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# Integrated nutrient, water and other agronomic options to enhance rice grain yield and N use efficiency in double-season rice crop

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ABSTRACT

Options to increase resource use efficiency and climatic yield potential of locally adapted super rice hybrids including combined water, nutrient and other agronomic management are limited. Hence, the aim of our three-year (six seasons) experiments during early-season (ESR; Luliangyou996) and late-season (LSR; C-liangyou396) rice in southern China was to identify key yield parameters and optimum resource use options to enhance the crop's climatic yield potential. Grain yield averaged across all three years with effective N management combined with post-anthesis shallow wetting and drying was 32.8% and 37.1% higher than the normal farmers' practice in Liuyang County in ESR and LSR, respectively. More spikelets $m^{-2}$ were the key to achieving high yield potential, further supported by increased leaf area index and high radiation interception and internal use efficiency. The split application of nitrogen in combination with shallow wetting and drying allowed for better N uptake, use efficiency and partitioning, leading to enhanced biomass and yield. The high yield potential, however, was not just a function of genetics and management but also depended on the climatic conditions prevailing, particularly temperature and radiation. In ESR, lower temperature during vegetative stage reduced overall biomass and sink size while subsequent higher temperature reduced the total grain filling period by 17 days compared with LSR, indicating a climatic condition-driven decline in yield potential rather than lower genetic potential of the super hybrids. A lack of correlation of spikelets $panicle^{-1}$ and spikelets $m^{-2}$ with grain-filling percentage in LSR provided evidence that a larger sink does not necessarily result in poor grain filling when sufficient time and assimilates for grain filling are provided, which is more climate dependent. Our work highlights the benefits of integrating nutrient, water and agronomic management options to achieve high NUE and grain yield.



## 1. Introduction

Over the centuries, rice (*Oryza sativa* L.) has been the major source of calories for a large proportion of the world population and the predicted exponential increase in population over the coming decades will exert tremendous pressure on increasing rice productivity (production per unit area). In an attempt to solve this problem, the rice scientific community has taken up the challenge to develop rice varieties that can increase productivity under unfavorable scenarios, for example, water scarcity. Recent progress in breeding has made it possible to achieve an increase of more than one ton per hectare under severe drought stress (Verulkar et al., 2010). However, a recent analysis comparing rice farm yields and potential yield under non-stress (free from both biotic and abiotic stresses) flooded conditions over three decades at IRRI showed a 60% and 100% yield gap in the wet and dry season, respectively (Fischer and Edmeades, 2010). Compared to the great challenge to increase yields under harsh environments, there is a relatively greater potential to enhance yield by 2.4–4.5 t $ha^{-1}$ under non-stress fully flooded conditions.

Giving more importance to genetic diversity in rice breeding programs on the one hand is essential to increase yield potential but this increase could be seriously restricted in the absence of an appropriate agronomic approach. Hence, to achieve the target increase in yield, it is imperative to consider genetic and management options simultaneously to exploit the true genetic potential of

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**Table 1**
Experimental treatments imposed during the early and late seasons of 2009, 2010, and 2011.

| Treatment | Fertilizer (N–P–K–Zn–Si kg $ha^{-1}$) | N splits (kg N $ha^{-1}$) (B–MT–PI–Fl) | Management | | |
|---|---|---|---|---|---|
| | | | Nursery | Spacing (cm) [hills $m^{-2}$] | Water management |
| Early-season rice (ESR) | | | | | |
| T1 | 0–45–90–0–0 | – | Wet raised seedbed | 16.7 × 20 [30] | Continuous flooding; shallow wetting and drying (SWD) |
| T2 (FP) | 150–30–60–0–0 | 120–30–0–0 | Wet raised seedbed | 20 × 20 [25] | Continuous flooding; field drained after flowering |
| T3 | 120–45–90–5–0 | 60–24–36–0 | Wet raised seedbed | 16.7 × 20 [30] | Continuous flooding; SWD |
| T4 | 180[a]–50–100[b]–5–50 | 90–36–36–18 | Dry raised seedbed | 13.3 × (16.7 + 33.7) [30] | Continuous flooding; SWD |
| T5 | 150–50–100[b]–5–0 | 75–30–45–0 | Dry raised seedbed | 13.3 × 26.5 [28.4] | Continuous flooding; SWD |
| Late season rice (LSR) | | | | | |
| T1 | 0–45–90–0–0 | – | Wet raised seedbed | 20 × 20 [25] | Continuous flooding; SWD |
| T2 (FP) | 165–30–60–0–0 | 132–33–0–0 | Wet raised seedbed | 23.3 × 23.3 [18.4] | Continuous flooding; field drained after flowering |
| T3 | 135–45–90–5–0 | 67.5–27–40.5–0 | Wet raised seedbed | 20 × 20 [25] | Continuous flooding; SWD |
| T4 | 195[a]–50–100[b]–5–50 | 97.5–39–39–19.5 | Two-stage seedlings | 16.7 × (16.7 + 33.7) [24] | Continuous flooding; SWD |
| T5 | 165–50–100[b]–5–0 | 82.5–33–49.5–0 | Two-stage seedlings | 13.3 × 30 [25] | Continuous flooding; SWD |

[a] 20 kg N $ha^{-1}$ in the form of oilseed cake fertilizer was applied as basal dose and is inclusive in the total N indicated in the table; B, MT, PI, and FL are basal, maximum tillering, panicle initiation stage, and just before flowering, respectively.
[b] Additional $KH_2PO_4$ was applied as foliar spray at 3 kg $ha^{-1}$ soon after heading. FP,farmers' practice. Numbers within square brackets indicate number of hills $m^{-2}$.

high-yielding rice varieties under defined climatic conditions. One good example is the agronomic revolution in Latin America, where yield increased from 5.4 t $ha^{-1}$ during 2000 to 7.2 t $ha^{-1}$, in 2008, an increase of 33% in spite of using varieties bred two to three decades ago (Zorrilla et al., 2012). On the other hand, in Asia the major focus has been on obtaining much higher yielding varieties with limited emphasis on the agronomic package that goes with them, making it harder to achieve the realistic genetic potential. Additionally, the focus on testing resources, that is, nitrogen levels (Zhang et al., 2009; Wang et al., 2012a,b), water management (Bouman and Tuong, 2001; Bouman et al., 2005), other fertilizers/nutrition in combination with N (Dobermann et al., 1998, 2002), and nitrogen and water management interactions (Belder et al., 2005; Sun et al., 2012) independently, fails to capture the impact a holistic package would have on enhancing rice yield potential. Studies involving a combination of different agronomic practices such as different planting density, water management, different nutrient composition, etc., are limited, in particular for China (Peng et al., 2009). Realizing that such integrated practices could have a differential impact on grain yield, which is further influenced by different climatic conditions, six field experiments over three years involving two environmental conditions and super hybrid rice varieties were carried out (i) to identify an integrated agronomic practice to enhance rice production in southern China and to quantify the impact across two different rice seasons; (ii) to estimate the critical factors for enhancing yield and their interaction with environmental factors such as solar radiation; and (iii) to quantify dynamic N partitioning and its use efficiency across different agronomic combinations that affect yield.

## 2. Materials and methods

### 2.1. Site description

Field experiments were conducted during the early season from late March to July and the late season from mid-June to late October of 2009, 2010, and 2011 in the same field in Liuyang County, Hunan Province, China (28°09′ N, 113°37′ E, 43 m asl). The soil at the experimental site was clayey with pH 6.30, 18.4 g organic C $kg^{-1}$, 1.09 g total N $kg^{-1}$, 7.81 mg $kg^{-1}$ available P, and 98.55 mg $kg^{-1}$ available K, estimated for soil collected from the upper 20 cm in 2009 before the start of the experiments.

### 2.2. Genetic material

Early-season super hybrid rice variety "Luliangyou996" (LLY996) developed by crossing Lu18S X 996 was used in all the early-season experiments, whereas a late-season super hybrid rice variety, "C-liangyou396" (CLY396), developed by crossing C815S X R396 was used in all the late-season experiments. Both these super hybrids were developed in Hunan Province using the two-line hybrid technology (Chen et al., 2007) and the generic characteristics of similar super hybrid rice varieties have been elucidated elsewhere (Yuan, 2001).

### 2.3. Crop husbandry

Pre-germinated seeds were sown in the seedbed. The seedbed and water management for seedling raising varied between the treatments, with nurseries maintained either (i) under slightly wet condition in a dry seedbed or (ii) in a wet seedbed maintained wet and flood conditions before and after the 2nd leaf emergence, respectively or (iii) two-stage seedlings wherein the seeds are sown in a wet seedbed in the field for 15 days, after which the seedlings are densely transplanted in another wet seedbed for another 15 or more days and re-transplanted with different spacing as mentioned in Table 1.

Land preparation was carried out by first puddling followed by harrowing and leveling the soil in the field. Twenty-seven and thirty-day-old seedlings were transplanted in the field in early- and late-season rice (ESR and LSR), respectively. Five different treatments with a range of nutrients and other management options were imposed in each season (Table 1). The fields were flooded for 5 days after transplanting and continuously maintained at shallow water until 5 days before panicle initiation, after which the fields were drained for 5 days and irrigated again at the start of panicle initiation and maintained continuously flooded until the start of flowering, after which the combined shallow water depth with wetting and drying (SWD) was followed in all the treatments, except in T2 (farmers' practice), in which the fields did not receive any irrigation after flowering. In SWD water management, the fields were irrigated to a water depth of around 3.0 cm and allowed to dry and then re-irrigated to a shallow depth of 3.0 cm just before any cracks developed on the soil surface (Sujono et al., 2011). In T1, T2, and T3, two seedlings $hill^{-1}$ were transplanted, whereas, in treatments T4 and T5, three to five seedlings $hill^{-1}$ were transplanted in both early- and late-season rice. During late-season rice (LSR), a