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RESPONSE DIFFERENCES OF PHOTOSYNTHETIC CHARACTERISTICS OF A SUPER HYBRID RICE CULTIVAR UNDER TRANSPLANTED AND DIRECT-SEEDED CONDITIONS TO NO-TILLAGE

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ABSTRACT

A field experiment was conducted at the research farm of Hunan Agricultural University, Hunan, China in single rice season. Super high-yielding rice Liangyoupeijiu (LYPJ) was grown both in transplanting and direct seeding conditions under conventional tillage (CT) and no-tillage (NT) systems to determine the effects on photosynthetic characteristics. Differences in response of photosynthetic characteristics to NT were found in transplanting and direct-seeding conditions. For transplanting, the negative effects of NT on the photosynthetic capability came from the decreasing ratio of chlorophyll *a*/*b*, the soluble protein contents per unit fresh weight and the specific leaf weight (SLW) which were stronger than the positive effects of NT through the increasing of the chlorophyll content per unit fresh weight at midtillering (MT), panicle initiation (PI) and heading (HD) stages, which led to net photosynthetic rate per unit leaf area (P_N) in NT which was slightly lower than in CT at all of the three growth stages. For the direct seeding, the negative effects of NT on the photosynthetic capability was found through the decreasing of the chlorophyll contents, the soluble protein contents per unit fresh weight which were stronger than the positive effects of NT through the increasing of the chlorophyll *a*/*b* ratio and the SLW at MT, whereas the negative effects of NT on the photosynthetic capability came from the decreasing of the chlorophyll contents, the soluble protein contents per unit fresh weight which were weaker than the positive effects of NT came from the increasing of the SLW at PI and HD stages, which caused P_N in NT was slightly lower than that in CT at MT whereas it was slightly higher at PI and HD stages.

Keywords: photosynthetic capability, chlorophyll content, soluble protein content, specific leaf weight, super high-yielding rice, no-tillage, transplanting, direct seeding

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop of China and its productivity is critical to national food security (Fan *et al.*, 2009). In order to break rice yield stagnation and feed growing population, China has started to develop the super high-yielding rice (Wang *et al.*, 2005). Up to 2016, 125 cultivars with great yield potential had been approved as the super high-yielding rice by the Ministry of Agriculture of China. Nevertheless, the rice yield not only depends upon the genetic characters but also the environments and the agronomic practices (Zou *et al.*, 2003). So how to make a full play of the yield potential is still a new topic for the development of the super high-yielding rice.

In China, transplanting is the most common method of rice establishment, and simple and labor-saving technique of direct seeding becomes increasingly attractive along with the popularization of efficient agriculture in recent years (Wu *et al.*, 2005). Conventional tillage (CT), namely ploughing followed by harrowing, is the dominant system for preparation of paddy fields in both the transplanted and the direct-seeded rice production of China. However, the system requires a large amount of energy and labor (Bhushan *et al.*, 2007). Additionally, CT may accelerate mineralization of organic matter, reduce soil fertility, increase water consumption, and deteriorate chemical and physical properties of soil (Chen *et al.*, 2007). Therefore, it is necessary to seek an alternative system. No-tillage (NT) system, characterized by minimal soil disturbance (Parmelee *et al.*, 1990), may be a good choice as it has potential benefits include reducing production costs through saving in fuel, equipment and labor (Allmaras and Dowdy, 1985) as well as soil conservation (Uri, 1997). Now a days, there are approximately 90 million hectares of land were cultivated under NT in worldwide (Monneeveux *et al.*, 2006).

LiangYouPeiJiu (LYPJ), the first super high-yielding hybrid rice cultivar of China, has been widely cultivated in southern China in past few years (Lü and Zou, 2003). Compared with traditional cultivars, this hybrid rice has higher photosynthetic activities in mid and late stages of leaf development (Zhang *et al.*, 2007) and less photo inhibited under strong midday sunlight (Wang *et al.*, 2005). Recently, some studies have been done on its photosynthetic characteristics under different growing environments (Chen *et al.*, 2004). However, limited information is currently available on the responses of its photosynthetic characteristics to NT under both the transplanted and the direct-seeded conditions. In the present study, LYPJ was grown in both transplanting and direct seeding conditions under CT and NT systems, and photosynthetic capability, chlorophyll content, chlorophyll *a*/*b* ratio, soluble protein content and specific leaf weight (SLW) were analyzed at different growth stages. Therefore, this study was conducted to determine whether NT had effects on photosynthetic characteristics under the transplanted and the direct-seeded conditions and whether these effects were differences between these two

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conditions.

2. MATERIALS AND METHODS

2.1 Site and soil

A field experiment was conducted at the research farm of Hunan Agricultural University, central China's Hunan Province (28°11′ N, 113°04′ E and 32 m altitude) during single rice growing season. The research farm is located in the East-Asian monsoon climatic zone and has a moist sub-tropical monsoon climate with distinct four seasons. 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}.

2.2 Plants and treatments

Liangyoupeijiu **(**LYPJ), an *indica-japonica* hybrid (Pei-ai64S × 9311) developed by Jiangsu Academy of Agricultural Sciences of China, was used in the experiment. In each growing season, LYPJ established both in the transplanting and the direct seeding under CT and NT systems and arranged in a randomized complete block design with four replications using plot size of 30 m^2. Land preparation for the plots of CT was carried out by water buffalo plouging followed by harrowing, and for the plots of NT involved herbicide application and soaking. For transplanting, seedlings were raised in nursery beds, and 25-days-old seedlings were manually transplanted at a spacing of 20 cm × 20 cm with one seedling per hill between May 31st and June 24th. For direct seeding, water-soaked seeds were manually broadcasted onto the soil surface at a seed rate of 22.5 kg ha^{-1} between May 11th and June 1st. Fertilizer urea was used for N, single superphosphate for P, potassium chloride for K with doses of N, P_2O_5 and K_2O of 150, 90 and 180 kg ha^{-1}, respectively. Water management adopted a strategy of flooding-midseason drainage-reflooding-moist intermittent irrigation but without water logging. Weeds, insects and diseases were controlled as required to avoid yield loss.

2.3 Sampling and measurements

At midtillering (MT), panicle initiation (PI) and heading (HD) stages in the growing season of 2009, eight plants (two per replication) were selected to determine the net photosynthetic rate per unit leaf area (P_N) with a portable photosynthesis system (*LI-6400*, *Li-Cor*, Lincoln, NE, USA) on the uppermost fully expanded leaves. Meanwhile, twenty pieces (five per replication) of the uppermost fully expanded leaves from different plants were collected for measuring the contents of chlorophyll, soluble protein and sugar per unit fresh weight, and all green leaves from four

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plants (one per replication) were removed for determining SLW. The contents of chlorophyll *a*, chlorophyll *b* and the total chlorophyll were measured by extracting with a mixture of ethanol: acetone: distilled water = 4.5:4.5:1 (v/v/v) for 24 h (Yang *et al.*, 2007) according to the procedure of Arnon (1949), and the chlorophyll *a*/*b* ratio was calculated using the chlorophyll a content divided by chlorophyll b content. The soluble protein content was determined with the protein-dye binding method introduced by Braford (1976) using bovine serum albumin as the standard. SLW was measured in milligrams of dry matter per square centimeter of leaf area (Laza *et al.*, 2001), in which the dry matter was determined after oven-drying at 80℃ to constant weight, the leaf area was determined by measuring length and maximum width of the leaf and calculated as leaf area = leaf length × maximum leaf width × 0.75 (Umashankar *et al.*, 2005).

2.4 Statistical analysis

Experimental result was expressed as mean and standard error of four replications. Differences between the means were compared using Duncan's New Multiple Range Test (Duncan, 1955).

3. RESULTS AND DISCUSSION

Under the transplanted condition, the contents of chlorophyll *a*, chlorophyll *b* and the total chlorophyll per unit fresh weight in NT were increased at all of the three growth stages compared with in CT (Fig. 1 *A*-*C*), especially at HD stage, the contents of chlorophyll *b* and the total chlorophyll per unit fresh weight in NT were significantly higher than those in CT by 18% and 15%, respectively ($P < 0.01$ and $P < 0.05$, respectively; Fig. 1 *B*, *C*). It is known that the chlorophyll content is an indicator for photosynthetic capability of plant (Hassanzadeh *et al.*, 2009), and many studies showed that the photosynthetic capability had positive correlation with the chlorophyll content (Chen *et al.*, 2008; Hu *et al.*, 2007; Sinclair and Horie, 1989). So there was no doubt that NT could improve the photosynthesis if the photosynthetic capability was only related to the chlorophyll content. Unfortunately, both the developmental status of photosynthetic organs and the photosynthetic capability are also positively related to the chlorophyll *a*/*b* ratio (Yang *et al.*, 2008). In the present study, the chlorophyll *a*/*b* ratios in NT were decreased than in CT at all of the three growth stages, especially at MT stage, the chlorophyll *a*/*b* ratio in NT was significantly lower than that in CT by 7% ($P < 0.05$; Fig. 1 *D*). Therefore, the positive effect of NT on the photosynthesis through the increasing of the chlorophyll content per unit fresh weight must be reduced by the decreasing of the chlorophyll *a*/*b* ratio. Moreover, the soluble protein content is also closely related to the photosynthetic capability because a large proportion of the soluble protein is Rubisco (Stitt and Schulze, 1994), which is the most important enzyme involve in the CO_2 fixation and its contents is thought to be a rate-limiting factor for the light-saturated rate of the photosynthesis at atmospheric CO_2 pressure (Makino *et al.*, 1985). In this study, the

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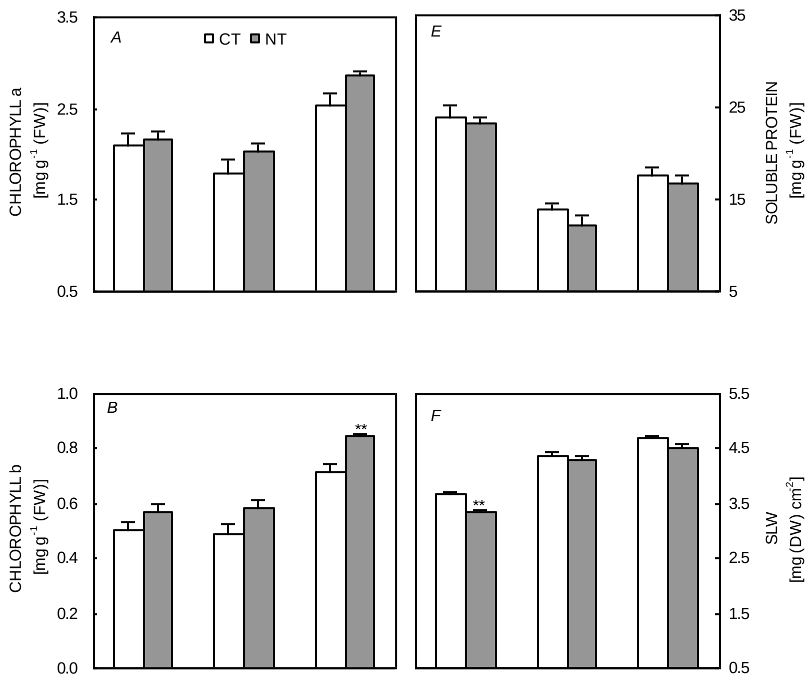
soluble protein contents per unit fresh weight in NT were slightly lower compared with those in CT at all of the three growth stages (Fig. 1 *E*), and this must had negative effect on the photosynthetic capability of NT. Furthermore, SLW in NT were lower compared with than in CT at all of the three growth stages, especially at MT, SLW in NT was significantly lower than in CT by 8% ($P < 0.01$; Fig. 1 *F*). This indicated that the positive effect of NT on the photosynthesis through the increasing of the chlorophyll content per unit fresh weight might be further reduced while the negative effect of NT on the photosynthesis through the decreasing of the soluble protein content per unit fresh weight might be further strengthened in per unit leaf area. Finally, P_N in NT was slightly lower than in CT at all of the three growth stages (Fig. 1 *G*), and this revealed that the negative effects of NT on the photosynthetic capability came from the decreasing of the chlorophyll *a*/*b* ratios, the soluble protein contents per unit fresh weight and the SLW were stronger than the positive effects of NT through the increasing of the chlorophyll content per unit fresh weight at all of the three growth stages.



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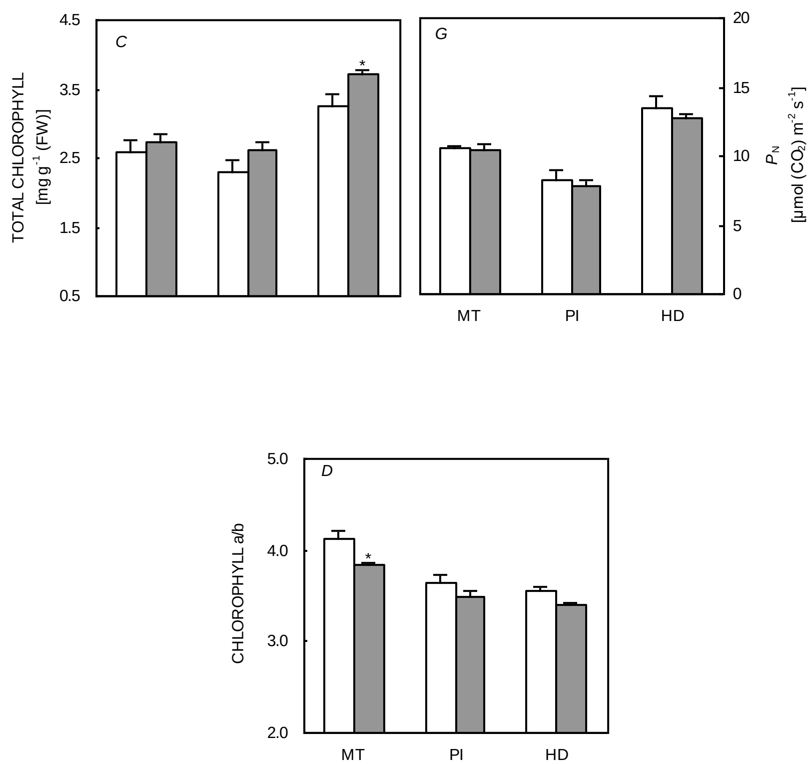

Fig.1. Chlorophyll a contents (*A*), chlorophyll b contents (*B*), total chlorophyll contents (*C*), chlorophyll a/b ratios (*D*), soluble protein contents (*E*), specific leaf weight, SLW (*F*) and net photosynthetic rate, P_N (*G*) in the leaves of super high-yielding hybrid rice Liangyoupeijiu established by transplanting under conventional tillage (CT: *empty columns*) and no-tillage (NT: *full columns*) systems at midtillering (MT), panicle initiation (PI) and heading (HD) stages. *Vertical bars* show standard errors ($n = 4$). * and ** represent significance at the 0.05 and 0.01 probability levels, respectively.

On the other hand, under the direct-seeded condition, the contents of chlorophyll *a*, chlorophyll *b* and the total chlorophyll per unit fresh weight in NT were decreased compared with in CT at all of the three growth stages (Fig. 2 *A*-*C*), especially at PI, the chlorophyll *a*, chlorophyll *b* and the total chlorophyll contents per unit fresh weight in NT were significantly lower than in CT by a similar percentage (about 16%; $P < 0.05$, $P < 0.01$ and $P < 0.05$, respectively; Fig. 2 *A*-*C*). However, the chlorophyll *a*/*b* ratio in NT was slightly higher than in CT at MT while it was close at PI and HD (Fig. 2 *D*) stages. Under NT, the soluble protein content per unit fresh weight was lower than in CT at all of the three growth stages, especially at MT, the soluble protein content per unit fresh weight in NT was significantly lower than in CT by 26% ($P < 0.01$; Fig. 2 *E*). In contrast, SLW was higher in NT compared with in CT at all of the three growth stages, especially at MT, SLW in NT was significantly higher compared with that in CT by 5% ($P < 0.05$; Fig. 2

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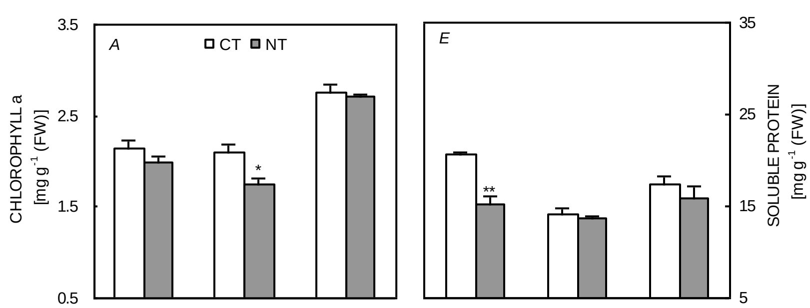
F). Ultimately, P_N in NT was slightly lower than that in CT at MT whereas at PI and HD stages it was slightly higher in NT than in CT (Fig. 2 *G*). All these indicated that the negative effects of NT on the photosynthetic capability through the decreasing of the chlorophyll contents, the soluble protein contents per unit fresh weight were stronger than the positive effects of NT through the increasing of the chlorophyll *a*/*b* ratio and the SLW at MT, whereas the negative effects of NT on the photosynthetic capability came from the decreasing of the chlorophyll contents, the soluble protein contents per unit fresh weight were weaker than the positive effects of NT came from the increasing of the SLW at PI and HD stages. It was also shown that the responses of the photosynthetic characteristics of LYPJ to NT were differences between the transplanted and the direct-seeded conditions. Earlier, many studies had demonstrated that there were discrepancies between the transplanted and the direct-seeded rice in some indexes which were directly or indirectly related to the photosynthesis, such as foliar N concentration (Dingkuhn *et al.*, 1990), root activities (Naklang *et al.*, 1996), morphological characteristics (Wiangsamut *et al.*, 2006) and gas exchange (Chen *et al.*, 2009), and these discrepancies might lead to further differences in the responses of the photosynthetic characteristics of the transplanted and the direct-seeded rice to the growing environment changes. For example, in the present study, panicles per unit area in NT was lower than that in CT under the transplanted condition whereas it was similar under the direct-seeded conditions (data not shown), which could make light conditions were differences between NT and CT in the transplanted rice and similar between NT and CT in the direct-seeded rice at the late growth stages. It has been known for a long time that many angiosperm plants acclimate to changing the light conditions by a change in the ratio of outer antenna complexes to the core complexes of photo system (PS) I and PS II. Since the chlorophyll *b* is mainly localized in light harvesting complex II, the outer antenna of PS II, the changing ratio of the complexes means also a change in the ratio of chlorophyll *a*/*b* (Rüdiger, 2002). And these might be why there were certain discrepancies between NT and CT in the ratios of chlorophyll *a*/*b* under the transplanted condition but similar under the direct-seeded condition at PI and HD stages.



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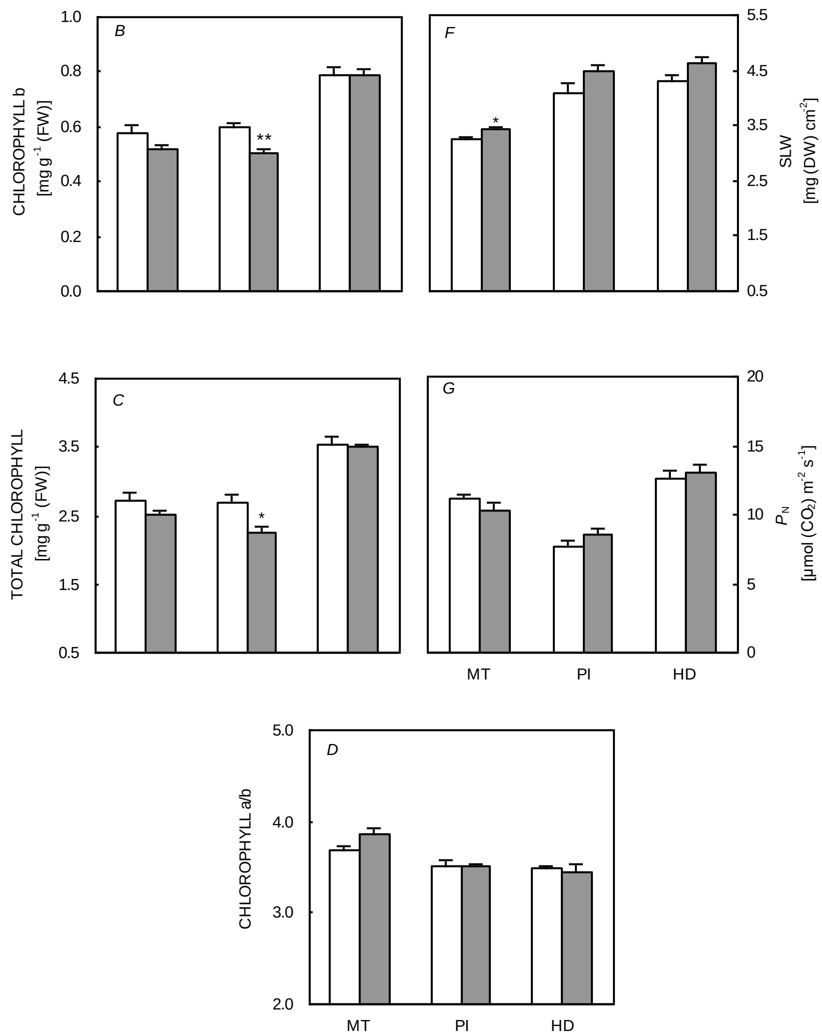

Fig.2. Chlorophyll a contents (*A*), chlorophyll b contents (*B*), total chlorophyll contents (*C*), chlorophyll a/b ratios (*D*), soluble protein contents (*E*), specific leaf weight, SLW (*F*) and net photosynthetic rate, P_N (*G*) in the leaves of super high-yielding hybrid rice LiangYouPeiJiu established by direct seeding under conventional tillage (CT: *empty columns*) and no-tillage (NT: *full columns*) systems at midtillering (MT), panicle initiation (PI) and heading (HD) stages. *Vertical bars* show standard errors (n = 4). * and ** represent significance at the 0.05 and 0.01 probability levels, respectively.

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