DEEP FERTILIZER PLACEMENT IMPROVES RICE GROWTH AND YIELD IN ZERO TILLAGE

DU, B.[1,2#] – LUO, H. W.[1,2#] – HE, L. X.[1,2#] – ZHENG, A. X.[1] – CHEN, Y. L.[1] – ZHANG, T. T.[1,2] – WANG, Z. M.[3] – HU, L.[3] – TANG, X. R.[1,2*]

[1]*Department of Crop Science and Technology, College of Agriculture, South China Agricultural University, 510642 Guangzhou, PR China*

[2]*Scientific Observing and Experimental Station of Crop Cultivation in South China, Ministry of Agriculture, 510642 Guangzhou, PR China*

[3]*Key Laboratory of Key Technology for South Agricultural Machine and Equipment, Ministry of Education, 510642 Guangzhou, PR China*

[#]*These authors have contributed equally to this work.*

**Corresponding author*
e-mail: tangxr@scau.edu.cn; phone/fax: +20-8528-0204-618

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Abstract. Effects of deep fertilizer placement on rice growth and yield were investigated with two rice cultivars *Meixiangzhan2* and *Xiangyaxiangzhan*. Four treatments of pre-transplant tillage + fertilizer application were set: (CK) twice puddling with rotary cultivator + manual surface broadcast; (CD) twice puddling through rotary cultivator + 10-cm deep mechanized placement; (ZB) no pudding + manual surface broadcast; (ZD) no pudding + 10-cm deep mechanized placement. Treatments CD and ZD both significantly improved the grain yield and panicle number unit area compared with treatments CK and ZB. Dry accumulation, chlorophyll contents and net photosynthetic rate at both the heading stage and maturity stage were enhanced by the deep fertilizer placement. Thus, we think the benefits of mechanical deep fertilizer placement have potential to break the production limitation and popularization in conservation tillage.
Keywords: *zero tillage, rice; deep placement of fertilizer, grain yield, photosynthesis, chlorophyll, dry matter accumulation*

Introduction

As a crop feeding more than half of the global population, the major species of rice (*Oryza sativa* L.) is only grown and consumed in Asia (Abid et al., 2015). The rice production and food security become increasingly important since the world population is rising year by year (Miao et al., 2011). Many factors affect the productivity of rice plants, such as the amount and application method of fertilizer. As reported, nitrogen application at 180 kg ($N \cdot ha^{-1}$) remarkably enhanced the net photosynthetic rate, yield, and total nitrogen and potassium accumulation (Pan et al., 2016). Nitrogen use at 60 $kg \cdot hm^{-2}$ at both the tillering stage and booting stage increased not only panicle number per hill and grain yield, but also the 2-acety-1-pyrroline (2-AP) contents of aromatic rice (Ren et al., 2017). Moreover, the silicon fertilizer also could improve net photosynthetic rates, 2-AP contents and rice yield (Mo et al., 2017).

Recently, the conversation tillage methods such as minimum tillage and zero tillage have increasingly attracted farmers and researchers because of the soil problems (e.g. poor soil structure) and the negative effect of tillage on soil organism. Compared with

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conventional tillage, rice under zero tillage accumulates more roots in the surface soil layer (Huang et al., 2018) and thus has more roots distributed in the soil fertilizer with high nitrogen content and less nitrogen fertilizer, which might be needed. However, zero- tillage rice takes long time to uptake the basal nitrogen, which induces the loss of nitrogen fertilizer (Cheng-Fang et al., 2011). Similarly, the nitrogen uptake in zero-tillage rice was delayed at early growth stages, due to the inhibition of root growth caused by the rhizospheric accumulation of inhibitory pseudomonads (Huang et al., 2012). Even worse, because of the labor shortage and increasing labor costs, rice farmers usually applied fertilizers only once before crop establishment just to avoid in season fertilizer application (Peng et al., 2008). Hence, the fertilizer use efficiency of zero-tillage rice should be enhanced.

Appropriate time and amount of nitrogen application could improve the nitrogen use efficiency (Sun et al., 2015; Mohanty et al., 1998). However, the mechanical hill transplanted rice synchronized with deep fertilizer placement was able to puddle, transplant and apply fertilizer simultaneously combining a harrow and a furrower opener. Deep placement of nitrogen fertilizer improved the nitrogen use efficiency, spikelet number per panicle and grain yield (Pan et al., 2017). Moreover, deep fertilizer placement significantly increased the grain yields compared with broadcasting (Bandaogo et al., 2015), and thus might be the most efficient and promising method to prevent fertilizer loss.

The present study was conducted in Guangdong (a major rice-producing province in South China) in order to examine the effects of deep fertilizer placement on rice photosynthesis and yield.

Materials and methods

Plant materials and growing conditions

Two rice cultivars, *Xiangyaxiangzhan* and *Meixiangzhan2* having a growth period of 111-114 days, were planted at early season of 2018 in Zengcheng (23°13’ N, 113°81’ E, altitude 11 m), Guangdong. The experimental site enjoyed a subtropical monsoon climate (*Fig. 1*). Before sowing, the seeds were soaked in water for 24 h, germinated in manual climatic boxes for another 24 h and shade-dried. The germinated seeds were sown in polyvinyl chloride trays for nursery raising. Then 15-day-old seedlings were transplanted to the field at the planting distance of 30×12 cm^2 on April 1, 2018 and harvested on July 16, 2018. The experimental soil in Zengcheng was sandy loam containing 20.12% organic matter, 1.408% total N, 1.068% total P, and 15.767% total K.

Treatment and plant sampling

The experiment was conducted in early season and the commercial compound fertilizer (YaraMila Fertilizer Company, China) was applied at the same amount of 105 kg·N·ha^{-1}. Four treatments of pre-transplant tillage + fertilizer application were set up: (CK) conventional manage practice, twice puddling with rotary cultivator + manual surface broadcast; (CD) twice puddling with rotary cultivator + 10 cm deep mechanized placement; (ZB) no pudding + manual surface broadcast; (ZD) no pudding + 10 cm deep mechanized placement. Ten random rice plants from each plot were collected for estimation of dry matter accumulation in the tillering stage (TS), heading stage (HS)

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and maturity stage (MS), respectively. Fresh leaves were sampled from the rice at each stage and immediately stored at -80 °C for determination of chlorophyll contents.

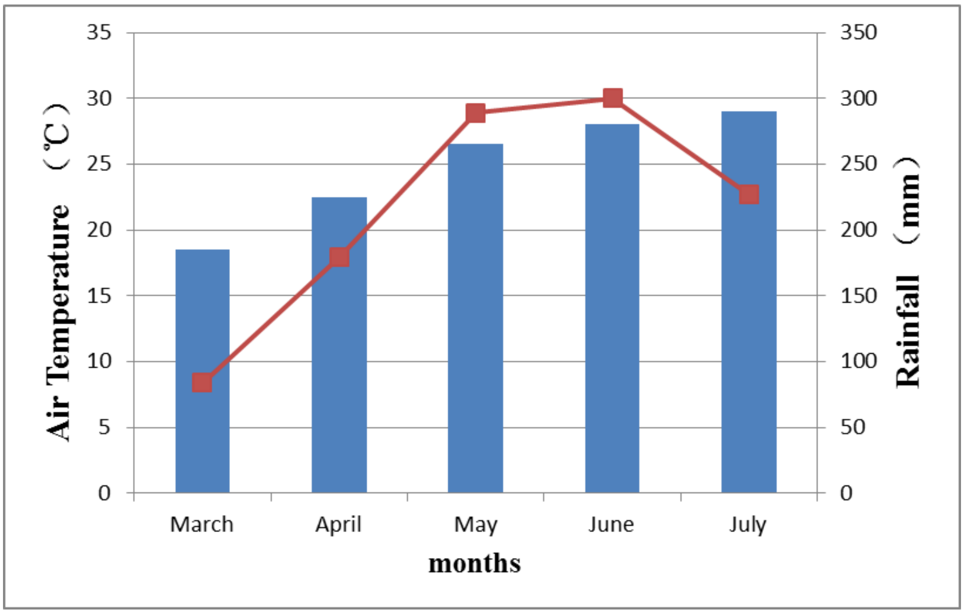

Figure 1. *Mean monthly temperature and rainfall during the experiment site*

Photosynthesis

Photosynthesis was measured at the three stages. Net photosynthetic rate and gas exchange attributes were measured using a portable photosynthesis system (LI-6400, LI-COR, USA) at 09:00–10:30 a.m. according to the standard method described by Kong et al. (2017).

Detection of chlorophyll contents

Typically, a ground leaf sample (about 0.1 g) was placed in a 15 ml centrifuge tube added with 95% absolute ethyl alcohol (10 ml) and then kept in the dark until the sample turned white. Then contents of total chlorophyll (total Chl), chlorophyll a (Chl a) and chlorophyll b (Chl b) were detected on a ultraviolet visible spectrophotometer at 645, 652 and 663 nm, respectively according to Anjum et al. (2016).

Yield and yield-related traits

At the maturity stage, the rice grains were harvested from one unit sampling area (25 m^2) in each plot and threshed by machine. Then after sun drying, the grain yield was determined on basis of the dry weight. Twenty five random hills of rice plants in each plot were sampled for calculating the average effective panicle number per hill. Then four hills of rice plants from each plot were taken to determine the yield- related traits.

Treatment design and statistical analysis

This study was managed as a randomized complete block design with four replicates (n = 4). Data were analyzed on Statistix 8.1 (Analytical Software, Tallahassee, FL,

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USA) at the probability level of 5% ($P < 0.05$). Differences among means were separated by using least significant difference (LSD) test.

Results

Grain yield and yield-related traits

The grain yield and related traits were all different to some extent under different tillage conditions and fertilizer applications (*Table 1*). The trend of yield was: CD = ZD > CK = ZB, but no significant difference between CD and ZD was found for either *Meixiangzhan2* or *Xiangyaxiangzhan*. The panicle number per unit area maximized in CD and minimized in ZB. Moreover, no remarkable difference among treatments was found in seed-setting rate or 1000-grain weight. *Xiangyaxiangzhan* had higher yield and seed-setting rate than *Meixiangzhan-2*.

Table 1. *Effects of tillage and fertilizer application on grain yield and yield-related traits*

Cultivar	Treatment	Panicle number per m^2	Grains number per panicle	Seed-setting rate (%)	1000-grain weight (g)	Yield (t hm^{-2})
Meixiangzhan2	CK	302.33±4.50c	78.33±5.81a	75.57±3.19a	19.97±0.68a	3.60±0.13b
	CD	350.00±6.49a	82.56±2.85a	80.50±3.08a	21.13±0.86a	4.08±0.18a
	ZB	278.33±5.24d	74.67±4.63a	81.13±1.08a	19.87±0.76a	3.51±0.13b
	ZD	339.67±7.22b	83.67±2.91a	83.30±0.84a	20.80±0.61a	3.89±0.27a
Xiangyaxiangzhan	CK	294.67±3.18b	87.33±6.36a	78.50±2.37a	20.53±0.70a	4.15±0.12b
	CD	346.33±3.30a	97.33±0.88a	80.53±1.40a	21.40±0.41a	5.73±0.11a
	ZB	272.00±8b	92.00±1.76a	79.97±1.85a	19.47±0.71a	3.80±0.11b
	ZD	335.33±7.02a	87.67±7.00a	83.17±2.05a	21.97±0.83a	5.34±0.19a

Means in the same column followed by different lower case letters for the same variety differ significantly at $P < 0.05$ by T-test, the same as below

Dry matter accumulation

Significant differences were found among different tillage and fertilizer applications (*Fig. 2*). For *Meixiangzhan2*, the trends at the tillering, heading and maturity stages were the same: CD > ZD > CK = ZB, but no significant difference between CK and ZB was found. For *Xiangyaxiangzhan*, compared with CK, dry matters were 1.52, 1.21, 1.34, 1.22, 1.32 and 1.23 fold higher in CD and ZD at the tillering, heading and maturity stages, respectively. No significant difference in dry matter accumulation was found between CD and ZD at the heading stage. In addition, at heading stage and maturity stage, there was higher dry matter weight in *Meixiangzhan-2* than *Xiangyaxiangzhan*.

Chlorophyll contents

The methods of fertilizer application significantly affected the chlorophyll contents (*Table 2*). For *Meixiangzhan2*, the trend of total Chl contents was: CD = ZD > CK = ZB at each stage, while no significant difference between CD and ZD and similar trends were observed in the contents of Chl a and Chl b. For *Xiangyaxiangzhan*, the contents of total Chl, Chl a and Chl b also maximized in CD, while the chlorophyll contents of

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ZD were all higher than both CK and ZB. Furthermore, the total chlorophyll and chlorophyll a content of *Xiangyaxiangzhan* at tillering stage and heading stage were higher than *Meixiangzhan-2*.

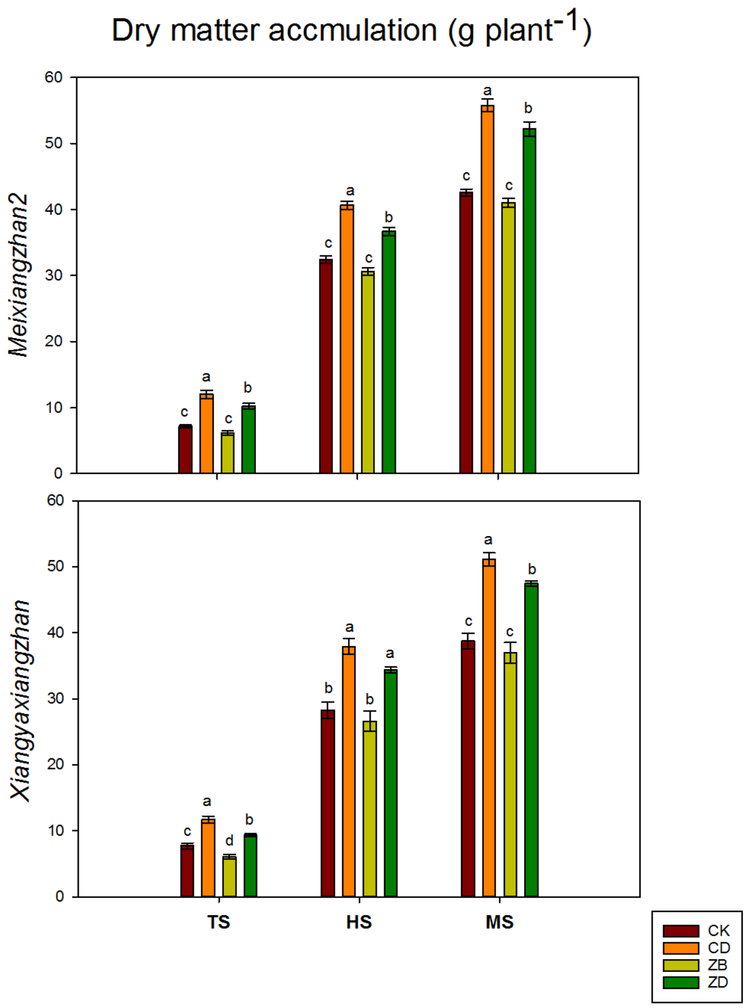

Figure 2. *Effects of tillage and fertilizer application on dry matter accumulations (TS mean tillering stage, HS mean heading stage, MS mean maturity stage, the same as below)*

Table 2. *Effects of tillage and fertilizer application on chlorophyll contents*

Cultivar	Treatment	Total Chl (mg·g^{-1})			Chl a (mg·g^{-1})			Chl b (mg·g^{-1})		
		TS	HS	MS	TS	HS	MS	TS	HS	MS
Meixiangzhan2	CK	2.87±0.06b	2.46±0.06b	0.65±0.02b	1.94±0.04b	1.59±0.04b	0.40±0.01b	0.69±0.02b	0.57±0.01b	0.15±0.01b
	CD	3.40±0.07a	2.83±0.03a	0.82±0.02a	2.30±0.05a	1.83±0.02a	0.49±0.01a	0.82±0.02a	0.65±0.01a	0.19±0.01a
	ZB	2.80±0.04b	2.42±0.06b	0.60±0.03b	1.89±0.03b	1.56±0.04b	0.36±0.02b	0.67±0.01b	0.56±0.01b	0.14±0.01b
	ZD	3.22±0.06a	2.76±0.03a	0.77±0.0a	2.17±0.04a	1.79±0.02a	0.46±0.01a	0.78±0.02a	0.64±0.01a	0.17±0.01a
Xiangyaxiangzhan	CK	3.14±0.03b	2.65±0.04c	0.76±0.02b	2.14±0.02b	1.72±0.03c	0.47±0.01b	0.77±0.01b	0.63±0.01c	0.18±0.01b
	CD	3.55±0.05a	2.99±0.05a	0.92±0.04a	2.42±0.04a	1.95±0.03a	0.57±0.02a	0.87±0.01a	0.71±0.01a	0.21±0.01a
	ZB	2.77±0.12c	2.55±0.06c	0.74±0.03b	1.88±0.08c	1.66±0.04c	0.46±0.02b	0.68±0.03c	0.60±0.01c	0.17±0.01b
	ZD	3.45±0.12a	2.85±0.04b	0.88±0.03a	2.34±0.04a	1.85±0.02b	0.54±0.02a	0.84±0.02a	0.67±0.01b	0.20±0.01a

Photosynthesis

The net photosynthetic rates were quite different among the four treatments (*Fig. 3*). At tillering stage, no remarkable difference among CK, CD, ZB and ZD was found for either *Meixiangzhan2* or *Xiangyaxiangzhan*. However, at heading stage and maturity stage, the net photosynthetic rates in CD and ZD were significantly higher than ZB and CK, and the trends were: CD = ZD > CK = ZB. At tillering stage, *Meixiangzhan-2* had higher net photosynthetic rate than *Xiangyaxiangzhan* whilst at heading stage, net photosynthetic rate of *Meixiangzhan-2* was lower than *Xiangyaxiangzhan* and at maturity stage, there was no significant difference between two rice cultivars.

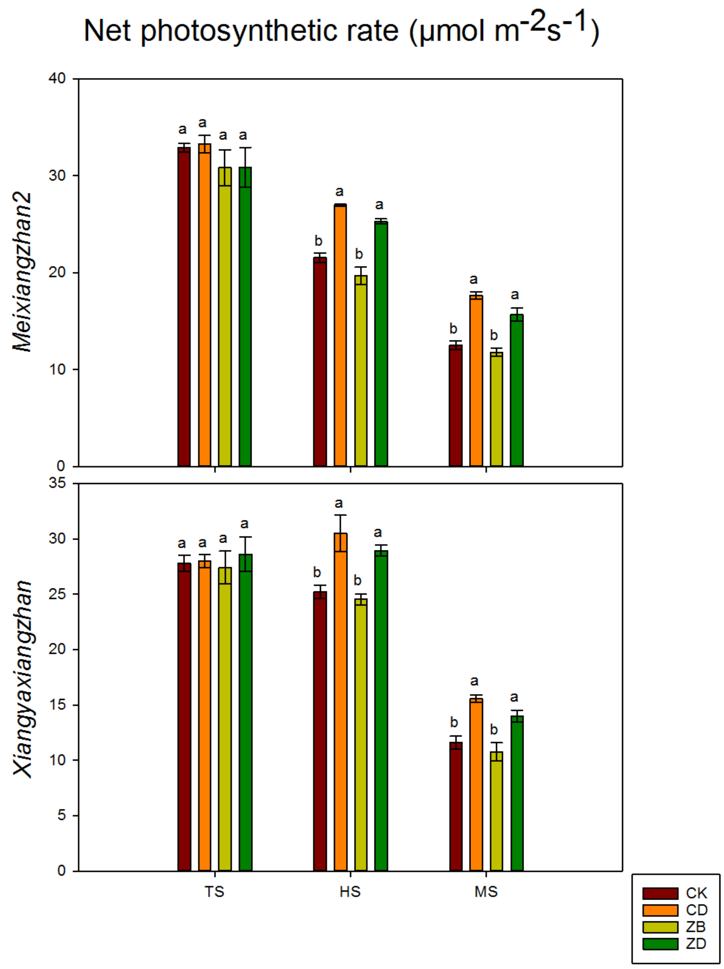

Figure 3. *Effects of tillage and fertilizer application on net photosynthetic rate*

Correlation analysis

As showed in *Table 3*, the rice yield was significantly and positively correlated with panicle number per m^2, grain number per panicle, 1000-grain weight, dry matter at tillering stage, total Chl content, and net photosynthetic rate at heading stage. The 1000-grain weight was also positively related with the net photosynthetic rate at heading stage. Furthermore, dry matter accumulation at maturity stage was significantly correlated with total Chl contents at all three stages as well as net photosynthetic rates at both heading stage and maturity stage.

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Table 3. *Relationship among yield, yield related traits, dry matter accumulation, chlorophyll contents and net photosynthetic rate*

Parameter		**Panicle number per m^2**	**Grains number per panicle**	**Seed-setting rate**	**1000-grain weight**	**Dry matter accumulation**			**Total chl**			**Net photosynthetic rate**		
						TS	HS	MS	TS	HS	MS	TS	HS	MS
Panicle number per m^2														
Grains number per panicle		-0.0033												
Seed-setting rate		0.2365	-0.1935											
1000-grain weight		0.4136*	-0.1422	0.4724*										
Dry matter accumulation	TS	0.9150**	0.001	0.2478	0.5331**									
	HS	0.8442*	-0.2057	0.1386	0.3662	0.8448**								
	MS	0.8692**	-0.2138	0.2479	0.4009	0.8744**	0.9823**							
Total Chl	TS	0.8118**	0.1176	0.2275	0.5663**	0.8337**	0.7015**	0.7261**						
	HS	0.7888**	0.1257	0.3132	0.5376**	0.8186**	0.6370**	0.6810**	0.8731**					
	MS	0.6991**	0.3622	0.3111	0.5013*	0.7293**	0.4815*	0.5158**	0.7738**	0.8835**				
Net photosynthetic rate	TS	-0.1799	-0.0576	-0.0559	-0.1039	-0.0877	0.1026	0.1002	-0.0899	-0.1561	-0.1503			
	HS	0.7289**	0.3622	0.3111	0.5013*	0.7293**	0.4815*	0.5158**	0.7738**	0.8835**	0.7653**	-0.1503		
	MS	0.8704**	-0.155	0.2587	0.4512*	0.8836**	0.8766**	0.9045**	0.7523**	0.6763**	0.5528**	0.0431	0.5528	
Yield		0.5759**	0.5444**	0.1996	0.5227**	0.5467**	0.3287	0.3176	0.6916**	0.7090**	0.7661**	-0.0333	0.7661**	0.3634

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Discussion

Normally, puddling not only is a helpful method to prevent the loss of water and nutrients, but also decreases the weeds and volunteer rice in rice production (Sharma et al., 2018). In China, the conventional tillage (by moldboard plowing and rotavating) is the most widely used for paddy field preparation (Huang et al., 2011). However, this practice requires abundant energy and labor, accelerates organic mineralization, reduces soil fertility, increases water consumption, and even damages the physiochemical properties of soils (Chen Song et al., 2007; Bhushan et al., 2007). Thus, zero tillage has become increasingly attractive in these years because of the benefits of saving fuel, equipment, and labor as well as conserving soil (Huang et al., 2011). However, without the advantages which are only provided by puddling, the growth of zero tillage rice might not be good as much as that in conventional tillage. Our study evidences this consideration by showing that the rice yield under ZB condition is lower than CK for both *Meixiangzhan2* and *Xiangyaxiangzhan*, though not significantly. At tillering stage, the total Chl, Chl a and Chl b contents and plant dry weight in ZB were remarkably lower than in CK for *Xiangyaxiangzhan*, indicating the paddy field without puddling preparation might inhibit the early growth of rice.

Studies suggest that deep fertilizer placement is the most efficient and promising method to inhibit the fertilizer loss while improving the fertilizer use efficiency in rice production (Liu et al., 2015; Savant et al., 1990). Huda et al. (2016) revealed placement of urea briquettes significantly increased rice grain yield and nitrogen recovery efficiency compared with broadcast prilled briquettes across seasons and different water regimes. The present study showed deep placement of compound fertilizer significantly increased the grain yield. The yield and panicle number per m^2 under ZD treatment were both significantly higher than either CK or ZB for two cultivars. Even no significant difference between ZD and CD was found in yield and its related traits. Our results agreed with Pan et al. (2017) who found mechanical deep placement of compound fertilizer significantly improved the grain yield of hill direct-seeded rice because of the larger grain number per panicle and seed-setting rate and that the photosynthetic rate at heading stage was improved by the deep fertilizer placement. Moreover, in addition to the heading stage, the net photosynthetic rate at maturity stage was also increased by deep fertilizer placement, while no significant difference among different treatments was found at tillering stage in our research. These results indicate the deep fertilizer placement could improve the rice growth at middle and later stages, which was mainly because it reduced the nutrition loss. For example, deep placement of nitrogen fertilizer induced the reduction of NH_4^+-N concentrations in the soils while applying floodwater from hydrolyzed nitrogen fertilizers because of lower soil urease activities than surface broadcasting (Liu et al., 2015). Hence, mechanical deep placement of fertilizer could be an efficient method to break the limitations on the production and popularization of conversation tillage.

Conclusions

Deep placement of commercial compound fertilizer enhanced the rice growth under zero tillage in terms of chlorophyll contents, dry matter accumulation and net photosynthetic rate. Deep fertilizer placement also improved the grain yield and panicle

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number per unit area in zero tillage. Continuing advancements in such emerging technology will be very helpful to the production and popularization in conversation tillage.

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