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RESEARCH ARTICLE

AEROBIC RICE'S YIELD PERFORMANCE AND NITROGEN USE EFFICIENCY UNDER VARIOUS NITROGEN FERTILIZER RATES

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ABSTRACT

Aerobic rice, a water-saving cultivation system rice could thrive well in rain-fed areas in Sarawak which lacks in drainage and irrigation system, with appropriate fertilizer management practices. Since nitrogen (N) as a major determinant factor in rice yield is required differently based on cultivation system, soil and other in-situ conditions, a study was conducted to determine the optimum N fertilizer rate while assessing nitrogen use efficiency of aerobic rice in Lundu, Sarawak. Four N fertilizer rates (T1=0, T2=100, T3=200 and T4=300 kg N/ha) were tested with split application of urea (46% N) at 23%, 31%, and 46% at 5, 25, and 45 days after emergence (DAE) using MRIA1 variety. The findings indicated that an increase in N fertilizer of more than 100 kg N/ha had no discernible impact on yield. The highest yield recorded was 3.31 t/ha in T2 and decreased to 2.99 t/ha and 2.86 t/ha respectively in T3 and T4, while T1 recorded 1.12 t/ha. Meanwhile, significant differences in partial factor productivity (PFP_N), agronomic efficiency (AE_N), apparent recovery efficiency (RE_N) and physiological efficiency (PE_N) were observed between the treatments with descending efficiency trends at higher N fertilizer rates. Optimum NUE values were recorded in T2 with PFP_N = 29.30 kg/kg; AE_N = 14.56 kg/kg; RE_N = 0.26 kg/kg; and PE_N = 55.64 kg/kg. Therefore, it can be concluded that 100 kg N/ha is recommended for aerobic rice cultivation in Tanjung Purun, Lundu, as yield and NUEs were optimized.

KEYWORDS

Aerobic rice, nitrogen, nitrogen use efficiency (NUE), yield

1. INTRODUCTION

The production of irrigated rice, a crucial element of food security, is at risk due to the growing scarcity of water sources. In Asia, 17 million ha of irrigated rice fields may experience physical water scarcity, while 22 million ha of irrigated rice farming regions may experience economic water scarcity by 2025 (Tuong and Buoman, 2003). Therefore, to address the limitation of water sources, a water-saving production system such as aerobic rice may be able to offer as an alternative solution. In aerobic rice productions system, the soils remain aerobic during the growing period but supplementary irrigation is applied when necessary (Kreye *et al.*, 2009). Aerobic rice is suited for water-shorts environments with favorable soils using high yielding rice varieties which are directly seeded. Sarawak's rice field which is mostly rain-fed with lacks of drainage and irrigation system are one of the targeted areas that aerobic rice system could be introduced and potentially thrived well. With the introduction of specialized variety to aerobic rice system, considerable high yield potential and shorter maturation period compared to photoperiod sensitive traditional varieties currently planted by farmers in Sarawak can transform mono-cropping into double-cropping cultivation. This could possibly increase the current domestic rice production, thus improve the state rice's self-sufficiency level (SSL).

Being a newly introduced technology locally, aerobic rice system is lacking in terms of its agronomic and nutrient management. Nitrogen (N) fertilizer is universally recognized as a key component to high yield and optimum economic return of rice production. A studies stated that adequate N supply is important at various growth stages in rice yield determination since panicle number is determined in vegetative growth stage, while spikelet number, spikelet weight and sterility during spikelet filling or reproductive growth stage (Fageria *et al.*, 2010). Furthermore, N requirement might vary greatly depending on the cultivar and soil texture (Bond *et al.* 2006; Norman *et al.* 2005). Others reported that Nitrogen requirement for aerobic rice is between 120 and 150 kg N/ha and to be applied at early tillering, active tillering and panicle initiation stage, respectively (Sariam *et al.*, 2014).

Belder *et al.* (2005) reported that aerobic rice system had a relatively lower N uptake than flooded environments. This is due to the fact that nitrate, which is the dominant form of nitrogen in aerobic systems, can leach from the soil and result in various pathways for N availability and losses (Belder *et al.,* 2005; Mahajan *et al.,* 2011). According to previous research, the environmental loss of applied nitrogen fertilizer ranges from 50% to 70% (Coskun *et al.*, 2017). The low recovery of N is usually associated with its loss by leaching, denitrification, and volatilization. Recent study reported that only 22% of 150 kg N/ha applied was taken up by the crop, while 31% remained in the soil and roots after harvest (Priyanka *et al.*, 2002). This has contributed to the low yield of aerobic rice of 3 – 4 t/ha as compared to flooded rice which yielded more than twice (Atlin *et al.*, 2006).

In order to improve grain yield while reducing nutrient losses, better nutrient management is needed to improve the Nutrient Use Efficiency (NUE) since it varies depending on variety grown as well as agronomic practices adopted (De Datta, 1970). Several indices could be calculated to determine the NUE. These include partial factor productivity (PFP), agronomic efficiency (AE), apparent recovery efficiency (RE), physiological efficiency (PE) and internal efficiency (IE). Under rain-fed conditions, NUE reported was 20%, while maximum NUE recorded at research plot reached 55%, with the mean of 45% (Balasubramaniam *et al.*, 2004). The differences between actual farms and research plots allows to provide better assessment on the potential to increase this factor through better Nitrogen management (timing, method of application, sources and rates) or site-specific approach. Therefore, it is important to determine the optimum N fertilizer rate based on the existing in-situ condition since the soil physicochemical varies among different landscapes while to ensure the success of this new technology before being introduced to the local farmers. Hence, a study was conducted in rain-fed area of Tanjung Purun, Lundu using MRIA1 rice variety under aerobic conditions.

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2. MATERIALS AND METHODS

2.1 Experimental Design

Field experiment was carried out in Tanjung Purun, Lundu, Sarawak, a rain-fed rice cultivation area which is located at 82 km from Kuching city centre. The experiment was set up using a randomized complete block design (RCBD) with five replications, four Nitrogen (N) rates, and a 5 m by 5 m plot for each treatment. The four N rates applied were 0, 100, 200 and 300 kg N/ha, respectively. Nitrogen was applied three times at 5, 25 and 45 days after emergence (DAE) with 23%, 31% and 46% split, respectively. For all treatments, potassium (K) was applied at 5 DAE and 45 DAE at 60 kg K_2O/ha respectively, while phosphorus (P) was applied at 5 DAE at 60 kg P_2O_5/ha. Urea (46% N), triple super phosphate (46% P_2O_5) and muriate of potash (60% K_2O) were used in this study. The physicochemical characteristics of the soil, which was categorized as riverine alluvium clay under the Gley soils group, are shown in Table 1.

Table 1: Physicochemical Characteristics of The Soil in The Study.

Properties	Mean values
Particle size distribution:	
Fine sand (%)	8.3
Coarse sand (%)	1.1
Silt (%)	41.3
Clay (%)	49.3
Silt + Clay (%)	90.6
pH	5.4
C (%)	2.76
N (%)	0.30
Available P (ppm)	29.85
Exchangeable K ($cmol_c kg^{-1}$)	0.42
CEC ($cmol_c kg^{-1}$)	19.1

2.2 Crop Establishment and Management

MARDI Rice Aerob 1 (MRIA1) variety which has 90 days of maturation period was used in this study. Dry seed at 150 kg/ha seed rate was sowed continuously in rows with 30 cm spacing between rows. Each plot was separated by one meter with periphery raised bund of 30 cm x 30 cm in height and width. Throughout the growing period, the experiment only relied on rain for water supply. Standard pest, disease and weed control was applied based on MARDI's Aerob Rice Cultivation Technology Manual (Sariam *et al*., 2013).

2.3 Yield Components Determination

At harvest, all panicles from 10 rows of 4 meter each were collected, placed into different paper bags, and labelled accordingly. Grain yields for each treatment are corrected and reported as per hectare basis at the standard moisture content of 14%. Straw yield, number of panicles, number of spikelets per panicle, 1000 grain weight and filled grain (%) were determined from four hills of each plot. The formula below was used to determine the grain harvest index (GHI).

$$\text{Grain harvest index (GHI)} = \frac{\text{Grain yield (kg)}}{\text{Grain + Straw yield (kg)}}$$

2.4 Plant Sampling for N Uptake Analysis

The same four hills from each plot which were used for yield components determination were cut at ground level. Leaves and stems were separated in various paper bags in accordance to the respective treatments. Prior to drying, the fresh weight of the stem and leaves was recorded. All these samples were oven-dried at 70°C until consistent weight was attained. Each sample was weighed and grounded before subsamples were taken for N content determination using the standard Kjeldahl method (Bremner and Mulvaney, 1982). The N concentrations (%) in grain and straw were multiplied with their respective yield to determine the nitrogen uptake. Then, nitrogen use efficiency (NUE) indices were calculated using the equation below as described by (Dobermann and Fairhurst, 2000):

i. Partial factor productivity (PFP_N) = kg grain/ kg N applied

= GY_{+N} / FN

ii. Agronomic efficiency (AE_N) = kg grain yield increase/ kg N applied

= ($GY_{+N} - GY_{0N}$) / FN

iii. Apparent recovery efficiency (RE_N) = kg N taken up/ kg N applied

= ($UN_{+N} - UN_{0N}$) / FN

iv. Physiological efficiency (PE_N) = kg grain yield increase/ kg N fertilizer taken up

= ($GY_{+N} - GY_{0N}$) / ($UN_{+N} - UN_{0N}$)

Where:

GY_{+N} = grain yield in a treatment with N application (kg/ha)

GY_{0N} = grain yield in a treatment without N application (kg/ha)

FN = amount of fertilizer N applied (kg/ha)

UN_{+N} = total plant N uptake measured in aboveground biomass at maturity in a treatment with N application (kg/ha)

UN_{0N} = total plant N uptake measured in aboveground biomass at maturity in a treatment without N application (kg/ha)

2.5 Statistical Analysis

The data collected was tabulated to make analysis of variance (ANOVA) and Tukey's Test was used for mean comparisons on the parameters measured according to Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1 Yield of Aerobic Rice

Grain yield of aerobic rice as affected by different N fertilizer applications is shown in Figure 1. Although significant difference in yield was only observed between T1 and the other three treatments, however, there was an increase in yield of aerobic rice by 148% to 174% when N fertilizer was applied (T2, T3 and T4) as compared to T1. Highest yield of 3.31 t/ha was recorded in T2 with the application of 100 kg N/ha. This is consistent with studies conducted in the Philippines found that aerobic rice yields ranged from 1.5 to 7.4 t/ha and 3 to 4 t/ha, respectively (George *et al*., 2002; Atlin *et al*., 2006).

However, the yield was reduced insignificantly when N fertilizer was increased to 200 kg N/ha (T3) and 300 kg N/ha (T4). This might be due to differences in soil N dynamics and pathways in dry sown rice system, which lead to varying N fertilizer recoveries. According to Zhang *et al.* (2009), grain filling in aerobic rice may be constrained by a poor post-assimilate contribution, which could have an impact on yield performance even with higher rate nitrogen applications.

Furthermore, a studies reported that in aerobic rice cultivation system, nitrate (NO_3^-) is the dominant form of N which results in different pathways of N availability and losses compare to ammonium (NH_4^+) in flooded environments (Belder *et al.,* 2005; Mahajan *et al*., 2011). Moreover, NO_3^- ion requires more energy to metabolize as compared to NH_4^+ in flooded rice. Sasakawa and Yamamoto (1978) also found a one-hour lag phase in the uptake of nitrate in experiment using rice seedlings compare to ammonium uptake which was taken up within the first 10 minutes. This would affect the availability of the seedlings to produce tiller which is one of the yield determinant factors. The present of oxygen (O_2) as in aerobic condition also decreased nitrate uptake by rice which affect the yield potential even though more N fertilizer is applied (Sasakawa and Yamamoto, 1978).

3.2 Yield Components of Aerobic Rice

Grain harvest index (GHI), panicle number, 1000 grain weight, spikelet number and percentage of filled spikelet are shown in Table 2. The grain harvest index (GHI), which measures the ratio of dry grain yield to total biomass dry weight, is a crucial factor in regulating how photosynthetic product is distributed between shoots and grains, which in turn affects grain yield (Ishii, 1995). The addition of more N fertiliser did not result in significant variations in GHI values, and the only treatment in this study where GHI exhibited significant differences was T1. Kiniry *et al.* (2001) reported that GHI ranged widely between 0.35 and 0.62, showing the significance of these factors for yield enhancement across cultivars, regions, seasons, and ecosystems (Kiniry *et al*., 2001). From this study, GHI recorded was between 0.34 and 0.48. Additionally, the total biomass and yield of aerobic rice will be greatly impacted by the increase in nitrogen

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rate from 0 to 150 kg/ha (Lampayan *et al*. 2010). While GHI is a measure of the economically useful fraction of the biological yield, total dry biomass weight is a measure of a crop's photosynthetic performance which can be manipulated through better nutrient management such as fertilizer application timing and sources that can contribute to yield increment (Yoshida, 1981).

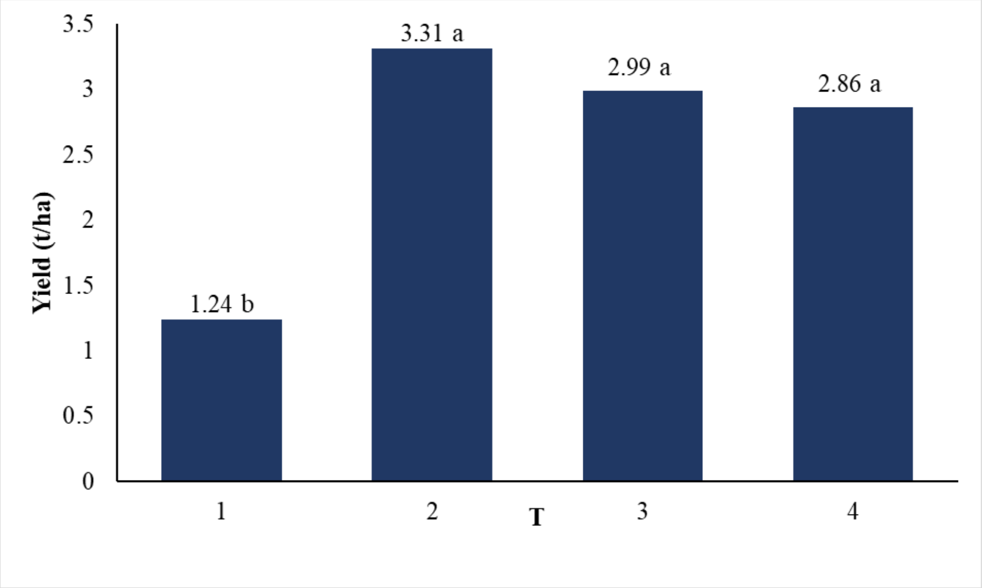

Figure 1: Aerobic rice yield under different rate of Nitrogen fertilizer treatment.
Means followed by a different letter are significantly different at p<0.05 according to Tukey's significant difference test.

Table 2: Grain Harvest Index (GHI), Panicle Number/M², 1000 Grain Weight, Spikelet Number/ Panicle and Filled Spikelet (%) For Each Treatment.

T	GHI	Panicle no. / m²	1000 grain weight (g)	Spikelet no. / panicle	Filled spikelet (%)
T1	0.34 b	93 b	27.1	82 b	51.5 b
T2	0.46 a	156 a	28.3	95 ab	72.7 a
T3	0.48 a	141 a	28.0	101 a	69.4 a
T4	0.45 a	133 ab	27.6	109 a	68.8 a

Within a column, means followed by a different letter are significantly different at p<0.05 based on to Tukey's significant difference test.

Grain productivity relies on both panicle and its total spikelet number. Application of N resulted in 43.0% to 67.7%, 15.9% to 32.9% and 33.6% to 41.2% increase in panicle number/m², spikelet number/panicle and percentage of filled spikelet (%) respectively compared to T1. Application of 46% of total N in this study at panicle initiation stage has influenced spikelet differentiation that improved the yield components by improving grain filling process which is in accordance with the findings as reported by (Guindo *et al*., 1994). Furthermore, stated that the amount of N absorbed throughout the reproductive growth stage, in addition to the contribution of photosynthesis, is the most crucial component in determining the number of spikelets (Ishii, 1995). However, when more than 100 kg N/ha of fertilizer was applied, no significant differences were observed despite the additional N applied in T3 and T4. This is primarily due to the applied N fertilizer remained in the soil and not absorbed by the plants as also reported by (Priyanka *et al*., 2002). Gebrekidan and Seyoum (2006) also found that percentage of filled spikelet was reduced when N application is more than 150 kg/ha. Increased N fertilizer rates favored vigorous growth of the rice plant, which led to competition for metabolic resources among spikelets and impacted the fertile spikelet production (Gebrekidan and Seyoum, 2006; Hasegawa *et al*. 1994; Wu *et al*. 1998).

Among the yield components, the 1000 grain weight is the least significant because the hull size controls it rigidly and it is a stable varietal characteristic (Yoshida, 1981). As shown in this study, when no significant difference was observed, the grain would not grow to a larger size than permitted by its hull size regardless of how favorable the weather or nutrient supply were. There was also a slight reduction observed in 1000 grain weight with increasing levels of N fertilizer. This is probably caused by the insufficient supply of carbohydrates to individual spikelet due to competition effect resulted by vigorous rice growth and the increased number of its spikelet (Hasegawa *et al*. 1994).

3.3 Nitrogen Uptake

Table 3 shows the results on grain-N uptake, straw-N uptake and total aboveground N uptake (TNU) of aerobic rice cultivated at different N levels. The results showed that grain-N uptake between T1 and all other three treatments were significantly different. Although there was no significant difference in grain-N uptake between treatments receiving N at different levels, grain-N uptake did seem to gradually increased when N levels were raised. While straw-N uptake increased significantly as more N fertilizer was supplied. According to Kiniry *et al*. (2001), translocation of nitrogen from leaves to grain during grain filling process causes the nitrogen content in rice grains to be higher than in the straw, as shown in this study (Kiniry *et al*., 2001).

Total aboveground N uptake (TNU) differs significantly only between T1 and the other treatments. However, there is a positive relationship between grain yield (GY) and total nitrogen uptake (TNU) at maturity (Figure 2), with 82% of the variability in grain yield attributable to TNU. Therefore, TNU should be improved in order to boost the production potential of aerobic rice since this will promote vigorous vegetative development and supply sufficient carbohydrate to spikelets during grain filling.

Table 3: Grain-N Uptake, Straw-N Uptake and Total Aboveground N Uptake (TNU).

T	Grain-N uptake	Straw-N uptake	TNU
T1	14.45 b	16.94 c	31.39 b
T2	37.04 a	23.11 bc	60.15 a
T3	38.79 a	25.33 ab	64.13 a
T4	41.95 a	31.61 a	73.55 a

Within a column, means followed by a different letter are significantly different at p<0.05 based on to Tukey's significant difference test.

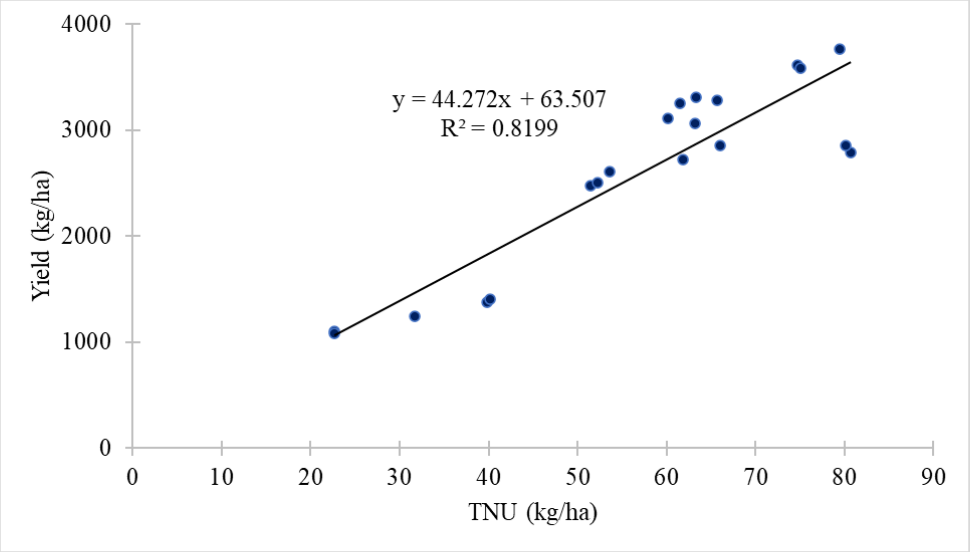

Figure 2: Relationships between total aboveground N uptake (TNU) at maturity and yield for all treatments.

Table 4: Partial Factor Productivity (PFP_N), Agronomic Efficiency (AE_N), Apparent Recovery Efficiency (RE_N) And Physiological Efficiency (PE_N) Of Aerobic Rice.

T	PFP_N	AE_N	RE_N	PE_N
T1	-	-	-	-
T2	29.30 a	14.56 a	0.26 a	55.64 a
T3	12.90 b	5.53 b	0.15 b	41.36 a
T4	8.32 c	3.41 b	0.13 b	26.11 b

Within a column, means followed by a different letter are significantly different at p<0.05 based on to Tukey's significant difference test.

3.4 Nitrogen Use Efficiency (NUE)

Results on partial factor productivity (PFP_N), agronomic efficiency (AE_N), apparent recovery efficiency (RE_N) and physiological efficiency (PE_N) are shown in Table 4. There are significant differences observed between the treatments with descending efficiency trends when higher rates of N fertilizer were applied.

PFP_N refers to kg yield produced from every kg N applied. Analysis of PFP_N values in this study demonstrated a significant difference between all treatments. When N was increased from 100 to 300 kg N/ha, PFP_N decreased from 29.30 to 8.32 kg grain per kg N applied. This result is consistent with Singh *et al.* (2015), who found that increasing N fertilizer from 90 to 150 kg/ha caused PFP_N to decline from 48.2 to 31.0 kg grain per kg of N applied. Singh *et al.* (1998) reported that when N levels applied was enhanced, as in this study, nutrient response was decreased. The same situation was discovered by Prasad *et al.* (2000), who showed that the PFP_N value declined from 84 kg grain/kg N at 40–60 kg N/ha to 32 kg grain/kg N at 121–180 kg N/ha. It can be assumed that this condition might be due to higher N losses when more N fertilizer was applied (Daftardar and Savant, 1995; Singh et al., 2015; Singh et al., 1998; Prasad et al., 2000).

AE_N of applied N is the additional yield produced from each kg of applied N. In this study, AE_N value varied from 3.41 to 14.56 kg grain/kg N applied. The results also indicated that AE_N analysis only showed significant different between T2 and both T3 and T4. Similar to PFP_N, application of N at 100 kg/ha has the highest AE_N value. In accordance with Prasad *et al.* (2000), when the amount of N was increased from 40 – 60 to 121 – 180 kg N/ha, the AE_N in rice reduced from 22 to 13 kg grain/kg N. In general, AE_N ranged from 0 to 35 kg/kg, while in Asian farmers' field, AE_N recorded is 10 – 15 kg grain per kg N applied (Dobermann and Fairhurst, 2000).

RE_N value represents the quantity of N that the crop recovers and absorbs. It was regarded as the key indicator for describing rice's characteristics for N uptake and utilization. In this study, 26% (0.26 kg/kg) of N is recovered when 100 kg N/ha (T2) was applied. This was significantly different when compared with RE_N values at T3 and T4, respectively. Although, all treatments with N applied (T2, T3 and T4) were within the general 0% to 90% of recovery range (Dobermann and Fairhurst, 2000). However, these findings suggested that more applied N are lost rather than being taken up by the rice plant. A total loss of 74%, 85% and 87%, respectively are recorded across the three treatments with applied N. Data from this study also indicated that RE_N value was decreased with increasing N applications, which was in line with the finding by (Tayefe *et al.*, 2011). However, Quanbao *et al.* (2007) found that RE_N increased before peaking at 225 kg N/ha, then considerably decreased following the application of 300 kg N/ha in clay soil. This suggested that at higher N levels, RE_N values decrease as also observed in other NUE indices. This could probably be due to the limitation of the rice plant to take up extra N saturated in the soil because of water stress which could limit the transpiration process as it reduces the mass flow of nutrient to roots (Quanbao *et al.*, 2007).

PE_N value represents the additional yield produced for each additional kg of N uptake. Additionally, it demonstrates a plant's capacity to produce an economic yield from a specific amount of acquired fertilizer nutrients (Dobermann and Fairhurst, 2000). PE_N in a plant is greatly influenced by genotypic traits like harvest index and internal nutrient use efficiency (Dobermann and Fairhurst, 2000). In this study, PE_N values recorded were significantly different only between T4 and both T2 and T3. PE_N values varied from 26.11 to 55.64 kg grain/kg N uptake. As for 100 kg N/ha applied, 50 kg additional grain was produced per kg N uptake which was the highest among all treatments. PE_N values in this study were decreased when more N fertilizer was applied. This finding was similar to Tayefe *et al.* (2011) and Quanbao *et al.* (2007). Quanbao *et al.* (2007) further found that PE_N under clay soil as in this study was lower when compared to sandy soil. In addition, the alternating wet and dry soil conditions may promote nitrification and denitrification processes, causing nitrogen to be lost as N_2 and N_2O (Prasad, 2011). Priyanka et al. (2002) discovered that after harvest, 31% of the 150 kg N/ha applied remained in the soil and roots, while only an average of 22% is being absorbed by the crop.

There are several ways to increase NUE of aerobic rice such as proper management of crop, soil and fertilizer application and techniques. Since, NUE depended on crop yield; therefore, it is the most important component to be addressed critically. Effective crop agronomic management which includes proper nutrient practices; pest, disease and weed control; superior variety with optimum seed rate and date of sowing could improve crop yield potential (Prasad, 2007). Improving Nitrogen uptake of the crop would also help improve yield potential. This could be achieved by matching the Nitrogen supply with the crop demand.

Soil and plant testing are two crucial methods to determine the optimum N supply and crop demand. By adjusting the N fertilizer application based on indigenous soil N could eliminate over supplying and improve crop N uptake. Soil chemical analysis could considerably increase NUE by assisting in predicting the amount of N fertilizer to be applied in advance.

Additionally, nondestructive methods of plant testing such as SPAD chlorophyll (Peng *et al*., 1996) and leaf colour chart (Buresh, 2007; Yang *et al*., 2003) readings could be used for adjusting the crop's N need during the growing season. When the leaf nitrogen status falls below the empirically calibrated threshold as established by the SPAD and/or leaf colour chart, N fertilizer is applied. To improve N uptake further and reduce N losses, fertilizer application method also plays a significant role. According to De Datta *et al*. (1989) and Mohanty *et al*. (1999), deep placement or incorporation of nitrogen fertilizer rather than broadcasting could help boost crop N uptake and hence improve NUE. All these factors could be regarded as it would improve crop yield potential through better N uptake and NUE (Mohanty *et al*., 1999).

4. CONCLUSION

Optimum yield, yield components and NUEs of aerobic rice in this study were recorded with the application of N fertilizer at 100 kg/ha, thus is recommended for aerobic rice cultivation using MRIA1 variety in Tanjung Purun, Lundu.

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