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Response of Irrigated Direct-Seeded Rice Yields to Different Nitrogen Rates and Precipitation Patterns

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ABSTRACT: *In Peninsular Malaysia, irrigated direct-seeded lowland rice cultivation results in higher yields during the off-season (April-July) as compared to the main-season (October-January). However, farmers still apply the same amount of nitrogen (N) at both growing seasons. A study was conducted to assess the response of rice yield components to different N rates and different precipitation patterns. This work was conducted in a 27-acre field with six N treatments, i.e. 0, 80, 120, 160, 200 and 240 kg N ha^{-1} in three continuous planting seasons from October-2012 to January-2014. In the first planting during main-season (S1), treatment with 120 kg N ha^{-1} showed significantly higher panicle number per m^2 (PM), 1000-grain weight (GW) and estimated grain yield (GY). Meanwhile, treatment with 200 kg N ha^{-1} significantly increased panicle number m^{-2}, spikelet number per panicle (SP), percentage of filled spikelet (FP) and estimated grain yield (GY) in the second planting during off-season (S2). In the third planting during main-season (S3), 120 kg N ha^{-1} still showed significantly higher PM, spikelet number per m^{-2} (SM), GW and GY. S3 showed the highest grain yield per input of N, followed by S1 and S2. In all three seasons, grain yield was positively correlated with PM, SP and SM. This study indicates that 120 kg ha^{-1} produces the highest grain yield during the main-season, which typically receives more rain water that contributes additional N to the rice field throughout the planting season. During the off-season, however, 200 kg ha^{-1} is required as the optimal N rate.*

Key words: *Nitrogen, Precipitation, Rice, Main-season, Off-season.*

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food source for almost half of the world population. In Malaysia, the current self-sufficiency of rice is about 72% and is required to increase to 90% by 2020. To maximize grain yield, growers often apply a higher nutrient inputs, especially nitrogen (N), for both planting seasons (i.e. main-season and off-season) within the cropping year. More often than not, the N input exceeds the minimum amount required for maximum crop growth. It is well recognized that overuse of N fertilizers in rice fields accompanied by lesser yield returns can trigger environmental problems (Fan *et al*., 2006; Lin *et al*., 2007; Xie *et al*., 2010; Dong *et al*., 2012). Low N use efficiency in lowland rice is associated with N loss via several pathways within the soil-water-plant system. The main pathways for N loss are volatilization of ammonia (NH_3), leaching of nitrate (NO_3) and de-nitrification to nitrous oxide (N_2O) (Zhang *et al*., 2011; Liu *et al*., 2012; Xu *et al*., 2013; Cao *et al*., 2013).

Current N management strategies in cereal crop production are plagued by low fertilizer efficiency which inevitably leads to economic losses and environmental contamination (Fageria and Baligar, 2005). Current N management strategies in cereal crop production also overlooks year-to-year weather variations and sometimes fail to account for soil N mineralization, ignoring indigenous N supply (Shanahan *et al*., 2008). Month-to-month variations in weather within each cropping cycle can be significant enough to affect large differences in yield potential. There is an urgent need to establish food security with regard to rice production. There is a simultaneous pressure to protect the environment from fertilizer overuse. As such, growers are being encouraged to use high efficiency fertilizers for irrigated lowland rice cultivation.

An increasing world population is also associated with a decrease in arable land, which makes intensive rice cropping necessary in the future (Dawe *et al*., 2000). Muller *et al*. (2012) reported that closing the rice

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yield gap to 100% of attainable yields would require a 47% increase in global rice production. Rice yield is typically determined by its yield components, which include the effective panicle number m^{-2}, number of spikelet panicle^{-1}, percentage of filled spikelet and 1000-grain weight. Many studies have been conducted to clarify the influence of panicle number m^{-2} and number of spikelet panicle^{-1} to grain yield (Yoshida *et al.*, 2006; Yan *et al.*, 2010; Huang *et al.*, 2011), and the influence of these yield components to rice yield varied simultaneously with N management and weather phenomenon (Katsura *et al.*, 2008; Liu *et al.*, 2013, Sui *et al.*, 2013).

Therefore, the objective of this study was to assess the response rice yield components to different N rates and different precipitation patterns under irrigated lowland direct-seeded rice system.

MATERIALS AND METHODS

Site description

This work was conducted in a 27-acre farmer's field located at Semanggol, Perak, Malaysia(4.949418° N, 100.606614° E) from October of 2012 through January of 2014. First planting (S1) and third planting (S3) were performed during the main-season, which started in October and ended in January. Meanwhile, second planting (S2) was performed during the off-season, which starts in April and ends in July. Precipitation (mm) and mean temperature (° C) data throughout each planting season (D0 through D90) are given in Table 1. The field had a silty clay soil (54.5% clay, 43.0% silt, 2.5% sand) with 4.89 g kg^{-1} organic matter, 0.20 g kg^{-1} total N, C:N of 14.48 and pH(H_2O) of 5.44.

Table 1
Weather conditions at trial site during season 1, season 2 and season 3

	*D0-D30		D31-D60		D61-D90	
Season	*Precipitation (mm)*	*Mean temperature (° C)*	*Precipitation (mm)*	*Mean temperature (° C)*	*Precipitation (mm)*	*Mean temperature (° C)*
1	397.1	27.9	88.1	28.0	302.5	27.9
2	145.3	28.6	102.7	29.0	108.4	28.6
3	301	27.3	291.6	27.4	114.6	27.6

*D0-D30 indicates from sowing of seeds (D0) to 30 days after sowing (D30).
Data source: Malaysian Meteorological Department, 2014.

Experimental design and treatments

An on-farm N fertilizer trial was set up with six levels of N, i.e. 0, 80, 120, 160, 200 and 240 kg ha^{-1} using urea (46% N) as the N source. Phosphorus (P) and potassium (K) were applied using Tri-superphosphate (90 kg of P_2O_5 ha^{-1}) and Muriate of Potash (160 kg of K_2O ha^{-1}), respectively. A completely randomized design with three replications per treatment was employed. Fertilizer application was made in three splits, i.e. 3-leaf stage at 15-20 days after sowing (DAS), active tillering stage at 35-40 DAS and prior topanicle initiation stage at 55-60 DAS (Table 2). The variety of rice used in this trial was MR220-ClearField® which was direct-seeded under irrigation. The rice field was flooded between 15 DAS and 80 DAS.

Table 2
Split application of N treatment corresponding to different rice growth stages

Treatment (kg ha^{-1})	*15-20 DAS*	*35-40 DAS*	*55-60 DAS*	*Total N applied*
N0	0	0	0	0
N80	44	36	0	80
N120	44	52	24	120
N160	44	68	48	160
N200	44	80	76	200
N240	44	92	104	240

Sampling and measurements

Rice yield components were measured at the end of each growing season and expressed as: effective panicle number per m^2 (PM), filled-spikelet per panicle (FS), unfilled spikelet per panicle (US), spikelet number per panicle (SP), spikelet number per m^2 (SM), percentage of filled spikelet (FP), 1000-grain weight (GW) and estimated grain yield (GY).

Plants were hand-harvested at 105 DAS every season. Plant sampling was carried out systematically using a 1 m^2 quadrant. A total of fifteen plant samples were obtained from each treatment unit at 10 x 10 m grids. Total number of effective panicles in each quadrant were counted, then separated into three broad groups, i.e. short (< 15 cm), medium (15-20 cm) and long (> 20 cm). From each panicle group, one panicle was selected and counted for the number of filled and unfilled spikelet, then averaged out to register FS, US and SP (Mudzakkir, 1977). Weight per 1000 grains was determined from the harvested crop of each quadrant based on the international procedure for seed testing. The GY (t ha^{-1}) for every quadrant was computed by applying an equation modified after Yoshida (1981) as follows: $GY = PM \times SP \times FP \times GW \times 10^{-5}$.

Data analysis

Data for each season were analysed using one-way analysis of variance (ANOVA) in SAS® 9.4. The honest significance different test (Tukey) at 95% confidence level was used to determine differences between treatment means. Pearson correlation was used to test the linear strength between variables.

RESULTS

Effect of different nitrogen rates on rice yield components and grain yield in the main-season (S1 and S3)

Rainfall during S1 and S3 was 787.7 mm and 707.2 mm, respectively. Comparatively the main-season is wetter than the off-season (Table 1). During S1 and S3, N had a highlysignificant effect on all rice yield components. The rate of 120 kg N ha^{-1}accountedfor the highest mean in PM (375, 376), SM (44689, 43730), FP (64.10%, 81.59%), GW (26.42 g, 26.95g) and GY (7.45 t ha^{-1}, 9.63 t ha^{-1}), for both S1 and S2, respectively (Table 3). Notably, a significant increase in FS, FP and GY was recorded between S1 and S3 for the 120 kg N ha^{-1} treatment. Between S1 and S3, significant increase in FS (78 to 95), FP (64.10 to 81.59 %) and GY (7.45 to 9.63 t ha^{-}1) was recorded. Meanwhile, FP for all treatments in the main-season of 2013 (S3) was comparably higher than the main-season of 2012 (S1) (Table 3). There was no significant difference in GW between both main-seasons across all N treatments, with the exception of 160 kg N ha^{-1}. Results indicate that fertilizer application in three splits at 15-20 DAS, 35-40 DAS and 55-60 DAS can enhance FS under irrigated lowland direct-seeded rice system, thus increasing GY during the main-season. GY per every unit of N input showed that the rate of 120 kg N ha^{-1}gave the highest return at 62.08 kg grain per kg N during S1 and 80.25 kg grain per kg N during S3.

Effect of different nitrogen rates on rice yield components and grain yield in the off-season (S2)

Different precipitation patterns affect the optimal N supply as manifested in the yield components under irrigated direct-seeded rice. The off-season (S2) had a rainfall of 356.4 mm during the first 90 days of rice growth (Table 1). The highest mean inPM (414), SP (113), SM (47059), FP (83.82%) and GW (25.81g) was achieved at the rate of 200 kg N ha^{-1}(Table 4). In addition, GY increased by 49.41% at the rate of 200 kg N ha^{-1} in comparison to the untreated control (Fig. 1). GY per every unit of N input showed that the rate of 200 kg N ha^{-1} gave the highest return at 50.95 kg grain per kg N during S2.

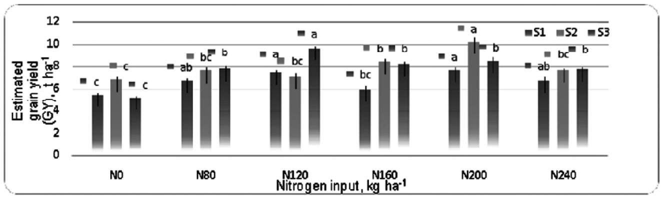

Figure 1: Estimated grain yield response to different nitrogen inputs across differentseasons (S1, S2, S3)

Pearson correlation between yield components and grain yield across all seasons

Significant positive correlation was recorded between PM and GY at S1 ($r = 0.74$), S2 ($r = 0.73$) and S3 ($r = 0.71$). GY also significantly correlated with SM and FS at

Table 3
Yield components of rice subjected to different N rates in the main-season of 2012(S1) and 2013 (S3)

Season	*N (kgha^{-1})*	*PM*	*FS*	*US*	*SP*	*SM*	*FP (%)*	*GW (g)*	*GY (t ha^{-1})*
S1	0	267 bA	82 abA	50 abA	132 abA	34738 cA	62.58 bcB	25.09 cA	5.46 cA
	80	317 bA	83 abB	46 bA	130 abcA	40347 abcA	64.56 abcB	25.82 bA	6.72 abB
	120	375 aA	78 bB	45 bcA	123 bcA	44689 aA	64.10 abcB	26.42 aA	7.45 aB
	160	281 bB	82 abA	59 aA	141 aA	39837 abcA	58.43 cB	25.18 cB	5.93 bcB
	200	369 aA	81 abB	35 cA	116 cA	41833 abA	70.37 aB	26.03 abA	7.63 aA
	240	285 bA	90 aB	44 bcA	134 abA	37585 bcA	67.69 abB	26.08 abA	6.73 abA
S3	0	286 cA	73 cB	25 bB	98 dB	27748 cB	74.52 bA	25.06 dA	5.18 cA
	80	295 cA	101 aA	22 bcB	123 abA	36182 bA	82.00 aA	26.25 cA	8.10 bA
	120	376 aA	95 abA	21 bcB	117 bcA	43730 aA	81.59 aA	26.95 abA	9.63 aA
	160	336 bA	90 bA	19 cB	109 cB	36907 bA	82.84 aA	27.01 aA	8.25 bA
	200	329 bB	98 abA	22 bcB	120 abA	39461 bA	81.40 aA	26.37 bcA	8.53 bA
	240	305 cA	99 aA	29 aB	128 aA	39112 bA	77.04 bA	25.96 cA	7.80 bA

Means followed by lowercase alphabets compare the N-treatments in the same season while means followed by uppercase alphabets compare the same N-treatment between seasons.

Means with different alphabets are significantly different at $p < 0.05$ (Tukey).

PM = effective panicle number per m^2, FS = filled-spikelet per panicle, US = unfilled spikelet per panicle, SP= spikelet number per panicle, SM = spikelet number per m^2, FP = percentage of filled spikelet, GW = 1000-grain weight and GY= estimated grain yield.

Table 4
Yield components of rice subjected to different N rates in the off-season of 2013 (S2)

N(kg ha^{-1})	*PM*	*FS*	*US*	*SP*	*SM*	*FP(%)*	*GW(g)*	*GY(t ha^{-1})*
0	364 b	73 d	26 a	99 c	36312 b	74.18 d	25.15 b	6.82 c
80	337 b	89 ab	24 ab	113 a	37720 b	78.60 bc	25.66 b	7.62 bc
120	355 b	81 bcd	19 c	99 c	34917 b	81.21 ab	25.21 b	7.12 bc
160	355 b	90 ab	20 bc	110 ab	38484 b	81.69 ab	26.48 a	8.37 b
200	414 a	96 a	18 c	113 a	47059 a	83.82 a	25.81 ab	10.19 a
240	372 ab	80 cd	23 ab	103 bc	38263 b	77.48 cd	25.72 b	7.63 bc

Means followed by different alphabets are significantly different at $p < 0.05$ (Tukey).

PM = effective panicle number per m^2, FS = filled-spikelet per panicle, US = unfilled spikelet per panicle, SP = spikelet number per panicle, SM = spikelet number per m^2, FP = percentage of filled spikelet, GW = 1000-grain weight and GY = estimated grain yield.

Table 5
Pearson correlation between rice yield components in the main-season of 2012 (S1), 2013 (S3) and in the off-season of 2013 (S2)

Season		*PM*	*FS*	*US*	*SP*	*SM*	*FP*	*GW*	*GY*
S1	PM	1.0000	-0.1689	-0.3402	-0.3791	0.7061*	0.2473	0.3508	0.7428*
	FS		1.0000	-0.0813	0.6543*	0.3156	0.5058*	-0.1227	0.5039*
	US			1.0000	0.7005*	0.1679	-0.8751*	-0.2313	-0.3618
	SP				1.0000	0.3534	-0.3018	-0.2633	0.0863
	SM					1.0000	0.0184	0.1309	0.8203*
	FP						1.0000	0.1316	0.5476*
	GW							1.0000	0.2796
	GY								1.0000
S2	PM	1.0000	-0.0104	-0.0120	-0.0153	0.8064*	0.0044	0.1106	0.7269*
	FS		1.0000	-0.2208	0.9206*	0.5241*	0.6281*	0.0748	0.6518*
	US			1.0000	0.1777	0.0875	-0.8828*	-0.0186	-0.1734
	SP				1.0000	0.5638*	0.2802	0.0680	0.5882*
	SM					1.0000	-0.0604	0.0997	0.8173*
	FP						1.0000	0.0532	0.4294
	GW							1.0000	0.2357
	GY								1.0000
S3	PM	1.0000	0.1095	-0.2790	-0.0093	0.6821*	0.3159	0.4237	0.7070*
	FS		1.0000	0.0450	0.9217*	0.7451*	0.5171*	0.2932	0.7581*
	US			1.0000	0.4289	0.1184	-0.8219*	-0.4182	-0.2022
	SP				1.0000	0.7197*	0.1485	0.1028	0.6070*
	SM					1.0000	0.3219	0.3572	0.9338*
	FP						1.0000	0.5498*	0.6018*
	GW							1.0000	0.5972*
	GY								1.0000

*Coefficients of variation larger than 0.5 are significant at á<0.05.

PM = effective panicle number per m^2, FS = filled-spikelet per panicle, US = unfilled spikelet per panicle, SP = spikelet number per panicle, SM = spikelet number per m^2, FP = percentage of filled spikelet, GW = 1000-grain weight and GY = estimated grain yield.

S1 (r = 0.80 and 0.50), S2 (r = 0.82 and 0.65) and S3 (r = 0.93 and 0.76) (Table 5). Results indicate that yield components such as PM, SM and FS influenced GY across all seasons under irrigated direct-seeded rice.

Discussion

Yield difference under irrigated direct-seeded rice was mainly caused by constant N input for both main- and off-seasons. Although N supply drives crop productivity, low nitrogen use efficiency is a major problem in irrigated rive cultivation (Cassman *et al.*, 1998). Currently, Malaysian farmers cultivate irrigated direct-seeded rice by applying the same rate of N fertilizer during main- and off-season.

In the main-season of 2012 and 2013, application of 120 kg N ha^{-1}in three splits (44 kg N ha^{-1} at 15-20 DAS, 52 kg N ha^{-1} at 35-40 DAS and 24 kg N ha^{-1}at 55-60 DAS) significantly produced the highest grain yield. Comparatively, N application in the off-season required an increased amount of N, i.e. from 52 to 80 kg ha^{-1} (second application) and from 24 to 76 kg ha^{-1} (third application) to achieve maximum grain yield. Our data suggest that applying about 80% of N from the total application of 120 kg N ha^{-1}within the early growing season (i.e. between initial tillering and maximum tillering) is a crucial strategy in achieving maximum grain yield during the main-season. In the off-season, however, about 40% of N from the total application of 200 kg N ha^{-1} within the mid-growing season produced the highest grain yield. Ida *et al*., (2009) noted the importance of maintaining source activity to enhance N translocation to the panicle for greater grain yield.

Reduced N input which still produced higher grain yield in both main-seasons can be attributed to rain water, which has been shown to supply N to the rice plant (Dobermann and Fairhurst, 2000). Due to lesser sunny days during the main-season in comparison to theoff-season, N loss via ammonia (NH_3) volatilization is reduced. Typically, N from fertilizer urea applied to rice fields is susceptible to NH_3 volatilization under relatively high temperature and surface water pH (Cai, 1997). Zhu and Chen (2002) reported that total gaseous loss of N fertilizer via NH_3volatilization and de-nitrification during the growing season in rice soils of China accounted up to 40% of the applied N. In addition, the proportion of NH_3 loss increased with N application rates because NH_3volatilization fluxes increased linearly with increasing ammonium (NH_4^+-N) concentrations in the surface water (Cao *et al*., 2013). As such, the off-season would require more N, in comparison to the main-season, to achieve maximum grain yield under irrigated direct-seeded rice cultivation.

Effective panicle number per m^2 (PM) and spikelet number per m^2 (SM) are the primary determinants of rice grain yield, and have often been considered as yield limiting factors in rice breeding programs (Ying *et al*., 1998; Katsura *et al*., 2007). In this study, the high positive correlations between grain yield and PM as well as SM across all three seasons clearly reiterate the importance of PM and SM toward rice grain yield.

CONCLUSION

Continuous planting ofirrigated direct-seeded rice cultivation over three seasons showed that optimal N rate for grain yield and its components were influenced by precipitation patterns. Current N management in Malaysian rice fieldsd is regards the effects of precipitation when estimating crop fertilizer N requirements. Split application of N increased the effective panicle number per m^2,spikelet number per m^2 and filled-spikelet per panicle, which are important yield components in achieving maximum grain yield under irrigated direct-seeded rice system. Furthermore, grain yield per every unit of N input was higher in the main-season than in the off-season. This study showed that an appropriate N fertilizer strategy is crucial so as to avoid the source-sink tradeoff in rice cultivation under different weather conditions.

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