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Full Length Article

Optimizing Nitrogen-split Application Time to Improve Dry Matter Accumulation and Yield in Dry Direct Seeded Rice

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Abstract

Low nitrogen use efficiency (NUE) is important yield limiting factor in rice. This study evaluated the response of split application time of N on total dry matter accumulation and yield in dry direct seeded rice (DSR). Total crop required N (143 kg ha^{-1}) was applied in different splits viz. three splits with one-half at sowing, remaining half at tillering and anthesis; one-third each at sowing, tillering and anthesis; in two splits one-half each at sowing and tillering; sowing and anthesis; and at tillering and anthesis. Maximum pre-anthesis total dry matter (TDM), LAI, CGR and NAR were recorded for two N splits applied at sowing and anthesis followed by three splits each at sowing, tillering and anthesis. Application of two splits at sowing and anthesis also produced maximum total and panicle bearing tillers, kernels per panicle, 1000-kernel weight, straw and kernel yield, and harvest index following three equal splits. Response of panicle length and sterile splikelets to N splits was non-significant. Significant and positive relationship of TDM produced at anthesis with kernel yield and growth attributes was also found. In conclusion, two or three splits particularly with N supply at sowing and anthesis were better to improve crop growth, dry matter and yield in DSR and could be attributed to better nutrient uptake and reduced N losses increasing crop NUE. © 2013 Friends Science Publishers

Keywords: N use; Sink size; Dry matter partitioning; Leaf area index; Harvest index

Introduction

Direct seeded rice (DSR) is becoming popular as alternative to conventional transplanting under continuous flooding in Asia including Pakistan (Farooq *et al.,* 2011). But grain yield are relatively low in direct seeded rice systems due to low harvest index (Bouman *et al.,* 2006; Zhang *et al.,* 2009; Rehman *et al.,* 2011a). Low primary productivity and post-anthesis nitrogen assimilation or limited translocation of dry matter from vegetative to reproductive sinks usually constraints for high harvest index (Zhang *et al.,* 2009).

Nitrogen is one of the yield limiting nutrients affecting growth and quality in rice systems (Nambiar and Ghosh, 1984; De Datta *et al.*, 1988; Khan *et al.*, 2012) and accounts for 67% of the total applied fertilizers worldwide (Vlek and Byrnes, 1986). Nitrogen use efficiency (NUE) of rice is usually low due to volatilization, runoff, denitrification and leaching losses (Modgal *et al.,* 1995). Moreover, direct seeded rice soils are often exposed to dry and wet conditions and difference in N dynamics and losses pathways often results in different fertilizer recoveries in aerobic soils (De Datta and Buresh, 1989). Even high and non-synchronous applied N may limits grain yield due to limited grain filling rate by decrease in post-anthesis assimilates translocation (Zhang *et al.,* 2009). Further absence of transplanting, shallow roots under direct seeded conditions results in low N uptake during early growth stages (Zhang and Wang, 2002). Previous reports also indicate that high yielding rice cultivars usually exhibit vigorous vegetative growth under direct seeded condition and perform poorly during reproductive stages due to N deficiency. However, high plant density and absence of transplanting shock in these cultivars produce high leaf area and tillers under favorable growing conditions (Dingkuhn *et al.,* 1990, 1991; Schnier *et al.*, 1990a, b). Thus reduced sink size may be the yield limiting factor in direct seeded rice (Bouman *et al*., 2006; Guang-hui *et al.*, 2008; Zhang *et al.*, 2009).

Nonetheless, nitrogen application has great impact on crop yield in rice when acquired during early and mid tillering stages to produce high number of panicles and obtain optimum spikelets per panicle and high percentage of filled spikelets (Murty *et al.*, 1992). While for high yield, N application time should be balanced to fulfill the crop requirement before and after anthesis (Mahajan *et al.,* 2011). In addition, current fertilizers schedules used for traditional rice system are not optimal for DSR. Thus, for maximum yield and increased NUE, optimum nitrogen schemes require to be developed for this rice system (Mahajan *et al.*, 2011). High fertilizer N efficiency in rice can be achieved through N efficient varieties; improved timing, application

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methods and better incorporation of basal fertilizer without standing water (De Datta, 1986; Ali *et al.,* 2007).

Split application is one of strategies for efficient use of N fertilizers throughout the growing season by synchronizing with plant demand, reducing denitrification losses and improved N uptake for maximum straw and grain yield, and harvest index in DSR (Bufogle *et al.,* 1997, Wilson *et al.,* 1989, Fageria, 2010, Lampayan *et al.,* 2010). Beldar *et al.* (2005) compared flooded and aerobic rice systems for crop performance using 150 kg ha^{-1} N applied in three splits and found decreased growth, yield and low N fertilizer recoveries under aerobic condition. Higher N losses accounted were gaseous in their study and it was also suggested to optimize the dose and time of N application (Beldar *et al.,* 2005). Recently, Mahajan and Timsina (2011) evaluated response of DSR to different nitrogen rates when applied in four splits but no comparison among splits was reported. However, further studies to evaluate crop dry matter and N translocation response to nutrient supply to find optimum N management strategies for improved productivity and NUE in DSR were suggested (Mahajan and Timsina, 2011).

As a result of hot climatic conditions and high pH in calcareous soils of Pakistan, 22–53% of applied N is lost as ammonia volatilization (Hussain and Naqvi, 1998) and NUE ranges from 30-45% under traditional rice system (Zia *et al.,* 1997). These differences in soil N dynamics and pathways of losses in DSR results in varied N fertilizer recoveries. This suggest optimizing split doses to different crop growth stages for high yield in DSR and find appropriate management of nitrogenous fertilizers to improve NUE. Very few reports highlight these areas how N application in different splits may affect dry matter accumulation and contributes towards grain yield in direct seeded rice under different nitrogen and water management conditions.

Materials and Methods

Source of Seed and Experimental Details

Seeds of fine rice *cv.* Super Basmati *(Oryza sativa* L.) obtained from Rice Research Institute, Kala Shah Kakoo, Sheikhupura, Pakistan were used. Field experiment was conducted during 2008 at Agronomic research area (31°30'N, 73°05'E and 214 m msl), University of Agriculture, Faisalabad, Pakistan. The experimental soil was sandy clay loam with pH of 7.9, EC 0.31 dS m^{-1}, organic matter of 0.85%, total nitrogen 0.053%, available phosphorus 5 mg kg^{-1}, exchangeable potassium 152 mg kg^{-1} and Zn of 1.27%. Experiment was laid out in randomized complete block design with net plot size of 7 m x 3.3 m. After soil analysis report, the recommended N (143 kg ha^{-1}) was applied into two or three splits with different proportions top dressed as; N_1=½ N sowing (S) + 1/4 tillering (T) + 1/4 anthesis (An), N_2=1/3 N sowing + 1/3 N tillering + 1/3 N anthesis, N_3= ½ N sowing + ½ N tillering; N_4= ½ N sowing + ½ N anthesis and N_5= ½ N tillering + ½ N anthesis. Urea (46% N) was used as fertilizer source while whole phosphorus and potassium @ 88-68 kg ha^{-1} were applied at tillering using single super phosphate and sulphate of potash (50% K_2O) and similar practice was used for $ZnSO_4$ (21% Zn) applied @ 25 kg ha^{-1}.

Crop Husbandry

Pre-saturation irrigation was applied to achieve the field capacity level. The seed bed was prepared by applying five plowings each followed by leveling with tractor drawn implements. Previous crop was wheat. Seeds osmoprimed with $CaCl_2$ (2.2%) for 48 h (Rehman *et al.,* 2011b) were drilled on July 02, 2008 at field capacity level in 22.5 cm spaced rows using single row hand drill and seed rate of 75 kg ha^{-1}. The crop was irrigated weekly basis when pan evaporation reading reached 4 cm (40 mm) to keep the soil moisture at field capacity level. About 14 irrigations were applied in addition to rainfall and withheld about one week before harvesting at physiological maturity. All other agronomic practices were kept uniform and weeds were controlled manually once without chemical control. For other plant protection measures, like disease control, there was no use of synthetic pesticides. Harvesting was done manually at harvest maturity when panicles were fully ripened at approximate moisture of 23%. Threshing of each plot was done separately.

Dry Matter Accumulation, Agronomic Traits and Yield Components

For growth analysis, samples were harvested from randomly selected area of 100 × 100 cm of each replication of respective treatments. After harvesting, samples were immediately weighed for fresh weight and later on plants were separated into leaves, stem with leaf sheath and at anthesis into panicles. Further measurements for leaf area and dry matter production were taken while for dry weight, planting material (leaves, stem and panicles) was mixed with similar ratio and oven dried at 70°C till constant weight. Dry weight was expressed in kg ha^{-1} for dry matter production. Leaf area was measured using leaf area meter (CL-203, Laser leaf area meter CID, Inc. U.S.A) and LAI was calculated as reported by Watson (1947). Leaf area duration, crop growth rate and net assimilation rates were measured according to Hunt (1978).

At physiological maturity, measurements for plant height and yield components were taken by harvesting 12-hill area from the ground level. At harvest maturity, an area of 6 m^2 was harvested manually and measurements for grain, straw yields and other related components were taken. Harvest index was calculated as the ratio between economic yield and straw yield.

Weather Data and Statistical Analysis

The weakly average values of experimental weather conditions i.e. temperature, rainfall, relative humidity and pan evaporation for whole crop growing season collected from a metrological station located at 5 km are presented in the Fig. 1. The data collected was analyzed using appropriate statistical package by Fisher's analysis of variance technique to test the significance, while treatment means were compared by Least Significant Difference (LSD) test at $P < 0.05$ (Steel *et al.*, 1997). Microsoft Excel program was used to present data graphically and determine correlation.

Results

Total Dry Matter Production

Application of N in two or three splits at different crop stages showed significant effect on total dry matter produced (TDM) of direct seeded rice and response was linear (Fig. 2). Among different splits, maximum pre- and post anthesis dry matter was produced at 96 or 116 days after sowing (DAS) when one-half or one-third of total N was incorporated at sowing or anthesis than splits without receiving nitrogen at any of these crop stages. Maximum pre- and post anthesis TDM was recorded for two splits with one-half of N applied at sowing and anthesis. However, this increase in dry matter was followed by three N splits one-third applied at sowing, tillering and anthesis respectively. While minimum dry matter was produced for two splits without N applied at sowing (Fig. 2). Nonetheless, strong and positive correlation of total dry matter produced at anthesis (96 DAS) was found with kernel yield (Table 2).

Agronomic Traits and Yield Components

Kernel yield, its determinants and harvest index were significantly influenced by N applied in two or three splits at different crop growth stages in DSR (Table 1). Response was variable for plant height with maximum for three N splits one-third applied at sowing, tillering and anthesis and was similar with application of one-half N in two splits at sowing and tillering stages. Highest total and panicle bearing tillers per unit area were found for two splits when one-half N was incorporated at sowing and top dressing of remaining half at anthesis stage. These increase in tiller numbers were followed by three N splits one-third each applied at sowing, tillering and anthesis stages (Table 1). Although effect of different N splits on panicle length and sterile spikelets was non-significant but comparatively maximum panicle length and minimum sterile spikletes was recorded for two N splits one-half applied at sowing and anthesis. Interestingly, maximum number of branches per panicle was recorded for two N splits top dressed as one-half at tillering and anthesis followed by other splits having similar number of branches. Similarly, 1000-kernel weight was highest for two or three N splits and was statistically similar for two N splits one-half applied at tillering and anthesis (Table 1). Maximum straw yield was recorded for application of three N splits one-third each and was statistically similar to two or three splits, while found less for N top dressed at tillering and anthesis stages. Among all splits, maximum kernel yield and harvest index was recorded in plots receiving N in two splits one-half at sowing and anthesis and was followed by N application in three equal splits at sowing, tillering and anthesis. While minimum values for kernel yield and harvest index were found for one-half N splitted at tillering and anthesis (Table 1).

Association of Dry Matter and Growth Attributes with Yield and its Attributes

N split application before and at anthesis had also great influence on growth attributes such as LAI, CGR, NAR (Fig. 3) and total dry matter produced at different days after sowing in DSR (Table 2). N application in different splits at basal or tillering stages significantly affected LAI, CGR and NAR before anthesis (Fig. 3), which in turn resulted in high dry matter production at 96 DAS in direct seeded rice. A positive and strong correlation of growth attributes with total dry matter produced (Table 2) as well for kernel yield was found (Table 2). Nonetheless, correlation of total tillers was also positive with total dry matter produced at anthesis while of total dry matter with kernel yield and harvest index was strong with relatively low values for latter (Table 2).

Similarly, to measure sink size effect of N splits, a relationship between yield determinants and kernel yield was also determined (Table 3). Correlation of panicle bearing tillers, panicle length, kernel numbers per panicle, 1000 kernel weight with kernel yield and of kernel yield with harvest index was positive. While relationship of kernel yield was found strong only with fertile tillers and to some extent for number of kernels per panicle and harvest index. Nonetheless, correlation of number of branches per panicle and sterile spikelets with kernel yield and of fertile tillers with sterile spikelets was negative (Table 3).

Discussion

Application of N in two or three splits at different crop stages significantly affected the growth, dry matter production and yield formation in direct seeded rice (Fig. 1; Table 1). Highest total dry matter was produced at pre- and post-anthesis stage with one-half N applied in two splits at sowing and anthesis or one-third each at sowing, tillering and anthesis (Fig. 1). Direct seeded rice utilizes N very efficiently and enhances availability of NO^{-}_{3}-N and NH^{+}_{4}-N during early growth stages improves the root and shoot growth under aerobic soil conditions and increased tiller formation (Lin *et al.*, 2005). Thus, earlier start of tillering

Table 1: Influence of different N splits on agronomic traits and yield components in dry direct seeded rice

N split applications	Plant height (cm)	Total tillers (m^{-2})	Panicle bearing tillers (m^{-2})	Panicle length (cm)	No. of branches per panicle	No. of kernels per panicle	Sterile spikelets per panicle	1000-kernel weight (g)	Straw yield (t ha^{-1})	Kernel yield (t ha^{-1})	Harvest index
N1=½ N sowing + 1/4 tillering + 1/4 anthesis	88.62 d	435.00 c	414.00 b	24.38	9.40 c	118.00 b	9.37	19.07 b	7.45 ab	3.13 c	0.42 c
N2=1/3 N sowing + 1/3 N tillering + 1/3 N anthesis	100.20 a	439.30 b	410.70 b	25.46	10.30 b	118.70 b	9.73	20.17 a	7.50 a	3.21 b	0.43 b
N3= ½ N sowing + ½ N tillering	98.63 ab	403.00 d	383.30 d	25.47	10.07 b	117.80 b	9.73	20.33 a	7.47 ab	2.90 d	0.39 d
N4= ½ N sowing + ½ N anthesis	94.75 c	493.00 a	451.30 a	26.13	10.10 b	120.30 a	8.97	20.71 a	7.44 b	3.53 a	0.48 a
N5= ½ N tillering + ½ N anthesis	97.22 b	403.30 d	391.00 c	25.29	10.93 a	117.80 b	9.93	19.98 ab	6.41 c	2.49 e	0.39 d
LSD	1.68	3.29	3.78	n.s.	0.29	1.41	n.s.	0.94	0.06	0.01	0.01

Means sharing the same letter did not differ significantly at P=0.05

Table 2: Correlation between various growth attributes, total dry matter accumulated and kernel yield at anthesis (96 DAS) as influenced by N splits in dry direct seeded rice

X- variable	Y-variable	Regression equation		Correlation coefficient (r)
LAI	Total dry matter	y = 805.77x + 2579.1	$R^2 = 0.8909$	0.95
CGR	Total dry matter	y = 109.71x + 5375.5	$R^2 = 0.8306$	0.91
NAR	Total dry matter	y = 585.5x + 5267	$R^2 = 0.8115$	0.90
Total tillers per unit area	Total dry matter	y = 10.152x + 3312	$R^2 = 0.7979$	0.89
LAI	Kernel Yield	y = 0.7358x - 1.644	$R^2 = 0.8684$	0.93
CGR	Kernel Yield	y = 0.1002x + 0.9096	$R^2 = 0.8096$	0.90
NAR	Kernel Yield	y = 0.5613x + 0.6988	$R^2 = 0.8716$	0.94
Total dry matter	Kernel Yield	y = 0.0009x - 3.8824	$R^2 = 0.9427$	0.97
Total dry matter	Harvest index	y = 1E-05x + 0.2575	$R^2= 0.3571$	0.60

Table 3: Correlation between various yield components and kernel yield in as influenced by N split applications in dry direct seeded rice

X- variable	Y-variable	Regression equation		Correlation coefficient (r)
Fertile tillers	Kernel Yield	y = 0.0124x - 2.0368	$R^2 = 0.7232$	0.85
Panicle length	Kernel Yield	y = 0.0868x + 0.855	$R^2 = 0.0463$	0.22
Branches number per panicle	Kernel Yield	y = -0.3813x + 6.9297	$R^2 = 0.3105$	-0.56
Kernel numbers per panicle	Kernel Yield	y = 0.2008x - 20.741	$R^2= 0.4394$	0.66
1000 kernel weight	Kernel Yield	y = 0.1051x + 0.9471	$R^2 = 0.042$	0.21
Sterile spikelets	Kernel Yield	y = -0.3144x + 6.0566	$R^2 = 0.2661$	-0.52
Fertile tillers	Sterile spikelets	y = -0.0134x + 15.033	$R^2 = 0.3118$	-0.56
Kernel yield	Harvest index	y = 0.0136x + 0.3229	$R^2 = 0.2936$	0.54

and increased root growth from vigorous stand in direct seeded crop might resulted from basal applied N in splits containing on-half or one-third and hence more biomass accumulated at vegetative stage (Fig. 1; Sanoh *et al.*, 2004).

Incorporation of N at sowing ensures balanced supply for leaf growth which increased the leaf expansion during early vegetative stages and better utilization of radiations (Sinclair and Muchow, 1995). Increased pre-anthesis crop growth rate and accumulation of more dry matter under direct seeded condition reported by Zhang *et al.* (2009) and Katsura *et al.* (2010) also confirms our results. Increased tillering density (Table 1) also resulted in rapid increase of LAI, high pre-anthesis CGR and NAR with total dry matter (Fig. 3) as indicated by significant and positive correlation of these growth attributes with total dry matter produced at 96 DAS (Table 2). Nonetheless, production of less dry matter at pre- or post-anthesis stage in splits without N supply at anthesis might resulted from reduced photosynthetic rate at later crop stages due to reduced leaf N concentration (Schnier *et al.*, 1990a; Dingkuhn *et al.*, 1991) or high with timely availability of N or increased NUE in treatments with N splits at anthesis (Sathiya and Ramesh, 2009; Mahajan *et al.*, 2011). Zhang *et al.* (2009) also reported that split fertilizer application increased dry matter accumulation due to improved N uptake before anthesis and reduced N losses under aerobic condition.

Increased straw and kernel yield, harvest index was recorded by N application in two or three equal splits (Table 1) might resulted from increased LAI and dry matter accumulated at anthesis (Fig. 2). This provided an improved carbohydrate generating source as found by positive relationship of grain yield with LAI and dry matter accumulated at 96 DAS in present study (Table 2). Przulj and Momcilovic (2001) reported that final yield in rice is determined by accumulation of 20-40% pre-anthesis sugars and starch and remaining by dry matter supplied from photosynthetic production after anthesis (Yoshida (1972). Moreover, high kernel yield by two splits at sowing and anthesis is also reflected by positive relationship between CGR and dry matter accumulated at anthesis or with grain

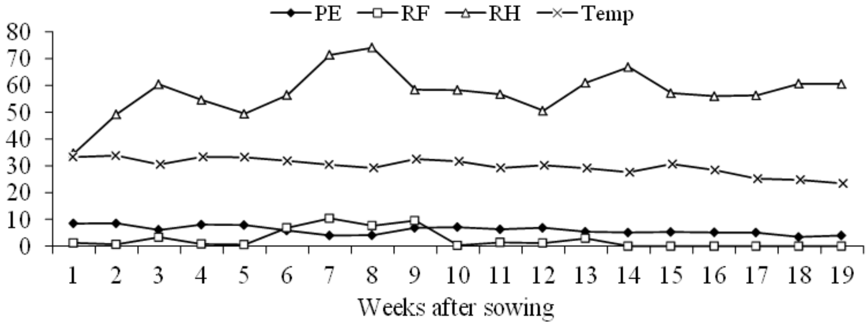

Fig. 1: Meteorological conditions of the paddy during 2008, RF; Rainfall (mm day^{-1}), PE; Pan Evaporation (mm day^{-1}), Temp; Temperature (°C), RH; Relative humidity (%) during whole crop season from sowing up to harvesting

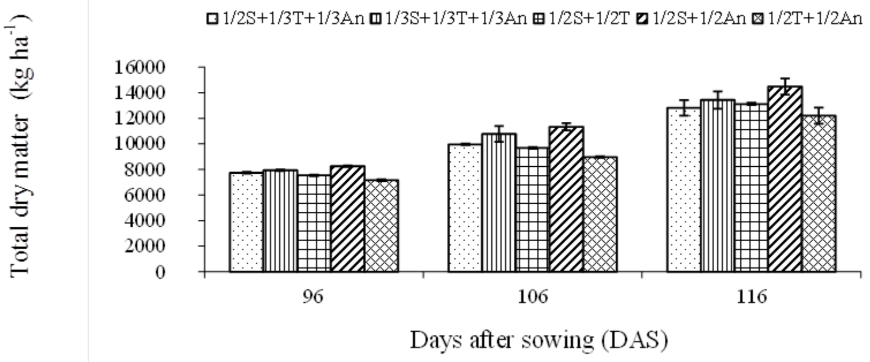

Fig. 2: Influence of N split applications on total dry matter production (kg ha^{-1}) at different days after sowing in dry direct seeded rice

S=sowing, T=tillering, An=anthesis

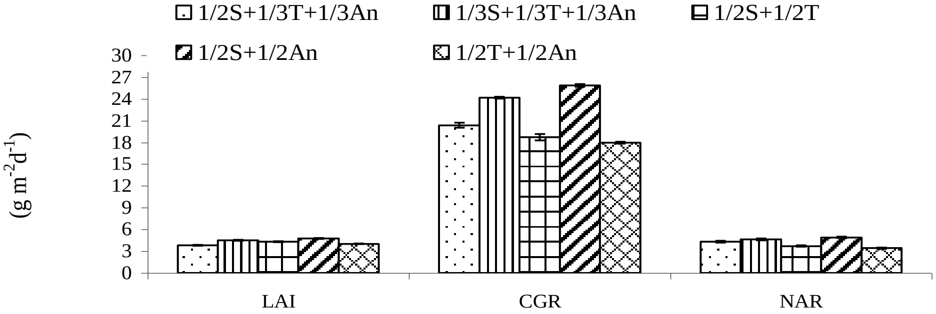

Fig. 3: Influence of N split applications on leaf area index (LAI), crop growth rate (CGR; g $m^{-2}d^{-1}$) and net assimilation rate (NAR; g $m^{-2}d^{-1}$) at anthesis (96 DAS) in dry direct seeded rice

S=sowing, T=tillering, An=anthesis

yield indicating accumulation of high pre-anthesis dry matter and its translocation from stems and leaves into grains (Zhang *et al.*, 2009; Table 2). Similarly harvest index was highest for these N splits due to increased translocation of dry matter towards growing sink which increased the total number of filled grains per panicle (Zhang *et al.*, 2009; Table 1). Similar response was observed for increased total and panicle bearing tillers, number of kernels per panicle and 1000 kernel weight by two or three equal N splits could be attributed to improved nutrition and plant growth due to increased N uptake (Kumar and Rao, 1992; Thakur, 1993)and significant correlation of increased filled grains with total dry matter translocation from stems and leaves into grains is also reported (Zhao *et al.*, 2006). Positive correlation of kernels number per panicle and 1000-kernel weight with kernel yield was also found in present study (Table 3). Nonetheless, these correlation values were relatively small as found by Zhang *et al.* (2009) that reduced grain filling rate limited the sink size and more carbohydrate supply from post-anthesis photosynthesis is needed for high grain filling in aerobic rice. Negative correlation of number of branches per panicle, sterile spikelets with kernel yield and of sterile spikelets with fertile tillers indicates the limited sink size could be the reasons for low yield in our experiment (Table 3). Mahajan *et al.* (2011) reported that increasing panicle number per unit area and high filled grains per panicle are important determinant of sink size and DSR crop due to better translocation of assimilates to panicle during anthesis can result in high fertile florets and kernel yield (Zhang *et al.,* 2007; Patel *et al.,* 2010). Nonetheless, improved crop performance associated with increasing N splits in our experiment might be due to better N uptake and reduced N losses benefitting the crop.

In conclusion, two or three N equal splits applied at sowing, tillering or anthesis increased growth attributes, dry matter accumulation and yield due to better crop nutrition and reduced N losses. N application in three splits was not better than two splits; however, further studies with N splits at different fertilizer rates under direct seeded aerobic rice systems are warranted for further improvement in NUE and crop productivity while considering economics.

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