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Research Article

Yield Performance and Nutrient Uptake of Red Rice Variety (MRM 16) at Different NPK Fertilizer Rates

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Global demand for high-quality rice and healthy food has increased, especially to the affluent and health-conscious consumers. Red rice has been consumed because of its health benefits. Red rice has met the concepts of productivity and quality that emerged to supply the demands for products that improve the eating pattern of its consuming population. Red rice is based on food industries especially for nutrition-based food products and baby food products. For the case on Malaysia, limited domestic supplies of red rice have led to full dependency on imported red rice supplies in the country. Recent statistics showed that the Sarawak state can be one of the potential areas for the development of red rice production due to its vast land resources; proper guidelines which suit the agroecosystem in Sarawak for cultivation of red rice are essential. As for rice production in general, proper application of fertilizers enhances the yield and to a certain extent sustains soil productivity. Considering the needs to establish a proper fertilizing program especially for red rice production in Sarawak, a preliminary study was conducted to evaluate the yield and yield components of red rice variety (MRM 16) with three levels of NPK fertilizers (Treatment 1, control; Treatment 2, 60 : 35 : 40; Treatment 3, 120 : 70 : 80; and Treatment 4, 180 : 105 : 120 (proportions of N, P_2O_5, and $K_2O{\cdot}ha^{-1}$, respectively)). The experiment was conducted in the pot trial during main season 2016 (December 2016–April 2017). The yield parameters including rice yield, panicle no./m^2, 1000-grain weight, spikelet number per panicle, and percentage of filled spikelets were collected. The results showed that yield was not significantly affected by the increment of the NPK fertilizer added at a rate of more than 60 kg/ha N, 35 kg/ha P, and 40 kg/ha K (T2). From the study, it was observed that the yield and yield components of red rice variety (MRM 16) were best in T2 (60 kg/ha N, 35 kg/ha P, and 40 kg/ha K).

1. Introduction

Rice is a staple food for more than half of the world population [1]. In Asia, rice is important as a source of income to a million of rice farmers and landless workers [2]. Malaysia requires an additional rice production by 1,320,000 tonnes per year to fulfill the 90% self-sufficiency level in rice production for year 2060 to support the population growth rate [3]. In the state of Sarawak, 134,260 ha land is planted with wetland and upland rice. A total of rice production in Sarawak is 237,111 tonne [4]. Sarawak is the country's fifth largest rice producer, after Kedah, Perak, Kelantan, and Perlis. According to Teng [5], several areas in Sarawak have been identified as suitable for lowland rice production, namely, Banting, Bijat, Lingga, Paloh, Pulau Bruit, Sungai Sebelak, and Samarahan.

Red rice has a great potential to be marketed as a health-based food product which includes baby food product due to its valuable nutritional contents especially antioxidant properties [6]. Red rice is valued for its antioxidant properties. It is used in breads, coloured pasta, vinegar, alcoholic beverage, drugs, and cosmetics [7]. Procyanidins are the main compounds with antioxidant activity of red rice ([8]). In Malaysia, limited domestic supplies of red rice have led to dependency on imported red rice supplies in the country. Since the Sarawak state is one of the potential areas for the development of red rice production due to its vast land resources, proper guidelines which suit the agroecosystem in Sarawak for cultivation of red rice is essential.

Fertilizer is the major input and one of the most important factors in rice production. Good fertilizer management can increase rice yield and reduce production cost. It is required to supply the nutrient requirements for plants and to attain high performance in the rice plant [9]. Practice of proper management strategies like adequate rate and timing of fertilizer application can increase rice yield and influence cost of production. Nitrogen (N), phosphorus (P), and potassium (K) are applied as fertilizers in large quantities to rice fields, and a deficiency of either of the nutrient leads to yield losses. There are many factors that influence the nutrient absorption including cultivar, soil type, fertilizer type, fertilization technology, and environmental factors [10–12]. Imbalanced N, P, and K fertilization application can affect soil productivity [13]. Proper guidelines, especially for the fertilizing program for production of red rice, are yet to be in place in Sarawak. Therefore, to achieve a potential yield of red rice, adequate nitrogen, phosphorus, and potassium fertilization at the proper dates and proper rate is essential. No study on the effect of nitrogen, phosphorus, and potassium on yield and yield components of red rice has been done in Sarawak, and the site-specific fertilizer requirement is not known. The findings will help to facilitate the potential of different fertilizer rates in the red rice field before being introduced to local farmers. The objectives of this study were to (i) evaluate the yield and yield components of red rice at different fertilizer rates and (ii) to determine the nutrient uptake of red rice cultivated at different fertilizer rates.

2. Materials and Methods

2.1. Experimental Design. Altogether 100 pots of 28 cm in diameter and 30 cm in height were used in this experiment. The experiment was laid out in randomized complete block design (RCBD) with 5 replications and conducted during main season 2016 (December 2016–April 2017) in greenhouse at MARDI Kuching, Sarawak. Amount of fertilizers applied in each pot was calculated based on the pot surface area. Nitrogen, potassium, and phosphorus rates for each treatment are shown in Table 1.

Nitrogen (urea) was applied at 5, 25, 45, and 65 days after transplanting (DAT), respectively. Phosphorus (Triple superphosphate) was applied in two equal splits at 5 and 45 DAT, while potassium (muriate of potash) was applied in two equal splits at 5 and 45 DAT, respectively. The physicochemical properties of the soils used in this study are summarized in Table 2.

Table 1: Nitrogen, potassium, and phosphorus rates for each treatment.

Treatment	N (kg/ha)	P (kg/ha)	K_2O (kg/ha)
T1 (control)	0	0	0
T2	60	35	40
T3*	120	70	80
T4	180	105	120

*Recommended treatment by MARDI, 2008.

Table 2: Physicochemical properties of the soils used in the study.

Properties	Mean values
Particle-size distribution	
Silt (%)	50.1
Clay (%)	45.6
Sand (%)	4.4
Silt + clay (%)	95.7
pH	5.2
C (%)	5.8
N (%)	5.0
C : N ratio	19.5
Available P (ppm)	37.4
CEC (cmolckg^{-1})	21.4
EC (μS cm^{-1})	173.8
Exchangeable K	1.5

2.2. Crop Establishment. A red rice variety MRM 16 which was developed by MARDI from crossing MRQ72 and ER6275 was used in this study. The MRM 16 seeds were soaked in clean water for 24 hours and incubated for 24 hours before sowing. The 25-day-old seedlings were transplanted with one seedling to each pot. Pest control and weeding and other intercultural operations were done as needed.

2.3. Determination of Yield Parameter. Panicles from each plant in pots were collected at maturity (115 days). Panicles were placed into bags and labelled to determine yield and yield components. Grain and panicles were separated. Filled and empty grains were separated and counted. Then, filled grain was weighed. Yield component data (total spikelet number per panicle, 1000-grain weight, number of panicles, and percentage of filled grains) from all treatments were determined. Straw (except spikelet) and grain fresh and grain dry weight for each sampling were recorded. The grain harvest index (GHI) was calculated by using the following formula [14]:

$$\text{grain harvest index} = \frac{\text{grain yield}}{\text{grain + straw yield}}. \quad (1)$$

2.4. Plant Sampling for Nutrient Uptake Analysis. After final growth performance, data were collected and panicles were harvested; each plant from each pot was cut at the ground level. According to treatment, leaves were separated from the stem and placed in different paper bags. Then, leaves and stem fresh weights were recorded prior to drying. All samples were oven-dried at 70°C until constant weight. Before subsamples were taken for N determination, each sample was weighed and ground. Nutrient content in the vegetative parts and grains was measured by using the standard micro-Kjeldahl procedure (Bremner and Mulvaney) [15]. Nutrient uptake in grain and straw was calculated by multiplying the nutrient concentration (%) in grain and straw by their respective yield.

2.5. Statistical Analysis. The data were analyzed using analysis of variance (ANOVA) of SPSS 22. Tukey's test [16] was carried out for mean comparisons on the parameters measured between all treatments. Treatments were compared using the analysis of variance at $p \leq 0.05$. Correlation analysis was also performed to evaluate the relationship between yield and N, P, and K uptake.

3. Results and Discussion

3.1. Grain Yield of Rice. Grain yield of all fertilizing treatments was higher than that of the control (Figure 1). Yield was not significantly affected by the increment of the NPK fertilizer added at a rate of more than 60 kg/ha N, 35 kg/ha P, and 40 kg/ha K. Further increase did not result in significant change because grain filling may be limited by a low contribution of postassimilates. Yields in this study were similar to the grain yield of the red rice variety given by MARDI. Variety MRM 16 in this study produced 4.1, 4.3, and 4.2 tonne/ha in Treatments T2, T3, and T4, and this was similar to the expected amount by MARDI at a range of 4.0–4.5 tonne/ha.

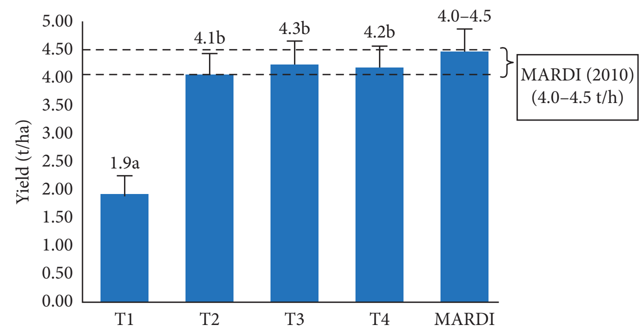

Figure 1: Yield of MRM 16 as affected by four different fertilizer rates 1.9 ± 0.07 a (T1), 4.1 ± 0.06 b (T2), 4.3 ± 0.13 b (T3), 4.2 ± 0.10 b (T4). Within a column, means followed by a different letter are significantly different at 0.05 probability level according to the Tukey's significant difference test.

3.2. Yield Components of Rice

3.2.1. Number of Panicles, Total Number of Spikelets, and Filled Spikelet Percentage. Grain yield was examined by breaking the yield into its four yield components: number of panicles, spikelet number/panicle, filled spikelet percentage, and 1000-grain weight. Total dry biomass weight, grain harvest index (GHI), panicle number/m^2, 1000-grain weight, spikelet number per panicle, and percentage of filled spikelets per panicle of red rice variety (MRM 16) grown in pot culture conditions differed among treatments (Table 3).

Application of NPK resulted in significantly different percentages of filled spikelets, spikelet numbers per panicle, and panicle numbers/m^2 compared to T1. With NPK levels above T2, the rice plant did not show an increase in yield components. The filled spikelet percentage was reduced when more N, P, and K fertilizer was applied. There was an increase in the proportion of unfilled spikelets per panicle. Wu et al. [17] also reported similar results that increasing the rates of N, P, and K fertilizers favoured vigorous growth of the rice plant. This resulted in competition for metabolic supply among spikelets and affected the production of fertile spikelets. The maximum filled grain was related to T3 with 64.6% filled grains. T1 gave the minimum of filled grains percentage (39.3%). However, the result indicated that there was no significant difference when more N, P, and K fertilizer was applied. The results showed that 1000-grain weight was not significantly affected by N, P, and K fertilizer treatments. Increase in N, P, and K fertilizer application did not affect the grain weight. This probably caused a genetical character fixed by an individual variety [18]. According to Yoshida [19], 1000-grain weight is the least important component among all yield components because it is rigidly controlled by the hull size. Value of 1000-grain weight is affected by maturity conditions. Reductions in 1000-grain weight were also observed with the increase of N, P, and K fertilizer rates. This is probably caused by absence of enough amount of stored substance to retransfer to kernel and also reduction in the photosynthesizing area and lowliness of sump which has a deterring effect on producing organs [20].

3.3. Nutrient Uptake

3.3.1. Relationship between the Grain Yields and Total Aboveground N, P, and K at Maturity across All Treatments. The effects of N, P, and K fertilization on nutrient uptake of the rice plants in the pot trial were determined. Analysis of variance (ANOVA) for grain yield, total aboveground N, P, and K uptake, and N, P, and K harvest index (NHI, PHI, and KHI) is shown in Table 4. The grain yield (GY) only showed significant difference between 0 kg N/ha and the other three N rates (Figure 1). Total aboveground N uptake (TNU) differs significantly between all treatments. Grain yields showed a strong positive relationship to the total aboveground N at maturity across all treatments (Figure 2).

Highest uptake of total nitrogen was recorded with an application of 180 kg N/ha, 105 kg P/ha, and 120 kg K/ha. A low nitrogen uptake with zero application (T1) of fertilizer indicates that the indigenous soil nitrogen supply was very low. Nitrogen uptake steadily increased from the fertilizer source as the rate of the applied fertilizer nitrogen increased. Improvement in N uptake with increased N levels was reported by Sandhu and Mahal [21]. N fertilizer significantly improved rice plant N uptake and also increased the grain yield. However, when N rates exceeded 120 kg kg/ha, grain yield decreased, but plant N uptake increased significantly. This study also found that yield was not affected with the increment of the NPK fertilizer more than 60 kg N/ha, 35 kg P/ha, and 40 kg K/ha.

Nitrogen harvest index (NHI) was referred as N partitioning or the ratio of grain N uptake to the total aboveground plant N uptake. NHI analysis showed significant differences between T1 and all other three treatments, respectively. This is an agreement with Artacho et al. [22], who reported that N fertilization was not significantly affecting NHI. NHI values recorded as in Table 4 were ranging between 0.5 and 0.6 and showed that more than half of the N fertilizer applied was taken up by the rice plant. N concentration in grain is always higher than straw [23]. According to Quanbao et al. [24], NHI was reversed when N application rate was increased.

Table 3: Total dry biomass weight, grain harvest index (GHI), panicle number/m^2, 1000-grain weight, spikelet number per panicle, and percentage of filled spikelets per panicle of red rice variety (MRM 16) grown in pot culture conditions as affected by different treatments.

Total dry biomass (t/ha)	GHI	Panicle no./m^2	1000-grain weight (g)	Spikelet no./panicle	Filled spikelet (%)
11.20 (±0.96)a	0.14 (±0.02)a	228 ± 8a	28.7a	122 ± 7.59a	39.3 ± 6.24a
16.44 (±2.40)b	0.19(±0.03)b	276 ± 8b	28.9a	153 ± 5.42b	64.1 ± 2.07b
18.02(±0.40)b	0.19 (±0.01)b	280 ± 9b	29.1a	155 ± 6.45b	64.6 ± 3.4b
16.56(±1.79)b	0.20(±0.02)b	276 ± 15b	28.8a	157 ± 2.06b	62.3 ± 0.37b

Within a column, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's significant different test. Data are expressed as mean ± standard deviation.

Table 4: Analysis of variance (ANOVA) for grain yield, total aboveground N, P, and K uptake, and N, P, and K harvest index (NHI, PHI, and KHI).

NPK (kg/ha)	GY (kg/ha)	TNU	NHI
T1	1.94 ± 0.07a	48.0 ± 3.19a	0.5 ± 0.03a
T2	4.09 ± 0.06b	127.8 ± 1.90b	0.6 ± 0.00 b
T3	4.26 ± 0.13b	166.2 ± 7.51c	0.6 ± 0.01b
T4	4.20 ± 0.10b	170.0 ± 8.82cd	0.6 ± 0.03b
NPK (kg/ha)	GY (kg/ha)	TPU	PHI
T1	1.94 ± 0.07a	12.5 ± 0.54a	0.4 ± 0.0a
T2	4.09 ± 0.06b	27.7 ± 0.73b	0.4 ± 0.01ab
T3	4.26 ± 0.13b	31.3 ± 1.86c	0.4 ± 0.02ab
T4	4.20 ± 0.10b	31.7 ± 1.21c	0.4 ± 0.01ab
NPK (kg/ha)	GY (kg/ha)	TKU	KHI
T1	1.94 ± 0.07a	42.2 ± 1.86a	0.11 ± 0.00ab
T2	4.09 ± 0.06b	92.0 ± 2.25b	0.12 ± 0.00bc
T3	4.26 ± 0.13b	103.0 ± 6.22bc	0.12 ± 0.01 abc
T4	4.20 ± 0.10b	111.9 ± 5.13cd	0.11 ± 0.00a

Within a column, means followed by a different letter are significantly different at the 0.05 probability level according to Tukey's significant difference test. NHI = nitrogen harvest index; PHI = phosphorus harvest index; KHI = potassium harvest index; TNU = total aboveground N; TPU = total aboveground P; TKU = total aboveground K.

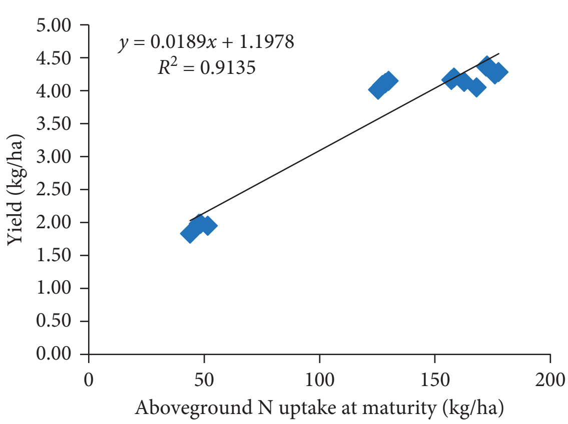

Figure 2: Relationship between the grain yields and total aboveground N at maturity across all treatments.

There was also a strong positive relationship between the grain yields and total aboveground P at maturity across all treatments (Figure 3). The total aboveground P uptake (TPU) differed significantly after the T2 treatment when NPK levels increased. This might be because when more water-soluble P was applied, the available P content in the soil increased [25]. According to Surekha et al. [26], during the nutrient absorption process, anion nutrients like H_2PO_4 are cotransported with NH_4^+, which was absorbed by rice roots; counter release of protons (H^+) takes place to balance the charge. This may cause a decrease in the pH and in turn releases the dissolution of insoluble P compounds in oxidized rhizosphere, which helps absorb more P by the rice plant. PHI values recorded in this study were ranging between 0.4 and 0.5; almost half of P fertilizer applied was taken up by the rice plant. However, PHI analysis only showed significant differences between T1 and all other three treatments, respectively.

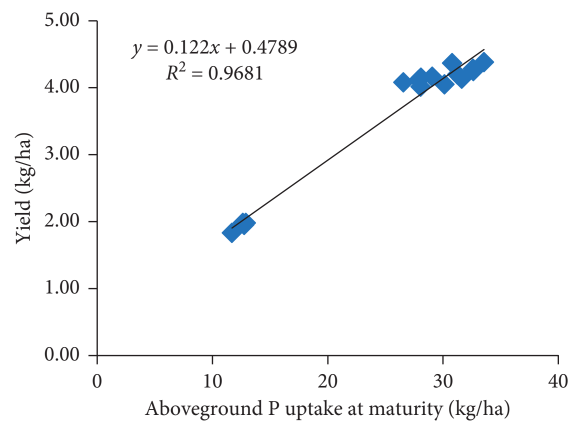

Figure 3: Relationship between the grain yields and total aboveground P at maturity across all treatments.

Similarly, there was a strong positive relationship between the grain yields and total aboveground K at maturity across all treatments (Figure 4). The total aboveground K uptake (TKU) differs significantly when NPK levels increased. Potassium is especially important for grain filling and for reproductive organs. This might be the reason for the large K uptake with increased K levels. Panaullah et al. [27] have reported that the majority of K uptake was in straw compared to grain. Potassium harvest index (KHI) was significantly influenced by NPK rates (Table 4).

The aboveground plant N, P, and K uptake in T1 was 48.0 kg N ha^{-1}, 12.5 kg P ha^{-1}, and 42.2 kg K ha^{-1}, respectively, with an average estimated grain yield (GY) of 1.94 t ha^{-1}, whereas aboveground plant N, P, and K uptake in T2 was 127.8 kg N ha^{-1}, 27.7 kg P ha^{-1}, and 92.2 kg K ha^{-1}, respectively, with an average estimated GY of 4.09 t ha^{-1}. The aboveground plant N, P, and K uptake in T3 was 166.2 kg N ha^{-1}, 31.3 kg P ha^{-1}, and 103.0 kg K ha^{-1} with an average estimated GY of 4.26 t ha^{-1}, whereas aboveground plant N, P, and K uptake in T4 was 170.0 kg N ha^{-1},

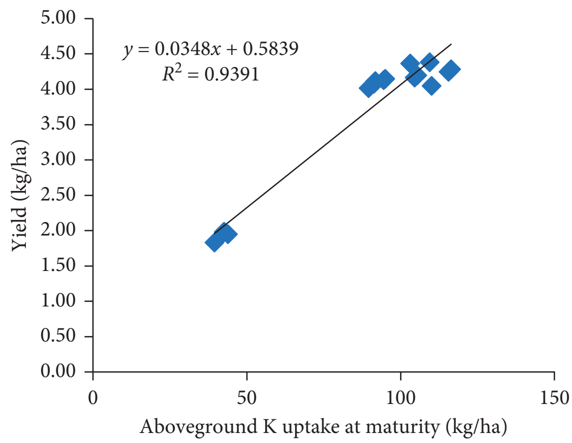

Figure 4: Relationship between the grain yields and total aboveground K at maturity across all treatments.

31.7 kg P ha^{-1}, and 111.9 kg K ha^{-1}, respectively, with an average estimated GY of 4.20 t ha^{-1}. There was a positive relationship between GY and aboveground plant at maturity. Additionally, GY increased with increasing nutrient uptake in this study.

4. Conclusions

Yield performance of red rice MRM 16 did not increase as fertility increased above the lowest application rate. Application of 120_N 70_P 80_K produced the highest yield of 4.26 t/ha as compared to that obtained with lower fertilizer of NPK (1.94 t/ha). Red rice variety (MRM 16) is suitable to be cultivated in Bijat soil, Sarawak, and using fertilizer rates of T2 (N_{60}·P_{35}·K_{40}) which gave similar results when using T3 (recommended treatment) and was more economical. There were no significant effects of fertilizer added at a rate of more than 60 kg/ha·N, 35 kg/ha·P, and 40 kg/ha·K on yield, total dry biomass, GHI, 1000-grain weight, spikelet number per panicle, and filled spikelet percentage. However, this study found that yield and yield components of MRM 16 were better in treatments receiving the NPK fertilizer than in control. Nitrogen (N), phosphorus (P), and potassium (K) are applied as fertilizer in large quantities to rice fields and a deficiency of either nutrient leads to yield losses and triggers complex molecular and physiological responses. Increasing total N, P, and K uptake and NHI, PHI, and KHI are more important rather than applying more fertilizers. This could increase red rice yield, improve soil, water, and air quality, and also reduce nutrient input cost.

Data Availability

The data used to support the findings of this research are available upon request to the author.

Disclosure

The authors have the following similar unpublished master dissertation from this project: M. Zarifah, "Growth performance, yield and yield components of red rice (MRM16) at different fertilizer rate cultivation at Bijat soil," University Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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