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Impact of Rice Residues Application on Rice Growth, Yield and Some Paddy Soil Properties

[1]Azza Ebid, [1]Hideto Ueno and [2]Adel Ghoneim
[1]University Farm, Faculty of Agriculture, Ehime University 498 Ko, Hattanji,
Ehime 799-2424, Japan
[2]Agricultural Research Center, Field Crops Research Institute,
Rice Research and Training Center, 33717 Sakha-Kafr El-Sheikh, Egypt

Abstract: To study the short term effects of rice residue management in comparison with mineral fertilizer on rice growth, yield, N uptake, changes of ammonia concentration, pH and EC of flooded water. Biomass yield was significantly higher in the mineral fertilizer and rice residue than in the control treatment. Total N uptake by rice was not significantly affected by rice residue incorporation. A lower N uptake in the rice residue plots can be attributed to relatively high C/N ratios. The result suggests that the application of rice residue at a suitable time is crucial for maximizing the beneficial effects of rice residue application. In particular, the increased immobilization process in early stages and the subsequent gradual remineralization allowed plant to utilize N more efficiently. Rice residue application noticeably reduced the pH of the flooded water as compared with mineral fertilizer alone.

Key words: Rice residue, N uptake, flooding, soil properties

INTRODUCTION

High quantities of inorganic fertilizer, particularly nitrogen (N), have been used to increase world food production. By the year 2020, it is estimated that 70% of plant nutrients will have to come from fertilizer (Ayoub, 1999). Commonly, large amounts of applied fertilizers are not taken up by crops and thus could cause negative environmental impact (Bockman *et al*., 1990). The practice of crop residue incorporation needs a judicious supplementation with nutrients especially N and P (Salvator and Sabbe, 1995). This supplemented fertilizer N is necessary because soil microorganisms consume considerable amounts of soil mineral N needed for crop residue decomposition. Sustainable agriculture became a major issue of global concern during this decade (Lewandowski *et al*., 1999). Agronomic practices aimed at reducing the dependence on inputs such as chemical fertilizers, e.g., incorporation of crop residues can contribute to sustainability mainly through improvement of soil fertility as judged by organic carbon, available P and potassium (K) content. Moreover, it was suggested that although in the sub-tropics and tropics it is difficult to increase soil Organic Matter (OM) content substantially and therefore, it is highly desirable to add crop residues and other OM to the soil, whenever possible to maintain soil fertility (Nowak *et al*., 1998). Situations exist where there is an overabundance of agricultural wastes such as rice residues that may pose serious pollution or disposal problems (Bevacqua and Mellano, 1994). Such wastes could be used to advantage as a nutrient source or even to conserve the environment, if they can be shown to have beneficial effects on soil properties (Mubarak *et al*., 2003). Information regarding the effect of rice residues on yield and nutrient uptake, soil properties is still needed. The aim of this study was to assess the effects of application of organic residues (rice residues) on rice growth and yield, N uptake and on the changes of soil pH, EC and NH_3 concentration in the flooded and soil water.

Corresponding Author: Adel Ghoneim, Faculty of Agriculture, Ehime University 498 Ko, Hattanji, Matsuyama, Ehime 799-2424, Japan

MATERIALS AND METHODS

Site and Experiment Setup

Pot experiment was carried out under greenhouse conditions in 2004-2005 at the Experimental farm, Ehime University, Matsuyama city, Japan, (33° 57' N, 132° 47' E) with the elevation of 20 m above sea level. The soil used was gray lowland paddy soil (Eutric Fluvisols in FAO/UNESCO) with characteristics are (Table 1). Air-dried soil was sieved to pass through a 2 mm mesh. The herbage residues of rice plants (root, hull and straw) were cut into 5 cm long pieces and used for experiment. The treatments were set up in a completely randomized design: (1) control pots (no organic material amendment), (2) ^{15}N-mineral fertilizer pots labeled with ^{15}N (99.7 atom %), (3) rice hull pots {10 g (9.22 g dry matter) pot^{-1}}, (4) rice root pots (5 g pot^{-1}), (5) incorporated straw pots at rate 5 Mg ha^{-1} {10 g (18.4 g dry matter) pot^{-1}} and (6) incorporated straw at rate 10 Mg ha^{-1} (20 g pot^{-1}). N fertilizer was applied at rate of 80 kg ha^{-1}. Phosphorus and K fertilizer (phosphorus oxide (P_2O_5) and potassium chloride) were applied at rate of 1.0 and 0.3813 g pot^{-1}, respectively, on 12 June. Wagner pots (0.02 m^2) were filled with 2.50 kg air-dry soil mixed with equivalent volume of amendments. The rice residues added 2 weeks before transplanting. Three 17-day-old seedlings of rice (*Oryza sativa* L. cv.) Sakha 102 was transplanted to the center of each pot with four replicate on 12 June.

Sampling and Analysis

Rice growth parameters (plant height, number of tillers and leaf chlorophyll content) were measured at 0, 9, 18, 25, 43, 57 and 113 days after transplanting (DAT). Chlorophyll content was measured with a chlorophyll meter (SPAD-502; Minolta Co. Ltd., Japan). Rice plants were harvested by cutting above the soil surface and thoroughly washed, first under running tap water and finally with distilled water to remove soil particles and plant debris. The plants were then separated into grain, straw and root and oven dried to constant weight at 70°C. The dried samples were weighed before grinding and ground into a fine powder with an electric mill in preparation for chemical analysis. Total N and ^{15}N content in grain, straw and root were determined.

Ammonia Measurement

Soil samples were collected using porous ceramic cups at 12 and 25 days after transplanting and ammonia concentrations were using indophenol method. The cups are buried in the soil at required depth and water samples are collected by pumping air out of ceramic cup. This sets up a pressure gradient between the soil and the inside of the cup. If soil water is held at matrix suctions less than the

Table 1: Chemical constituents of soil used in the study

Constituent	Mean
pH (H_2O)	6.800
EC (dS m^{-1})	0.370
Cation exchange capacity (cmol$^+$ kg^{-1})	9.230
Total carbon (g kg^{-1})	14.600
Total nitrogen (g kg^{-1})	1.500
C/N ratio	9.700
Sand (%)	58.500
Silt (%)	28.100
Clay (%)	13.400
Available phosphorus (g kg^{-1})	1.897
Exchangeable potassium (g kg^{-1})	0.624
Exchangeable magnesium (g kg^{-1})	0.341
Exchangeable calcium (g kg^{-1})	1.450
NH^+_4-N (mg kg^{-1})	2.000

negative pressure introduced to the cup, water will move from the soil into the cup until the pressure equilibrates. The ammonia in the flooded and soil water was measured by method of (Scheiner, 1976). The soil solution samples were used directly for determination of pH and electrical conductivity (EC). The pH of the standing water in the flooded water was determined at 0, 8, 14, 35 and 45 days after transplanting. The pH (H_2O) and EC of the soil were measured by using a pH and conductivity meter (D-24; Horiba Ltd., Japan), respectively, using a suspension of soil and deionized water in a ratio of 1:5 (shaken on a reciprocal shaker for 30 min).

Statistical Analysis

All data was subjected to analysis of variance (ANOVA) at first, then the significance of differences between the treatments was determined by a multiple comparison test with the Tukey-Kramer method at ($p<0.05$) using KyPlot software packages (Kyenslab Inc., Tokyo, Japan).

RESULTS AND DISCUSSION

Rice Growth

There were no significant differences between treatments in mean plant height. However, plant growth was marginally faster in the mineral fertilizer than in the rice residues treatment from 30 to 60 days after transplanting (Fig. 1a). Number of tillers showed similar trend with a significant differences in maximum and productive tiller numbers observed with mineral fertilizer treatments compared with rice residue treatments (Fig. 1b). The total number of tillers pot^{-1} was higher in mineral fertilizer treatments than in rice residues. Generally, the number of tillers is determined during the vegetative growth period and is mainly governed by tillers capacity of cultivars, planting density and the availability of mineral nutrition, particularly nitrogen (Yoshida *et al*., 1981). Changes over time in chlorophyll content are shown in Fig. 1c. The highest mean value was recorded at 25 DAT and was followed by a rapid decline in chlorophyll content in both mineral fertilizer and rice residues treatments. These results indicated that the importance of basal application of readily chemical nutrients (Ebid *et al*., 2007; Ghoneim *et al*., 2006).

Yield and Yield Component

Numbers of panicles, 1000 grain weight, ripening ratio and yield pot^{-1} were somewhat higher in mineral fertilizer than other treatments. However, the difference was not significant at $p<0.05$ between the rice residues in mean numbers of panicles, numbers of grains pot^{-1}, ripening ratio (Table 2). Rice grain yield were significantly greater in chemical fertilizer and rice residue compare with zero-N plot.

Biomass Yield and N Uptake

There was a significant increase in the biomass of rice with the application of amendments as compared to control (Table 3). Mineral fertilizer accounted for the highest dry weight flowed by rice root treatment. However, there was no significant difference in dry weight between rice hull and rice straw. Nitrogen uptake varied between the grain, straw and root in all treatment. Total N uptake were

Table 2: Yield and yield components of rice (*Oryza sativa* L.) cv. Sakha 102

Treatments	No. of panicle pot^{-1}	No. of grain pot^{-1}	Ripening ratio (%)	1000 grain wt. (g)	Yield (g pot^{-1})
Control	9.0a$^{\#}$	716.8a	68.5a	26.1a	17.3a
Mineral fertilizer	14.3b	132.0b	73.5b	27.7b	27.7b
Rice root	9.8c	724.8c	61.4c	26.8a	16.6a
Rice hull	9.3c	790.0c	60.1c	25.4c	16.3a
Rice straw 10 g	9.0c	851.5c	59.0c	27.3b	18.1c
Rice straw 20 g	10.5c	846.5c	66.6a	27.0b	19.4c

$^{\#}$ Mean within a column followed by the same letter(s) are not significantly different (Tukey-Kramer test; $p<0.05$), n = 5

Table 3: Dry weight and total N uptake by rice Sakha 102 amended with mineral fertilizer and rice residues

	Dry weight (g pot^{-1})				N uptake (mg pot^{-1})			
Treatments	Root	Straw	Grain	Total	Root	Straw	Grain	Total
Control	4.9a	17.9a	15.3a	38.1a	56.6a	145.1a	227.6a	429.3a
Mineral fertilizer	8.3b	29.5b	27.7b	65.5b	71.8b	267.4b	386.7b	725.9b
Rice root	6.4c	20.0c	12.6a	39.0a	56.4a	169.5c	171.2c	397.1c
Rice hull	5.1a	19.9c	16.6a	41.6c	45.8c	167.1c	223.2a	436.1a
Rice straw 10 g	5.7c	22.3c	18.1c	46.1c	48.9c	192.8d	229.8a	471.5d
Rice straw 20 g	5.7c	22.9c	19.3c	47.9c	45.4c	197.3d	268.1d	510.8d

Mean within a column followed by the same letter(s) are not significantly different (Tukey-Kramer test; $p<0.05$), n = 5

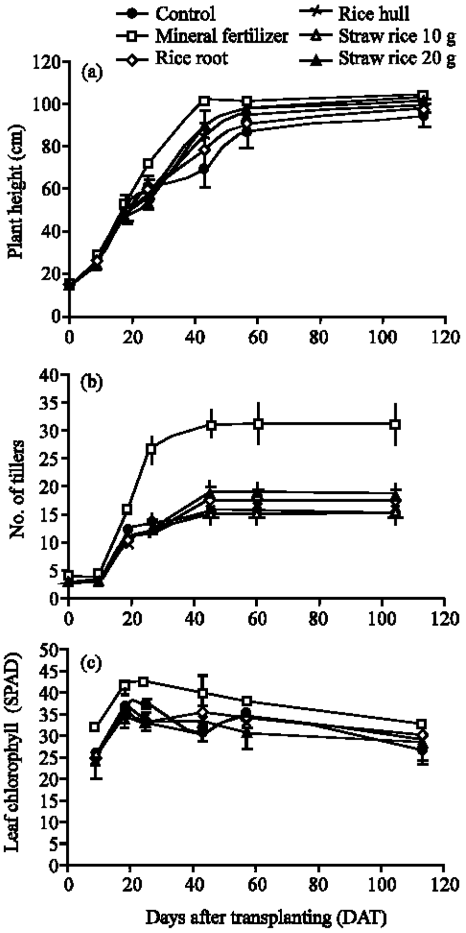

Fig. 1: Changes in plant height (a), tiller number (b) and leaf chlorophyll (c) in rice plants grown in soil amended with mineral fertilizer and rice residue. Bars referred standard deviation of the mean

significantly ($p<0.05$) higher than that control and other rice residues. The rice residues amendment also caused a significant increase in the total plant N compared to control treatments but the rate of straw application had no significant effect. The reasons why most organic amendments supply low amounts of available N is immobilization after organic matter decomposition and N mineralization. In

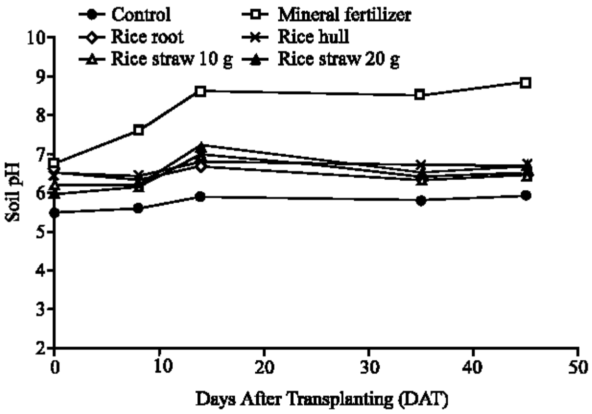

Fig. 2: Soil pH over a period of 50 days in a soil amended with mineral fertilizer and rice residues

addition, the N from organic matter is also involved in other soil processes such as nitrification and denitrification. The higher N uptake in the mineral fertilizer treatment when compared with the rice residues can be attributed to higher amounts of available N (Ghoneim *et al.*, 2006). The lower rate of rice residues decomposition might be attributed to the presence of highly decomposition resistant compounds (i.e., lignin) for bacteria and a high C/N ratio. Moreover, the addition of mineral nitrogen could not facilitate decomposition in the short time experiment due to relatively high lignin content of rice straw and especially decomposition of rice straw by microorganisms is hardly possible. Because of a high C/N ratio, the plant residues used in this experiment have a low N content and a high C/N ratio and expected to induce N immobilization during decomposition in soil (Ebid *et al.*, 2007).

The Effects on Soil pH, EC and Ammonia Content

The effects of rice residues application and mineral fertilizer on the flooded water pH of rice are shown in Fig. 2. Rice residue treatments markedly reduced the pH of the flooded water as compared to mineral fertilizer alone. The pH values of flooded water showed an appreciable increase during the first two week of the experiment, they stabilized around pH = 6.0-7.20, then slightly declined during the following days. There were no significant differences between rice residues treatments in the pH changes. Such pH variations are common in flooded soil systems and are due to the proton removal from the system when Fe^{3+}, Mn^{4+} and SO_4^{2-} are reduced during anaerobic respiration and to the consumption of the dissolved CO_2 by photoynthetising plant. Moreover, addition of organic matter to flooded soil raises the NH_4^+ concentration of floodwater and leads to a pH increase (Sommer and Hutchings, 2001). Decreasing in soil pH following organic materials can be partially attributed to the high release of organic aids causing mobilization of native calcium present as $CaCO_3$ in the soil.

During the decomposition of the rice residues, changes in the EC of the soil-organic matter mixture were observed (Fig. 3). The soil EC in rice residues displayed high values, ranged between 6.0 and 8.4 dS m^{-1} at first two weeks after transplanting. However, the EC of the mineral fertilizer and control plots had the lowest EC values during the experiment period. These results possibly reflect the concentration of the mineralized nutrients (NO_3, available P, K, Ca, Mg, etc.) and certain water-soluble compounds (organic acids or low-molecular weight organic compounds) in the soil after rice residue application. The EC values of rice straw, root and hull were significantly higher than mineral fertilizer and the peaks reach the plateau after 4 weeks after rice residues application and then, the EC decreased. Since, we applied the rice residues two week before transplanting of the rice

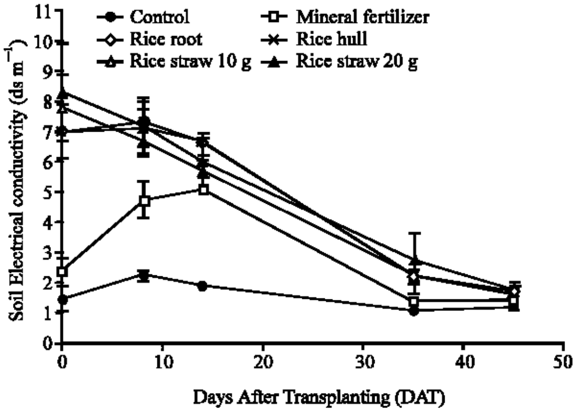

Fig. 3: Soil EC over a period of 50 days in a soil amended with mineral fertilizer and rice residues

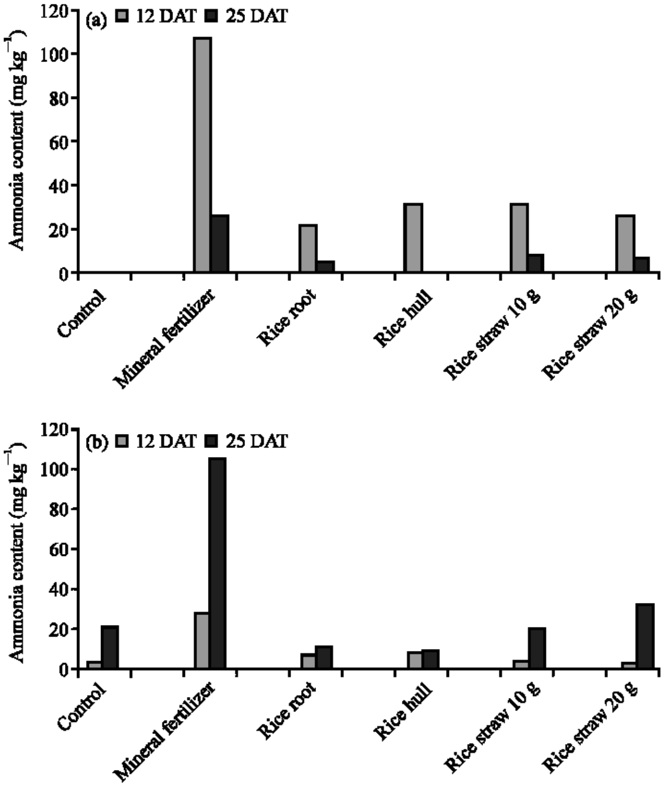

Fig. 4: Ammonia content in flooded water (A) and soil water (B) in a soil amended with mineral fertilizer and rice residues

plant. It is proposed that the soil solution EC determined at 4 weeks after submergence can be used as an index of general fertility of wetland soils. This proposition is based on the finding that the soil solution EC provides a measure of the concentration of nutrient elements mobilized in solution.

The ammonia concentration in the flooded water and soil water varied with the N sources; in particular the NH_3 content in mineral fertilizer was the highest of those in all treatment (Fig. 4). The highest ammonia content was recorded at 12 DAT and was followed by a rapid decline in both mineral fertilizer and rice residues because of rice N uptake. The large difference in the content of NH_3 between mineral fertilizer and rice residue was mostly due to the temporary immobilization of N. In addition, rice residue is characterized by their slow decomposability and may be associated with the polyphenol content or the lignin/N ratio (Kumar and Goh, 2003). However, further studies on gross N mineralization, denitrification and immobilization from rice residue should be carried out to clarify the complete details of N dynamics in the soil.

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