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Increasing rice grain yield by split application of nitrogen rates

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Abstract

Rice is the world's second most commonly grown cereal crop and more than half its population consumes it as a carbohydrate source. Proper nitrogen management is the key to improve rice grain production. This study aimed to determine the critical nitrogen split application time and proportion at different rice growth stages. A total of 15 nitrogen split applications were evaluated in randomised complete block design (RCBD) with three replications at Ladang Merdeka Mulong, KADA, Kelantan during off-season in 2019 and main-season in 2019/2020. The fertiliser rate of 105 kg N/ha : 52 kg P_2O_5/ha : 87 kg P_2O_5/ha was used in off-season in 2019/2020 and 97 kg N/ha : 43 kg P_2O_5/ha : 84 kg was used in main-season 2019/2020. The results showed that different splitting applications and amounts of nitrogen significantly influenced the number of panicles/m^2, spikelets/m^2 and the rice grain yield. Spikelets/panicle, percentage of filled grain and 1000 grain weight were similar for all treatments. Our findings suggested that, applying nitrogen at three different stages (20% of nitrogen at 3-leaf stage, 30% at active tillering and 50% at 10 days before panicle initiation) is an effective strategy in increasing rice grain yield.

Keywords: split nitrogen, rice grain, fertilisation, grain yield

Introduction

In Malaysia, rice is given the most priority in the national food security agenda. According to Che Omar et al. (2019), in Malaysia's Budget Report 2018, the government offered RM2.3 billion in assistance and incentives, including input and price subsidies. Furthermore, rice has become the most important food crop in Malaysia, despite other commercial commodities such as palm oil and natural rubber. Due to a lack of available agricultural land and high production costs, the government heavily regulates the domestic rice market by subsidising rice farmers and implementing price support schemes to boost domestic production. Despite these initiatives, rice productivity has improved slowly and over many years, the country only produced 65% to 70% of its own needs (Ali 2017). The development of new fertiliser technologies affects rice production and rice grain yields are highly dependent on appropriate fertilisation systems (Nordin Md et al. 2015). Inadequate fertiliser application reduces crop yield, causes nutrient depletion and depletes soil fertility (Aishah et al. 2010). A study by Yousaf et al. (2017) in China showed that the highest rice yield was observed under NPK application followed by NP and NK, while the lowest yield was under PK fertilisation. These results indicated that fertilisation under NPK for rice was statistically better than the other fertiliser treatments. Ran et al. (2018) suggested that more accurate fertilisation strategies are needed to respond to soil, environmental and terrain changes. According to Guo et al. (2017), farmers in China practice higher nitrogen (N) input and improper application resulting in lower rice grain yield. Rodriguez (2020) reported that N is an essential nutrient because it could increase tillering, leaf area growth, biomass production and grain yield. Thus, proper timing and splitting of N are the foundation of science-based nutrient management. In rice cultivation, nitrogen fertiliser is essential for yield and quality (Zhang et al. 2020).

Many studies highlight the importance of adequate N fertiliser application for promoting higher rice grain yield. Nitrogen promotes rapid rice production, increasing the leaf area, spikelets per panicle and the percentage of filled grain (Dobermann and Fairhurst 2000). Sufficient N must remain in leaves to allow photosynthesis to continue, yet sufficient N must be transported to grains to permit normal grain development and adequate reserves to be stored (Shiratsuchi et al. 2006). Sufficient N at panicle

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initiation could meet crop N demand during grain filling (Blumenthal et al. 2008) and provide higher grain yield (Perez et al. 1996). Application of 50% N at panicle initiation increased the grain yield compared to 25% and 34 % at panicle initiation, respectively (Raj et al. 2014). Grain yield, the number of productive tillers and harvest index were improved when N was applied at sowing, tillering and panicle initiation compared to without nitrogen at panicle initiation (Gebremariam and Barakdan 2016). Application of 30% N at the vegetative stage and 70% at the reproductive stage increased the number of effective tillers, plant height, straw yield, panicle length, % filled spikelet and grain yield (Tadesse et al. 2017). According to Kamruzzaman et al. (2014), the three-N split applications at 15 days after transplanting (DAT) followed by 30 DAT and 45 DAT at equal rates significantly improved rice grain yield. The findings were similar to Pan et al. (2012) who reported that N split applications at basal (30%) followed by 10 DAT (20%) and 36 DAT (50%) increased grain yield and nitrogen recovery efficiency. However, Youseftabar et al. (2012) showed that four-N split applications at basal, mid-tillering, panicle initiation and flowering stages at equal N rates produced the highest grain yield. In addition, Djaman et al. (2018) also reported that four-N split applications of 40, 30, 20 and 10% applied at 14 DAT, panicle initiation, booting and flowering stages produced the highest grain yield.

These studies indicate that proper nitrogen management is the key to improving rice grain production. However, studied are still required for rice cultivation in Malaysia to split the N into three or four applications to improve the rice grain yield. Therefore, the objective of this field study was to evaluate N splitting (3-N split against 4-N split) at different growth stages of rice.

Materials and methods

Study site and soil

The study was conducted during the off season in 2019 and main season in 2019/2020 at Ladang Merdeka Ismail Mulong, Kemubu Agricultural Development Authority (KADA) Kota Bharu, Kelantan. The longitude and latitude of the study area were 6.05°N and 102.24°E. Ladang Merdeka Ismail Mulong is currently the second largest under the Ladang Merdeka project, which covers 98.97 ha with rice cultivation. The Ladang Merdeka project combines much idle paddy land with planned cultivation that can help increase country rice production. Ladang Merdeka is one holistic infrastructure development project due to irrigation and drainage systems, roads farms and land levelling supplied in one complete package. The soil was sampled at 0 to 20 cm depth before trial and was physically and chemically characterised (*Table 1*). According to USDA textural triangle, the soil was classified as silty clay.

Fertiliser treatment and application

The total fertiliser rate of 105 kg N/ha: 52 kg P_2O_5/ha: 87 kg K_2O/ha during off season in 2019 and 97 kg N/ha: 43 kg P_2O_5/ha: 84 kg K_2O/ha during main-season 2019/2020 were used in the experiment. The treatment consists of 15 different splits of nitrogen fertiliser application that were applied at different rice growth stages. A total of 20% and 30% of N were applied at 7 DAT and 25 DAT as a standard for all N treatments (*Table 2*). The treatments applied were Urea (46%), triple super phosphate (46% P_2O_5) and muriate of potash (60% K_2O). For each treatment full amount of phosphorus and potassium were applied at 7 DAT according to off-season and main season fertiliser rate recommendations. The treatments were arranged in randomised complete block design with three replications.

Table 1. Soil physical and chemical properties before planting

Parameters	Rice soil (0 – 20 cm)
pH	5.7
CEC $cmol_{(+)}$/kg	18.4
Organic C (%)	2.78
Total nitrogen (%)	0.2
Available P (mg/kg)	38.0
Exchangeable K $cmol_{(+)}$/kg	0.23
Coarse sand (%)	0.08
Fine sand (%)	0.15
Silt (%)	45.83
Clay (%)	53.98

Experimental plots

The plot size was 5 m x 5 m and the experimental plots were bunded manually to control the mixing of treatments. All crop management followed the guidelines of the (Manual Teknologi Penanaman Padi Lestari), MARDI (Othman et al. 2008). The high-yielding variety MARDI Siraj 297 was used in this study with 105 maturation days after transplanting. Seeds were soaked for 24 hours in water and left in moist condition with shading for 36 hours for good establishment. The healthy seedlings with similar plant height were selected for uniformity purpose. The 18 days old seedlings were manually transplanted with a planting distance 18 cm x 30 cm with three seedlings per point. Data on plant growth, yield and yield components were collected from the experimental plots.

Measurement of rice grain yield and yield components

Four hills per treatment above ground biomass were taken as sampling points to determine yield components at maturity. Panicles were hand-threshed and filled spikelets were separated from unfilled spikelets. The total number of filled and empty spikelets were added to determine the total spikelets/m^2. The 1000-grain weight was determined

Table 2. Splitting and timing of nitrogen fertiliser for each treatment

Treatment	3-leaf stage (7 DAT) % N	Active tillering (25) % N	PI –10 (35) % N	PI – 5 (40) % N	PI – 0 (45) % N	PI + 5 (50) % N	PI + 10 (55) % N	Heading (65) % N	Total N-split
T1	20	30	50	0	0	0	0	0	3
T2	20	30	0	50	0	0	0	0	3
T3	20	30	0	0	50	0	0	0	3
T4	20	30	0	0	0	50	0	0	3
T5	20	30	0	0	0	0	50	0	3
T6	20	30	40	0	0	0	0	10	4
T7	20	30	0	40	0	0	0	10	4
T8	20	30	0	0	40	0	0	10	4
T9	20	30	0	0	0	40	0	10	4
T10	20	30	0	0	0	0	40	10	4
T11	20	30	30	0	0	0	0	20	4
T12	20	30	0	30	0	0	0	20	4
T13	20	30	0	0	30	0	0	20	4
T14	20	30	0	0	0	30	0	20	4
T15	20	30	0	0	0	0	30	20	4

Note: PI = panicle initiation. – = days before; + = days after. DAT = days after planting

from filled spikelets which were dried to 14% moisture content and weighed on a precision balance (ME3002, Mettler Toledo). Grain moisture content was measured with a digital moisture tester (Model SS-7, Satake). Spikelets per panicle, percentage of filled grain (100 x filled spikelets/m^2 total spikelets/m^2), 1000-grain weight and harvest index (100 x yield/total dry weight) were calculated.

Tiller's number/m^2 was calculated based on tiller numbers from four hills. The mean tiller number per hill was multiplied by 18 (18 hills/square meter = 18 x 30 cm spacing) as the number of tiller numbers per square meter. Panicles/m^2 were calculated based on panicles numbers from four hills. The mean number of panicles per hill was multiplied by 18 (18 hills/m^2 = 18 x 30 cm spacing) as the number of panicles/m^2. Measurements were taken 90 days after transplanting.

The grain yield was calculated based on the weight of 4 x 4 m of each plot. The grain yield was converted to mass/ha (kg/ha). The final grain yield followed the calculation proposed by Dobermann and Fairhurst (2000).

$$\text{Grain yield} = [(\text{PlotGy} \times [(100 - \text{MC})/86)])/1000] \times 10000/A$$

The PlotGy is grain yield per plot adjusted to 14% moisture, MC is grain moisture content and A is harvested area.

Data analysis

All data were expressed as means ± standard error and analysed using the ANOVA procedure in the SAS Statistical software package (version 9.4 for windows). Differences among treatments were determined using the least significant difference (LSD) test at the 0.05 probability level.

Results and discussion

Table 3 shows the computed F values for the differences in yield components between the two study seasons and the N-split treatments. The results showed a significant difference (p <0.01) in spikelet panicle and a significant difference (p <0.05) in spikelet/m^2, 1000-grain weight and rice grain yield and no significant different (p >0.05) in panicle/m^2 and filled grain among the two seasons. The computed F values also showed a significant difference (p <0.05) in panicle/m^2, spikelet/m^2, 1000-grain weight

Table 3. Analysis-of-variance of F-values of yield components and rice grain yield among season and N-split treatments

Source	DF	Panicle/m^2	Spikelet/panicle	Spikelet/m^2	Filled grain (%)	1000-grain weight (g)	Yield (t/ha)
Season (S)	1	NS	**	*	NS	*	*
Off-season 2019		292 ± 6.4a	103 ± 1.5b	30027 ± 634b	92.2 ± 0.3a	28.4 ± 0.09b	7.9 ± 0.11b
Main-season 19/20		264 ± 6.3a	169 ± 2.4a	44537 ± 1208a	92.1 ± 0.3a	29.4 ± 0.08a	9.3 ± 0.10a
Treatment (T)	14	*	NS	*	NS	NS	**
S x T	14	NS	NS	NS	NS	NS	*
Error	56						
Corrected total	89						

Values are means ± standard error. NS, not significant at the p = 0.05. **Significant at the p <0.01. *Significant at the p <0.05

and rice grain yield among the N-splits treatment. There was a significant interaction (p <0.05) between season and treatment in rice grain yield but not on other yield parameters (*Table 3*).

In off season 2019, the number of panicles/m^2 (292) was statistically similar to the main-season 2019/2020 (264). *Table 4* shows T12 (4-N splits) produced the highest number of panicles with the application of N at the 3-leaf stage (20%), active tillering (30%), five days before panicle initiation (30%) and at heading (20%). The increase was 16.8% compared to T1, the highest among the 3-N splits treatment. In addition, T4 showed the lowest panicle number (238) in all treatments. Nitrogen contributes to rice panicle formation by stimulating cell division in the reproductive stage (Jahan et al. 2022). Applying N during this stage promotes the production of dry matter and ensures the nutrition needed for the development of panicles (Zhou et al. 2022). Split applications of nitrogen resulted in N utilization more efficiently, contributing to greater photosynthesis towards the sink and the source and sink relationship of rice changes at this specific period (Kumar et al. 2017). Each tiller has the potential to produce a panicle which is a crucial component of grain yield (Yoshida 1981). An extraordinarily high number of panicles in T12 may be due to the application of N for this particular treatment that produced late emerging tillers. Increasing N fertiliser improved the traits of main stems and early-emerging tillers and produced many low-yield late-emerging tillers. The late-emerging tillers reflect the average of all panicles with fewer spikelets/panicle and low filled grain (%) than panicles from the primary tillers (Wang et al. 2017). Our experimental findings, which showed that T12 had an average of fewer spikelets/panicle and less filled grain (%), may help to explain these behaviours (*Table 4*).

Season significantly influenced the number of spikelets per panicle. During off-season 2019 the number of spikelets (103) was considerably lower than the main season 2019/2020 (169) by 39% (*Table 3*). Spikelet number was influenced by temperatures rather than nutrients application where it could increase when temperature drops from 31 °C to 25 °C (Yoshida 1973), or decrease as the temperature increase from 29.6°C to 36.2 °C (Jagadish et al. 2007). In addition, when the temperature at booting stage increased from 9°C to 20 °C the spikelet number may decrease (Souza et al. 2017). Vaghefi et al. (2013) studied the impact of temperature on rice yield production in KADA from 2013 to 2030, the maximum and minimum temperature increase yearly by about 0.03 and 0.04 °C and 0.13 and 0.06 °C in the main-season and off season, respectively. Higher temperatures may explain the lower number of spikelets per panicle in the off-season 2019 than in the main-season. One of the most important characteristics of rice productivity is the floret number/panicle. The number of florets is established in the early stages of panicle development. It is well known that applying nitrogen fertiliser before panicle initiation increases floret number (Ding et al. 2014). In addition, Zhou et al. (2017) reported that nitrogen applications, which included 35% as basal fertiliser, 15% at the early tillering stage, and 50% at the panicle initiation stage, greatly improved the number of spikelets per panicle. However, in this study, the application of different N at different rice growth stages did not influence the number of spikelets/panicle. *Table 2* shows the highest spikelets/panicle in T1 (147) were slightly higher than T13 (143) by 2.8%, considering the difference between the highest for giving N separately, which were 3-N splits and 4-N splits, respectively. This is in line with Castro and Siddique (2000) and Huang et al. (2022) reported that applying different nitrogen rates did not show any significant difference in number of spikelets/ panicle. According to Ju et al. (2021), pre-transplanting and panicle initiation stages were the N reduction-sensitive phase which a low amount of N decreases the number of spikelets per panicle because of a decrease in leaf area

Table 4. Yield components of rice subjected to various N treatments

Treatment	Panicle/m^2	Spikelet/panicle	Spikelet/m^2	Filled grain (%)	1000-grain weight (g)	Yield (t/ha)
T1	292bc	147	42510a	92.6	29.1	9.480a
T2	274bcd	142	38599abcd	93.3	29.3	8.58bcde
T3	288bc	142	41421ab	92.9	29.6	8.913bc
T4	239d	135	31370f	92.9	29.1	7.81g
T5	252cd	132	32262f	92.2	29.1	8.09efg
T6	279bcd	137	37540abcde	92.0	29.0	8.73bcd
T7	303ab	133	40027abc	91.3	28.9	8.99ab
T8	278bcd	132	36198bcdef	92.8	28.8	8.74bcd
T9	277bcd	134	35922bcdef	91.2	28.7	8.31defg
T10	269bcd	135	35296cdef	92.2	28.9	8.42cdef
T11	269bcd	139	37437abcde	91.6	28.7	8.79bcd
T12	340a	128	42905a	91.6	28.8	9.06ab
T13	272bcd	143	38630abcd	92.4	28.9	8.72bcd
T14	282bcd	136	35813bcdef	92.0	28.4	8.00fg
T15	256cd	131	33299cd	91.9	28.3	8.18efg

No shared letter indicates statistical significance at the p <0.05 level within the same column.

index and lower shoot and root biomass which affected the aboveground growth. However, Ju et al. (2021) also reported that when N applied at the early stage of rice growth is sufficient, N could still be absorbed and utilised later for optimal growth. Therefore, a total of 50% N applied to the rice plants at the vegetative and tillering were considered sufficient and met the rice plants' nutritional needs for optimal spikelets production, which explained the balance of 50% at later growth stages is not an essential factor for floret development.

The number of spikelets per unit area is expressed as the product of the number of panicles per unit area and the number of spikelets/panicle (Shiratsuchi et al. 2007; Fukushima 2019). In this study, a significant difference in season on spikelets/m^2 was contributed by a more significant number of spikelets per panicle in main-season 2019/2020 than in off-season 2019 (*Table 3*). As affected by treatment, there was also a significant difference in spikelets/m^2. *Table 4* showed that T12 produced the highest number of spikelets/m^2 (42905) with the application N at the 3-leaf stage (20%), active tillering (30%), five days before panicle initiation (30%) and at heading (20%). However, T12 was not statistically different compared to T1 (42510). According to Yoshida (1981), Zhang et al. (2013) and Li et al. (2014) spikelet per square meter significantly correlated with final grain yield. Thus, increasing spikelets/m^2 could boost the rice grain yield. The contribution of early emerging tillers remaining consistent at roughly 50% of N and followed by another 30% for the late emerging tillers could account for a more significant number of spikelets per square meter (Wang et al. 2017) as, shown in T12 by a significantly higher number of panicle per square meter. However, as mentioned earlier, this application scarifies the number of spikelets/panicle. It is always a good indicator for farmers to have similar results in yield components but reduce the N-split applications for better time management. Thus, as T12 was comparable to T1, the N management could be considered only three split applications.

Filled grain (%) was not affected by season (*Table 3*). In off-season 2019, the number of filled grain (92.2%) was statistically similar to the main-season 2019/2020 (92.1%). A low percentage of filled grains could limit the rice grain yield potential (Zhang et al. 2013). Zheng et al. (2010) reported that grain filling is a process of starch synthesis in grain that originates through the degradation of non-structural carbohydrate (NSC) assimilated in the leaf and stem prior to heading and the translocation of carbon assimilates from leaf after heading. The greater accumulation and translocation of NSC is useful for grain filling. Wei et al. (2011) suggested that delaying nitrogen dressing for longer photosynthesis to improve grain filling to ensure sufficient carbohydrate supply to the spikelets during the filling stage. Ma et al. (2022) reported that twice splits of N compared to a single application delayed the flag leaf senescence and increased the photosynthetic rate of the flag leaves, thus improving grain filling in wheat. The photosynthetic CO_2 uptake rate at the grain filling stage improved when nitrogen topdressing was applied at the initial stage of flag-leaf extension, contributing to significant final grain yield (Liu et al. 2020). The NSC stored in lower parts of the rice stem at the pre-heading stage contributes to a major starch source for grain filling, and NSC remobilisation to panicle occurs after heading (Wakabayashi et al. 2022). The flag leaf wholly developed is the end of the booting stage (Badriyah et al. 2022) or commonly fully emerges 18 days before heading (Yoshida 1981). Based on the studies mentioned above, the increase in grain filling depends on the ability of NSC accumulation and remobilisation in leaves and stems before heading, which is contributed by the efficient rate of photosynthesis due to flag leaves senescence because of N applied between booting and heading stages. Therefore, N fertiliser applied to the rice plants before heading is essential for photosynthesis activities for NSC accumulation as it is synchronised with flag leaf development. The current study explained that rice plants treated with 10 – 20% N at the heading stage mostly showed slightly lower grain filling percentages (*Table 4*).

The present study showed that N fertiliser did not influence the 1000-grain weight. However, 3-N split applications generally provide a slightly more positive impact than 4-N split applications. Yoshida (1981) mentioned that the 1000-grain weight was a constant characteristic because the hull controls grain size. Thus, the grain cannot grow bigger than that hull regardless of the rice plant's optimum weather and nutrient supply. According to Li et al. (2018) the final size of the grain is coordinately controlled by cell proliferation and cell expansion in the spikelet hull, which sets the storage capacity of the grain and limits grain filling. Fang et al. (2016) found that *D2/SMG11* influences the expression of several known grain size genes involved in regulating cell expansion. The panicle initiation stage determines the rice grain weight because sufficient amounts of non-structural carbohydrates (NSC) increases the rice grain's length and width, resulting in an increased in rice grain size (Wu et al. 2022). The present study suggests that the 3-N splitting and the final 50% of N applied during the maximum tillering to booting stages (T1-T5) may provide more photosynthesis rate. Greater photosynthetic activities could maximise the NSC production and accumulation in rice plants. Thus, triggering and influencing the expression of related genes that later increase the grain size and consequently greater the grain weight even though the increase was not significant compared to 4-N splits.

The rice grain yield was significantly higher in the main-season 2019/2020 compare to off-season 2019 by 17.7% (*Table 3*). Significantly higher spikelets/m^2 in the main-season 2019/2020 contributed to the grain yield. However, there was a significant interaction between seasons, and N splits treatments on rice grain yield. Generally, the average rice grain yield (*Table 4*) was highest in T1 (9.48 t/ha) but did not significantly different with T12 (9.06 t/ha) and T7 (8.99 t/ha). The current study indicates that improving N-split applications at the

3-leaf stage (20%), active tillering (30%) and ten days before PI (50%) could achieve a high yield, and it may not necessary to apply added N fertiliser at the heading and the later growth stages. This could be because the high proportion of N applied to seedlings at tillering stages play critical roles that contribute to optimal root biomass, root length and root oxidation activity, which translates to better nutrient absorption and growth of the aboveground plant parts (Ju et al. 2021). This is in line with studies reported by Hirzel et al. (2011), Islam et al. (2009) and Kamruzzaman et al. (2014) that 50 – 60% of N applied at early planting and tillering and followed by 40 – 50% at the reproductive stage was found to be the most beneficial for grain yield improvement. Notably, in T12 and T17, the N was applied at 30% and 40%, respectively, ten days before PI could indicate the importance of N at this particular stage in maximizing the rice grain yield, but it required added 20% and 10% at the heading stage for yield maintenance. On the other hand, T4 (7.81 t/ha) had the lowest rice grain yield and did not significantly differ from T5 (8.09 t/ha), T9 (8.31 t/ha), T14 (8.00 t/ha) and T15 (8.18 t/ha). T4 and T5 had among the lowest rice grain yield may be because 50% of N applied after panicle initiation may not benefits the rice plants and adversely impact the yield components due to the delayed N uptake for NSC accumulation and consequently produced the low spikelet per square meter. Similar behavior also occurs in T9, T14 and T15, except in T10.

The relationship between yield components and rice grain yield is presented in *Table 5*. Spikelets per panicle (r = 0.70), spikelets/m^2 (r = 0.61), and 1000-grain weight (r = 0.57) had significant and positive correlations with rice grain yield. Yoshida (1981) reported that the number of spikelets/m^2 contributes about 60.2% of the final grain yield and was the most important component limiting factor of the rice grain yield. However, spikelets per square meter, percentage of filled grain and 1000-grain weight contribute about 81.4 % of variation in rice grain yield. In contrast, some studies report that the number of panicles/m^2 was the most important component of yield accounting for 87% of the variation in rice grain yield (Mandana et al. 2014). In our study, the partitioning of the total sum of squares presented in Table 6 explains the percentage of variation for all traits. All characteristics had a considerable variation due to seasons that ranged from 0.08% to 86.5%. In contrast, variations were observed in treatment that ranged from 2.1% to 27.0%. These results clearly showed that seasonal factors influenced the variability in plant traits. The variability was well expected because the main-season was consistently have higher temperature compare to off-season but received heavier precipitation, resulting in average rice yield higher in the main-season than in the off season (Tan et al. 2021). The current results agreed with Mandana et al. (2014) that panicle/m^2 was the most critical factor determining the rice grain yield.

Table 5. Correlation analysis between yield component and rice grain yield

Yield component	Rice grain yield
Panicle/m^2	-0.14NS
Spikelet/panicle	0.70**
Spikelet/m^2	0.61**
Filled grain (%)	0.013NS
1000-grain weight (g)	0.57**

Note: **significant <0001

Conclusion

Agronomically optimising the timing of nitrogen (N) fertiliser application can increase crop yield. A split nitrogen application allows a significant portion of nitrogen to enhance nutrient efficiency and mitigate the loss of nutrients until the plant is ready to utilise it. Under the T12 treatment, there was a significant increase in panicles/m^2 and spikelets/m^2, which helped the ultimate goal of greater rice grain yield. However, the 4-N split applications may reduce the grain filling (filled grain %) and 1000-grain weight. T12 had a comparable yield to T7; only the amount of N varied in the third and fourth applications but with similar timing. However, both of these treatments had a lower yield than T1. This study suggested that split applications of N at three different growth stages (20% of N at 3-leaf stage, 30% at active tillering and 50% at 10 days before panicle initiation) is an effective strategy to increase the rice grain yield and reduce the labour cost.

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Table 6. Estimation of variance in rice grain yield and yield components

Source	DF	% of variation					
		Panicle/m^2	Spikelet/ panicle	Spikelet/m^2	Filled grain (%)	1000-grain weight (g)	Yield (t/ha)
Season (S)	1	11.3	86.5	56.8	0.08	42.8	54.7
Treatment (T)	14	27.0	2.1	12.4	10.7	16.6	20.7
S x T	14	6.1	1.7	3.1	23.5	8.1	8.1

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