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Improving rice grain yield in KADA by site-specific nutrient management

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Abstract

Blanket fertilising recommended in KADA may lead to over-fertilising or under-fertilising in some areas. Site-specific nutrient management (SSNM) strategies increase rice grain yield effectively. An experiment at nine different locations was performed in a single factor completely randomised design. The treatments were complete N, P and K fertiliser, P and K fertiliser without the N component, N and K without the P component, N and P without K component and NPK omission altogether. This study aimed to determine the SSNM approaches to gain rice yield in KADA. The parameters taken were yield components and grain yield. SSNM did not influence spikelets/panicle, spikelets/m^2 and 1000-grain weight. Complete NPK, NK and NP fertiliser significantly had greater filled grain (%) than NP and without NPK fertilizer. Our results showed that N was the limiting factor for filled grain (%) production. Application of 105 kg N/ha, 44 kg P_2O_5/ha and 78 kg K_2O/ha could increase rice grain yield from 6.0 t/ha to 7.0 t/ha in KADA. Recommendations based on SSNM strategies could solve low grain yield and provide balance and sustainable rice cultivation in KADA.

Keywords: rice, fertiliser recommendations, soil nutrient, site-specific nutrient management

Introduction

Rice is a highly prioritised commodity in Malaysia's national food security agenda. According to Che Omar et al. (2019), the government spent RM2.3 billion in support through incentives, including input and price subsidies, in Malaysia's 2018 budget report. Despite these efforts, rice productivity has been difficult to rise, and the country has consistently produced 65% to 70% of its domestic needs for many years (Ali 2017). According to Ramli et al. (2012), the self-sufficiency level (SSL) in Malaysia under the current scenario with total fertiliser subsidy if remained the same (urea, compound and NPK fertiliser) could decrease gradually to 55.6% in 2025 due to no improvement in yield and no increment in fertiliser usage. This is despite an increasing trend in total consumption because of population growth at 2% per year. Kemubu Agricultural Development Authority (KADA) is one of the important granary areas to enhance self-sufficiency level of rice in Malaysia. The average rice production is only 3.86 t/ha, the third-lowest of all the granaries, even though KADA is the second greatest planted area of the eight granaries (Intan Nurdiah and Abdullah 2013). Farmers heavily depend on subsidised fertiliser. Increasing the fertiliser rate significantly increases the rice yield in granary areas (Ramli et al. 2012; Vaghefi et al. 2016). However, most of the farmers are reluctant to buy additional fertilisers beyond the subsidised quantity (Alam et al. 2011). Soil survey carried out in selected areas in KADA in 1982 showed no differences in soil characteristics but had low fertility that could limit and make it less suitable for intensive rice cultivation (Kaishoven et al. 1984) and the use of fertilisers could solve these constraints. According to Kari (2018), the government has been practising readjustment of price since 1980 to support increase of rice grain yield. Most farmers are concerned over the suitability of subsidised fertilisers with the soil type. Site-specific nutrient management as a technique for optimising fertiliser application to meet the field-specific needs of crops could increase crop production and profitability (Bana et al. 2020).

Site-specific nutrient management (SSNM) for irrigated rice cultivation and nutrient application based on crop demand is essential (Peng et al. 2010). The principle features of SSNM are site-specific application based on soil tests for nitrogen, phosphorus and potassium and optimal use of available nutrients in the soil (Verma et al.

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2020). This provides a fundamental method to precision nutrient applications required by rice plants. However, rice plants supply of required nutrients mostly does not meet the demand in achieving high rice grain yields (Dass et al. 2014). Research conducted by Rodriguez (2020) identified that nitrogen is an essential nutrient because it could increase tillering, leaf area growth, biomass production and grain yield and these yield components could be improved further by SSNM through proper N timing and splitting.

In Northwest India, field-specific macronutrient management enhanced rice and wheat crop yields by 12% and 17% and saved a significant amount of N by 8% and 10% for rice and wheat (Khurana et al. 2008). A study conducted in the states of Punjab, India, showed SSNM reduced N input between 15 – 35% and significantly increased rice and wheat grain yield by 4 – 8% (Sapkota et al. 2021). Field-specific nutrient management adapted from SSNM tested at Odisha State in Eastern India showed an increase in rice grain yield between 2.8 – 7.9 t/ha as compared to previous yields between 1.7 – 6.3 t/ha and this technique provide a uniform application of nutrients (Sharma et al. 2019). According to Shahi et al. (2020), SSNM enhances the yield and profitability of maize under sub-humid conditions in Meerut, Uttar Pradesh, India as compared to the recommended dose of fertiliser through improving the soil fertility and nutrient uptake in maize plants. A study conducted on hybrid sunflower seed production in Southern Karnataka, India showed significantly higher seed yield (1003 kg/ha) by 26% compared to the recommended dose of fertiliser (797 kg/ha) because of balanced and optimal quantity of nutrients at the root zone, which allowed the crop to use and accumulate more total dry matter, which was then translocated into seeds through SSNM techniques (Patil et al. 2018). Yield maximisation for soybean using SSNM techniques was significantly higher than recommended dose of fertiliser, as greater nutrient availability and uptake improved translocation of food assimilates from vegetative to reproductive parts (Sankalpa and Math 2018). Based on these previous studies, crops yield could be achieved greater than recommended dose of fertiliser or blanket fertiliser through adopting SSNM which can ensure efficient use of nutrients. Blanket fertiliser application recommendations may lead to over-fertilising or under-fertilising in some areas (Richards et al. 2016). Thus, the SSNM study aims to optimise the supply of soil nutrients to match the rice requirements for farmers in KADA.

Materials and methods

Site location

Ladang Merdeka in KADA namely, Meranti, Ana, Manan, Kolam, Teratak Pulai, Senor, Mulong, Tok Lebir and Jabil were chosen for the experiment. Soil samples were collected at two different depths before planting. A depth of 0 – 20 cm for soil nutrient analysis and a depth of 20 – 40 cm for mechanical analysis. The sampling grids of 50 m x 50 m from each location comprising 144 soil samples were collected. The collected soil samples were air-dried, crushed and sieved to pass through a 2 mm sieve and stored at room temperature under dark conditions until analysis was done. Soil pH was determined by a digital pH meter. Organic carbon was determined by the Walkey-Black method. Cation exchange capacity (CEC) and exchangeable potassium (K) were determined by the ammonium acetate leaching method with 1 M ammonium acetate at pH 7. The total nitrogen (N) was determined by the Kjeldahl method, while the available phosphorus (P) was determined by the method of Bray and Kurtz.

Site-specific nutrient management trials

Each location involved five treatments. The treatments used were with complete nitrogen (N), phosphorous (P) and Potassium (K) receiving all three N, P and K fertiliser; 0-N (N omission) receiving P and K fertiliser but no N component; 0-P (P omission) receiving N and K but no P component; 0-K (K omission) receiving N and P but no K component; 0-NPK (NPK omission) receiving none of the N, P and K components. Urea as a source of N was applied at 103.10 kg N/ha in four split applications at 5 days after transplanting (DAT), 20 DAT, 45 DAT and 65 DAT which were 23.80 kg N, 36.80 kg N, 34.0 kg N and 8.60 kg N, respectively. Triple Super Phosphate (TSP) as a source for P fertiliser was applied in three split applications, at 5 DAT (28.0 kg P_2O_5), 45 DAT (23 kg P_2O_5) and 65 DAT (1.5 kg P_2O_5). Muriate of Potash (MOP) as a source of K fertiliser was applied in three split applications; 5 DAT (14.0 kg K_2O), 45 DAT (35 kg K_2O) and 65 DAT (12.5 kg K_2O). The experiment was conducted during off season in 2019 and main season between 2019 – 2020.

Recommendation for weed, pest and disease control in SSNM were followed based on Othman et al. (2008). The plots were 5 m x 5 m plots with 1 m separation between treatments. An earthen bund surrounded each plot to retain water and prevent flow between plots of water with fertilisers. MARDI Siraj 297 variety was chosen as the planting material and it was transplanted after 18 days of sowing in a seedling tray.

Yield and yield components

Number of panicles from four hills were used to calculate panicles number/m^2. Then, the mean of panicle/hill multiplied with 18 (18 hills/m^2 = 30 x 18 cm spacing) as the number of panicles number/m^2. Measurements were recorded at 90 days after transplanting. A total number of filled grains and unfilled grains per panicle selected from eight panicles from the main tiller of eight hills were used to calculate the percentage of filled grain (%) as the formula below.

% filled grain = (filled grains/total number of grains) x 100

A total of 1000 grains from each plot were selected randomly and weighed with portable automatic electronic balance at 14% moisture content to calculate 1000-grain weight and expressed in gram (g).

A total of grain weight from the central 4 m x 4 m of each plot was used to calculate the grain yield and expressed in t/ha. The final grain yield followed the calculation based on Dobermann and Fairhurst (2000).

Grain yield = ((PlotGy x [(100-MC)/86])/1000)x 10000/A

Where PlotGy is grain yield/plot adjusted to 14% moisture, MC is a grain moisture content, and A is the area of plot harvested.

Nitrogen, phosphorous and potassium nutrient calculation

The calculation of N, P and K fertiliser nutrients from the gap between the nutrients required by the crop to achieve a specific yield and the indigenous supply of the nutrient followed Witt et al. (2002) as below:

$FN = (GY - GY_{0N}) \times UN/REN;$
$FP = (GY - GY_{0P}) \times UP/REP \times 2.292\ [-15\%];$
$FK = (GY - GY_{0K}) \times UK/REK \times 1.2\ [-15\%];$

Where FN, FP and FK are the recommended fertiliser N, P_2O_5 and K_2O rates in kg/ha; GY is the desired yield goal (t/ha); GY_{0N}, GY_{0P} and GY_{0K} are the grain yields measured in nutrient omission plots (0-N, 0-P, 0-K) (t/ha); UN, UP and UK are the plant uptake requirements of 17.5 kg N, 2.6 kg P and 15 kg K per ton grain yield; and REN, REP and REK are the expected fertiliser recovery efficiencies of 45 – 50% for N, 25% for P and 50% for K. In addition, Witt et al. (2002) pointed out to reduce 15% of P and K fertiliser rates, as K is returned into soil at each harvest through incorporation of straw.

Statistical analysis

The general linear model procedure in Statistical Analysis System (SAS 9.3) software was used to perform an analysis of variance (ANOVA) to compare the main effects of treatment and season. The location was treated as replication. Mean values of the treatments were compared using the least significant difference test (LSD) at the $p < 0.05$ probability level.

Results and discussion

The soil chemical and physical analysis for nine locations is presented in *Appendix 1*. According to Naim et al. (2015), for rice cultivation, soil pH between 5.5 – 6.5 is optimum. The present study showed that Ladang Merdeka Ana, Kolam, Teratak Pulai, Tok Lebir and Jabil had pH lower than 5.5. Manickam et al. (2020) reported that cation exchange capacity (CEC), ($cmol_{(+)}$ / kg) is a useful indicator of soil fertility because it shows the soil's ability to hold nutrients. In which, CEC ≥ 20 is considered high. In this study, all locations had moderate CEC (11 – 19) except for Meranti, Manan, Kolam, Teratak Pulai and Jabil which could be considered borderline. CEC is soil pH-dependent, as CEC increased with increasing soil pH (Edmeades 1982). Thus, low pH at the study location was related to low CEC. To increase the pH, liming is essential (Naim et al. 2015). In intensive rice cultivation, indigenous nitrogen (N) in soil is always insufficient and N fertilisation is required. The optimum total N for rice cultivation is between 0.2 – 0.3% in soil (Dobermann and Fairhurst 2000). In this study, Kolam, Teratak Pulai, Senor, Tok Lebir and Jabil had lower total nitrogen content (%) in soil which was below 0.2%. At the same time Manan and Mulong had total nitrogen of 0.2% in soil which could be considered borderline. However, Meranti and Ana showed optimum N in soils. The mean concentration of available P (>40 mg/kg) and exchangeable K (>0.1 $cmol_{(+)}$/kg) in soil exceeds the optimum level (Aishah et al. 2010). Based on USDA soil classification all site locations are silty clay except for Senor which was clay (*Appendix 1*). The Senor soil contains a high proportion of clay more than 54% and 38% of silt compared with others ranging from 42 – 53% clay and 45 – 55% silt. Genrally, soil texture is a fixed property that cannot be altered until a considerable volume of these components is added or removed (Chinachanta et al. 2020). However, clay and clay loams, silty clay loams, or silt loams are considered the most desirable for rice cultivation. Soil with high clay and silt content provide conditions for slow water percolation (Ferrero and Tinarelli 2008). These soil have finer particles that can retain more water and nutrients needed by rice plants (Dou et al. 2016). Thus, we can anticipate that the yield performances between these nine locations may not differ much because of the soil texture.

Analysis of variance on yield components and rice grain yield is presented in *Table 1*. According to the results of ANOVA, filled grain (%) and rice grain yield were significantly affected by treatment. Spikelet/panicle and 1000-grain weight were significantly affected by season. No significant interaction between treatment and season was observed in this study. Spikelet/m^2 was not affected by treatment and season.

The number of spikelets/panicle is crucial for rice productivity. Nitrogen is a key nutrient that limits the crop's growth and yield potential. Studies have shown that the application of nitrogen fertiliser during the early panicle stage can increase the number of spikelets/panicle (Ding et al. 2014; Fongfon et al. 2021). This trait is affected by different physiological factors such as water regime in a series of physiological processes that involve the development of floret differentiation (Liu et al. 2021). Other studies demonstrated that the spikelet number could only be influenced by temperatures where it could increase in conditions of temperature drop from 31 °C to 25 °C (Yoshida 1973), declined as the temperature increases from 29.6 °C to 36.2 °C (Jagadish et al. 2007) and decrease when the temperature at the booting stage

Table 1. Significance of mean squares in the analysis of variance (ANOVA) of rice grain yield across nine locations and two seasons.

Source	Mean square					
	Spikelet/ panicle	Panicle/m^2	Spikelet/m^2	Filled grain (%)	1000-grain weight (g)	Yield (t/ha)
Treatment (T)	ns	ns	ns	**	ns	**
Season (S)	*	ns	ns	ns	**	ns
Main-season	114	254	29249	80.9	25.7	4.6
Off-season	106	264	27802	80.1	27.9	4.43
T x S	ns	ns	ns	ns	ns	ns
Mean	110	259	28525	80.6	26.8	4.5

increased from 9 °C to 20 °C (de Souza et al., 2017). Additionally, water stress caused a higher rate of pre-flowering spikelet abortion and spikelet number was reduced by half on average because of inhibited cell growth or carbohydrate metabolism in the floral organs (Kato et al. 2008). Our research showed that despite the treatment without N, P and K (NPK omission) the performance of spikelets/panicle was comparable to the full application of nutrients and the spikelet per panicle was higher in the main season than in the off season by 7.5%. Thus, in this study, the number of spikelets is closely related to rice plant genotypes and environment rather than nutrients application and the number of spikelets/panicle is highly affected under drought conditions (off season).

The number of spikelets/m^2 is the product of the number of spikelets/panicle multiplied by the number of panicles/m^2. Application of P improved rice growth in terms of panicles/m^2 (Atakora et al. 2015; Badawi et al. 2019). In low P-environments, rice plants could regulate root growth with stronger vigour to adapt to a low-phosphorus condition to maintain normal growth but could decrease the number of panicles (Deng et al. 2020). Our results showed that the number of spikelets/panicle and number of panicles/m^2 was not significant (*Table 1*) thus the number of spikelets/m^2 was also not affected by any treatments. This is because the available P in the soil was adequate for rice plants to maintain normal growth and generate optimal rice panicles.

The filled grain (%) was significantly higher in NK fertilisation (P-omission plot; 86.5%) but did not differ between full NPK (85.8%) and NP (K-omission plot; 83.8%). However, these treatments were significantly different with PK (N-omission plot; 73.3%) and without any NPK (NPK omission; 73.5%). Yesuf and Balcha (2014) reported that N fertiliser has a positive effect on filled grains in rice. It was found that the highest filled grain percentages have resulted from N balanced fertilisation because N nutrition is important for both source and sink development. In this study, the response of filled grain (%) to the P and K fertiliser was not as sensitive as that of N fertilisation (*Figure 1*). Rice filled grain (%) was the lowest without N fertilisation as shown by PK treatment even though the available P and exchangeable K in soil were optimal for rice growth. Thus, our studies indicate that N could be the limiting factor for rice to obtain maximum filled grain (%).

Omission treatments did not affect 1000-grain weight. However, the grain weight was affected by season. According to Borrell et al. (1999), N fertilisation did not affect grain size but significant genotypic variations suggest that the grain size is more readily manipulated by genetic than agronomic factors. Other studies have also reported that 1000-grain weight was not affected by N, P and K because it is a strong genetic fixed by an individual variety (Masni and Wasli 2019), relatively stable (Zhou et al. 2017) and a constant characteristic because the size of grain controlled by the size of the hull (Yoshida 1981). Thus, it is unsurprisingly 1000-grain weight did not influence by omission treatments. In winter oats, for example, grain width was most affected by environment during grain filling where high temperatures reduce the width length and consequently lower the 1000-grain weight (Howarth et al. 2021). Our results showed that 1000-grain weight was higher by 8.7% in the off season than in the main season could be due to higher temperature

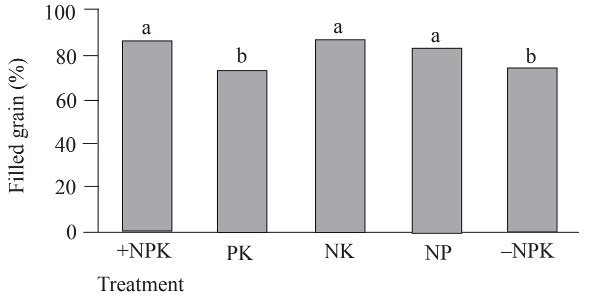

Figure 1. Filled grain (%) as a response to different SSNM treatments

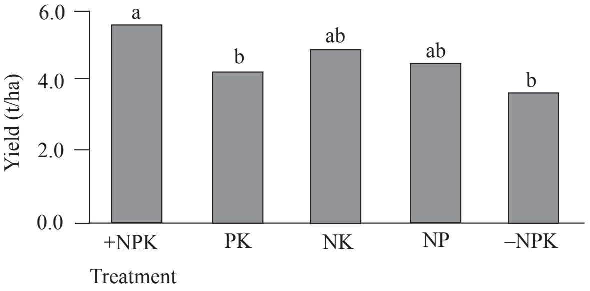

Figure 2. Grain yield as a response to different SSNM treatments

during grain filling may limit the grain size production. *Figure 2* showed the yield differences between treatments. The highest grain yield was obtained from full NPK fertilisation that produced 5.51 t/ha. In fertiliser omission plots, the highest grain yield was obtained from the P omission plot (treated only NK fertiliser) followed by the K omission plot (treated only NP fertiliser) but statistically had no difference in grain yield. The P and K omission plots yielded 4.84 t/ha and 4.45 t/ha respectively. The grain yield in full NPK fertilisation was higher by 14% and 24% compared to P and K omission plots respectively. The lowest grain yield was obtained from the NPK omission plot (-NPK) but statistically had no difference in rice grain yield with the N omission (treated only PK fertiliser) plot. The grain yields were 3.63 t/ha and 4.16 t/ha, respectively. Results of this study showed the remarkable influence of N fertilisation on rice grain yield. According to Mwamba Kalala et al. (2017) nitrogen was the first limiting nutrient for rice cultivation and yield obtained from field plot excluded N always resulted in low yield. Ran et al. (2018) reported that the importance of the relative nutrients affecting rice yield was N fertiliser followed by K and P. This was because the direct effect of N fertilisation on rice grain yield by increasing the number of panicles, promoting better stomatal conductance, net photosynthesis and transpiration rate. According to Sun et al. (2014) rice flowering time (heading date), is an important agronomic trait where heading at a proper time is the most critical step for grain production. Advanced flowering reduces the vegetative phase leads to a reduction of grain yield. In addition, according to Ye et al. (2019), rice flowering was delayed by 1 – 4 days after application of N, and the more the N application, the later the flowering. N fertilisation extended flowering time, whereas P and K fertilisation had little effect on flowering time. The present study showed that without N (treatment received only PK and without NPK) fertiliser had the lowest grain yield. We speculate that without adequate N the rice plants tend to induce early flowering and had the lowest grain filling rate and shorter grain filling period to complete the full cycle as shown by lower filled grain (%) in PK (N omission plot) and without NPK (NPK omission plot). On the other hand, that the highest grain yield (NPK treatment) was obtained by the insignificant highest in spikelets/panicle, panicles/m^2, spikelets/m^2 (data not shown) and greater in filled grain (%).

Based on Witt et al. (2002) fertiliser calculation, NPK requirement to increase rice grain yield up to 7.0 t/ha in KADA is recommended at 105:44:78. In comparison, the currently subsidy package in KADA for rice cultivation is 103:53:62. Rice farmers are often risk-averse, reluctant to adjust fertiliser practices and lack the financial capital to buy additional fertiliser. Thus, a new fertiliser package typically aims for a yield that is only slightly higher than the farmer's historical yield to reduce fertiliser costs (Buresh et al. 2019). In this study, the new fertiliser rate for KADA would increase 2% of N and 26% K but lower 17% of P. Application of P and K fertilisation do not respond in soil with high P and K concentration (Mwamba Kalala et al. 2017). According to Budiono et al. (2019) nutrients that exceed the optimum level, such as P and K concentration high in the soil, only a low rate of P and K fertiliser should be applied as maintenance. This study showed that N requirements in KADA were inadequate to contribute to high rice grain yield while P application was more than adequate. However, the K application was higher than the subsidy recommendation even though the soil analysis showed that K concentration in soil was at the optimum level. According to Banerjee et al. (2018) K fertilisation is unavoidable to obtain a high grain yield even though the soil has high available K content. According to them, rice plants response to K uptake in soils high with K may be restricted by magnesium concentration in soils that could limit the right balance between the efficiency and effectiveness of K fertiliser. Another finding also reported that K replenishment through fertiliser was inadequate because K removal by rice plants have been removed in excess of the amount of K added to the soil (Islam et al. 2016; Saha et al. 2009). Thus, the new rate recommendation for KADA with slightly higher N, reduce P and increase in K to accommodate the nutrient contents in soil that were low of total N, exceeded the optimum value of P and K.

Conclusion

The high yield potential of rice grain in KADA can never be exploited with inadequate and unbalanced fertilisation. Site-specific nutrient management (SSNM), based on soil indigenous nutrients on nine locations showed that 105 kg N/ha, 44 kg P_2O_5/ha and 78 K_2O/ha could improve rice grain yield up to 7.0 t/ha in KADA.

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Appendix 1. Soil chemical and physical characteristic on selected area in KADA for omission study

Parameter	Mean								
	Meranti	Ana	Manan	Kolam	Teratak Pulai	Senor	Mulong	Tok Lebir	Jabil
Soil chemical									
pH	5.5	5.3	5.5	5.4	5.2	5.5	5.7	5.4	5.3
CEC cmol$_{(+)}$/kg	20.7	17.7	21.7	21.02	21.5	17.6	18.4	18.1	21.9
Organic C (%)	2.64	4.13	1.90	2.29	2.19	1.45	2.78	1.75	2.05
Total Nitrogen (%)	0.23	0.29	0.20	0.19	0.19	0.16	0.2	0.12	0.16
Available P (mg/kg)	57.3	48.4	52.7	49.6	32.84	71.32	38.0	53.3	56.4
Exchangeable K cmol$_{(+)}$/kg	0.33	0.21	0.30	0.17	0.17	0.22	0.23	0.41	0.17
Soil physical									
Coarse sand	0.20	0.63	0.02	0.95	9.08	6.55	0.08	0.13	0.33
Fine sand	0.33	0.20	0.20	0.40	1.48	0.88	0.15	0.40	0.18
Silt	51.00	46.88	49.00	54.20	47.20	38.18	45.83	55.05	55.60
Clay	48.50	52.30	47.43	44.43	42.30	54.43	53.98	44.38	43.95
USDA soil texture	Silty clay	Silty clay	Silty clay	Silty clay	Silty clay	Clay	Silty clay	Silty clay	Silty clay