

EFFECT OF SIMULATED FLOODING AND NITROGEN APPLICATION ON NITROGEN UPTAKE OF RICE

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Abstract

In lowland rice production systems, flooding patterns vary during the cropping period and this poses a serious challenge to productivity due to the effect of flooding on the availability and uptake of nitrogen. The aim of this study was to examine the influence of various flooding patterns on nitrogen use in rice grown under simulated wetland conditions. Rice was grown in a greenhouse at 0, 110 and 220 kg N ha⁻¹ under well watered control conditions, continuous flooding, early flooding at tillering, and late flooding post-tillering. The results showed that continuous and early flooding increased tiller production and grain yield compared to late flooding or non-flooded conditions. Although the highest grain yields under the different flooding patterns were obtained with 220 kg N ha⁻¹, the combination of 110 kg N ha⁻¹ and early flooding also significantly increased tiller productivity, nitrogen recovery, and agronomic nitrogen use efficiency (NUE). There is the need to regulate the supply of nitrogen and water resources if grain yield and NUE has to be increased at minimal costs. Also, compared to well-watered conditions, rice production under flooded conditions lead to increased productivity and N rate must match realistic target yields. Best results are obtained when flooding occurs in the early rather than later parts of the season.

Introduction

Rice is a principal grain crop in many sub-Saharan African countries where it is a major source of carbohydrates for thousands of households. It is produced mainly for subsistence by rural farm families with very little or no modern agricultural inputs, including fertilizers. The rice farming system in sub-Saharan Africa is dominated by shifting cultivation in upland fields where about 78- 90% of the crop is produced under rain-fed conditions (Balasubramanian *et al.*, 2007). As a result, yield is low and seldom exceeds 1.5tha⁻¹. By 2006, rice consumption had exceeded production (Nasrin *et al.*, 2015) by at least 50%, primarily as a consequence of declining output since the latter part of the 1980s (WARDA, 2007).

Although rice is not an aquatic plant, its yield can be improved with above average moisture supply (Sarwar and Khanif, 2005; Kikuta *et al.*, 2017). Currently, sub-Saharan African farmers are shifting towards lowland rice culture characterized by periodic flooding, to achieve increased productivity with the improved water supply associated with the lowlands, and also, promote sedentary farming (Dolo, 2009). Due to the uncertain flooding patterns associated with these lowlands, there is a need to develop insights into the effect of flooding patterns on the production of the crop. Of the major fertilizer resources, nitrogen is the most intensively used in rice cropping systems. Insufficient plant nitrogen results in chlorosis, reduced photosynthesis and stunted growth, while excessive amounts encourage luxuriant growth, lodging, diseases, and delays maturity (Takebe and Yoneyama, 1989; Peng *et al.*, 2010). Like nitrogen, elevated

soil moisture regimes promote the growth and development of rice crops (Juraimi *et al.*, 2009; Kikuta *et al.*, 2017). In most countries, rice is grown in wet or lowlands where water conditions are not easily predictable, particularly in respect of flooding times. Excessive moisture can negatively influence nitrogen use efficiency, and consequently, crop yield. This study therefore, examined the effects of different simulated flooding patterns and nitrogen application rates on the growth and yield of rice.

Materials and Methods

The study was conducted in a greenhouse with day / night temperatures of 30°C / 20°C at the Life Sciences Campus of the University of KwaZulu-Natal in Pietermaritzburg. The cultivar “Golden Mountain # 1” (GM-1) was used in this study. The experiment was a factorial combination of four simulated flooding regimes and three nitrogen rates, laid out in a completely randomized block design with four replications. The water regimes which were simulations of possible field moisture situations in wetland rice cropping were: well watered control (NF), continuous flooding (CF), early flooding (EF), and late flooding (LF). Double layer of clear plastic bags of 15 microns thickness were used to line the inner portion of the 4.8 L pots containing the flooded treatments, to prevent leakage through the pot drainage holes. Each pot was then filled with 10 kg air-dried soil (28% clay, 1.5% organic matter, 1.5% acid saturation) and well watered. Two hills were sown per pot with three seeds per hill, spaced 17 cm apart at a depth of 1 cm. Prior to sowing, seeds were soaked in tap water for 24 h, following which they were incubated at 30 °C for another 24 h in order to stimulate vigorous germination. The plants were thinned to one seedling per hill at two weeks after sowing.

Tensiometers (Irrometer Company, California) were used to monitor the soil water status in the root zones of the plants subjected to no flooding, to ensure they were always well watered and soil moisture tension in the root zone was kept below 15 k Pa throughout the experimental period. The flooding regimes were achieved by maintaining standing water at 5 cm from the soil surface in the 4.8 L pots. Commencing at 21 days after sowing (DAS), the early flooding regime lasted until 51 DAS (i.e. 30 days) when tillers had fully formed, while the continuous flooding regime lasted up to 7 days before harvest (i.e. 70 days). The late flooding commenced at 51 DAS (near booting) and lasted for 40 days i.e. until 7 days before harvest. Urea (46% N) was applied at 0, 110, and 220 kg N ha⁻¹, in three split doses of 50% at 20 DAS; 25% at mid tillering (45 DAS) and 25 % at booting (60 DAS). The amount of fertilizer was calculated on the basis soil analysis results. There was a basal application of 20 kg P ha⁻¹ using single super phosphate and no other fertilizers were required.

A portable plant efficiency analyzer (Hansatech, UK) was used to measure the leaf chlorophyll fluorescence at 30 DAS and at heading (65 DAS). A circular spot on the upper surface of each leaf was dark adapted for 20 minutes using dark adaptation clips, and the maximum quantum yield of photochemistry (Fv/Fm) recorded. Tiller production was monitored weekly from three weeks after sowing until heading. At heading, one plant per pot was randomly harvested for leaf area, above ground biomass, and nitrogen determination. Leaf area per plant was measured with a portable leaf area meter (LI-3000, LI-COR Biosciences) equipped with a LI-3050A belt conveyor. Above ground dry matter was measured after oven-drying at 70 °C for 48 h to constant masses. Plant tissue nitrogen concentration was determined by the Dumas combustion method, using a Tru Spec CN – elemental analyzer (LECO Corporation). Whole dried shoot material was ground to powder using a ball mill (Spex Industries 8000). Sub samples of 0.125 g were weighed, sealed in tin capsules and loaded for analysis.

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Nitrogen uptake at heading was determined as the product of the above ground dry mass and tissue nitrogen concentration. Nitrogen use efficiency (NUE) was assessed as nitrogen recovery efficiency and agronomic efficiency as:

$$\text{Recovery efficiency} = \frac{\text{uptake from N fertilized pot} - \text{uptake from non fertilized pot}}{\text{N applied}} \times 100$$

$$\text{Agronomic efficiency} = \frac{\text{grain weight in N fertilized pot} - \text{grain weight in non fertilized pot}}{\text{N applied}} \times 100$$

Panicle number, spikelet fertility, and grain weight were measured at maturity. Unfilled spikelets were separated from filled spikelets by water flotation. Grain weight was determined at grain moisture content of 14 %.

The data were subjected to analysis of variance (ANOVA) using the windows statistical software package, GENSTAT version 12. The means of treatments showing significant difference were subjected to Least Significance Difference (LSD) test. Relationship between factors was further assessed by Pearson's correlation and regression analysis using the statistical software SPSS 15.0 for Windows.

Results and Discussion

Tiller and panicle production

A high number of tillers ($P < 0.001$) was produced under both continuous and early flooding compared to the well watered controls and late flooding treatments (Figure 1a).

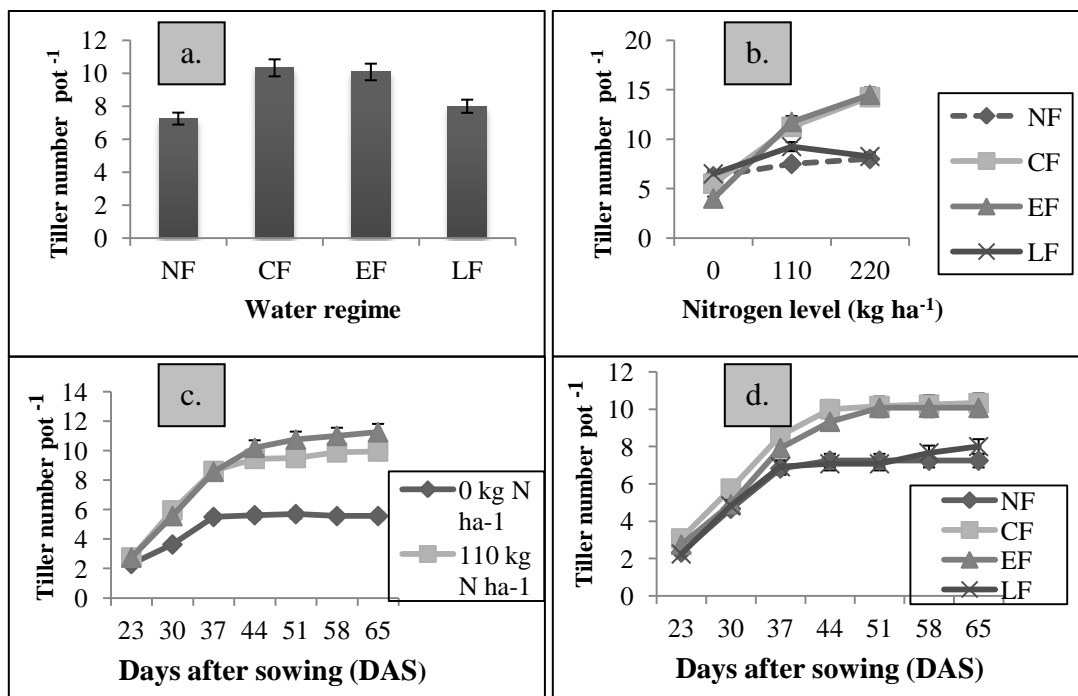


Fig. 1. Effect of flooding regimes and nitrogen rates on tiller production in rice grown in greenhouse conditions. Error bars show 95% CI of means.

Chlorophyll fluorescence

The ratio of variable fluorescence to maximum fluorescence (Fv/Fm) neither changed with nitrogen rate, nor with water regime at both 30 DAS and at heading (65 DAS). Mean values ranged from 0.77 to 0.79 at 65 DAS, and 0.79 to 0.80 at heading (Figure 2d), indicating that the plants were relatively free from stress.

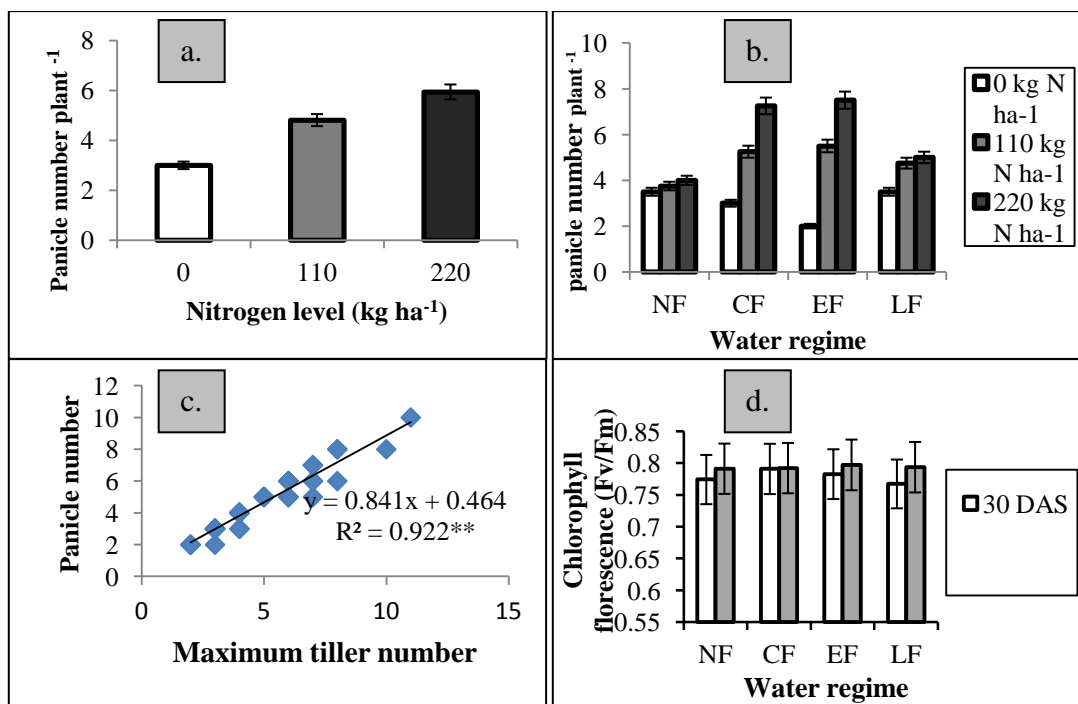


Fig. 2. Effect of flooding regimes and nitrogen rates on panicle production and chlorophyll fluorescence in rice grown in greenhouse conditions. Error bars show 95% CI of means

Leaf area, dry mass and nitrogen status

There was a significant interaction ($P < 0.001$) between the nitrogen rates and water regimes in respect of leaf area and shoot dry mass (Figures 3a and 3b). When no nitrogen was applied, these parameters were significantly higher for those grown under early flooding compared to the other water regimes. At 110 kg N ha⁻¹, water regime did not affect leaf area development, however, leaf area increased with continuous and late flooding at 220 kg N ha⁻¹.

At 220 kg N ha⁻¹ plants had the highest nitrogen concentration compared to those grown without nitrogen fertilizer (Figure 3c). Plants grown under non-flooded conditions also had high ($P < 0.01$) concentration compared to those continuously flooded. Plant tissue nitrogen concentration increased with increasing nitrogen input under all but the late flooding water regime, in which nitrogen concentration showed little increase beyond the 110 kg N ha⁻¹ rate. Plant nitrogen uptake was 4 - 5 times higher at 110 and 220 kg N ha⁻¹ than for the control

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treatment. However, uptake was only 1.3 times higher at 220 kg N ha⁻¹ compared to 110 kg N ha⁻¹ (Figure 3d). At 110 kg N ha⁻¹, there was no significant difference in nitrogen accumulation for all the water regimes. At 220 kg N ha⁻¹, nitrogen uptake by plants in both the continuous and early flooding regimes was significantly higher than those of the other two moisture regimes.

Nitrogen use efficiency

Nitrogen recovery was higher at 110 than at 220 kg N ha⁻¹ (Figure 4a). Also, recovery at both nitrogen levels was higher with continuous and early flooding compared to the non-flooded and late flooded regimes. Nitrogen recovery was less than 42% in all treatments but poorest in the late flooding treatment. The agronomic nitrogen use efficiency i.e. the ability of plants to increase yield in response to fertilizer input was higher for 110 than 220 kg N ha⁻¹ under all the moisture regimes (Figure 4b). At both nitrogen levels, agronomic nitrogen use efficiency was highest for early flooding, followed by continuous flooding.

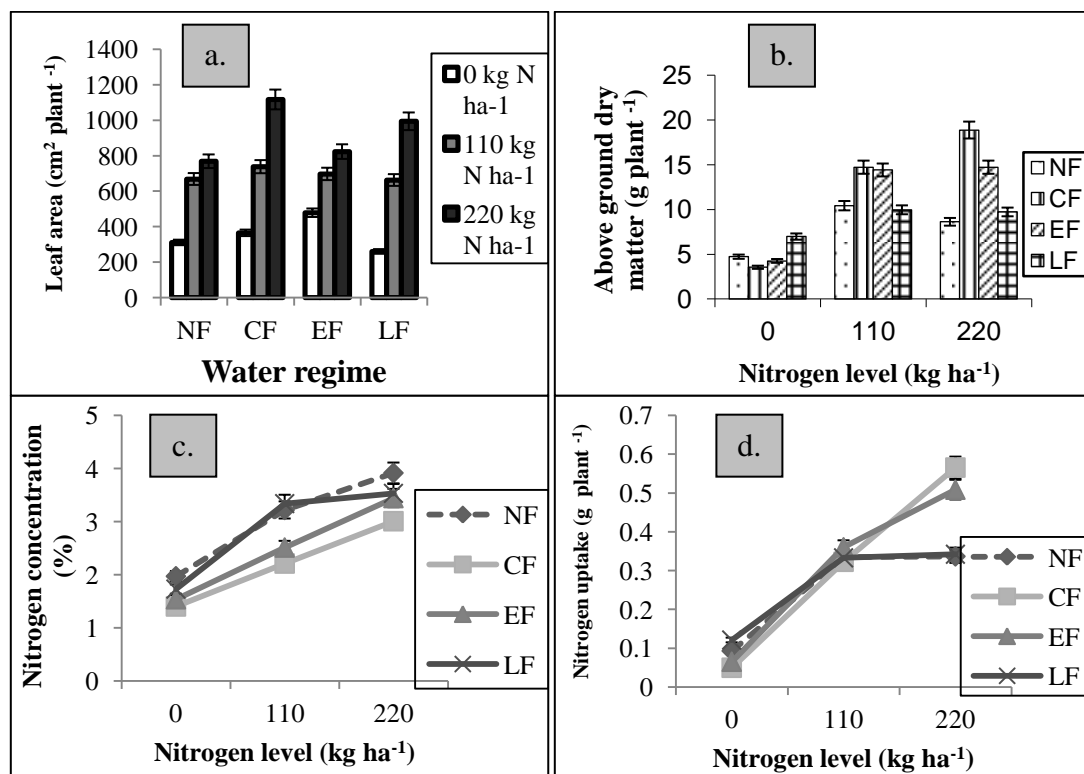


Fig. 3. Effect of flooding regimes and nitrogen rates on leaf area, dry mass, nitrogen concentration and uptake in rice grown in greenhouse conditions. Error bars show 95% CI of means.

Spikelet fertility and grain yield

Spikelet fertility reduced only slightly ($P < 0.05$) in plants grown under continuous flooding (Figure 4c). Nitrogen rate did not affect ($P > 0.05$) spikelet fertility (Figure 4d) and overall,

spikelet fertility was always higher than 80% irrespective of treatments. There was nearly a two-fold increase in grain yield per plant when nitrogen rate increased from 0 to 110 kg ha⁻¹; however, only a small increase was observed beyond this level (Figure 5a). Plants subjected to early flooding produced the highest grain yield ($P < 0.01$) compared to those in the non-flooded and late flooding regimes (Figure 5b). Without nitrogen, yield was lower as a result of continuous and early flooding. At 110 kg N ha⁻¹, yield increased with flooding irrespective of when it occurred. However, at 220 kg ha⁻¹ yield was limited by the non-flooded and late flooding treatments.

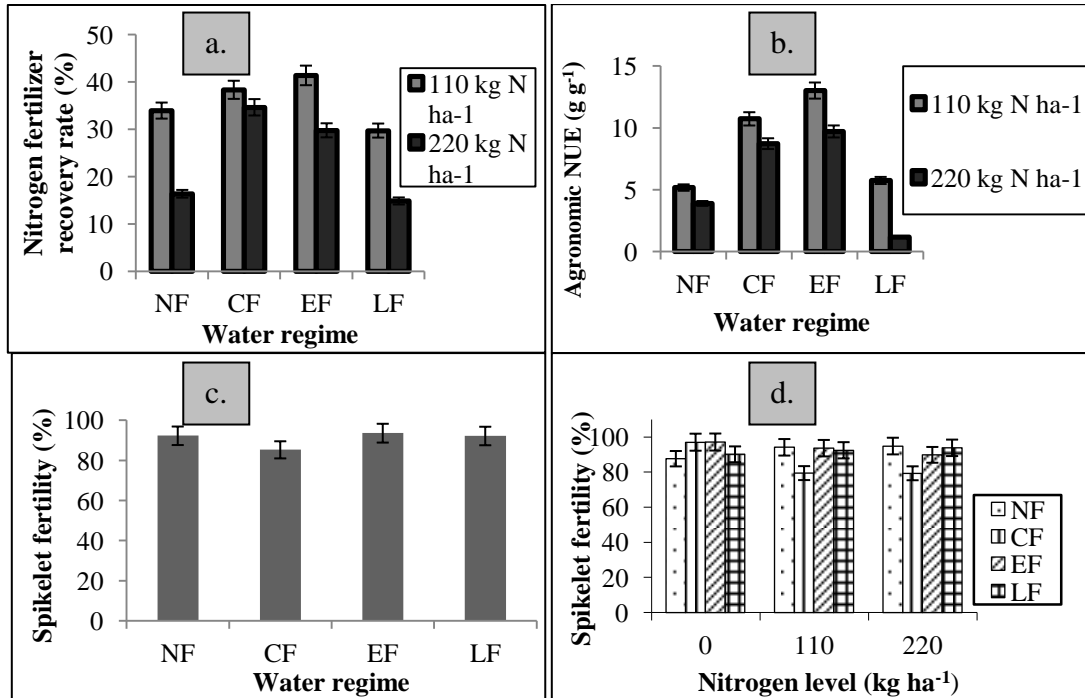


Fig. 4. Effect of flooding regimes and nitrogen rates on nitrogen recovery, agronomic use efficiency, and spikelet fertility in rice grown in greenhouse conditions. Error bars show 95% CI of means.

Relationship between tiller number, dry mass nitrogen uptake and grain yield

There was a significant positive linear relationship ($r^2 = 0.82$, $P < 0.001$) between tiller and panicle number on one hand and grain yield on the other (Figure 5c). Although panicle yield was strongly dependent on tillering ($r = 0.96$), only 77% of the variation in grain yield could be explained by the maximum number of tillers produced. Assessment of grain yield as a combined function of tillers and panicles revealed a non-significant estimate of the tiller coefficient (t pr. > 0.05), suggesting that unlike tillers, panicles were the principal determinants of grain yield (Figure 5c). Grain yield was positively related ($r = 0.85$) to shoot biomass at heading (Figure 5d) as well as total accumulated nitrogen in the plant ($r = 0.89$) at that time (Figure 6). Grain yield increased by 0.813 g (t pr. < 0.001) for every gram of increase in above ground dry matter and by 24.9 g for every gram of nitrogen accumulated by the time of heading.

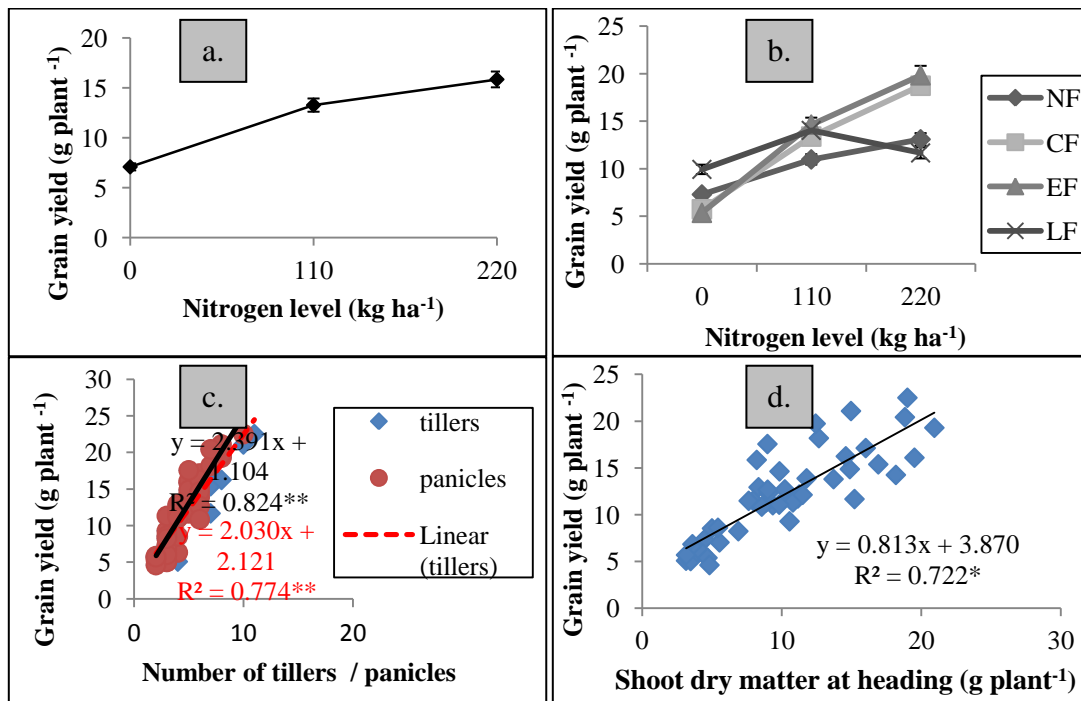


Fig. 5. Relationship between nitrogen application rate, shoot dry mass and tillers/panicle with grain yield. Data points show means for different nitrogen application rates. Error bars show 95% CI of means.

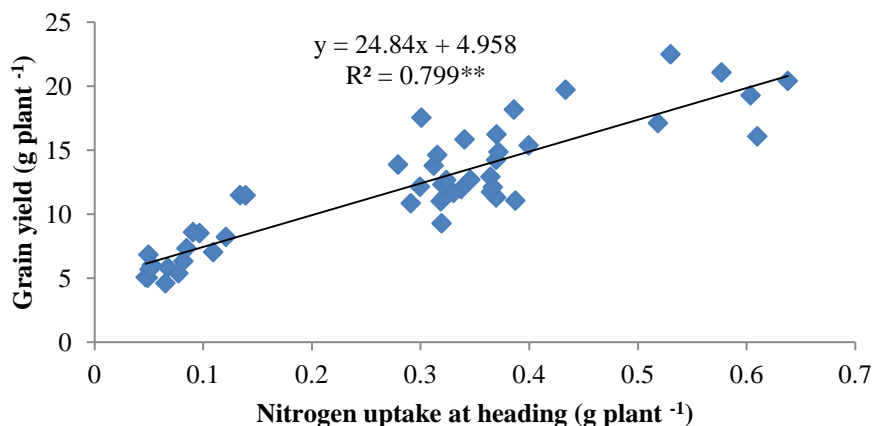


Fig. 6. Relationship between nitrogen uptake at heading and grain yield. Data points represent counts for both water regimes and nitrogen dosage (n = 48).

The overall grain yield response to the nitrogen treatments strongly correlated with the number of tillers, panicles and nitrogen uptake. However, the diminishing response between 110 and 220 kg ha⁻¹ suggests that beyond the requirements for a realistic target yield e.g. 6 t ha⁻¹ at the 110 kg N ha⁻¹ level in this study, the excessive biomass has little immediate benefit to grain yield. Such diminishing returns have been reported (Tilman *et al.*, 2002; Li *et al.*, 2015). Nitrogen application rate affected spikelet fertility only to a little extent as plants grown without nitrogen fertilizer did not produce many empty spikelets but rather only a few grain-bearing tillers. Prolific tillering, coupled with inadequate nitrogen can lead to a reduction in the percentage of fertile spikelets (Mauad *et al.*, 2003).

The fact that both N recovery and agronomic N use efficiency were higher at 110 kg N ha⁻¹ than at 220 kg N ha⁻¹, raises questions about the fate of excessive nitrogen application. Low efficiency of nitrogen use at higher nitrogen rates have been attributed to losses via pathways such as NO₂, NO and N₂ emissions, and NH₃ volatilization or to immobilization by soil microorganisms (Hirel *et al.*, 2007). To ensure efficient agronomic use of nitrogen, Peng *et al.* (2006) have recommended the reduction of nitrogen rate to around 120 kg ha⁻¹ in high tillering rice plants, a value close to the most efficient one adopted in this study, and to the 70-90 kg ha⁻¹ reported by Shultana *et al.* (2015).

In the current study, both continuous and early flooding treatments increased the number of tillers and panicles, above ground biomass, leaf area and nitrogen uptake and grain yield suggesting that they are better in lowland production than late flooding or non-flooded conditions. In the current study, however, because plants subjected to continuous or early flooding produced the highest grain yield in response to nitrogen compared to the other two water regimes, we suggest that those patterns of flooding are better for yield improvement. Late flooding was the least useful of the flooded treatments as it not only led to reduced N uptake and N use efficiency but also stimulated the production of late and unproductive tillers with the potential for interfering with harvesting of mature panicles produced earlier in the season. The poor nitrogen use efficiency obtained under the late flooding and non-flooded conditions indicates that most of the applied nitrogen was wasted in those treatments.

Conclusion

Based on the findings of the study it was concluded that both continuous and early flooding led to a significant increase in nitrogen recovery, nitrogen use efficiency and grain production. All the simulated flooding conditions produced better yields than the non-flooded conditions. This suggested that irrespective of the flooding pattern, better yields were associated with lowland conditions although late flooding was the least desirable of the options. Thus flooding regimes are significant for improved yields, in lowland areas that are fed by abundant rainfall.

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