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Managing Rice Residues and Fertilization to Improve Nutrient Use and Productivity of Irrigated Lowland Rice

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ABSTRACT

Two field experiments were conducted in two sites with different soil properties to determine the appropriate management of rice residues coupled with cultural practices, including land preparation and fertilization to improve the nitrogen use efficiency and productivity of irrigated lowland rice. The study showed that in general, mowing of rice stubbles and either plowing or rotavating the soil did not affect the plant nutrient uptake (PNU), grain and straw yields, and yield components. In 2010 dry season, the highest PNU, yield, and return on investment (ROI) were obtained from the Minus-one Element Technique (MOET)-based fertilization compared to Nutrient Manager (NM)-based. In contrast, NM-based treatments had higher agronomic (AEN) and physiological efficiency of fertilizer nitrogen (PEN) due to higher level of N applied using the MOET compared to NM-based fertilization. In 2010 wet season, the incorporation of rice straw alone increased the uptake of P and K, similar to the crop supplied with additional inorganic fertilizer. Inorganic fertilizer treatments with or without additional chicken manure (CM) had higher grain and straw yields, yield components specifically number of tillers and panicles compared to CM and control treatments. The AEN of NSIC Rc212 was highest in plots with RIF, while CM produced the highest PEN due to higher percentage utilization or absorption of N in treatment with the least amount of N applied. Supplemental inorganic fertilizers in addition to rice residues and CM are indispensable to increase the rice yield. Incorporation of 4-5 t ha^{-1} rice straw for one cropping season of rice is not sufficient to significantly increase the N uptake and yield of the subsequent rice crop. The 2 month-fallow period after incorporation of straw and stubbles prior to transplanting did not affect rice yields suggesting that this length of time was sufficient to decompose the incorporated rice residues. The application of organic materials like rice straw and chicken manure was also instrumental in attaining adequate level of ROI. Therefore, continuous recycling and incorporation of rice straw in the soil during fallow period is not detrimental to the subsequent rice crop and contributes to the soil nutrient reserves which may lead to the improvement of yield and income in the long run.

Keywords: Fallow period, mowing, nutrient uptake, nitrogen-use efficiency, rice straw management

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INTRODUCTION

Sustaining soil productivity is an important factor to consider in ensuring adequate food supply for the unabated population growth. It also helps in the mitigation of the worsening poverty in many developing countries like the Philippines. Soil, being an important economic resource, should be managed appropriately to enhance and sustain their productivity. Effective utilization of waste biomass produced in the farm is one strategy which can easily be done by farmers without the need for a big capital. Burning has been a common farmers' practice to eliminate straws left after harvest, however this practice causes air pollution and nutrient losses. Recycling of plant biomass such as rice straw instead of burning is one strategy to effectively conserve and utilize the nutrients from crop residues. Bird *et al.* (2001) found that the recycling of biomass may also result in slow-release of available nutrients upon the decomposition of microorganisms.

About 40% of nitrogen (N), 30-35% of phosphorus (P), 80-85% of potassium (K), and 40-50% of sulfur (S) taken up by rice remains in rice residues at crop maturity. The nutrients contained in 1 t of rice straw based on percent dry matter basis are 0.5-0.8% N, 0.16-0.27% phosphate (P_2O_5), 1.4-2.0% potash (K_2O), 0.05-0.10% S and 4-7% silicon (Si). On the other hand, the removal of nutrients per ton for rice grain are 10.5 kg N, 4.6 kg P_2O_5, 3 kg K_2O, 1.5 kg manganese (Mg), and 0.5 kg calcium (Ca). For rice straw, 7 kg N, 2.3 kg P_2O_5, 17.5 kg K_2O, 2 kg Mg, and 3.5 kg Ca is absorbed from the soil (Dobermann and Fairhurst, 2002).

The carbon-nitrogen (C:N) ratio of oven-dried rice straw is about 60:1 (Yoshida, 1981). Components of rice straw are mainly cellulose and hemicellulose encrusted by lignin, in addition to a small amount of protein, which makes it high in carbon-nitrogen ratio. Therefore it is resistant to microbial decomposition compared to straw from other protein-rich grains such as wheat and barley (Abdulla, 2007). When organic materials having high C:N ratio such as rice straw and stubble are applied to the soil, only 10-20% of N is assimilated by the rice crop, 10-20% is lost through various pathways, and 60-80% is immobilized in the soil (Singh, 2001). According to Lefroy *et al*. (1997), the rate of residue decomposition can be increased or decreased through: timing, placement, preparation and incorporation of the residues; the control of soil moisture; and the concurrent application of nutrients in inorganic fertilizers to prime decomposition. It is therefore necessary that the rice residues are incorporated during the fallow period to allow for partial to complete decomposition process prior to transplanting resulting in availability of nutrients to subsequent rice crops.

Singh (2001) showed that addition of 10 tons rice straw per hectare at 4-5 weeks before transplanting rice is equivalent to the basal application of 40 kg N ha^{-1} as urea. Kessel *et al.* (2008) reported that incorporation of rice straw did not reduce grain yield after 5-6 years of alternative straw management practices when recommended rates of N fertilizers were used. They added that in the first years following the incorporation of rice straw, a small increase of fertilizer N input might be needed to offset N immobilization. However, a pronounced effect of increased N availability became apparent after 3 years following the incorporation of straw (Kessel *et al.*, 2008). Rice grain yields, nutrient uptake, and recovery efficiency of N were not influenced by straw management in a study conducted in Northwest India (Singh *et al.*, 2001).

This study will serve as a benchmark for managing field rice residues after harvest, including the importance of mowing and incorporation of rice stubbles, method of land preparation, rate of fertilization based on diagnostic tools, and kind of fertilizers on the N use and productivity of irrigated lowland rice. The objectives of the study were to determine the effect of straw management (mowed vs. unmowed and mowed vs. unmowed vs. partial removal of straw) on nutrient uptake and yield of irrigated lowland rice; and the effect of other cultural practices such as land preparation (plowing vs. rotavation) and fertilization variables (Minus-One Element Technique, Nutrient Manager, chicken manure, recommended inorganic fertilizer, recommended inorganic fertilizer plus chicken manure) in combination with different straw management on nitrogen use efficiency (NUE), nutrient uptake, and productivity of irrigated lowland rice.

MATERIALS AND METHODS

Time, Place and Description of the Study

The study consisted of two experiments. Experiment 1 was undertaken during the dry season, from December 2009 to March 2010 under irrigated condition at Masaya, Bay, Laguna, Philippines. It was laid out in a split-split plot design with four replications. The two main plots represented the management of rice straw after harvest: 1) mowed (M), and 2) unmowed (UM). The subplots consisted of two methods of land preparation:

1) plowed (P), and 2) rotavated (R). The sub-subplots compared the fertilizer recommendations given by different diagnostic tools, namely: 1) control (straw and chicken manure only) (C), 2) MOET-based fertilizer recommendation (MOET), and 3) Nutrient Manager-based recommendation (NM).

Experiment 2 was conducted from August to November 2010, wet season, at C8-Area 3 of the UPLB Experiment Station, Los Baños, Laguna. The experiment was arranged in a 2-factor complete factorial in RCBD with four replications. The first factor was based on the management of rice straw after harvest namely: 1) mowed (M), 2) unmowed (UM), and 3) straw partially-removed (SPR). The methods of fertilizer management were superimposed in each mainplots: 1) control (straw only) (C), 2) chicken manure application (CM), 3) recommended inorganic fertilizer (RIF), and 4) recommended inorganic fertilizer plus chicken manure (RIF+CM).

In both experiments, nutrient uptake, NUE, productivity (yield and yield components), and return on investment were determined.

Soil Characteristics and Rice Varieties Used in the Study

The soil type in Experiment 1 was Calumpang silty clay which had a pH of 6.6 and organic carbon (OC) content of 2.9%. The N, P and K contents were also relatively high at 0.27%, 31 ppm (Olsen) and 0.59 cmolc kg^{-1}, respectively. The average mineralizable N content of the soil was 0.021%, which was 7.8% of the total N. Mineralization of soil N generally refers to the conversion of organic N to inorganic N such as, NH_4^+ and NO_3^- (Sarkar and Haldar, 2005). The initial C:N ratio of the soil was 11, which was at the medium range. The low value of C:N was due to high level of N in the soil.

In Experiment 2, the soil type was Lipa clay which had a pH of 6.4. The OC content was 1.77%, while total N, available P and exchangeable K contents were 0.15%, 51 ppm, and 0.92 cmolc kg^{-1} soil, respectively. Average mineralizable N content of the soil was 0.043%, which was 27.7% of the total N. The C:N ratio was 12 which was at the medium level.

The test variety planted in Experiment 1 was 'Burdagol', a traditional rice variety which matures in 105-110 days, while the variety used in Experiment 2 was NSIC Rc212 (Tubigan 15) which matures in 115 days.

Field Establishment and Composition of Treatments

In Experiment 1, the plot size was 5 m x 4 m (20 m^2), with a planting distance of 20 cm x 20 cm. In the mowed plot, rice stubbles left after harvest were mowed up to ground level using a hand tractor drawn mower (Figure 1). In the unmowed plots, the rice stubbles remained standing until the field was plowed. The threshed straws were spread back to the field in both cases. It was ensured that the amount of rice straw in both main plots was at the same rate of 4 t ha^{-1} (oven dry basis). Rice straws incorporated contained 0.78% N, 0.07% P, 1.38% K and 0.38% S.

Chicken manure, with a pH of 7.5, 2.52% N, 1.86% P, 3.45% K, 4.16% Ca and 0.36% S, was applied at the rate of 1 t ha-^{1} in all plots soon after mowing of the mowed plots. After application of chicken manure, the field was flash-flooded to incorporate the rice straw and stubbles for faster decomposition.

Plowing was characterized by a complete turnover of the soil, while rotavating simply stirred the crop biomass with the soil (Figure 2). Land preparation was done 2 weeks after spreading of rice straw, while transplanting was done 2 months after mowing and spreading of rice straw.

The MOET is a biological technique which operates on the context that the plant extracts elements from the soil and the amount absorbed from the soil is reflected on its relative growth (Descalsota *et al*. 2002). Thus, the test can show farmers the limiting nutrient(s) in the soil. The basic principle of MOET is based from the Leibig's (1828) "law of the minimum" which states that the level of plant production (or yield) can be no greater than that allowed by the most limiting of the essential plant growth factors. Nutrient Manager is designed to help agricultural extension workers, crop advisors, and farmers to quickly formulate fertilizer guidelines based on specific rice field, farmer's practices (Castillo *et al*. 2010). The equivalent amount of N, P, K and S from rice straw and chicken manure, including the rates of inorganic fertilizers applied as recommended by the different diagnostic tools, are listed in Table 1.

In Experiment 2, the plot size was 5 m x 4 m (20 m^2) with a planting distance of 26 cm x 21 cm. On the mowed plot, the left over stubbles after harvest of NSIC Rc82 were cut at the ground level using a grass cutter. The rice stubbles after harvest in the unmowed and SPR plots were not cut and retained as is. Threshed rice straw was returned to each corresponding plot except for the SPR plots. The SPR plots simulated the farmer's practice, wherein threshed straws after harvest are not returned to the field.

Together with the remaining stubbles, the threshed rice straws were applied to the mowed and unmowed plots so that each treatment received 5 t ha^{-1} (oven-dried weight) straw biomass. The incorporated rice straw contained 0.45% N, 0.21% P and 0.62% K.

The amount of straw biomass received by the SPR plots was less than 5 t ha^{-1}. Based on the amount of straw stubble obtained from a 1 m^2 area, it was noted that the ratio of remaining stubble to the additional threshed straw was approximately 70:30. Land preparation was done 1 month after mowing and spreading of rice straw, while transplanting was done another month later. Therefore, the straw was allowed to decompose for a period of 2 months. Figure 3 shows the difference between mowed, unmowed, and SPR management practices.

Chicken manure having a pH of 7.4, 14.2% OC, 1.79% N, 1.27% P, 2.51% K, and C:N ratio of 8 was applied at the rate of 3 t ha^{-1}. The recommended inorganic fertilizer at the rates of 92 kg N, 0 kg P, and 30 kg K ha^{-1} was based on the result of the MOET test conducted earlier. The rates of nutrients applied for each fertilizer treatment are listed in Tables 2 and 3.

Data Gathered

Nutrient uptake. Straw and grain samples collected from each treatment were analyzed for total N, P, and K to determine the nutrient uptake expressed in kg ha^{-1}. The methods used in the chemical analyses of straw and grain after dry ashing were Kjeldahl, Vanadomolybdate, and Flame Photometer for N, P and K, respectively.

Nitrogen Use Efficiency. The efficiency of fertilizer N for grain production, expressed as agronomic efficiency of N (AEN) and physiological efficiency of N (PEN) were computed for each of the fertilizer treatments to determine the most efficient fertilizer management practice. The AEN is the increase in yield per unit of fertilizer N applied, while PEN is the increase in yield per unit total N uptake of the crop. These are computed as follows:

1) $$\text{Agronomic Efficiency of N, AEN (kg kg}^{-1}\text{)} = \frac{(Y_f - Y_c)}{(N_f - N_c)}$$

2) $$\text{Physiological Efficiency of N, PEN (kg kg}^{-1}\text{)} = \frac{(Y_f - Y_c)}{(TNU_f - TNU_c)}$$

Figure 1. Mowing of rice stubbles left after harvest

Figure 2. Plowed (left) and rotavated (right) experimental plots

Figure 3. Plots with mowed (leftmost), unmowed (center) and straw partially removed (rightmost) treatments

Table 1. Nutrient rates applied for each of the fertilizer treatments, 2010 DS

Treatment	Nutrient (N-P-K-S) Rates Applied (kg ha^{-1})			
	Rice Straw* (4 t ha^{-1})	Chicken Manure* (1 t ha^{-1})	Inorganic Fertilizer	Total
1. Control	31-3-55-15	25-19-35-4	-	56-22-90-19
2. MOET-based	31-3-55-15	25-19-35-4	90-25-0-66	146-47-90-85
3. NM-based	31-3-55-15	25-19-35-4	41-18-0-66	97-40-90-85

*Rates based on the analysis of rice straw and chicken manure incorporated
MOET: Minus-One Element Technique
NM: Nutrient Manager

Table 2. Nutrient rates applied for each of the fertilizer treatments on mowed (M) and unmowed (UM) straw management treatments, 2010 WS

Treatment	Nutrient (N-P-K) Rates Applied, (kg ha^{-1})			
	Rice Straw (5 t ha^{-1})	Chicken Manure (3 t ha^{-1})	Inorganic Fertilizer	Total
Control	23-11-31	-	-	23-11-31
CM	23-11-31	54-38-75	-	77-49-106
RIF	23-11-31	-	92-0-30	115-11-61
RIF + CM	23-11-31	54-38-75	92-0-30	169-49-136

CM: Chicken manure
RIF: Recommended inorganic fertilizer

Table 3. Nutrient rates applied for each of the fertilizer treatments on straw partially removed (SPR) management treatment, 2010 WS

Treatment	Nutrient (N-P-K) Rates Applied, (kg ha^{-1})			
	*Rice Straw (3.5 t ha^{-1})	Chicken Manure (3 t ha^{-1})	Inorganic Fertilizer	Total
Control	16-8-22	-	-	16-8-22
CM	16-8-22	54-38-75	-	70-46-97
RIF	16-8-22	-	92-0-30	108-8-52
RIF + CM	16-8-22	54-38-75	92-0-30	162-46-127

* SPR treatments received only 70% (standing straw stubbles only) of the 5 t ha^{-1} incorporated straw
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Where: Y_f = grain yield of fertilizer treatment (kg ha^{-1}); Y_c = grain yield of control treatment (kg ha^{-1}); N_f = N applied from fertilizer (straw and chicken manure plus inorganic fertilizer) in kg ha-1; N_c = N applied to control (straw plus chicken manure) in kg ha^{-1}; TNU_f = total N uptake of plants receiving fertilizer treatments (kg ha^{-1}); and TNU_c = total N uptake of plants in the control treatment (kg ha^{-1}).

Grain and straw yields. Yields were obtained from a harvest area of 3 m x 4 m (12 m^2) per plot. The crop was cut at the ground level, threshed and weighed. One hundred grams of grain sample was oven-dried at 60ºC for 72 h to determine moisture content. Likewise, 500 g straw sample per plot was weighed fresh, then oven-dried at 70ºC for at least 72 h. Grain yield was expressed in t ha^{-1} at 14% moisture content, while straw yield was reported in oven-dried weight.

Plant height and yield components. Samples consisting of 12 hills were randomly selected from the inner border rows of each plot to measure the plant height, number of tillers, and panicles. From the 12 hills selected per plot, 2 panicles per hill were randomly selected having a total of 24 panicle samples representing each plot. These samples were used to determine the number of spikelets per panicle, number of filled and unfilled grains per panicle, and weight of grains. The weight of 100 filled grains was subsampled from the 24 panicles.

Return on investment. The return on investment was calculated in order to determine the economic profitability of the fertilizer management practices/treatments. The ROI was obtained by getting the product of grain yield and price of palay divided by the production cost as shown in the formula:

$$ROI = (\text{Grain yield} \times \text{Price of palay}) / \text{Production cost}$$

The production cost included expenses incurred from land preparation, transplanting, irrigation, maintenance, weeding, harvesting, threshing, and fertilizer inputs.

Statistical Analysis

The data was analyzed using SAS 9 to determine the differences between treatment means at 5% level of significance by Least Significant Difference (LSD).

RESULTS AND DISCUSSION

Effect of Straw Management

Nutrient uptake. In general, there were no significant differences observed in the grain, straw and total nutrient uptake of N, P and K during the dry and wet cropping seasons using Burdagol and NSIC Rc212, respectively, as test varieties (Table 4). It was evident from the two experiments that nutrient uptake did not vary much with the different straw management.

Grain and straw yields. Straw management did not significantly affect the grain and straw yields of both Burdagol and NSIC Rc212. During the dry season, no significant differences were observed in the grain yield of mowed (M) (4.9 t ha^{-1}) and unmowed (UM) plots (5.1 t ha^{-1}) of Burdagol. In wet season, M treatment with 3.7 t ha^{-1} grain yield was comparable to the UM and the straw partially-removed (SPR) treatments both of which yielding 3.8 t ha^{-1} (Table 5). The same trend was observed with straw yield of Burdagol and NSIC Rc212. Mean straw yields of the M and UM plots of Burdagol were both 3.9 t ha^{-1}. Mowed and UM treatments of NSIC Rc212 both yielded 3.6 t ha^{-1} straw, which was comparable to the SPR treatment with 3.7 t ha^{-1} (Table 6).

Plant height and yield components. Generally, the results were consistent in showing no response of straw management to plant heights and yield components consisting of number of tillers, panicles, spikelets, filled and unfilled grains, and weight of 100 grains as shown in Table 7.

Effect of Land Preparation Methods

Nutrient uptake. The different methods of land preparation, whether plowed or rotavated, did not affect the NPK uptake in both straw and grains of Burdagol established during the dry season (Table 8).

Grain and straw yields. There was no marked difference in the grain yield of plowed and rotavated plots both obtaining 5 t ha^{-1}. The straw yields from plowed (3.8 t ha^{-1}) and rotavated (4.0 t ha^{-1}) straw were also comparable (Table 9).

Table 4. Nutrient uptake of the straw and grain of Burdagol and NSIC Rc212 as affected by straw management (2010 DS and WS)

Parameter	Treatment				
	Burdagol (2010 DS)		NSIC Rc212 (2010 WS)		
	M	UM	M	UM	SPR
Grain Uptake (kg ha^{-1})					
Total N	27.1 a	28.4 a	31.3 a	28.5 a	28.6 a
Total P	12.9 a	13.0 a	6.6 b	7.3 ab	8.4 a
Total K	12.4 a	12.4 a	5.1 a	5.1 a	5.6 a
Straw Uptake (kg ha^{-1})					
Total N	17.5 a	17.8 a	18.2 a	16.9 a	17.9 a
Total P	7.2 a	5.9 a	3.4 a	3.0 a	2.9 a
Total K	54.5 a	49.4 a	30.0 a	32.1 a	30.0 a
Total Crop Uptake (kg ha^{-1})					
Total N	44.6 a	46.1 a	49.5 a	45.5 a	46.5 a
Total P	20.0 a	19.0 a	10.0 a	10.4 a	11.3 a
Total K	67.0 a	61.8 a	35.2 a	37.1 a	35.6 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
M: Mowed
UM: Unmowed
SPR: Straw partially-removed

Table 5. Mean grain yields at 14% MC of Burdagol and NSIC Rc212 as affected by straw management (2010 DS and WS)

Straw Management	Grain Yield (t ha^{-1})	
	Burdagol	NSIC Rc212
	2010 DS	2010 WS
Mowed	4.9 a	3.7 a
Unmowed	5.1 a	3.8 a
SPR	-	3.8 a
cv (%)	*31*	*9*

In a column for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
SPR: Straw partially-removed

Table 6. Mean straw yields (oven-dried) of Burdagol and NSIC Rc212 as affected by different straw management (2010 DS and WS)

Straw Management	Straw Yield (t ha^{-1})	
	Burdagol	NSIC Rc212
	2010 DS	2010 WS
Mowed	3.9 a	3.6 a
Unmowed	3.9 a	3.6 a
SPR	-	3.7 a
cv (%)	*31*	*12*

In a column for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
SPR: Straw partially-removed

Table 7. Yield components of Burdagol and NSIC Rc212 as affected by different straw management (2010 DS and WS)

	Straw Management				
	Burdagol (2010 DS)		NSIC Rc212 (2010 WS)		
Parameter	M	UM	M	UM	SPR
Plant height at 46-47 DAT (cm)	72.3 a	75.2 a	73.2 a	71.1 b	72.3 ab
Plant height at harvest (cm)	92.1 a	95.1 a	113.2 a	111.9 a	112.3 a
Tiller count at 46-47 DAT (n)	13 a	13 a	15 a	15 a	15 a
Tiller count at harvest (n)	12 a	12 a	14 a	13 a	13 a
Panicle count (n)	11 a	11 a	13 a	13 a	13 a
Spikelet count (n)	96 a	97 a	98 a	92 a	94 a
Number of Filled Grains (n)	80 a	81 a	73 a	69 a	72 a
Number of Unfilled Grains (n)	16 a	16 a	25 a	23 a	27 a
Weight of 100 grains (g)	3.2 a	3.2 a	2.9 a	2.9 a	2.9 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
M: Mowed
UM: Unmowed
SPR: Straw partially-removed
DAT: Days after transplanting

Table 8. Nutrient uptake of the straw and grain of Burdagol as affected by method of land preparation (2010 DS)

Parameter	Method Of Land Preparation	
	Plowed	Rotavated
Grain Uptake (kg ha^{-1})		
Total N	29.6 a	25.8 a
Total P	12.1 a	13.8 a
Total K	11.3 a	13.5 a
Straw Uptake (kg ha^{-1})		
Total N	17.5 a	17.8 a
Total P	7.2 a	5.9 a
Total K	52.1 a	51.8 a
Total Crop Uptake (kg ha^{-1})		
Total N	47.1 a	43.6 a
Total P	19.2 a	19.8 a
Total K	63.4 a	65.3 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance

Table 9. Mean grain and straw yields, plant height and yield components of Burdagol as affected by method of land preparation (2010 DS)

Parameter	Treatment	
	Plowed	Rotavated
Grain yield (t ha^{-1})	5.0 a	5.0 a
Straw yield (t ha^{-1})	3.8 a	4.0 a
Plant height at 47 DAT (cm)	73.1 a	74.5 a
Plant height at harvest (cm)	93.3 a	93.9 a
Tiller count at 47 DAT (n)	12 b	13 a
Tiller count at harvest (n)	12 a	13 a
Panicle count (n)	11 a	11 a
Spikelet count (n)	98 a	96 a
Number of Filled Grains (n)	81 a	80 a
Number of Unfilled Grains (n)	16 a	16 a
Weight of 100 grains (g)	3.2 a	3.2 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
DAT: Days after transplanting

Plant height and yield components. It appears from the measured data of plant heights and yield components of Burdagol that land preparation methods have no consistent effect on these parameters (Table 9). The plant height at harvest ranged 93.9-93.9 cm. Tiller count and panicle counts at harvest ranged 12-13 and 11, respectively. On the other hand, count of spikelets, filled, and unfilled grains were 96-98, 80-81 and 16, respectively. The weight of 100 grains in both plowed and rotavated was 3.2 g.

Effect of Fertilization using Different Diagnostic Tools

Nutrient uptake. Table 10 shows that the different fertilization rates whether based on MOET or NM significantly increased the nutrient uptake of straw and grains over the control of Burdagol. In most cases though, MOET-based treated plants had the highest nutrient uptake followed by NM-based, while the control had the lowest. Apparently, higher amount of nutrients, specifically N and P, was applied in the MOET-based plots compared to the NM-based plots, hence the higher nutrient uptake. In addition, straw N and P uptakes were lower while relatively higher K uptake compared with the grain. Most of the N and P are allocated to the grains, whereas most of the K is retained in the straw.

The rice crop was able to take up significant amount of K even if it was not supplied with K coming from inorganic fertilizers. The only source of K was the applied rice residues and chicken manure, suggesting that these organic materials contributed to the K level in the soil. The 3-year study of Javier *et al.* (2002) revealed that although rice yield of straw-treated plots were lower than inorganic fertilizer-treated plots, that is, -rice straw had higher supply of K than the other sources of OM (indigo, wild sunflower, chicken manure) for 6 consecutive cropping seasons. Further, the highest soil K level was apparent throughout the growth stages of the rice plant.

Nitrogen use efficiency. Based on the results, the nutrient manager based (NM-based) treatment had higher agronomic efficiency of N (AEN) having 29.3 kg grain produced for every 1 kg N applied compared to MOET-based treatment with 23.3 kg grain per kg N (Table 11). The higher AEN in NM-based plots can be attributed to the lower fertilizer N applied compared to the MOET-based plots.

Table 10. Nutrient uptake of the straw and grain of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management						
	Burdagol (2010 DS)			NSIC Rc212 (2010 WS)			
	C	MOET	NM	C	CM	RIF	RIF + CM
Grain Uptake (kg ha^{-1})							
Total N	20.5 c	34.7 a	27.9 b	25.0 b	27.0 b	32.7 a	33.3 a
Total P	9.4 c	16.4 a	13.0 b	7.0 a	6.7 a	8.4 a	7.7 a
Total K	8.2 c	16.3 a	12.7 b	5.2 ab	4.6 b	5.7 a	5.5 ab
Straw Uptake (kg ha^{-1})							
Total N	11.6 c	22.7 a	18.7 b	15.2 b	14.8 b	19.6 a	21.2 a
Total P	4.2 b	8.1 a	7.3 a	3.4 ab	2.1 b	4.0 a	3.0 ab
Total K	33.2 c	69.1 a	53.7 b	28.1 a	26.4 a	35.1 a	33.2 a
Total Crop Uptake (kg ha^{-1})							
Total N	32.0 c	57.5 a	46.6 b	40.2 b	41.7 b	52.3 a	54.5 a
Total P	13.7 c	24.5 a	20.3 b	10.4 ab	8.8 b	12.3 a	10.7 ab
Total K	41.4 c	85.4 a	66.3 b	33.3 a	31.1 a	40.8 a	38.7 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
C: Control
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Table 11. Agronomic Efficiency of N (AEN) of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management				
	Burdagol (2010 DS)		NSIC Rc212 (2010 WS)		
	MOET	NM	CM	RIF	RIF + CM
Grain yield of Fertilizer treatment, Y_f (kg ha^{-1})	6,000	5,100	3,500	4,000	4,000
Grain yield of Control, Y_c (kg ha^{-1})	3,900	3,900	3,400	3,400	3,400
N applied to Fertilizer treatment, N_f (kg ha^{-1})	146	97	75	113	167
N applied to Control, N_c (kg ha^{-1})	56	56	21	21	21
AEN (kg grain yield kg^{-1} N applied)	23.3 a	29.3 a	1.9 a	6.5 a	4.1 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Similarly, NM-based plots echibited higher physiological efficiency of N (PEN), with 85.7 kg grain produced per total N uptake compared to MOET-based with only 82.4 grain per kg total N uptake (Table 12).

Grain and straw yields. Significant differences in grain and straw yields were observed under varying fertilizer recommendations as shown in Table 13. The MOET-based treatment produced significantly higher grain yield (6 t ha^{-1}) than the NM-based (5.1 t ha^{-1}), while the control had the lowest yield at 3.9 t ha^{-1}.

Likewise, highest straw yield was observed in the MOET-based plots with 4.8 t ha^{-1} followed by the NM-based with 4.0 t ha^{-1} and lowest was observed in the control plots with 2.8 t ha^{-1}. The significantly higher straw yield from the MOET-based compared to NM-based fertilizer treatment could be due to the higher amount of N (146 kg ha^{-1}) applied to the MOET plots than to the NM plots (97 kg ha^{-1}).

Plant height and yield components. Table 14 shows that at harvest control plots produced significantly shorter plants compared to those in the NM-treated plots, while the MOET-treated plots produced the tallest plants. The number of tillers and panicles per hill, spikelets, filled and unfilled grains of MOET- and NM-based fertilizer treatments were comparable and significantly higher over the control. On the other hand, the weight of 100 grains was not affected by fertilizer management.

Effect of Fertilization using Organic and Inorganic Fertilizer Combinations

Nutrient uptake. The N uptake in grains and straw of NSIC Rc212 fertilized with recommended rate of inorganic fertilizer (RIF) with or without chicken manure (RIF+CM) was comparable and significantly higher than the CM and control plots. However, the treatments did not significantly influence the uptake of P and K even in the control plots applied with rice straw only (Table 10). This is an indication that the incorporation of rice straw alone during the fallow period increased the uptake of P and K of the subsequent crop, similar to the crop supplied with additional inorganic fertilizer.

Table 12. Physiological Efficiency of N (PEN) of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management				
	Burdagol (2010 DS)		NSIC Rc212 (2010 WS)		
	MOET	NM	CM	RIF	RIF + CM
Grain yield of fertilizer treatment, Y_f (kg ha^{-1})	6,000	5,100	3,500	4,000	4,000
Grain yield of control, Y_c (kg ha^{-1})	3,900	3,900	3,400	3,400	3,400
Total N uptake of fertilizer treatment, TNU_f (kg ha^{-1})	57.5	46	41.7	52.3	54.5
Total N uptake of control, TNU_c (kg ha^{-1})	32	32	40.2	40.2	40.2
PEN (kg grain yield kg^{-1} total nitrogen uptake)	82.4	85.7	66.7	49.6	42

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Table 13. Mean grain and straw yields of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management								
	Burdagol (DS 2010)				NSIC Rc212 (WS 2010)				
	C	MOET	NM	*cv (%)*	C	CM	RIF	RIF + CM	*cv (%)*
Grain yield at 14% MC (t ha^{-1})	3.9 c	6.0 a	5.1 b	*10*	3.4 b	3.5 b	4.0 a	4.0 a	*6*
Straw yield, oven-dried (t ha^{-1})	2.8 c	4.8 a	4.0 b	*20*	3.1 b	3.2 b	4.1 a	4.1 a	*10*

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
C: Control
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Nutrient use efficiency. Highest agronomic efficiency of N (AEN) of NSIC Rc212 was obtained from the RIF with 6.5 kg of grain produced for every kg of N applied (Table 11). It was followed by RIF+CM and CM treatments with 4.1 and 1.9 kg grain per kg N applied, respectively. In terms of physiological efficiency of N (PEN), CM-treated plots had the highest PEN with 66.7 kg of grain produced for every kg of total N uptake. It was followed by RIF at 49.6 kg grain per kg total N uptake and lastly, RIF+CM at 42.0 kg grain per kg total N uptake (Table 12). Higher PEN was obtained in plots with lower rates of nitrogen applied.

The reported PEN and AEN for rice during the dry season is 50-70 kg kg^{-1} and 15-20 kg kg^{-1}, respectively (Wang *et al.* 2007). The generally low AEN is attributed to low yields obtained during wet season. Other factors which contributed to the low AEN were the high amount of rainfall received during the flowering stage of rice and the slightly lower solar radiation during the grain filling stage in November. These might have resulted to impaired grain filling, which lead to high percentage of unfilled grains. Percent filled grains of CM were 73%, while RIF and RIF+CM treatments had 76% and 71%, respectively.

Grain and straw yields. Fertilizer management significantly influenced grain and straw yields (Table 13). Plots with chicken manure (CM) and no fertilizer applied (control) gave comparable grain yields of 3.4 and 3.5 t ha^{-1}, respectively. Inorganic fertilizer (IF) with or without CM yielded 4.0 t ha^{-1} which was significantly higher than the former treatments evidently showing that a one season application of CM does not contribute to increase in yield.

Straw yields from the control and CM treatments were the same at 3.1 and 3.2 t ha^{-1}, respectively. These yields however, were significantly lower than the 4.1 t ha^{-1} obtained from the treatments which received inorganic fertilizers with or without chicken manure.

Plant height and yield components. Plant height was significantly increased with recommended inorganic fertilizer application with or without additional chicken manure compared to control and CM. Similarly, the yield components such as tiller and panicle counts per hill showed a positive response compared to control and CM application. However, the other yield components including number of spikelet, filled and unfilled grains and weight of 100 grains were not affected by the fertilizer treatments (Table 14).

Return on Investment of the Different Fertilizer Management

Table 15 shows the computation of ROI for each of the fertilizer treatments of Burdagol and NSIC Rc212. During the dry season, the MOET-based treatment gave the highest ROI of Php 1.80 for every peso invested followed by NM-based with an ROI of Php 1.60. The control had the lowest ROI with Php 1.30. This was due to the significantly higher yield of MOET-based treatment compared to NM-based and the control. It is interesting to note that the control gave a profitable ROI despite the fact that it was only applied with straw and chicken manure.

In wet season, the results showed that despite the lowest yield obtained by the control, it had the highest ROI of Php 1.8 for every peso spent, compared to the other fertilizer treatments. The control plot was applied with rice straw only at the rate of 5 t ha^{-1}. On the other hand, the ROI obtained from CM and RIF treatments did not differ both having ROI Php 1.7. The treatment RIF+CM had the lowest ROI of 1.6 owing to the high cost for fertilizer and labor.

Implication of Results

Effect of straw management and method of land preparation. In general, the present study showed that mowing of rice stubbles and methods of land preparation had no effect on plant nutrient uptake, grain and straw yields, and yield components. These observations were similarly evident in both field experiments conducted. Singh (2009) claimed that incorporation of rice residues before sowing or transplanting of rice significantly lowers crop yields. The results showed that the incorporation of rice stubbles in the unmowed plots, and even with additional threshed rice straw as in the mowed plots, did not adversely affect the rice yields. The 2 month-fallow period following incorporation of straw and prior to transplanting allowed the decomposition of rice straw and reduction of C:N ratio to an acceptable level preventing detrimental effect on plant growth (Castillo *et al.*, 2012).

Effect of fertilization using different diagnostic tools. In the first experiment conducted during the 2010 dry season, the highest PNU, grain and straw yields, plant height, yield components, and ROI of Burdagol were obtained from MOET-based fertilization compared to NM-based. The

Table 14. Plant height and yield components of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management						
	Burdagol (2010 DS)			NSIC Rc212 (2010 WS)			
	C	MOET	NM	C	CM	RIF	RIF + CM
Plant height at 46-47 DAT (cm)	68.0 b	80.6 a	72.8 b	67.9 b	68.4 b	75.9 a	76.6 a
Plant height at harvest (cm)	84.2 c	102.1 a	94.5 b	107.5 b	109.4 b	115.9 a	117.1 a
Tiller count at 46-47 DAT (n)	12 c	14 a	13 b	14 b	14 b	17 a	16 a
Tiller count at harvest (n)	11 b	14 a	13 a	12 b	13 b	15 a	14 a
Panicle count (n)	10 b	12 a	11 a	12 c	12 bc	14 a	14 ab
Spikelet count (n)	86 b	105 a	99 a	95 a	94 a	91 a	98 a
Number of Filled Grains (n)	73 b	86 a	82 a	72 a	68 a	70 a	74 a
Number of Unfilled Grains (n)	13 b	19 a	17 a	23 a	25 a	28 a	24 a
Weight of 100 grains (g)	3.2 b	3.2 ab	3.3 a	2.9 a	2.9 a	3.0 a	2.9 a

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
C: Control
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

Table 15. Return on investment of Burdagol and NSIC Rc212 as affected by fertilizer management (2010 DS and WS)

Parameter	Fertilizer Management						
	Burdagol (2010 DS)			NSIC Rc212 (2010 WS)			
	C	MOET	NM	C	CM	RIF	RIF + CM
Grain yield (kg ha^{-1})	3,900	6,000	5,100	3,400	3,500	4,000	4,000
Price of rice grain per kg (₱)	14	14	14	18	18	18	18
Production cost (P)	41,600	47,272	44,784	33,128	36,870	42,105	45,505
ROI	1.3 c	1.8 a	1.6 b	1.8 a	1.7 b	1.7 b	1.6 c
cv (%)		*10*			*7*		

In a row for each parameter measured, means followed by the same letter are not significantly different at 5% level of significance
C: Control
MOET: Minus-One Element Technique
NM: Nutrient Manager
CM: Chicken manure
RIF: Recommended inorganic fertilizer

higher yield of MOET-based plots was attributed to the higher amount of N and P applied compared to NM-based resulting to higher ROI of the former. With the application of only rice straw and chicken manure, the rice crop was able to take up significant amount of K suggesting that these organic materials contributed to the K level in the soil.

In contrast, NM-based treatments had higher agronomic and physiological efficiency of fertilizer N due to higher level of N applied using the MOET-based compared to NM-based fertilization. Wang *et al*. (2007) pointed out that high input rate of fertilizer N tend to decrease the agronomic and physiological use efficiency of irrigated rice. According to them, the negative effect caused by volatilization of large N concentration and accumulation at flowering stage was larger than the positive effect of post-flowering dry matter production and N redistribution at high N rate, so thus NUE decreased with increasing rates. Moreover, a high indigenous N supply of soil (INS) will result in higher N concentration in rice straw and produce the phenomenon of luxury consumption of N. Apparently, the soil used in this experiment, classified as Calumpang silty clay had a relatively high N content of 0.27%.

Effect of fertilization using organic and inorganic fertilizer combinations. In the second experiment conducted during the 2010 wet season, the N uptake, grain and straw yields, plant height, and yield components, specifically tiller and panicle counts, of NSIC Rc212 treated with RIF and RIF+CM were significantly higher compared to CM and control treatments. The incorporation of rice straw alone during the fallow period increased the uptake of P and K of the subsequent crop similar to the crop supplied with additional inorganic fertilizer.

The AEN of NSIC Rc212 was highest in plots with RIF followed by RIF+CM and lastly, CM. On the other hand, the PEN of CM-treated plots were highest, followed by RIF, and lastly RIF+CM. It seems that the equivalent amount of N applied in the RIF+CM plot was not taken up by the plants fully. Applied N from RIF plus CM may have been temporary immobilized or underutilized due to luxury consumption resulting in lower agronomic and physiological efficiency of N. Higher physiological efficiency of N was obtained from plots with lower rates of N applied. Further, this indicates that higher percentage utilization or absorption of N will occur in the treatment with the least amount of N applied. Thus, the rate and timing of N application must be carefully considered when making fertilizer recommendations to ensure that appropriate amount is supplied based on the demand of the crop. Too much application of N may lead to greater losses due to various processes and lower N use efficiency.

Mamaril *et al*. (1988) noted that the combination of inorganic and organic fertilizers could be one of the measures in minimizing yield decline over time. Organic materials contain not only N, P, and K but also the other essential nutrients which are not usually present in chemical fertilizers among the prevailing high analysis fertilizers in the market. The combined application of organic and chemical fertilizers may improve the fertilizer use efficiency of the latter materials.

Fertilizer management significantly influenced grain and straw yields. Plots with CM and no fertilizer applied (control) gave comparable grain yields. Inorganic fertilizer with or without CM was significantly higher than the CM and control treatments showing that a one season application of CM does not contribute to increase in yield. Javier *et al*. (2002) revealed that after 6 continuous rice cropping seasons (3 wet and 3 dry), chicken manure or rice straw had higher average yield than the unfertilized plants. Chicken manure was as good as the inorganic fertilizer in terms of nutrient supplement and grain yield. On the other hand, Kessel *et al*. (2008) noted that in the first years following the incorporation of rice straw, a small increase of fertilizer N input might be needed to offset N immobilization. However, a pronounced effect of increased N availability became apparent after 3 yr following the incorporation of straw.

The control treatment gave the highest ROI owing to its least cost of production. It is followed by CM and RIF treatments with comparable ROIs. The treatment RIF+CM gave the lowest ROI due to its high production cost because of high fertilizer use. It appears that the application of organic materials like rice straw and chicken manure helped attain adequate level of ROI.

CONCLUSION

Incorporation of 4-5 t rice straw for one cropping season of rice is not sufficient to significantly increase the N uptake and yield of the subsequent rice crop. The 2 months fallow period after incorporation of straw and stubbles prior to transplanting did not affect rice yields, suggesting that this length of time was sufficient to decompose the incorporated rice residues.

The incorporation of rice straw alone increased the P and K uptake similar to the crop supplied with additional inorganic fertilizer. The application of organic materials like rice straw and chicken manure were also instrumental in attaining adequate level of ROI. Therefore, continuous recycling and incorporation of rice straw in the soil during fallow period is not detrimental to the subsequent rice crop, but instead contributes to the soil nutrient reserves which may lead to the improvement of yield, income, and soil health in the long run.

In order to sustain or improve yield when organic materials are used in rice production, additional inorganic N fertilizer is recommended to offset the immobilized N in the soil while the organic matter is undergoing mineralization. However, the rate and timing of N application must be carefully considered when making fertilizer recommendations to ensure that appropriate amount is supplied based on the demand of the crop. Too much application of N may lead to lower agronomic and physiological efficiency as well as greater losses due to various processes.

Long-term field experiment on the effect of mowing of rice stubbles and incorporation into the soil of different levels of soil organic matter (SOM) is imperative to observe significant build-up of SOM and enhanced productivity of the soil.

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