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Response of Black, Red, and White Rice (*Oryza sativa* L.) Cultivars to Nutrient Management Under Highly Alkaline Soil

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ABSTRACT

Increasing rice productivity under highly alkaline soil is possible by using appropriate cultivars and efficient nutrient management. This study determined the agronomic and yield response of three rice cultivars to nutrient management under highly alkaline soil. It evaluated rice production's profitability using three rice cultivars influenced by nutrient management under highly alkaline soil. The experiment was laid out in a split-plot arranged in an RCBD with rice cultivars as the main plot and nutrient management as the subplot. Statistical analysis revealed that fertilized plants headed and matured earlier than unfertilized plants. A significant interaction effect was noted among rice cultivars under different nutrient management. The combination of organic and inorganic fertilizers increased the percentage of filled spikelets while reducing unfilled spikelets. Application of 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, and K_2O (T_4), significantly increased the number of productive tillers, the weight of grains hill-1, and grain yield (t/ha^{-1}) compared to plants applied with pure inorganic fertilizer. For cost and return analysis, black rice and T_4 achieved the highest gross margins of PHP 297,708.28 and PHP 269,845.68 respectively. The results indicated that using black rice applied with 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, and K_2O (T_4) is a highly effective and profitable option for lowland rice production under highly alkaline soil.

Keywords: alkaline soil, inorganic, nutrient management, organic, rice cultivar

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple crop of the majority of the human populace worldwide. This crop is mainly grown in the lowlands, especially under irrigated lowland ecosystems. It grows well in soil pH ranging from 5.5 to 6.5, which helps control sheath blight (Gnanamanickam et al 1992). However, Yu (1991) also stressed that many rice plants could grow best under a soil pH of 5.5 since soil pH affects many physical, chemical, and biological properties of the soil, which also affects the growth of lowland rice. However, rice production nowadays is greatly reduced by the conversion of rice fields into commercial areas, roads, residential,

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areas and parks, among others. Moreover, pest damage, improper nutrient management, physical (soil acidity, alkalinity, etc.), and environmental factors (typhoon, flooding, drought, etc.) contribute to its low productivity.

In this light, there is now an urgent need to tap unproductive lands, particularly acidic and alkaline soils, for rice cultivation to meet the high demand for food. Alkaline soils are so much of a problem for rice production since most applied or inherent nutrients are not soluble, thus less available in acidic soils (Watkins 2021). One of the most noticeable constraints in alkaline soils is generally the non-availability of iron. There are instances when non-soluble iron is present in abundant quantities and is therefore unavailable for plant use. Furthermore, the availability of phosphorus, including micronutrients zinc, copper, and manganese, is reduced in high pH values. Therefore, alkaline soils require further research, especially for rice cultivation. There is a great challenge nowadays since soil alkalinity limits lowland rice production and in effect, affects several countries including the Philippines.

Thus, alkaline-tolerant rice varieties and proper nutrient management must be used and managed more efficiently. There are potential rice varieties such as, red, black, and white rice, that might tolerate soil alkalinity. Aside from that, appropriate nutrient management strategies through an integrated approach might also be a useful technique for enhancing rice growth and development under such conditions. One method is the application of a combination of organic and inorganic fertilizers.

Hence, this study aimed to determine the agronomic and yield response of three rice cultivars to nutrient management under highly alkaline soil.

MATERIALS AND METHODS

The study was conducted in a lowland rice field at Brgy. Pomponan, which is situated approximately nine (9) kilometers away from the city proper of Baybay, Leyte. The soil is inherently alkaline (soil pH of 7.89) with the Himayangan clay loam soil series (Armecin et al 2011). An experimental area of 699.2 m^2 with calcium carbonate parent material due to continued weathering was used in this study. It was observed to have undergone limestone formation, resulting in high alkalinity due to the underlying limestone rock. The experimental site was prepared through proper tillage operations using a two-wheeled hand tractor. After land preparation, no lime material was applied in the area.

Before transplanting, soil samples were collected from the experimental site. The samples were submitted for soil pH analysis using the Potentiometric Method at a 1:1 soil-water ratio (PCARR 1980). The following parameters were measured: total N through Kjeldahl Method (Nelson & Sommers 1982), available P through Olsen Method (Olsen et al 1954), and exchangeable K through extraction method using atomic absorption spectrophotometry (ISRIC 1995). The available Na, Mg, Mn Ca, Fe, and Zn were analyzed at the Central Analytical Service Laboratory (CASL), PhilRootCrops, Visayas State University, Visca, Baybay City, Leyte. Another set of soil sample were collected separately from each treatment plot right after harvesting. The samples collected per plot were composited and analyzed for the same soil parameters mentioned above.

The area was laid out in a split-plot arranged in a Randomized Complete Block Design (RCBD) with three replications. The rice cultivar was designated as the main plot and the different nutrient management as the subplot. Each subplot measured 4 m x 3 m with 15 rows per plot. The replication and treatment plots were separated by 2 m and 0.70 m alleyways, respectively, to prevent contamination of treatments, facilitate farm operations, and data gathering. The different main plot treatments (Rice Cultivars) were M_1 - Black rice (Ballatinao cultivar), M_2 - Red rice (Red 64 cultivar), and M_3 - White rice (NSIC Rc216). The subplot treatments relative to nutrient management were: no fertilizer application - control (T_1), 120-60-60 kg ha^{-1} N, P_2O_5, K2 O (T_2), 5 t/ha^{-1} Poultry litter (T_3), and 2.5 t/ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4).

For the full inorganic fertilizer treatment, complete fertilizer and urea were used to satisfy the fertilizer recommendation of 120-60-60 kg ha^{-1} N, P_2O_5, K_2O ha^{-1}. The complete fertilizer was applied at 514.28 grams treatment $plot^{-1}$ 10 days after transplanting (DAT). The remaining N requirement was satisfied by broadcasting urea at 156.52 grams treatment $plot^{-1}$ during the panicle initiation stage. For the INM treatment (T_4) and pure poultry litter (T_3), poultry litter was applied basally seven (7) days before transplanting. The inorganic fertilizer for T_4 was satisfied using complete fertilizer at 257.15 grams $plot^{-1}$ and applied through a 10 DAT broadcast method. The remaining N requirement was met by broadcasting urea at 78.26 grams $plot^{-1}$ at the panicle initiation stage.

Twenty-one-day-old seedlings of the three rice cultivars were simultaneously transplanted at one to two seedlings per hill at a spacing of 20 cm x 20 cm between hills and between rows. Replanting was done at 7 DAT, while rotary weeding was done at 15 DAT. After that, hand weeding was done at 25-30 DAT, while spot weeding was employed to remove weeds around each hill.

Handpicking of Golden Apple Snail - GAS (*Pomacea canaliculata* L.) was done to eliminate the pest. Then, 25 g of Lannate (methomyl) insecticide was sprayed to control insect pests like rice ear bug (*Leptocorisa oratorio*) and case worm (*Nymphula depunctalis*, Guenee). Rat baiting was done one week before transplanting as a preventive measure and repeated during panicle initiation and heading stage.

Plants within the harvestable area (8.32 m^2) were harvested when ripened at 85% of the grain's $panicle^{-1}$ in each treatment plot. The panicles within the harvestable area were cut at the base using a sharp sickle. The sample panicles were threshed, dried for three days to attain 14% moisture content, and cleaned before gathering all the necessary data.

Data Gathered

The agronomic parameters gathered were the number of days from sowing to heading and maturity, plant height, leaf area index (LAI), and fresh straw yield (t/ha^{-1}). The root parameters gathered were the nodal root axis length per plant (cm), number of nodal roots per plant, root dry weight per plant (g), shoot dry weight per plant (g), and root-shoot ratio per plant. On the other hand, the yield and yield component parameters collected were the number of productive tillers per hill, panicle length (cm), percent of filled and unfilled spikelets panicle-1, the weight of grains per hill, the weight of 1,000 grains (g) and grain yield (t/ha^{-1}), as well as the harvest index. The cost and return analysis was calculated. Moreover, the data on rainfall, maximum and minimum temperatures, and relative humidity from the

PAGASA station from the start until the study's completion were collected.

Statistical Analysis

All data gathered were analyzed using the computer software Statistical Tools for Agricultural Research (STAR). The mean comparison was computed, adopting the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Rainfall, Temperature, and Relative Humidity

The total rainfall throughout the experiment was 552.10 mm. The highest rainfall was observed in week two with 113.80 mm, while no precipitation was recorded in week 10. The total rainfall requirement of lowland rice ranges from 450-700 mm throughout the growing period (FAO, 2000). Rice consumes about 4000 - 5000 liters of water per kg of grain produced (Chowdhury et al 2014). The maximum temperature recorded ranged from 27.31 °C to 31.90 °C, while the minimum temperature ranged from 23.24 °C to 27.32 °C.

The optimum rice cultivation temperature ranges from 25°C and 35°C (Ghadirnezhad & Fallah 2014). Likewise, relative humidity ranged from 78.00 to 101.86 %. The results imply that the rainfall, temperature, and relative humidity during the study were adequate for lowland rice production.

Soil Chemical Properties

The initial soil analysis results showed that the soil had a pH of 7.89 with 2.15 % organic matter, 0.15 % total N, 9.48 mg kg^{-1} available P, 0.0101 me 100 g^{-1} exchangeable K, 5,111.07 me 100 g^{-1} Ca, 342.66 me 100 g^{-1} Mg, a trace amount of Na, 1.58 mg kg^{-1} Fe, 8.04 mg kg^{-1} Mn, 3.24 mg kg^{-1} Cu, and 1.46 mg kg^{-1} Zn (Table 1). These imply that the soil is strongly alkaline, with low amounts of organic matter, total N, and available P, very low amount of exchangeable K, low amounts of Fe and Zn, a moderate amount of Cu, high amount of Mn, and very high amounts of Ca and Mg (Landon 1991). After harvest, the final analysis results revealed a slight decrease in soil pH from a strongly alkaline to a moderately alkaline level. However, a slight increase in OM, N, and K was observed, especially in treatment plots applied with 5 t ha^{-1} poultry litter (T_3), mainly attributed to the high contents of nutrient elements in the poultry litter applied (Table 1). The results aligned with Hamed et al (2011) and Amanullah et al’s (2007) studies which state that poultry manure is a source of N and P and provides nutrients such as Ca Mg, S, and Fe. A decrease in P's available amount was due to plants' utilization of the said element, especially those without fertilizer. On the other hand, the increase in the amount of Mg, Fe, Cu, and Zn and the decrease in Ca in the different subplot treatments indicate the decline in pH, especially in those plots applied with pure inorganic fertilizer at the rate of 120-60-60 kg ha^{-1} N, P_2O_5,K_2O (T_2).

Table 1. Soil test results before planting and after harvest of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

					MACRONUTRIENTS				MICRONUTRIENTS			
	pH	OM (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable (me 100 g $^{-1}$) K	Ca	Mg	Na	Extractable (mg kg $^{-1}$) Fe	Mn	Cu	Zn
Initial Soil Analysis												
Composite Sample	7.89	2.15	0.15	9.48	0.0101	5,111.07	342.65	trace	1.58	8.04	3.24	1.46
Final Soil Analysis												
Treatment												
T_1	7.54	2.98	0.19	2.32	0.0105	4779.23	384.43	trace	5.67	3.63	4.39	0.90
T_2	7.60	2.92	0.17	3.17	0.0151	4533.65	485.78	trace	6.80	5.07	4.78	1.02
T_3	7.60	3.25	0.19	7.29	0.0202	4912.50	508.00	trace	6.22	3.51	4.83	1.68
T_4	7.57	3.03	0.18	2.89	0.0193	4921.20	437.00	trace	6.41	4.73	4.84	1.13
Mean	7.58	3.05	0.18	3.92	0.016	4786.64	453.80	trace	6.28	4.24	4.71	1.18

Legend:

T_1 = No fertilizer application (Control)
T_2 = 120-60-60 kg ha^{-1}N, P_2O_5, K_2O
T_3 = 5 t ha^{-1} Poultry litterT_4 = 2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O

Agronomic Characteristics

The statistical analysis revealed that the agronomic parameters did not significantly vary among rice cultivars. Still, the number of days from sowing to heading and maturity (Figure 1a), plant height (cm) (Figure 1b), and fresh straw yield (t ha^{-1}) (Figure 1c) were significantly affected by the nutrient management adopted (Table 2). Rice plants applied with 2.5 tons ha^{-1} poultry + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4) were significantly taller (cm) and produced heavier straw yield (t ha^{-1}) compared to unfertilized (control) plants but comparable to those plants applied with 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) and those applied with 5 tons ha^{-1} poultry litter (T_3).

Table 2. Agronomic characteristics of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

Treatment	Number of days from sowing to		Plant height (cm)	Leaf area index (LAI)	Fresh straw yield (t/ha^{-1})
	heading	maturity			
Rice Cultivar					
M_1 = Black rice	88.58	121.58	88.99	2.96	10.40
M_2 = Red rice	88.67	122.42	89.54	3.05	9.58
M_3 = White rice	89.33	122.33	85.84	3.86	10.39
Mean	88.86	122.11	88.12	3.29	10.12
Nutrient Management					
T_1 = No fertilizer application (control)	93.67^a	123.89^a	79.40^b	3.18	7.14^b
T_2 =120-60-60 kg ha^{-1}N, P_2O, K_2O	89.89^b	123.00^{ab}	91.51^a	3.89	11.45^a
T_3 = 5 t ha^{-1} Poultry litter	85.11^d	119.44^c	89.23^a	3.30	10.54^a
T_4 = 2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O	86.78^c	122.11^b	92.35^a	2.79	11.35^a
Mean	88.86	122.11	88.12	3.29	10.12
C.V. (a) %	1.31	0.39	4.59	44.11	15.16
C.V. (b) %	1.37	0.86	4.18	38.69	15.48

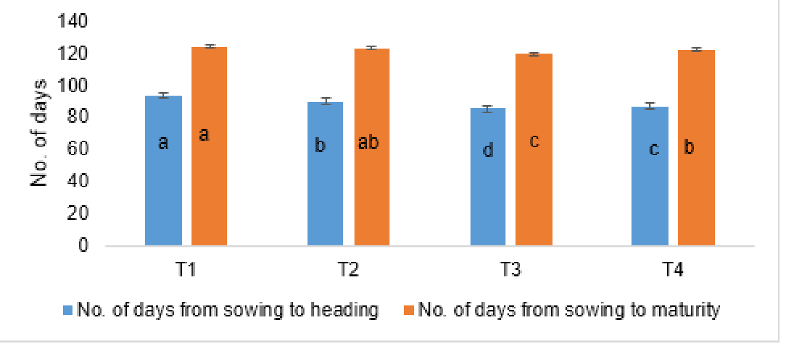
Means within a column with the same letter and no letter designation are not significantly different based on the 5% level of significance (LSD).

The results conformed with the findings of Orluchukwu et al (2018) that poultry litter application would significantly increase the plant height of lowland rice. These were also similar to the studies of Hossain et al (2010) and Sarker et al (2014), which found that straw yield would significantly increase with the application of poultry litter and different rates of inorganic fertilizers.

Meanwhile, Table 3 shows the nodal root (NR) axis length, number of nodal roots per plant, dry weight of root and shoot per plant, and root shoot ratio per plant as affected by rice cultivar and nutrient management (Table 3). The analysis of variance revealed that only the root: shoot ratio (Figure 2c) was remarkably influenced by the rice cultivar, but the number of NRs per plant and both the dry weight of root and shoot per plant were significantly affected by nutrient management. Fageria and Baligar (2005) reported that lower root dry weight as influenced by nutrient management was associated with a significant increase in rice grain and shoot weight.

Among rice cultivars, black rice significantly obtained the highest root: shoot ratio (0.33) (Figure 2c) irrespective of nutrient management. It means that black rice translocate more abundant assimilates for the formation of roots than the above-ground parts. On the other hand, regardless of cultivar, plants applied with fertilizers, whether organic, inorganic or their combination, obtained significantly higher NRs per plant (316.31 NRs) than the unfertilized plants (T_1).

1a)



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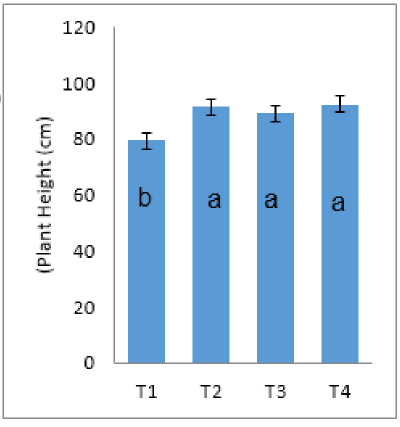
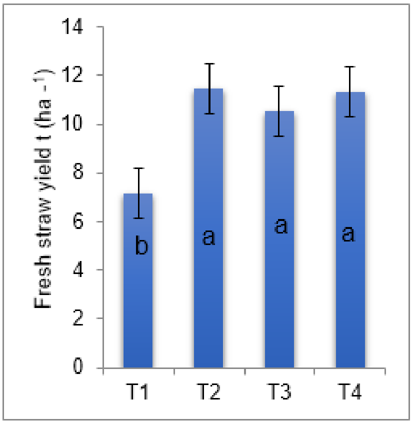


1c)



Treatment means with the same and without letter designations are not significantly different at 0.05 LSD

Legend:

T1 = No fertilizer application T3 = 5 t ha-1 Poultry litter

T2 = 120-60-60 kg ha-1 N, P2O5,K2O T4 = 2.5 t ha-1 Poultry litter + 60-30-30 kg ha-1 N, P2O5,K2O

Figures 1a, 1b,1c. Agronomic characteristics of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

In addition, dry weights of roots and shoots per plant (Figure 2b) were heavier in plants applied with 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4) comparable to plants with 5 t/ha^{-1} poultry litter (T_3) in terms of shoot dry weight. Plants applied with 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4) obtained comparable root dry weight with rice plants applied with 120-60-60 kg ha^{-1} inorganic fertilizer (T_2). Shoot dry weight of plants applied with 5 t/ha^{-1} poultry litter (T_3) were comparable with those applied with 120-60-60 kg ha^{-1} inorganic fertilizer alone. Roy et al. (2018) reported that heavier weights of root and shoot of rice could be due to the supplemental organic manure application, especially poultry litter, into the soil.

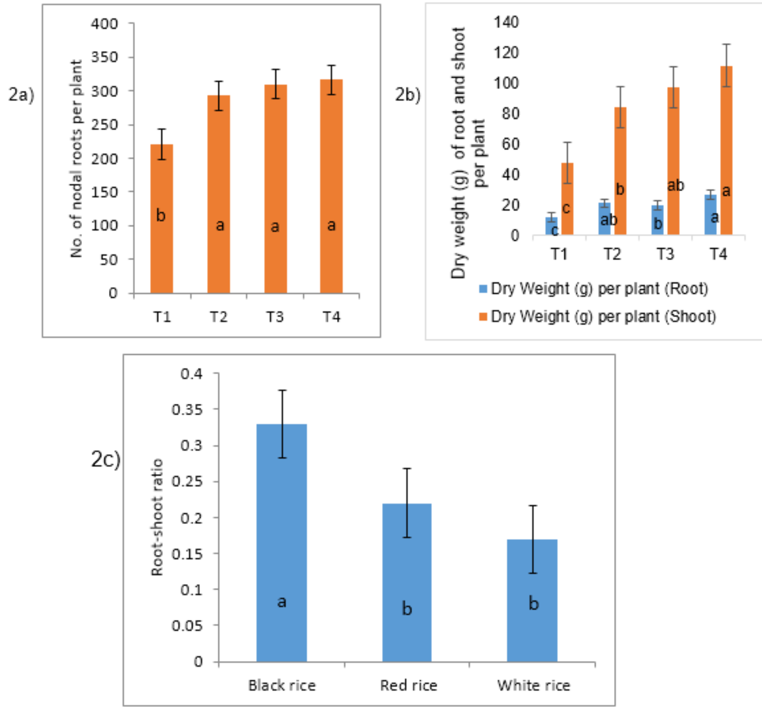
Table 3. Nodal root axis length, number of nodal roots per plant, dry weight of root and shoot per plant, and root shoot ratio per plant of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

Treatment	Nodal root axis length (cm)	Number of nodal roots per plant	Dry Weight (g) per plant		Root-shoot ratio
			Root	Shoot	
Rice Cultivar					
M_1 = Black rice	27.72	328.03	26.08	81.75	0.33^a
M_2 = Red rice	28.92	259.03	17.25	78.67	0.22^b
M_3 = White rice	30.37	267.23	16.17	95.08	0.17^b
Mean	29.00	284.76	19.83	85.17	24.00
Nutrient Management					
T_1 = No fertilizer application (control)	27.41	220.76^b	12.11^c	47.78^c	0.26
T_2= 120-60-60 kg ha^{-1} N, P_2O_5, K_2O	29.04	292.62^a	21.11^{ab}	84.33^b	0.25
T_3 = 5 t ha^{-1} Poultry litter	30.50	309.38^a	19.67^b	97.22^{ab}	0.22
T_4 = 2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1}N, P_2O_5,K_2O	29.07	316.31^a	26.44^a	111.33^a	0.24
Mean	29.00	284.76	19.83	85.17	0.24
C.V. (a) %	16.70	22.48	43.97	21.75	34.34
C.V. (b) %	8.07	16.97	31.28	20.22	23.83

In a column with the same letter and no letter designation, means are not significantly different based on a 5% level of significance (LSD).

Yield, Yield Components, and Harvest Index

The statistical analysis revealed that all yield and yield components and harvest index did not differ significantly among the rice cultivars tested (Table 4). However, the number of productive tillers hill-1, grain weight per hill, and grain yield (t/ha^{-1}) were significantly affected by the nutrient management adopted (Figures 3a, 3b 3c). A significant interaction between rice cultivar and nutrient management was observed on percent filled spikelets panicle-1 (Fig. 4a), percent unfilled spikelets panicle-1 (Fig. 4b), and panicle length (Fig. 4c). Regardless of rice cultivar, plants applied with 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha-1 N, P_2O_5, K_2O (T_4) significantly produced more productive tillers (11.43) comparable with those plants applied with 120-60-60 kg ha-1 N, P_2O_5, K_2O (T_2) (Fig. 3a).



Treatment means with the same and without letter designations are not significantly different at 0.05 LSD.

Legend:

T_1 = No fertilizer application (control) T_2 = 120-60-60 kg ha^{-1}N, P_2O_5, K_2O

T_3 = 5 t/ha^{-1} Poultry litter T_4 = 2.5 t/ha^{-1} Poultry litter+ 60-30-30 kg ha^{-1} N, P_2O_5, K_2O

Figures 2a, 2b, 2c. Number of nodal roots per plant, dry weight of root and shoot per plant, and root shoot ratio per plant of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

The plants applied with poultry litter at 5 t ha^{-1} (T_3) and those without (T_1-control) had few productive tillers. Thus, a combination of poultry litter and inorganic fertilizer resulted in a significant increase in rice tillers due to their synergistic effect of increasing nitrogen and phosphorus levels in the soil, which in turn promotes tillering (Belefant 2007).

For the weight of grains per hill (Fig. 3b) and grain yield (t/ha^{-1}), plants applied with 2.5 t ha-1 poultry litter + 60-30-30 kg ha-1 N, P2O5, K2O (T_4) had significantly heavier grains per hill (23.86g) compared to those plants applied with pure poultry litter at 5 t ha^{-1} (T_3) and unfertilized plants (T_1) (Fig. 3c). However, T_4 plants were comparable to those plants that received pure inorganic fertilizer (T_2). A similar trend was also noted in grain yield wherein rice plants in T_4 significantly obtained higher grain yield (t ha^{-1}) than those plants under T_3 and unfertilized plants (T_1) but comparable to those plants that received inorganic fertilizer at the rate of 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2). This result is similar to the findings of Hasanuzzaman et al (2010) that application of poultry litter at 4 t ha^{-1} + 50 % of recommended NPK produced the highest grain yield in rice.

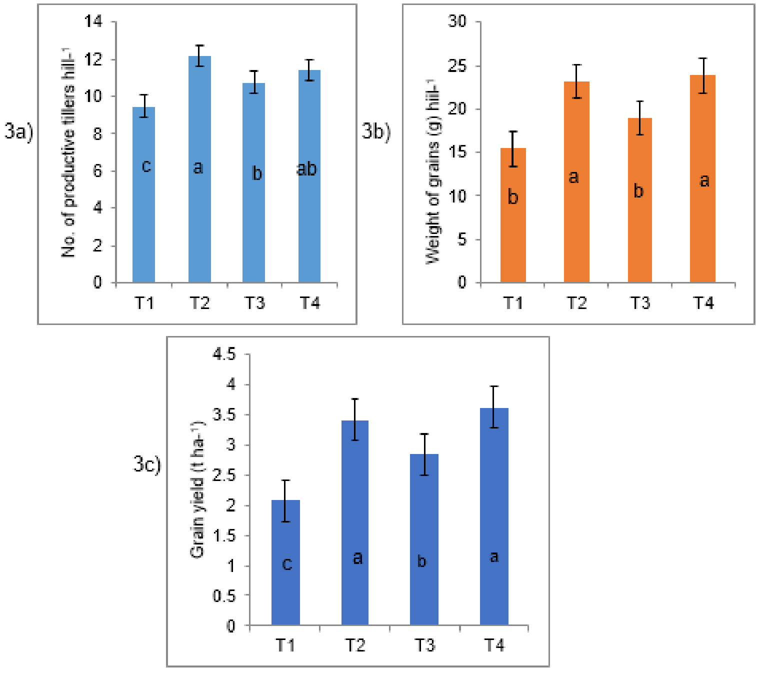
Table 4. Yield and yield components and harvest index of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

Treatment	No. of productive tillers hill^{-1}	Percent (%) filled spikelets panicle^{-1}	Percent (%) unfilled spikelets panicle^{-1}	Panicle Length (cm)	Weight of grains per hill (g)	Weight of 1,000 grains (g)	Grain yield (t ha^{-1})	Harvest Index
Rice Cultivar								
M_1 = Black rice	11.93	84.08	15.92	20.84	21.48	28.83	3.26	0.52
M_2 = Red rice	10.77	89.13	10.87	21.91	17.67	28.00	2.66	0.53
M_3 = White rice	10.18	91.45	13.71	24.60	21.90	29.17	3.06	0.52
Mean	10.96	88.22	13.50	22.45	20.35	28.67	2.99	0.52
Nutrient Management								
T_1 = No fertilizer application (control)	9.47^{c}	86.35	14.69	20.67	15.42^{b}	28.00	2.08^{c}	0.53
T_2 =120-60-60 kg ha^{-1} N, P_2O_5, K_2O	12.19^{a}	87.82	18.02	23.75	23.16^{a}	28.11	3.42^{a}	0.50
T_3 = 5 t ha^{-1} Poultry litter	10.76^{b}	88.56	11.44	22.06	18.96^{b}	28.67	2.85^{b}	0.54
T_4 = 2.5 t ha^{-1} Poultry litter+ 60-30-30 kg ha^{-1}N, P_2O_5, K_2O	11.43^{ab}	90.15	9.85	23.32	23.86^{a}	29.89	3.63^{a}	0.53
Mean	10.96	88.22	13.50	22.45	20.35	28.67	2.99	0.52
C.V. (a) %	17.67	3.44	22.07	4.80	18.52	5.42	20.75	7.17
C.V. (b) %	8.89	3.89	24.92	3.90	17.98	5.39	15.73	14.03

In a column with the same letter and no letter designation, means are not significantly different based on a 5% level of significance (LSD).

A significant interaction between rice cultivar and nutrient management was observed on the percent filled and unfilled spikelets and panicle length (Figures 4a, 4b, and 4c). Black rice significantly had a higher percentage of filled spikelets panicle^{-1} under combined organic and inorganic fertilizers, but this is sharply reduced under unfertilized crops. White rice also had a high percentage of filled spikelets panicle^{-1} under the combined application of organic and inorganic fertilizers, but this declined with inorganic fertilizer application alone. The result implies that increased filled spikelets panicle^{-1} under combined application of organic and inorganic fertilizers were due to the continuous supply of available nutrients (NPK) for the plant's immediate use that resulted in increased filled spikelets. This is similar to the findings of Siavoshi et al's (2011), who reported an increasing number of filled spikelets due to the combined chemical fertilizer and organic fertilizer application. On the other hand, the percent reduction in filled spikelets panicle-1 of white rice applied with inorganic fertilizer alone might be attributed to the slight damage of panicles due to rice bug infestation during the reproductive phase.

Nutrient management remarkably influenced the percentage of unfilled spikelets panicle^{-1} as reflected in Figure 4b. It connotes that applying organic and inorganic fertilizers reduced the percent unfilled spikelets panicle^{-1} of black rice. This remarkably increased in unfertilized plants (T_1) and plants applied with pure inorganic fertilizer at the rate of 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2). However, application of fertilizer at the rate of 120-60-60 kg ha^{-1} N, P_2O_5, K_2O (T_2) increased the percent of unfilled spikelets panicle^{-1} of white rice but this was significantly reduced in plants applied with pure organic fertilizer (T_3) and those without fertilizer (T_1). The plant's response to fertilization is the adjustment of the crop that would enhance their growth and development through faster translocation of nutrients, thereby reducing the percent of unfilled spikelets panicle^{-1}.



Treatment means with the same and without letter designations are not significantly different at 0.05 LSD.

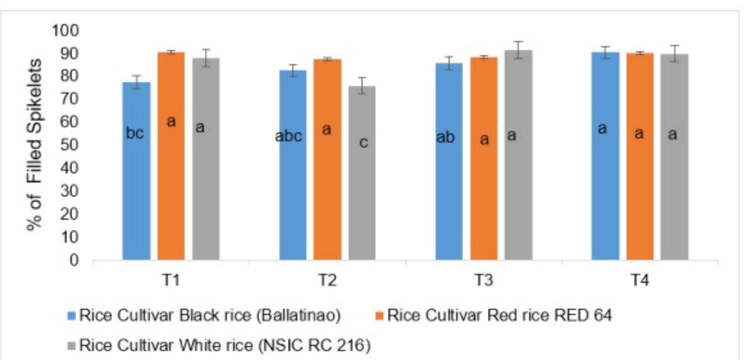
Legend:

T_1 = No fertilizer application (control) T_2 = 120-60-60 kg ha^{-1}N, P_2O_5,K_2O

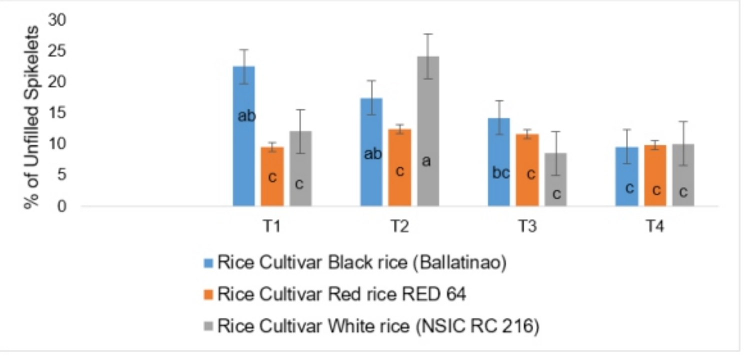
T_3 = 5 t ha^{-1} Poultry litter T_4 = 2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5,K_2O

Figure 3a, 3b, 3c. Yield and yield components of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

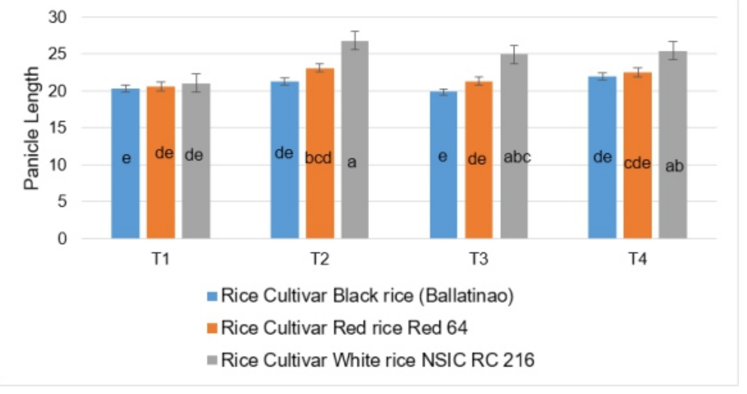
4a)



4b)



4c)



Treatment means with the same and without letter designations are not significantly different at 0.05 LSD.

Legend:

T_1 = No fertilizer application
T_2 = 120-60-60 kg ha^{-1} N, P_2O_5, K_2O
T_3 = 5 t/ha^{-1} Poultry litter
T_4 = 2.5 t/ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O

Figure 4a, 4b, 4c. Interaction between rice cultivars and nutrient management on percent filled spikelets (%) panicle^{-1}, percent unfilled spikelets (%) panicle^{-1}, and panicle length of lowland rice (*Oryza sativa* L.) grown under strongly alkaline soil

For panicle length (cm) (Figure 4c), white rice generally obtained longer panicles than the other rice cultivars regardless of nutrient management adopted. Similarly, this rice cultivar also remarkably achieved longer panicles when applied purely with organic and inorganic fertilizer and a combination of both. This is because plants that received fertilizers tend to thrive due to the sufficient available nutrients from the fertilizers, thus producing longer panicles. However, as the length of the panicle increases, the plant's nutrient requirement, specifically that of the white rice cultivar, considerably increases to sustain growth and development.

Cost and Return Analysis

The cost and return analysis revealed that black rice achieved a high gross margin of PHP 297,520.78 per hectare compared to red and white rice with gross margins of PHP 223,066.94 and PHP 140,153.73, respectively (Table 5). Thedifferences in gross margins were attributed to higher grain yield and the higher price of black rice compared to the two other rice cultivars.

Regarding nutrient management, plants applied with 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4) have obtained the highest gross margin of PHP269,845.68, followed by T_2 and T_3. The lowest gross margin (PHP 155,763.57) was obtained in unfertilized plants (T_1).

Table 5. Cost and return analysis of black, red, and white rice (*Oryza sativa* L.) cultivars as influenced by nutrient management under highly alkaline soil

Treatment	Grain Yield (t ha^{-1})	Milled Rice (t ha^{-1})	(%) Milling Recovery	Gross Income (PHP ha^{-1})	Total Variable Cost (PHP ha^{-1})	Gross Margin (PHP ha^{-1})
Rice Cultivar						
M_1 = Black rice	3.26	1.60	52.75	340,745.19	43,224.42	297,520.78
M_2 = Red rice	2.66	1.62	49.63	268,629.81	45,562.87	223,066.94
M_3 = White rice	3.06	1.49	58.91	191,706.73	51,553.00	140,153.73
Mean	2.99	1.57	53.76	267,027.24	46,780.09	220,247.15
Nutrient Management						
T_1-No fertilizer application (control)	2.08	1.09	55.14	188,701.92	32,938.35	155,763.57
T_2-120-60-60 kg ha^{-1}N, P_2O_5,K_2O	3.42	1.72	51.43	289,663.46	47,311.80	242,351.66
T_3-5 t ha^{-1} Poultry litter	2.85	1.54	55.17	260,817.31	47,789.63	213,027.68
T_4-2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O	3.63	1.94	53.31	328,926.28	59,080.60	269,845.68
Mean	2.99	1.57	53.76	267,027.24	46,780.09	220,247.15

**Based on the current price of milled rice at PHP 70.00 kg^{-1} for black rice, PHP 60.00 kg^{-1} for red rice, and PHP 40.00 kg^{-1} for white rice.*

CONCLUSION

The results indicate that nutrient management remarkably influenced the agronomic parameters such as the number of days from sowing to heading and maturity, plant height (cm), and fresh straw yield (t/ha^{-1}) of three rice cultivars under highly alkaline soil. The number of nodal roots per plant, root and shoot dry weight, number of productive tillers per hill, grains per hill, the weight of 1,000 grains, and grain yield of black, red, and white rice cultivars were also significantly influenced by nutrient management. Black rice significantly obtained high root and shoot ratios under alkaline soil that might indicate the crop's tolerance under soil alkalinity. A significant interaction between rice cultivar and nutrient management was noted on the percent filled and unfilled spikelets panicle^{-1}and panicle length. The combination of organic and inorganic fertilizers through the application of 2.5 t ha^{-1} Poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, K_2O (T_4) produced a remarkably higher number of productive tillers, the weight of grains $hill^{-1}$, higher grain yield (t/ha^{-1}), and achieved a high gross margin of PHP 269,845.68. Thereby, the study results indicate that planting black rice and applying 2.5 t/ha^{-1} poultry litter + 60-30-30 kg ha^{-1} N, P_2O_5, and K_2O (T_4) is productive and profitable for lowland rice production under highly alkaline soil.

RECOMMENDATION

Planting black rice (Ballatinao), regardless of nutrient management, is recommended under highly alkaline soil. The combined application of poultry litter and inorganic fertilizer at the rate of 5 t ha^{-1} + 60-30-30 kg ha-^{1} N, P_2O_5, and K_2O (T_4) should be tested further on other newly released climate-smart rice varieties.

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