisms for inorganic N that is and soil based immobilization, and nitrification-denitrification process should be taken into consideration. The denitrification rate of rice straw and rice straw compost was 27.2% and 38.5%, respectively, while residual soil N after harvest ranged from 56.2% to 55.1%, respectively. The differences in inorganic N were not consistent with N uptake from the soil (Table 3). The results show that rice residues exerted a small and short-term, positive effect on rice N uptake and N mineralization. This may be because rice straw was added just before transplanting with no additional chemical fertilizer amendment. When pre-plant fertilizer N is applied, N uptake tends to be concentrated toward the beginning of the season with soil N being the dominant N pool after fertilizer N supply has been depleted or immobilized (Bufogle et al., 1997). The relationship between fertilizer N uptake and total N uptake over the growing season depends on timing of the fertilizer N application (Guindo et al., 1994) and the amount of fertilizer N available (Bufogle et al., 1997). Incorporation of straw with a high C/N ratio may initially immobilize inorganic N because of the nutrients required to sustain microbial growth (Ebid et al., 2007). In this case, the timing of incorporation of rice residue is more important than the amount. Based on the outcome of these experiments, further studies on gross mineralization, denitrification, and immobilization of N from rice residue should be carried out to completely explain related N dynamics in soil. In addition, the role of starter N and the combination of rice with leguminous residues, or with chemical fertilizers to enhance the decomposition of rice residue need to be investigated.

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