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Effect of tillage on soil and crop properties of wet-seeded flooded rice

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ABSTRACT

No-tillage (NT) is an alternative cropping system for saving costs and conserving soils relative to conventional tillage (CT). However, NT effects on paddy soil and rice growth are still controversial or not fully understood. A fixed field experiment was conducted to compare soil and crop properties between NT and CT wet-seeded flooded super hybrid rice in Changsha, Hunan Province, China. After 6 years of continuous cropping, NT had higher contents of active organic carbon, NaOH hydrolysable N and NH_4OAc extractable K and higher activities of invertase, urease and acid phosphatase at 0–5 cm soil depth, higher bulk density at 5–10 cm soil depth, and higher contents of double acid P at 5–10 cm and 10–20 cm soil depths. NT or associated soil compaction caused an adverse root environment for NT rice at early growth stage, which resulted in a lower capacity of photosynthetic carbon metabolism and consequent reductions in number of tillers and aboveground biomass accumulation before heading. However, no reductions were observed in total aboveground biomass and grain yield in NT rice, because the negative effects of NT or associated soil compaction on aboveground biomass production before heading were compensated for by its positive effects on aboveground biomass accumulation after heading. On one hand, the reduction in growth before heading of NT rice made its population density lower but more suitable during heading to 20 days after heading, which led to a more appropriate leaf area index, a lower leaf senescence and a consequent increase in net assimilation rate. On the other hand, N uptake was delayed in NT rice, which was another critical factor in determining its low leaf senescence. Our study suggests that the negative effects of NT or associated soil compaction on crop growth at early growth stage do not necessarily become concerns in NT wet-seeded flooded rice production.

1. Introduction

No-tillage (NT), a combination of ancient and modern agricultural practices (Phillips et al., 1980), has potential benefits including reduced production costs though saving in fuel, equipment and labor (Allmaras and Dowdy, 1985) as well as soil conservation (Uri, 1997). NT can work in a wide range of climates, soils and geographic areas (Huggins and Reganold, 2008). In 1999 NT was adopted on about 45 million ha worldwide, growing to 72 million ha in 2003 and to 105 million ha in 2009 (Derpsch and Friedrich, 2009). It is considered that the development of NT agriculture is one of the revolutions that have greatly impacted agriculture throughout the world (Triplett and Dick, 2008). However, NT adoption rates are still low in European, Africa and most parts of Asia. About 85% of NT land lies in North and South America (Huggins and Reganold, 2008).

Paddy fields account for approximately 15% of the world's arable land (Xiao et al., 2005), and more than 90% of them are located in Asia. In order to produce enough food for the rapidly growing population, agriculture land use in Asia has become very intense (Bronson et al., 1997). In the past 40 years, intensification of rice-based cropping systems has helped ensure production of sufficient rice and other food crops (Buresh et al., 2005). However, continuous rice-based cropping systems practiced in Asia for several decades has led to declines in productivity and raised concerns about sustainability (Joshi et al., 2007; Guo et al., 2010). Long-term experiments suggest that the productivity of such continuous rice-based cropping systems can be sustained through soil and crop management practices that maintain the resource base (Buresh et al., 2005). The recent adoption of NT is considered beneficial in rice–wheat cropping system in South Asia (Joshi et al., 2007). There are about 5 million ha of NT being practiced in the Indo-Gangetic-Plains in a rice–wheat cropping system, where wheat is the NT crop (Derpsch and Friedrich, 2009).

China is one of the major rice production countries in the world (Xiong et al., 2002). In order to feed growing population, China established a nationwide mega-project on the development of super rice based on the ideotype concept in 1996 (Cheng et al., 1998). In 1998–2005, 34 commercially released super hybrid rice varieties were grown on a total area of 13.5 million ha and they

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produced an additional 6.7 million tonnes of rough rice in China (Cheng et al., 2007). Nevertheless, rice yield depends upon not only the genetic characters but also the agronomic practices (Zou et al., 2003). In China, conventional tillage is the most widely used method for land preparation of paddy fields, and transplanting is the traditional but still dominant method for rice establishment. The operation of transplanting requires a large amount of manpower (about 400 man-hour ha^{-1}) and the task is very laborious involving working in a stooping posture and moving in muddy field (Thomas, 2002). Paradoxically, labor availability is limited in China because an increasing number of young farmers have left for jobs in the cities leaving the older farmers behind (Derpsch and Friedrich, 2009). In recent years, the simple and labor-saving method of direct seeding became increasingly attractive along with the popularization of efficient agriculture in China (Wu et al., 2005).

There are many studies regarding the effects of NT on soil properties in rice-based cropping system. Soil compaction is one of the biggest concerns for newcomers to the NT farming community, as well as sometimes to farmers that have been practicing this technology for some time (Derpsch, 2003). Previous studies that have compared bulk density of NT and CT in paddy fields have produced conflicting results because soil bulk density is influenced by several factors such as time since last tillage, residue coverage, soil type and cropping system. In some studies larger bulk densities was found under NT than CT (Zhuang et al., 1999; Li et al., 2001; Iijima et al., 2005), whereas in some studies smaller bulk densities were recorded under NT than CT (Du, 1991; Chen et al., 1993; Feng et al., 2006). Ambassa-Kiki et al. (1996) reported that bulk density did not significantly vary between NT and CT under flooded conditions. Soil acidification is a major problem in soils of intensive Chinese agricultural systems (Guo et al., 2010). It is controversial whether NT leads to soil acidification in paddy fields. Huang (1988) reported that NT could lead to an accelerated soil acidification compared to CT, especially at the 0–5 cm soil depth. Feng et al. (2006) observed that there was no consistent difference in pH between NT and CT at 0–5 cm soil depth, while pH was usually higher under NT than CT at 5–10 cm soil depth. Soil fertility is fundamental in determining the productivity of all farming systems (Watson et al., 2002). It is generally accepted that paddy soils under NT management are rich in organic carbon and nutrients in the surface soil layer (Lal, 1986; Feng et al., 2006; Tang et al., 2007). Soil enzymes are sensitive to variations induced by natural and anthropogenic disturbances (Gupta et al., 1988; Dick, 1994). Gao et al. (2004) observed that NT paddy had higher soil enzyme activities at 0–20 cm soil depth. However, very little information is available on the relationships between soil enzymes and other soil properties in NT paddy soils. More importantly, there is still limited knowledge about the relationships between soil properties and crop yield formation in NT paddy.

Rice yield is the function of biomass production after heading (HD) and translocation of biomass accumulated before HD to grains (Yang et al., 2008). Although both are associated with grain yield, some studies has been suggested that the latter should be emphasized more than the former (Weng et al., 1982; Miah et al., 1996; Laza et al., 2003), whereas a number of crop physiologists have indicated the importance of increased biomass production after HD in rice (Murchie et al., 2002; Takai et al., 2006; Yang et al., 2008). There have been several reports describing NT effects on biomass production of rice (Liu et al., 2002; Iijima et al., 2005; Xu and Jiang, 2007; Dong et al., 2008; Wu et al., 2009). It is showed that NT rice usually produces a lower aboveground biomass before HD but a higher one after HD than CT rice. However, there is still a lack of understanding of the critical physiological processes that elaborate on the differences in aboveground biomass production between NT and CT rice. Moreover, previous studies were usually conducted under transplanting or seedling throwing conditions, and using ordinary rice cultivars. Limited information is currently available on the effects of NT on biomass production in direct-seeded super hybrid rice.

In our current study, we compared soil properties and crop biomass production and related physiological factors between NT and CT wet-seeded flooded super hybrid rice. Our objectives were (1) to determine the effects of NT on paddy soil properties, (2) to identify the physiological processes contributing to the effects of NT on rice biomass production, and (3) to understand the relationships between paddy soil properties and rice biomass production under NT conditions.

2. Materials and methods

2.1. Site and soil

A fixed field experiment was conducted at Changsha (28°11′N, 113°04′E and 32 m altitude), Hunan Province, China in 2004–2010. The location is situated in the East-Asian monsoon climatic zone and has a moist sub-tropical monsoon climate. The field was cropped with NT oilseed rape before the start of the experiment. The soil of the experimental field was clay loam with pH = 6.04, organic matter = 14.96 g kg^{-1}, total N = 1.40 g kg^{-1}, total P = 1.18 g kg^{-1}, total K = 18.13 g kg^{-1}, NaOH hydrolysable N = 137.0 mg kg^{-1}, Olsen P = 38.35 mg kg^{-1}, NH_4OAc extractable K = 113.3 mg kg^{-1}. The soil test was based on samples taken from the upper 20 cm of the soil.

2.2. Plants and treatments

Liangyoupeijiu, an *indica–japonica* hybrid (Peiai64S × 9311) developed by Jiangsu Academy of Agricultural Sciences of China and released in 1999, was used in the experiment. This cultivar has been approved as a super hybrid rice cultivar by the Ministry of Agriculture of China in 2005 because of its high yield potential. In each year, Liangyoupeijiu was grown under conventional tillage (CT) and no-tillage (NT) in the single rice-growing season (from May to October), and oilseed rape was grown under NT at 2 days after harvesting rice. Rice and oilseed rape stubbles were remained in all plots. Plots were arranged in a randomized complete block design with four replications using plot size of 30 m^2. The land preparation of the plots under CT (plowing and two harrowing) was with buffalo; and for the plots under NT, herbicide Gramoxone (paraquat 20%) was used (diluted 5 ml L^{-1} and applied at 750 L ha^{-1}) 7 days before sowing. Seeds were first sterilized by soaking in 0.3% trichloroisocyanuric acid solution for 12 h, and then washed and soaked in tap water for 24 h at room temperature. The soaked seeds were kept between thick layers of cotton cloth and allowed to germinate at room temperature. The pre-germinated seeds were manually broadcast onto the wet soil surface at a seed rate of 22.5 kg ha^{-1} (about 120 seeds m^{-2}) between May 11th and June 1st. Urea was used as a source of N, single superphosphate of P and potassium chloride of K with rates of 150 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1} and 180 kg K_2O ha^{-1}. N was split-applied: 90 kg ha^{-1} as basal, 45 kg ha^{-1} at mid-tillering, and 15 kg ha^{-1} at panicle initiation. P was applied as basal and K was split equally at basal and panicle initiation. In CT plots, the basal fertilizer was broadcast after the first harrowing and incorporated with the second harrowing. The regimen for water management was in the sequence of watering to saturation (from seeding to 1.5-leaf stage), flooding, midseason drainage, reflooding and moist intermittent irrigation but without water logging. Weeds, insects and diseases were controlled as required to avoid yield loss. However, the yield was detrimentally affected due to lodging caused by a typhoon in the growing season of 2005. There was no apparent difference in damage to the NT and CT rice. Hence, the data of 2005 were excluded from the analysis.