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Benefits of mechanized deep placement of nitrogen fertilizer in direct-seeded rice in South China

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ABSTRACT

Mechanical hill direct-seeded rice synchronous with deep placement of N fertilizer (MHDSR-NF) is an efficient alternative to conventional transplanted-flooded rice (CTFR), however, little is known about the effects of MHDSR-NF on grain yield, nitrogen use efficiency (NUE), and economic profitability. In present study, two types of N fertilizer viz., commercial compound fertilizer (CF) and ammonia bicarbonate (AB), placed mechanically at 10 cm of soil depth (M) or broadcasted manually (B), (written as CFM, CFB, ABM and ABB, respectively) in two rice cultivars viz., *Tianyou998* and *Yuxiangyouzhan* which were grown in both early and late seasons of 2014 in double rice cropping system of South China. Plants without N fertilizer application were taken as control (N0).

Compared to surface broadcasting, mechanically deep placement of N fertilizer enhanced NUE and grain yield significantly while improved nitrogen recovery efficiency (NRE) by 32.52–50.79%, 21.51–32.68%, and nitrogen agronomy efficiency (NAE) by 32.10–50.43%, 19.47–38.78%, of *Tianyou 998* and *Yuxiangyouzhan*, respectively, in both seasons. Compared to surface broadcasting, the grain yields of *Tianyou 998* and *Yuxiangyouzhan* under mechanically deep placement of N fertilizer were also increased by 6.31–8.03% and 4.70–6.78%, respectively, which were ascribed to the increased spikelet number per panicle. Furthermore, the lower production cost and the higher total return in CFM led to the highest benefit-cost ratio (BCR) in CFM, followed by CFB and ABM, whereas the lowest BCR was recorded for ABB. In addition, significant improvements were also observed in leaf area index, total aboveground biomass, and photosynthesis rate in CFM at the heading stage. Catalase (CAT) and Peroxidase (POD) activities of the uppermost leaves were significantly higher under deep placement of N fertilizer than surface broadcasting. Hence, mechanized deep placement of commercial compound fertilizer can be taken as an efficient fertilization method in mechanical hill direct-seeded rice in South China.

1. Introduction

Rice (*Oryza sativa* L.) feeds more than one half of the world's population while its major part is grown and consumed in Asia only (Shaiful Islam et al., 2009; Abid et al., 2015). It also feeds more than 60% population of China and contributes up to 40% of total national grain production (Wu et al., 2013). Thus, the production of rice becomes important to feed the increasing population of China and rest of the world (Miao et al., 2011). In traditionally transplanted rice production system, rice seedlings are transplanted in puddling conditions (Ashraf et al., 2014), which is no longer been suitable for China in present and/or will be in future due to severe labor scarcity, low efficiency due to laborious nature of work and lower profits and net returns (Uchida et al., 2009; Knight et al., 2011; Hamdollah and Attar, 2015; Tao et al., 2016). Hence, involvement of mechanization in rice production systems is the need of the day to address such issues and to solve rice production related problems effectively.

Direct-seeded rice (DSR) is a substitutive rice growing technique to classical transplanted-flooded rice with reduced production costs, labor and extra efforts for nursery raising, seedling uprooting, and transplanting (Chen et al., 2009; Chauhan et al., 2012; Ehsanullah et al., 2014; Liu et al., 2015a,b). This method of rice production favors earlier crop establishments, provides an opportunity to make better use of early season rainfall, and thus leading

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towards increased grain yield (Tuong et al., 2000; Wang et al., 2014), therefore, adoption of direct-seeded rice cultivation technique is increasing day by day among farmer community (Farooq et al., 2011). Usually, broadcasting is one of the main methods of DSR cultivation in South China in which farmers often broadcast pre-germinated rice seeds manually on the wet surface of puddled soils that most often leads to poor crop stand establishment due to uneven distribution and placement of rice seeds (Guan, 2011). Mechanical hill direct-seeded-rice growing technique is an efficient method that can solve the stand establishment related issues in DSR after germination and/or seedling emergence by placing the seeds uniformly in the field at designed depth, spacing with uniform seedling density (Zeng et al., 2014; Kargbo et al., 2016).

Both ammonia bicarbonate and compound fertilizer are two kinds of important fertilizers that may affect crops growth and yields (Liu, 2006). For example, Yang et al. (2011) reported that ammonia bicarbonate could regulate the activities of protective enzymes in rice. Compared to commercial compound fertilizer, coated compound fertilizer could improve the rice growth as well as grain yield by controlling the release of N, P, and K contents in the soils (Zou et al., 2005; Hu et al., 2007). Broadcasting of nitrogenous fertilizers in rice is probably the most slackly method of fertilizer application that leads towards extensive nitrogen losses (Miao et al., 2011).

Hence, application of N at suitable time and amount as well as uses of nitrification and urease inhibitors to improve nitrogen utilization have been reported previously (Mohanty et al., 1999; Ma et al., 2013; Sun et al., 2015). However, combined with a harrow and/or furrower opener, MHDSR-NF enables puddling, seeding, and fertilizer application operations simultaneously (Fig. 1a, b), thus favorable uniform seeding, and fertilizer application which could often results in well-aerated micro-environment, favorable soil conditions, even crop establishment and reduced pest and disease incidence (Zeng et al., 2014). Even though mechanical rice planting is presently being used in many regions world-wide, however, little information is available on the effects of MHDSR-NF on its nitrogen use efficiency, grain yield, and economic profitability. Hence, two field experiments were conducted with the aims of: (1) to examine the effects of mechanical hill direct-seeded rice synchronous with deep placement of fertilizer (MHDSR-NR) on nitrogen use efficiency of two rice cultivars; (2) to address the effects of MHDSR-NF on grain yield and its components of two rice cultivars; and (3) to compare the economic profitability of MHDSR-NF with manual broadcasting method.

2. Materials and methods

2.1. Fertilizer applicator

Mechanical hill direct-seeded rice machine synchronous with deep placement of fertilizer was developed by College of Engineering, South China Agricultural University, Guangzhou, China (Fig. 1a).

2.2. Experimental treatments and design

Field experiments were conducted in both early and late rice growing seasons (a typical rice farming system in South China) of 2014, respectively, at Experimental Research Farm, College of Agriculture, South China Agricultural University, Guangzhou City, China (113.18′E, 23.10′N with 18 m of elevation). Overall, this region has a sub-tropical and monsoon type of climate (Li et al., 2016), however, the mean monthly air temperature, precipitation, mean daily radiation, and average humidity during the rice growing seasons have also been presented in Table 1. The experimental soil was sandy loam with 1.14 g kg^{-1} total N, 1.18 g kg^{-1} total P, 20.96 g kg^{-1} total K, 74.37 mg kg^{-1} available P, and 103.20 mg kg^{-1} available K and 22.65 g kg^{-1} organic C. Field experiments were set up as randomized complete block design in triplicate with a gross plots size of 90 m^2 (15.0 m × 6.0 m). Two types of N fertilizers, i.e., commercial compound fertilizer (CF, total nitrogen contents TN = 15%, N: P_2O_5 = 15%:15%), and ammonium bicarbonate (AB, TN = 17.7%) were applied at the same amount of 120 kg N ha^{-1}. Commercial compound fertilizer was manufactured by Zhongxiang Phosphorus Fertilizer Company, China. Two application methods, i.e., 10 cm depth mechanized placement (M) and manual surface broadcast (B) were adopted with four combinations with N-fertilizer, i.e., CFM: commercial compound fertilizer mechanized applied to 10 cm depth of the soil, CFB: commercial compound fertilizer broadcasted manually on the soil surface, ABM: ammonium bicarbonate mechanized applied to 10 cm depth of the soil, ABB: ammonium bicarbonate broadcasted manually on the soil surface. Plots with no N fertilizer application were taken as control (N0). All fertilizer treatments also received the same amount of 120 kg P_2O_5 ha^{-1} as superphosphate (SOP) and 120 kg K_2O ha^{-1} as potassium chloride (KCL). Total N + P fertilizers were applied as basal, whilst 50% of K-fertilizer was applied as basal and 50% was top-dressed at panicle initiation stage.

Two regionally popular and widely adopted rice cultivars, i.e., *Tianyou998* (*Tianfeng A* × *Guanghui 998*, a three line hybrid type rice) and *Yuxiangyouzhan* (the inbred rice type) were developed by the Rice Institute, Guangdong Academy of Agricultural and Science, China. *Tianyou998* and *Yuxiangyouzhan,* had a growth period of 123 and 117 days as well as 122 and 118 days for early and late season of rice, respectively. Pre-germinated seeds of the both *Tianyou998* and *Yuxiangyouzhan*, were hill-seeded with direct-seeded machine at a space of 25 × 15 cm while each hill was planted with 3–5 seeds. In both seasons, the fields were prepared in water-ponding conditions and the standing water was drained two days before seeding. Pre-germinated rice seeds were sown in puddled soil on March 25 and July 12 for both early and late seasons of 2014, respectively.

Water management practices were followed as adopted by local farmers, where the field was drained off completely before seeding. No standing water was kept in the field from sowing to the three-leaf stage of rice, and then the field was re-flooded to about 3 cm water depth until the end of the tillering stage. Subsequently, the water was drained for about 7 days to control the production of non-productive/infertile tillers. At the following stages a water of 5–7 cm was kept to the grain-filling stage.

2.3. Leaf area index and total aboveground biomass

Plants were sampled randomly at mid-tillering (MT), panicle initiation (PI), heading stage (HS), and maturity stage (MS) from an area of 0.5 m^2 from each plot in both growing seasons. Plants were washed thoroughly to remove adhered soil while the aboveground plants parts i.e., leaves, leaf sheaths plus stems and panicles organs were separated from the roots after heading stage. Leaf area of all green leaf blades was measured with Li-Cor area meter (Li-Cor Model 3100, Lincoln, NE) and leaf area per m^2 (leaf area index, LAI) was then calculated. To record aboveground total biomass, the sampled plants were oven-dried at 70 °C till constant weight.

2.4. Determination of CAT and POD activities

Anti-oxidant enzyme activities i.e., catalase (CAT) and peroxidase (POD) were determined by following the methods of Li (2006) and Pan et al. (2013), respectively.