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Growth and yield response of lowland rice (Oryza sativa L.) to planting density and nutrient management

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ABSTRACT

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Planting density and nutrient management practices may affect lowland rice production. This study was conducted to evaluate their effects on growth and yield of lowland rice (NSIC Rc400), determine the appropriate number of seedlings hill^{-1} and nutrient management for optimum yield, and assess their profitability on rice. A split-plot arranged in Randomized Complete Block Design was used with three replications. Planting densities (M_1=1 seedling hill^{-1} and M_2=3-5 seedlings hill^{-1}) were designated as mainplots while nutrient management practices as subplots;T_1=0-0-0 (Control), T_2=120–60–60kg ha^{-1} N, P_2O_5, and K_2O, T_3=60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar urea spray, T_4=45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar urea spray, and T_5=30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar urea spray. Results revealed that M_1 produced more filled spikelets panicle^{-1} regardless of nutrient management. Early heading and maturity were noted at T_1, T_4 and T_5 treatments. Integrated nutrient application at T_3 significantly increased growth, and yield parameters of lowland rice with higher gross income and benefit-cost ratio, next to the recommended dose of inorganic fertilizer (T_2). This was due to the high labor and material cost incurred with the integrated nutrient application. Highest net income and benefit-cost ratio were obtained with M_1 and T_2. Transplanting 1 seedling hill^{-1} with combined inorganic and vermicast application (T_3) seemed appropriate for NSIC Rc400 especially if the farmer has his own vermicast production.

Keywords: Foliar urea, integrated nutrient management, lowland rice, N use efficiency, vermicast

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INTRODUCTION

Rice (*Oryza sativa* L.) is an important staple food crop in Asia. Globally, rice consumption in 2016 reached its maximum level at 518 MT and is projected to continue to grow steadily at around 1.1% per annum by 2025 (Grain Central 2018). In 2018, the world cultivated about 161.62M ha and produced around 728.07M tons of rough rice. In the Philippines, about 4.86M ha were cultivated and produced around 19.6M tons of rough rice with an average yield of 4.04t ha^{-1} (IRRI 2018). The increasing population coupled with the negative impacts of climate change put pressure on farmers to sustain increased rice production.

In the country, a number of challenges beset rice production. Aside from the above challenges, land area is also steadily decreasing due to urbanization and land degradation. Moreover, production practices like tillage, planting density, fertilization, water, and pest control need to be addressed to enhance productivity. Among these management practices, this study had a vital focus on planting density and fertilizer management.

According to Vijayalami et al (2016), plant density is an important factor for rice production because it influences radiation interception, photosynthetic rate, tiller production, nutrient uptake, and other physiological phenomena and eventually affects the growth and development of rice. Excessive seedlings per hill may result in mutual shading and lodging thus lower grain production. On the other hand, lesser seedlings per hill may result in underutilized space and nutrients, reduce the number of panicles per unit area resulting in low grain yield. If fewer seedlings per hill are used, the potential yield cannot be realized but excessive seedlings might not be cost-effective, too. Islam et al (2008) reported that an optimum number of seedlings per hill ensures both aerial and underground parts of plants grow normally through efficient utilization of solar radiation, water, and nutrients. Although, varieties differ in response to varying plant densities, increasing the number of plants to a certain level would likely increase yield.

Likewise, improper nutrient management increased production costs due to costly fertilizer (Bernal 2013) and may increase environmental risk (Sudhir et al 2010). However, Zamora (2007) stressed that fertilizer application is considered the most common and conventional cultural management practice to address infertile soil and supply adequate nutrient supply for better plant growth and development.

Addition of organic materials like vermicast is considered a good alternative to reduce risks of intensive inorganic N application. This lessens harm to human health and the environment (Jhan 2004). It also helps rehabilitate and sustain soil fertility of degraded or areas endangered of degradation due to intensive crop production and improper soil management practices (de la Cruz et al 2008). The combined use of organic and inorganic fertilizers has been used successfully to maintain and sustain soil fertility and crop productivity (Widowati et al 2012). Their combination had a synergistic effect thus an effective way to attain yields and sustain soil fertility comparable to pure inorganic application (Quimbo et al 2014).

Urea is an organic synthetic fertilizer that contains a high level of soluble nitrogen. It is one of the most common N sources used for foliar applications because it is highly soluble, inexpensive, and has a relatively low potential for injuring foliage (Bowman and Paul 1992). Furthermore, foliar application of urea is an effective method of nitrogen fertilization for cereals (Finney et al 1957) such as corn (Foy et al 1953), rice (De et al 1971, Thom et al 1981), and barley (Seth and Prassad 1965 and 1971). Moreover, foliar fertilization improves N use efficiency relative to soil application as it reduces leaching of nitrates into the groundwater and run-off losses of nutrients and release of N_2O and NO_2 into the atmosphere are reduced (Embleton et al 1986, Fallahi and Simons 1996, Khemira et al 1998).

It is therefore imperative to find out the optimum planting density and proper nutrient management that will improve the performance of lowland rice. Hence, this study was conducted to evaluate their effects on the growth and yield of lowland rice (NSIC Rc400), determine the appropriate number of seedlings per hill, and nutrient management for optimum yield, and profitability of rice.

MATERIALS AND METHODS

Land Preparation

An experimental area of 595m^2 was flooded for three weeks to soften the soil. This was harrowed twice at two weeks interval using a hand tractor. After the last harrowing, the field was leveled and a dike was constructed.

Soil Sample Collection and Analyses

Ten soil samples were randomly collected before land preparation at a depth of 0-20cm. Samples were composited, air-dried, pulverized, sieved at 2mm wire mesh, and analyzed for soil pH (potentiometric method at 1:1.25 soil water ratio, ISRIC 1995), organic matter (Walkley-Black Method, Nelson, and Sommers, 1982), total nitrogen (Kjeldahl Method, ISRIC 1995), available P (Bray #2 Method, ISRIC 1995) and exchangeable K (ammonium acetate method pH7.0 for extraction, ISRIC 1995) and was quantified using Buck Scientific 210 VGP Atomic Absorption Spectrophotometer. Soil pH, % organic matter, total N, and extractable P were analyzed at the Soil Research, Testing, and Plant Analysis Laboratory (SRTPAL), while exchangeable K was analyzed at the ACIAR-CFES Laboratory, VSU, Visca, Baybay City, Leyte.

For the final soil analysis, five soil samples were collected separately from each treatment plot after harvest. These were composited, processed, and analyzed for the same soil parameters mentioned above.

Experimental Design and Field Layout

The experiment was laid out in a split-plot arranged in Randomized Complete Block Design (RCBD) with three replications. Planting density was designated as the mainplot and nutrient management as the subplot. Replications and treatment plots were separated by 1.0m and 0.5m alleyways, respectively. Each subplot had an area of 5mx3m (15m^2) with 25 rows per plot at a planting distance of 20cmx20cm. This was conducted at Brgy. Patag, Baybay City, Leyte, Philippines from May 30 to September 18, 2018 during the wet season with silty clay loam soil. The different treatments were designated as follows:

A. Main plot (Planting Density)
M_1=1 seedling per hill (VSU Practice)
M_2=3-5 seedlings per hill (Farmer's Practice)
B. Sub plot (Nutrient Management)
T_1=0–0–0 (Control)
T_2=120–60–60kg ha^{-1} N, P_2O_5 and K_2O
T_3=60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea
T_4=45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea
T_5=30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea

Preparation of Urea as Foliar Spray

Urea (320g) was dissolved in water (2L). The dissolved solution was transferred to knapsack sprayer with 16L capacity and gradually added with water until its full capacity or 320g per tankload. This was thoroughly mixed by shaking the knapsack for proper dissolution. About 8 tankloads were used per hectare (2,560g urea ha^{-1}) or 3.84g $plot^{-1}$. The prepared solution was applied 5 times for T_3 and 10 times for T_4 and T_5. The total amount of nutrients applied per hectare throughout the cropping season is shown in Table 1.

Vermicast Procurement and Analysis

Seventy (70) kg of vermicast were procured from the Ecological Farm and Resource Management Institute (EcoFARMI), VSU, Visca, Baybay City, Leyte. Chemical analysis of vermicast used in the study indicated 5.5 pH, 13.71% organic matter, 1.27% total N, 0.0013% total P (13.42mg kg^{-1}), and 0.000039% total K (0.39cmol kg^{-1}).

Seedbed and Seedling Preparation

Lowland rice NSIC Rc400 variety was used at the seeding rate of 20kg ha^{-1} and 40kg ha^{-1} for 1 seedling per $hill^{-1}$ and 3-5 seedlings $hill^{-1}$, respectively. Two kilograms of seeds were soaked in water for 24h and then incubated for 48h before sowing on the seedbed. Wetbed area of 20m^2 (10mx2m) was prepared with a drainage canal around the bed. This was constructed outside the experimental area to avoid obstruction in the preparation of the experimental plots. Pre-germinated seeds were sown thinly and uniformly in the prepared beds. Ditches were constructed around the seedbed. Complete fertilizer at the rate of 1 tbsp m^{-2} was applied to the seedbed before sowing. The seedbeds were irrigated after 3 days to a depth of 2-3cm until the day that seedlings are ready to be pulled out.

Nylon nets protected the seedbed from damage due to rats, birds, and stray animals.

Table1. Total amount of nutrients (N, P_2O_5 and K_2O kg ha^{-1}) applied per treatment

Treatments	Amount of Nutrients per Hectare (kg ha^{-1})									
	N				P_2O_5			K_2O		
	Vermi	Inorganic	Foliar Urea	Total	Vermi	Inorganic	Total	Vermi	Inorganic	Total
T_1 = 0 – 0 – 0 (Control)	-	-	-		-	-		-	-	
T_2 = 120–60–60 kg ha^{-1} N, P_2O_5 and K_2O	-	120	-	120	-	60	60	-	60	60
T_3 = 60–30–30 kg ha^{-1} N, P_2O_5 and K_2O + 2.5 t ha^{-1} vermicast + weekly foliar spray of urea	31.75	60	5.89	97.64	7.5	30	37.50	0.13	30	30.13
T_4 = 45–30–30 kg ha^{-1} N, P_2O_5 and K_2O + 2.5 t ha^{-1} vermicast + weekly foliar spray of urea	31.75	45	11.78	88.53	7.5	30	37.50	0.13	30	30.13
T_5 = 30–30–30 kg ha^{-1} N, P_2O_5 and K_2O + 2.5 t ha^{-1} vermicast + weekly foliar spray of urea	31.75	30	11.78	73.53	7.5	30	37.50	0.13	30	30.13

Transplanting

Fifteen-day-old seedlings were uprooted and tied in small bundles. Seedlings were transplanted at a density specified in the treatments at a distance of 20cmx20cm between rows and hills. Replanting missing hills was done one week after transplanting.

Fertilizer and Its Application

After the construction of all treatment plots, the specified amount of vermicast (fresh weight basis) was incorporated into the soil two weeks before transplanting (WBT) using a rotary weeder. Basal application of 321g $plot^{-1}$ of complete fertilizer (14-14-14) following the rate of 30-30-30kg ha^{-1} N, P_2O_5 and K_2O for T_3-T_5 was applied 10 days after transplanting (DAT) by broadcasting. This was incorporated into the soil by using a rotary weeder. Top-dressing of urea (46-0-0) was done in split doses at 35 and 45 days after transplanting (DAT) at the rates of 98g $plot^{-1}$ for T_2, 49g $plot^{-1}$ for T_3, and 24.5g $plot^{-1}$ for T_4. Spraying was done at 6 in the morning as specified in the treatments starting three weeks after transplanting until the soft dough stage. To prevent contamination of spray mists to other treatments, a plastic enclosure was provided around the treatments during spraying.

Water Management

During transplanting, the area was drained. Three days after transplanting, it was irrigated gradually to a depth of 2.5 to 5cm depending on the growth phase of rice. Water level was reduced before the application of vermicompost and inorganic fertilizer. Two weeks before harvest, the whole area was totally drained to facilitate harvesting.

Pest Management

Golden apple snail or "golden kuhol" (*Pomacea canaliculata* Lamarck) was controlled by pasturing ducks for 25 days prior to transplanting. Handpicking was also done early in the morning and late afternoon.

Rotary weeding was performed ten days after transplanting to control weeds. Second operation was done ten days later followed by hill weeding to remove weeds close to rice that was not removed during rotary weeding. During the milking stage, spraying of 350mL panyawan-based insecticide mixed with 12.5g lannate per 16L water was done early in the morning to kill insects. Cleaning of dikes was done to prevent rat habitats. Baiting using zinc phosphide was done to control rat infestation. Ten grams zinc phosphide was mixed with 400g milled rice. Three tbsp of the mixture were placed inside a bamboo tube and strategically placed in the entire area.

Harvesting and Processing

Harvesting was done using sharp sickles when 85% of the grains in each panicle had ripened and had become firm. Panicles of sample plants within the harvestable area (9.24m^2) excluding two end rows on each side and two end hills at both ends of each row were cut at the base and threshed. These were sun-dried for 3 days to 14% MC and cleaned before gathering the necessary data.

Data Gathered

A. Agronomic characteristics –These included the number of days from transplanting to heading and maturity, plant height, leaf area index (Gomez 1972), and fresh straw yield (t ha^{-1}).

Leaf area=length x width x 0.75 (Yoshida 1981)
Leaf area hill^{-1}=total leaf area of middle tiller x total number of tillers

$$LAI = \frac{\text{Total leaf area (5 hills)}}{\text{Land area covered by five sample hills (2,000cm}^2\text{)}}$$

$$\text{Fresh straw yield (t ha}^{-1}\text{)} = \frac{\text{Straw yield (kg)}}{\text{Harvestable area (9.24m}^2\text{)}} x \frac{10000\text{m}^2\ \text{ha}^{-1}}{1000\text{kg t}^{-1}}$$

B. Yield and yield components –These included the number of productive tillers hill^{-1}, weight of panicles hill^{-1}, weight of grains hill^{-1}, number of filled and unfilled spikelets panicle^{-1}, percent filled spikelet, weight of 1000 seeds (g), and grain yield (t ha^{-1}).

Grain yield was determined by weighing the harvested grains obtained from the harvestable area in each treatment plot. The grains were cleaned, sun-dried for three days until 14% MC as attained before weighing, using moisture meter. Weight was converted into tons per hectare using the formula:

$$\text{Grain yield (t ha}^{-1}) = \frac{\text{Plot yield (kg)}}{\text{Harvestable area}(9.24\text{m}^2)} x \frac{10000\text{m}^2\,\text{ha}^{-1}}{1000\text{kg t}^{-1}}$$

C. Physiological Characteristics

1. Crop growth rate (CGR) – This was the rate of dry matter production per unit ground area per unit time. This was determined three weeks after transplanting until two weeks before the harvest period on biweekly interval. Three sample hills were taken from the border rows at each sampling period. CGR was determined using the following formula:

$$CGR = \frac{(\text{W}2 - W1)}{(T2 - T1)\ \text{LA}}$$

Where: W1 = total plant dry weight at time T1
W2 = total plant dry weight at time T2
T1–T2 = time interval between the first and second measurement
LA = land area

2. Net assimilation rate (NAR) – This was the rate of dry matter production per unit leaf area per unit time. This was calculated on the basis of dry matter and leaf area taken over time. Three randomly selected sample hills were taken from the border rows of each treatment plot at each sampling period. This was done three weeks after transplanting at biweekly interval until two weeks before harvest. Net assimilation rate was determined using the formula:

$$NAR = \frac{(W2 - W1)(\ln LA2 - InLA1)}{(LA2 - LA1)(T2 - T1)}$$

Where: In = natural logarith
LA1=leaf area at time T1
LA2=leaf area at time T2
W1=total plant dry weight at time T1
W2=total plant dry weight at time T2
T2 – T1=time interval between the first and second measurement

D. Harvest Index (HI)

This is the ratio of economic to biological yield. This was obtained by dividing the grain weight by total dry matter at harvest. Harvest index was determined by oven drying the grains and straws of three sample hills randomly taken from each treatment plot. The sample plants $plot^{-1}$ were cut closed to the ground. Straws were separated from the grains and oven-dried at 70˚C until the weight became constant. This was computed using the following equation:

$$HI = \frac{\text{grain dry weight in g of 3 sample hills}}{\text{grains + straw dry weight in g of 3 sample hills}}$$

E. Cost and Return Analysis

Total production cost was determined by recording all the expenses incurred throughout the conduct of the study from land preparation up to harvesting and land rental. These included the cost of chemical, materials, and labor used in the field. The gross income was determined by multiplying the yield of each treatment plot by the current price of palay per kilo. The net income was determined by subtracting the total production cost from the gross income for each treatment. The gross income, net income, and benefit-cost ratio were determined using the following formula:

Gross income = Grain yield (kg ha^{-1}) x current price kg^{-1}
Net income = Gross income - Total production cost
Benefit cost ratio = Net income (PHP ha^{-1}) / Total production cost (PHP ha^{-1})

F. Meteorological Data

Total weekly rainfall (mm), average minimum and maximum temperatures (^{0}C), and relative humidity (%) throughout the duration of the study were obtained from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) Station, VSU, Visca, Baybay City, Leyte.

G. Statistical Analysis

The consolidated data were analyzed using Statistical Tool for Agricultural Research (STAR) version 2.0.1 and the significant treatments were compared using Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

General Observation

The total amount of rainfall throughout the experimental period was 933.80mm. The highest rainfall was observed at week 9 with 168.60mm and lowest at week 10 with 3.60mm. The average water consumption of lowland rice ranges from 450-700mm throughout the growing period (FAO nd). It showed that the rainfall during the study period was adequate to meet the water demand for rice. Maximum temperature recorded ranged from 28.60^{0}C to 31.90^{0}C while the minimum temperature ranged from 23.65^{0}C to 25.45^{0}C. According to Yin et al

(1996), the optimum temperature for the normal development of rice plants ranges from 27°C to 32°C. Likewise, relative humidity varied from 75.00-89.00% which is more or less within the range. Optimum relative humidity for rice cultivation lies between 60% and 85% (Rathnayake et al 2016).

Replanting of missing hills was done one week after transplanting. Adults and egg masses of golden snails were collected by handpicking early in the morning and late in the afternoon to prevent further damage. For weed control, rotary and hand weeding operations were employed. Leaf folder and tungro infestations were observed during the vegetative stage (55 DAT) of the rice plants. However, infected tillers hill^{-1} were uprooted and buried under the paddy. Damage caused by rats was observed at booting and hard dough stages. Installing bait using zinc phosphide and cleaning the surrounding area was done to minimize the damage. At flowering to milking stages, the presence of rice bugs and black bugs were observed which caused spikelet discoloration. Spraying of 350 ml panyawan-based insecticide mixed with 12.5g Lannate in a 16L knapsack sprayer was done to kill the insects. At soft dough to ripening stage, grains were attacked by birds especially gorion (*Lonchura malaca*) which was minimized by guarding the field and installing scarecrows.

Soil Chemical Analysis

Initial soil analysis showed that the experimental area had a pH of 5.11 with 4.80% organic matter, 0.32% total N, 3.22mg kg^{-1} available P, and 0.14 cmol kg^{-1} exchangeable K (Table 2). These results indicated that the soil pH was strongly acidic, medium in organic matter and total N, and very low in phosphorus and potassium (Landon 1991).

Final soil analysis showed that percent organic matter, total N, and exchangeable K slightly increased while soil pH and available P decreased after the harvest of rice relative to initial analysis. Results suggest that the application of integrated nutrient management (T_3, T_4, and T_5) relatively increased the organic matter. For total N, only T_4 showed increase while T_1-T_5 indicated an increase in K content. This increase in soil organic matter after the harvest of rice could be due to the decayed plant parts and application of vermicast which contributed to the organic matter content in the soil. Phosphorus reduction in soil can be attributed to plant uptake and crop removal. Due to its low solubility and mobility in soil, P can be rapidly depleted in the rhizosphere by root uptake (Marschner 1995).

Table 2. Soil test results before and after harvest of lowland rice as affected by planting density and nutrient management

Treatment	pH	Organic matter (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})
Initial Soil Analysis	5.11	4.80	0.32	3.22	0.14
Final Soil Analysis					
Planting Density (PD)					
M_1=1 seedling hill^{-1} (VSU Practice)	4.51	4.89	0.37	2.68	0.32
M_2=3-5 seedlings hill^{-1} (Farmer's Practice)	4.57	4.80	0.28	2.67	0.36
Mean	4.54	4.85	0.33	2.67	0.34

Table 2 continued

Treatment	pH	Organic matter (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})
Nutrient Management (NM)					
T_1=0–0–0 (Control)	4.61	4.80	0.27	3.22	0.34
T_2=120–60–60kg ha^{-1} N, P_2O_5 and K_2O	4.57	4.80	0.30	2.15	0.37
T_3=60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea	4.52	4.89	0.29	2.79	0.35
T_4=45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	4.55	4.87	0.48	2.22	0.31
T_5=30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	4.46	4.95	0.29	2.95	0.33
Mean	4.54	4.85	0.33	2.67	0.34

Agronomic Characteristics of Lowland Rice

Table 3 shows the agronomic characteristics of lowland rice as affected by planting density and nutrient management. Statistical analysis revealed that planting density did not significantly affect the number of days from transplanting to heading (66.87–67.40) and maturity (96.87–97.40), plant height (121.48–123.49cm), leaf area index (4.78–5.04) and fresh straw yield (22.09–22.75t ha^{-1}) of rice. However, transplanting of 3-5 seedlings per hill produced slightly higher LAI and fresh straw yield (t ha^{-1}). These results agreed with the findings of Vijayalaxmi et al (2016) that transplanting 5 seedlings per hill at 20x20cm increased LAI and fresh straw yield due to higher plant population. Hasanuzzaman et al (2009) also found that transplanting 1 seedling per hill resulted in a lower leaf area index due to the lower tiller number produced per hill.

On the other hand, significant differences were observed in nutrient management used. Regardless of planting density, rice plants applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) headed and matured earlier than 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2). This agreed with the findings of Añasco (2015) that application of 15t ha^{-1} of vermicompost combined with inorganic fertilizer at the rate of 45-30-30kg ha^{-1} N, P_2O_5, and K_2O enhanced early heading and maturity. However, treatment plants applied with 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4), 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) and untreated control (T_1) headed earliest. The lesser amount of nutrients caused early heading and maturity hence shortened the vegetative stage of the plant and consequently its maturity period. In contrast, late heading and maturity of T_2 which received the recommended dose of inorganic fertilizer could be due to a higher amount of nutrients available for plants that prolonged the vegetative growth of lowland rice. The variation in plant maturity could be due to different nutrient sources, availability, and immediate release of major nutrients that are readily absorbed by the plants (Abit 2016).

Table 3. Agronomic characteristics of lowland rice as affected by planting density and nutrient management

Treatment	Number of days from transplanting to		Plant Height (cm)	Leaf Area Index	Fresh Straw Yield (t ha^{-1})
	Heading	Maturity			
Planting Density (PD)					
M_1 = 1 seedling $hill^{-1}$ (VSU Practice)	66.87	96.87	123.49	4.78	22.09
M_2 = 3-5 seedlings $hill^{-1}$ (Farmer's Practice)	67.40	97.40	121.48	5.04	22.75
Mean	67.14	97.14	122.49	4.91	22.42
CV (a) %	1.65	1.14	3.07	19.93	16.54
Nutrient Management (NM)					
T_1 = 0–0–0 (Control)	66.17^{c}	96.17^{c}	112.01^{d}	2.88^{b}	17.28^{b}
T_2 = 120–60–60kg ha^{-1} N, P_2O_5 and K_2O	68.83^{a}	98.83^{a}	128.65^{a}	6.28^{a}	26.30^{a}
T_3 = 60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea	67.50^{b}	97.50^{b}	124.22^{bc}	5.20^{a}	25.32^{a}
T_4 = 45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	66.67^{c}	96.67^{c}	126.51^{ab}	5.21^{a}	24.63^{a}
T_5 = 30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	66.50^{c}	96.50^{c}	121.05^{c}	4.98^{a}	18.54^{b}
Mean	67.14	97.14	122.49	4.91	22.42
CV (b) %	0.74	0.51	2.23	29.07	15.35
Pr (> F)					
PD	0.3190^{ns}	0.3190^{ns}	0.2805^{ns}	0.5305^{ns}	0.6738^{ns}
NM	0.0000^{**}	0.0000^{**}	0.0000^{**}	0.0122^{*}	0.0006^{**}
PD × NM	0.7132^{ns}	0.7132^{ns}	0.6504^{ns}	0.9848^{ns}	0.8389^{ns}

Means within a column and treatment followed by the same letter and those without letters are not significantly different at 5% level, LSD.

Plants applied with 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) grew taller compared to plants applied with 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) and unfertilized control (T_1) but not significantly different with those applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) and 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2).

Similarly, bigger leaf area indices were obtained on plants treated with 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) compared to unfertilized control (T_1) yet comparable to those plants applied with 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2), 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_3), 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5). This could be due to the inherently higher amount of nutrients applied in these treatments which have enhanced leaf development for the production of higher photoassimilates. Higher photoassimilates can result in higher dry matter accumulation as manifested in increased plant height and consequently straw yield. This conforms with the findings of Chaturvedi (2005) and Islam et al. (2010) that plants applied with a high amount of fertilizer obtained the highest straw yield.

In this study, fresh straw yield of those applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) and 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) were heavier than the unfertilized plants (T_1) but comparable to rice plants which received 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2). Application of 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) produced the least fresh straw yield which is comparable to the unfertilized control (T_1).

Yield and Yield Components of Lowland Rice

Table 4 shows the yield and yield components of lowland rice as affected by planting density and nutrient management. Statistical analysis revealed that among the parameters, only the number of filled spikelets $panicle^{-1}$ was significantly affected by planting density regardless of nutrient management. Transplanting lowland rice at 1 seedling $hill^{-1}$ produced more filled spikelets $panicle^{-1}$ than at 3-5 seedling $hill^{-1}$ with 129.83 and 110.07, respectively. This result contradicts the findings of Islam et al (2013) that increasing the number of seedlings per hill increased number of spikelets per panicle, due to interplant competition for space, light, and nutrients (Miah et al 2004 and Inaba and Kitano 2005).

On the other hand, the number of productive tillers $hill^{-1}$, weight of panicles $hill^{-1}$, weight of grains $hill^{-1}$, and grain yield were significantly affected by nutrient management used regardless of planting density. Higher number of productive tillers $hill^{-1}$ was observed on plants applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) and 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) than the unfertilized plants (T_1) but comparable to 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2) and 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5). However, application of 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) gave comparable results to the unfertilized control (T_1).

Plants applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) and 45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) produced heavier panicles and grains $hill^{-1}$ than unfertilized control (T_1) which resulted to highest grain yield (3.94t ha^{-1}) but not significantly different with treatments applied with 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2) and 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5). Bhuyan et al (2012) also found that foliar spraying of urea at the rate of 2kg of urea in 100L of water in Aman rice increased the length of panicle, number of filled grains per panicle, weight of 1,000 grains, and yield by 9.33%. Alam (2009) reported that application of 2% urea solution applied in the leaves as foliar + 43.24kg N ha^{-1} applied in the soil significantly increased the grain yield of boro rice to 5.18t ha^{-1} comparable to those applied with the recommended rate at 130kg N ha^{-1}.

Table 4. Yield and yield components of lowland rice as affected by planting density and nutrient management

Treatment	Number of			Percent filled spikelets panicle^{-1}	Weight (g)			Grain yield (t ha^{-1})
	Productive tillers hill^{-1}	filled spikelets panicle^{-1}	unfilled spikelets panicle^{-1}		panicles hill^{-1}	grains hill^{-1}	1000 grains	
Planting Density (PD)								
M_1=1 seedling hill^{-1} (VSU Practice)	12.71	129.83^a	49.93	71.83	45.08	37.74	27.08	3.29
M_2=3-5 seedlings hill^{-1} (Farmer's Practice)	13.60	110.07^b	40.92	73.06	39.12	32.39	27.10	3.02
Mean	13.16	119.95	45.42	72.45	42.10	35.07	27.09	3.16
CV(a) %	19.24	6.67	23.20	6.17	14.91	11.95	2.38	22.48
Nutrient Management (NM)								
T_1=0–0–0(Control)	10.50^b	100.05	40.13	71.42	28.09^b	22.95^b	26.12	2.21^b
T_2=120–60–60kg ha^{-1} N, P_2O_5 and K_2O	14.80^a	136.38	43.18	76.24	46.42^a	37.57^a	27.66	3.88^a
T_3=60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea	13.90^a	124.85	48.78	71.64	46.04^a	38.87^a	27.12	3.94^a
T_4=45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	13.80^a	122.73	48.83	71.64	44.19^a	37.22^a	27.23	3.40^a
T_5 = 30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	12.77^{ab}	115.73	46.20	71.29	45.75^a	38.72^a	27.33	2.34^b
Mean	13.16	119.95	45.42	72.45	42.10	35.07	27.09	3.16
CV(b) %	16.47	17.98	29.12	10.73	12.74	13.26	3.41	21.33
Pr (> F)								
PD	0.4356^{ns}	0.0212*	0.1439^{ns}	0.5285^{ns}	0.1215^{ns}	0.0731^{ns}	0.9540^{ns}	0.6453^{ns}
NM	0.0317*	0.1027^{ns}	0.7469^{ns}	0.7721^{ns}	0.0001**	0.0001**	0.0956^{ns}	0.0005**
PD × NM	0.8101^{ns}	0.6260^{ns}	0.5434^{ns}	0.6958^{ns}	0.8818^{ns}	0.9582^{ns}	0.8462^{ns}	0.0852^{ns}

Means within a column and treatment followed by the same letter and those without letters are not significantly different at 5% level, LSD.

Table 5 shows the harvest index and net assimilation rate of lowland rice as affected by planting density and nutrient management. Statistical analysis revealed that harvest index and net assimilation rate at 21 to 84 days after transplanting were not significantly affected by planting density and nutrient management used. However, transplanting at 1 seedling hill^{-1} produced a slightly higher harvest index (0.30) than at 3-5 seedlings hill^{-1} (0.28). In addition, slightly higher harvest index was obtained in plants applied with 30kg ha^{-1} N, 30–30kg ha^{-1} P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5). Harvest index is a variable factor in crop production where it indicates the plants' efficiency to convert the absorbed nutrients and products of photosynthesis into grains in proportion to the straw yield (Yang and Zhang 2010). It was observed that there was a continuous decrease in net assimilation rate as the rice plant matured. Sarwar et al (2013) similarly noticed that at maturity most of the assimilates are converted into yield rather than vegetative biomass.

Table 5. Harvest index and net assimilation rate of lowland rice as affected by planting density and nutrient management

Treatment	Harvest Index	Net Assimilation Rate (g m^{-2} d^{-1})			
		21-42 DAT	42-56 DAT	56-70 DAT	70-84 DAT
Planting Density (PD)					
M_1=1 seedling hill^{-1} (VSU Practice)	0.30	18.49	9.10	5.60	2.74
M_2=3-5 seedlings hill^{-1} (Farmer's Practice)	0.28	12.96	9.01	4.40	2.02
Mean	0.29	15.73	9.06	5.00	2.38
CV (a) %	20.91	26.63	26.06	19.93	25.51
Nutrient Management (NM)					
T_1=0–0–0 (Control)	0.28	15.89	9.50	4.84	2.38
T_2=120–60–60kg ha^{-1} N, P_2O_5 and K_2O	0.29	17.97	9.18	5.01	2.59
T_3=60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea	0.30	15.68	8.72	5.19	2.04
T_4=45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	0.27	12.64	7.96	4.93	2.53
T_5=30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	0.31	16.42	9.92	5.03	2.34
Mean	0.29	15.72	9.06	5.00	2.38
CV (b) %	21.30	28.01	28.10	20.03	23.02
Pr (> F)					
PD	0.6090^{ns}	0.0687^{ns}	0.9640^{ns}	0.2582^{ns}	0.0829^{ns}
NM	0.8259^{ns}	0.3628^{ns}	0.7169^{ns}	0.9982^{ns}	0.9346^{ns}
PD × NM	0.8807^{ns}	0.7518^{ns}	0.1256^{ns}	0.9305^{ns}	0.4860^{ns}

Means within a column and treatment without letter are not significantly different at 5% level, LSD.

Regardless of planting density, crop growth rate (CGR) was significantly affected by nutrient management at 21-56 DAT (Table 6). Lowland rice applied with 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) gave comparably higher crop growth rate at 21-56 DAT with 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2) but not significantly different to those plants treated with 30-45kg ha^{-1} N, 30–30kg ha^{-1} P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4 and T_5) and unfertilized control (T_1). Crop growth rate is a measure of crop productivity. It is the rate of dry matter accumulation per unit area per unit time. It was observed that there was a continuous increase in the growth rate of rice until 70 DAT and declined towards the maturity of the crop because some leaves senesced as the rice plant matured. Similar results were also obtained by Peng et al (2000) that crop growth rate decreased during the grain filling period that is from flowering to physiological maturity.

Table 6. Crop growth rate at different growth stages of lowland rice as affected by planting density and nutrient management

Treatments	Crop Growth Rate (g m^{-2} d^{-1})			
	21-42 DAT	42-56 DAT	56-70 DAT	70-84 DAT
Planting Density (PD)				
M_1=1 seedling $hill^{-1}$ (VSU Practice)	33.25	36.52	46.48	41.72
M_2=3-5 seedlings $hill^{-1}$ (Farmer's Practice)	30.02	36.93	50.78	39.92
Mean	31.64	36.73	48.63	40.82
CV (a) %	15.08	23.03	10.59	22.02
Nutrient Management (NM)				
T_1=0 – 0 – 0 (Control)	24.04^{b}	33.37^{b}	45.30	36.76
T_2=120–60–60kg ha^{-1} N, P_2O_5 and K_2O	40.68^{a}	42.95^{a}	49.34	46.85
T_3=60–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea	31.94^{ab}	37.11^{ab}	50.98	44.41
T_4=45–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	28.27^{b}	36.94^{b}	48.52	39.23
T_5=30–30–30kg ha^{-1} N, P_2O_5 and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea	33.24^{ab}	33.25^{b}	49.02	36.85
Mean	31.64	36.73	48.63	40.82
CV (b) %	13.54	13.24	18.92	21.85
Pr (> F)				
PD	0.4635^{ns}	0.9070^{ns}	0.1496^{ns}	0.6384^{ns}
NM	0.0316*	0.0203*	0.8696^{ns}	0.2266^{ns}
PD × NM	0.4156^{ns}	0.3294^{ns}	0.8945^{ns}	0.5205^{ns}

Means within a column and treatment followed by the same letter and those without letters are not significantly different at 5% level, LSD.

Cost and Return Analysis

The cost and return analysis of lowland rice NSIC Rc400 as affected by planting density and nutrient management is presented in Table 7. The variations in the cost and return of lowland rice could be attributed to the difference in the total production cost and yield. Transplanting of 1 seedling per hill produced a relatively higher net income of PHP22,655.07 ha^{-1} compared to 3-5 seedlings per hill of PHP17,697.60 ha^{-1} due to the higher yield obtained by the former treatment. On the other hand, application of 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2) gave the highest net income of PHP44,840.88 ha^{-1} among the fertilizer treatments at PHP21kg^{-1} prevailing price of palay and also higher benefit-cost ratio though comparable with the control (T_1). This was attributed to its lower production cost and higher grain yield among other treatments. Nevertheless, its grain yield, yield parameters, and other agronomic parameters were either higher or comparable with T_3. However, among other integrated nutrient treatments, plants applied with 60–30–30kg ha^{-1} N,

P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) obtained the second-highest net income of PHP26,431.55 ha^{-1} due to its highest grain yield and gross income but exhibited higher production cost. This resulted in to benefit-cost ratio of only 0.47 but comparable to unfertilized control (T_1) and 45–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_4) with PhP 23,125.67 ha^{-1} and PHP13,739.71 ha^{-1} net income, and 0.97 and 0.24 benefit-cost ratio, respectively. On the other hand, application of 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) resulted in a net loss of PHP-7,256.14 ha^{-1} due to lower grain yield and higher production cost incurred, that resulted to a benefit-cost ratio of -0.13. The high total production cost was attributed to the more frequent application of foliar spray of urea and labor in applying vermicast as a source of organic nutrients. This is a significant growth barrier for organic production since higher expenses, through materials and labor, are incurred in producing organic crops (Adhikari 2011, Uematsu and Mishra 2012).

CONCLUSION

Based on the results obtained, the following conclusions can be drawn:

1. Transplanting one seedling per hill produced more filled spikelets per panicle than 3-5 seedlings per hill regardless of nutrient management applied. Early heading and maturity were noted at T_1, T_4 and T_5 treatments. Application of integrated nutrients at 30–60kg ha^{-1} N, and 30kg ha^{-1} P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly or biweekly foliar spray of urea (T_3–T_5), significantly increased the plant height, LAI, fresh straw yield, number of productive tillers, weight of panicles and grains per hill, and grain yield. These results were comparable to plants treated with 120–60–60kg N, P_2O_5, and K_2O ha^{-1} (T_2).

2. Transplanting lowland rice (NSIC Rc400) at one seedling per hill produced slightly higher grain yield than at 3-5 seedlings per hill. Application of integrated nutrients at 45-60kg ha^{-1} N and 30kg ha^{-1} P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly or biweekly foliar spray of urea (T_3 and T_4) produced higher grain yield than plants treated with 30–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + weekly foliar spray of urea (T_5) and unfertilized control (T_1). The former integrated treatments however, produced comparable yield with the recommended dose of inorganic fertilizer at 120–60–60kg N, P_2O_5, and K_2O ha^{-1} (T_2).

3. Transplanting of one seedling per hill and application of 120–60–60kg ha^{-1} N, P_2O_5, and K_2O (T_2) resulted in highest net income and benefit-cost ratio. Among the integrated treatments, application of 60–30–30kg ha^{-1} N, P_2O_5, and K_2O + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) generated a higher net income and benefit cost ratio, next to the recommended dose (T_2).

RECOMMENDATIONS

1. It is recommended to transplant only one seedling per hill (VSU Practice) and apply 60–30–30kg N, P_2O_5, and K_2O ha^{-1} + 2.5t ha^{-1} vermicast + biweekly foliar spray of urea (T_3) for NSIC Rc400 especially if the farmer has his own vermicast production to lessen the cost of inorganic fertilizer while improving soil fertility.

2. It is also recommended that a similar study be conducted during dry season to verify the results of this study.

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