Puddling, Direct Seeding, Mechanical Transplanting for Rice: Effect on Soil Characteristics and Productivity of Rice

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Puddling, direct seeding, mechanical transplanting for rice: Effect on soil characteristics and productivity of rice

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Abstract

Why puddling? It is an important operation to minimize soil nutrient leaching and thereby increasing the availability of plant nutrients and achieving reduced soil condition. Good puddle field conditions are needed to create favorable environment for normal growth of rice plants. However, long-term effects of puddling could lead to forms of large clods in fine textured soils; resulting in negative effect on the soil characteristics, preventing seed-soil contacts and leading to decline in rice yield. This study was conducted in 2 years with treatment including; puddling the land twice with moldboard plow and pre-germinated seeds were hill-seeded with direct seeding machine (PD), puddling the land twice with rotary tiller and pre-germinated seeds were hill-seeded with direct seeding machine (RD), puddling the land twice with moldboard plow and 15-day-old seedlings were hill-transplanted with transplant machine (PT), and puddling the land twice with rotary tiller and 15-day-old seedlings were hill-transplanted with transplant machine (RT) to assess the effect of puddling, direct seeding, and mechanical transplanting on soil characteristics and rice yield. Results revealed significant improvement in the bulk density and increase in SOC, N, P and K in PD. The maximum microbial population was found in PD. Rice yield showed a higher productivity increase of 7.44 t·ha^{-2} and 3.91 t·ha^{-2} in 2017, and 7.85 t·ha^{-2} and 3.94 t·ha^{-2} in 2018 respectively for 1H and 2H (1H: 1st harvest, and 2H: 2nd harvest) in PD. Overall, PD was found to be the most suitable puddling and rice establishment approach under paddy fields for soil improvement and increasing rice yield.

Keywords Tillage · Establishment approach · Rice · SOC · Grain yield · Paddy field

Introduction

Rice *(Oryza sativa L.)* is cultivated in about 120 countries globally, about 214 and 173 million tons are produced in China and India respectively together accounting for more than 50% of the global production. 90% of the top 10 and 65% of the top 20 countries producing rice in the world are from Southeast Asia[1]. Consequently, enhancing and sustaining the cultivation of rice is indispensable for the global food security. Cultivation of rice in China is primarily thru by mechanical transplanting and direct seeding in paddy fields. The impact of puddling on rice output varies according to soil indicators and environmental conditions[2]. Puddling is done normally to create suitable soil environment for seed development, and easy transplanting of seedlings of rice by enhancing soil water evaporation, and breaking down and dispersing of soil aggregates into micro-aggregates and smaller particles[3,4]. Asia's rice production is mostly cultivated by traditionally transplanting of seedlings of 25–30-day-old into puddled soils, due to the fact that puddled-transplanted methods upsurge nutrient accessibility and impedes weed growth[5]. However, mechanical rice transplanting is the practice of transplanting young seedlings of rice which having been raised-up in a climatic box in a nursery using a paddy field transplanter. Rice seedlings between the optimum age of 14-18 days are transplanted onto the puddly field[6]. But, now, as a result of the looming water crisis and shortage of labor during transplanting, farmers in Asia are considering the option of direct seeding[7]. Direct seeding (DS) of rice is a technique of rice cultivation where the farmer directly sows the paddy seeds in the field, escaping transplanting process[8]. DS are done to save water, saves labor, decrease cultivation cost, cause less damage to soil physical health and less greenhouse gases production. The puddling type and the mode of rice establishment on the paddy fields has a direct effect on both soil characteristics and the grain yield, as an increase in grain yield is dependent on the improvement in the soil characteristics. The aim of this study is to assess the effect of puddling and two types of rice establishment approaches (direct seeding and mechanical transplanting) on soil characteristics and their influence on rice yield. Our hypothesis was that puddling type combined with direct seeding or mechanical transplanting will improve soil characteristics. We also anticipated that rice yield will be increased by the puddling and the establishment approaches.

Materials and methods

Site description

The study was initiated in 2017/18 at the Zengcheng Experimental Station (23°13' N, 113°81' E, altitude 11 m, Fig. 1) of the South China Agricultural University, located in Guangzhou City, Guangdong. The site has a subtropical monsoon climate, and the annual precipitation for 2017 (2660.09 mm), 2018 (2758.21 mm); annual wind speed for 2017 (23.4 m·s^{-1}), 2018 (24.7 m·s^{-1}); annual temperature for 2017 (21.3 °C), 2018 (22.8 °C); annual humidity for 2017 (728.3%), 2018 (713.8%), and the annual sunshine hours are 2017 (1707.2 h) and 2018 (1623.5 h). The soil of the study site is classified as *Lateritic Red Earth* developed from the Quaternary Red Earth[9]. The soil properties of the top soil layer (0-30 cm) of the ratoon rice field before the experiment are shown in Table 1.

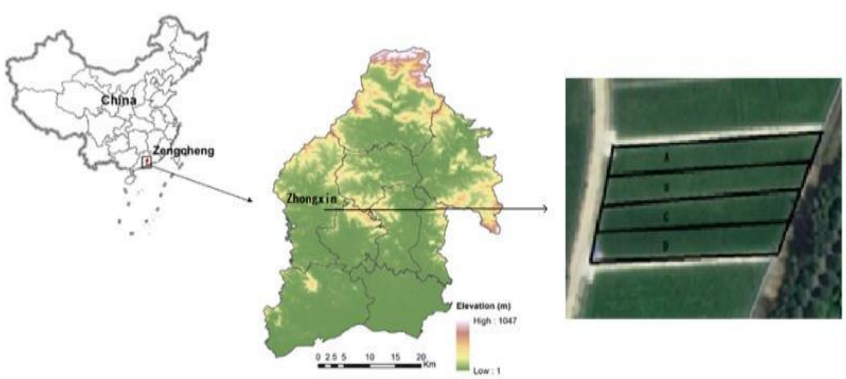

Figure 1. Site location of South China Agricultural University Research Station, Zhongxi Town, Zengcheng District, Guangzhou City, Guangdong Province

Table 1 Basic soil properties at 0-30 cm soil depth before the experiment.

Soil Physical properties					
Climate	Sand (%)	Silt (%)	Clay (%)	Soil Texture	Bulk density ($g\cdot cm^{-3}$)
Subtropical Monsoon	65	27	8	Sandy-loam	1.60

Soil Chemical properties							
pH	SOC ($g\cdot kg^{-1}$)	Av. N ($mg\cdot kg^{-1}$)	Av. P ($mg\cdot kg^{-1}$)	Av. K ($mg\cdot kg^{-1}$)	T N ($g\cdot kg^{-1}$)	T P ($g\cdot kg^{-1}$)	T K ($g\cdot kg^{-1}$)
5.65	10.04	39.52	13.32	31.19	0.50	0.26	15.10

Soil Biological properties					
Bacteria (×10 $cfu\cdot g^{-1}$ dry soil)	Fungi (×103 $cfu\cdot g^{-1}$ dry soil)	Actinomycetes (×104 $cfu\cdot g^{-1}$ dry soil)	Catalase [0.1NKMnO$_4$ ($mL\cdot g^{-1}$)]	Phosphatase [P_2O_5 ($mg\cdot kg^{-1}$)]	Urease [NH_4^+-N ($mg\cdot kg^{-1}$)]
2.21	1.21	2.80	1.61	69.03	47.50

SOC: soil organic carbon, Av. N: available nitrogen, Av. P: available phosphorus, Av. K: available potassium, T N: total nitrogen, T P: total phosphorus, T K: total potassium.

Experimental design and farm management

Two puddling practices, plowing (P) and rotary (R) were adopted with two establishment approaches, direct seeding (D) and mechanical transplanting (T). The treatment description is as below[10]:

- Moldboard plowing with direct seeding (PD): Before planting, the land was puddle twice with plow cultivator. Pregerminated seeds were hill-seeded with direct seeding machine at a space of 25×15 cm while each hill was planted with 4–6 seeds.
- Rotary tillage with direct seeding (RD): Before planting, the land was puddle twice with rotary cultivator. Pregerminated seeds were hill-seeded with direct seeding machine at a space of 25×15 cm while each hill was planted with 4–6 seeds.
- Moldboard plowing with mechanical transplanting (PT): Before transplanting, the land was puddle twice with plow cultivator. 15-day-old seedlings were hill-transplanted with transplant machine at a space of 25 × 15 cm while each hill was transplanted with 4–6 seedlings.
- Rotary tillage with mechanical transplanting (RT): Before transplanting, the land was puddle twice with rotary cultivator. 15-day-old seedlings were hill-transplanted with transplant machine at a space of 25 × 15 cm while each hill was transplanted with 4–6 seedlings.

A fragrant rice cultivar, *Meixiangzhan-2,* with maturity period between 111-114 days and widely planted in South China, sown on direct hill drop method by 2BDCSP Precision Rice Hill-Drop Drilling Machine and transplanted by YANMAR VP7D25 Rice Transplanter was used in the experiment. Before sowing, the seeds were soaked in water for 24 h, germinated in manual climatic boxes for another 12 h and shade-dried. Some of the germinated seeds were sown in polyvinyl chloride trays for nursery raising.

Soil sampling and analysis

Pre-soil and after rice were harvested, bulk soil samples were collected from three locations on each of treatment plot using an auger. Soil samples collected from the same soil layers (0-10, 10-20 and 20-30 cm) at each treatment plot were mixed. Soil samples for physical, chemical and biological determination were obtained in each treatment plot using a cylinder (500 mm diameter). Soil samples collected were sealed using aluminum lunch boxes and returned to the laboratory for analysis.

Soil bulk density measurement

Soil bulk density was used as a significant indicator of changes in soil structure and water retention capacity[11] and was progressively determined from 50 mm diameter sampler cores to a depth of 30 cm. The soil was measured from undisturbed soil cores collected from four depths (0-10, 10-20 and 20-30 cm). Soil cores were weighed wet, dried in an oven at 105 ºC for 48 h, and weighed again to determine the soil bulk density[12].

Soil chemical characteristics measurements (pH, SOC, available NPK and total NPK)
Soil pH was determined using the combined glass electrode method[13,14]. SOC was determined by 0.5mol/L potassium sulfate extraction-high temperature external thermal potassium dichromate oxidation-volume method[15]. Available N was determined by Alkali solution diffusion method[14]. Available P was determined by Bray No. 1 extract method[16]. Available K was determined by the Colorimetric method (Whittles and Little, 1950). Total N was determined by Kjeldahl distillation method[15]. Total P was determined by Sodium hydroxide melting - molybdenum antimony colorimetric method[15]. Total K was determined by Alkali fusion - flame photometer or atomic absorption spectrophotometer method[15].

Soil biological characteristics measurements (Bacteria, fungi, actinomycetes, urease, catalase and phosphatase)
Soil bacteria, fungi and actinomycetes were determined by the Plate inoculation method[15]. Soil urease was determined by Automated calorimetric method[15]. Soil catalase was determined by Volumetric method[15]. Soil phosphatase was determined by Phenyl phosphate sodium colorimetric method[15].

Grain yield analysis
Rice grain were harvested at maturity from three sampling areas (1.00 m^2) randomly selected in each plot and machine-threshed. Harvested grains were sun-dried at 13.5% moisture content and weighted in order to determine the grain yield. FUQIANG 4LZ-427 Full-Fill Grain Combine Harvester was used to harvest the whole rice filed.

Statistical analysis
Statistical analysis was conducted using IBM SPSS software 23.0 (SPSS Inc., Chicago, IL, USA). Duncan's multiple range test (DMRT) at 5% probability was performed to compare the means of different treatments.

Results

Soil bulk density as affected by puddling and rice establishment approach
Soil bulk density values in 2017 and 2018 (1H: 1st harvest, and 2H: 2nd harvest) were affected by puddling and rice crop establishment approaches (Fig. 2). Significant differences (1.65, 1.59, 1.47 and 1.54 $g\cdot cm^{-3}$ and 1.61, 1.54, 1.48 and 1.52 $g\cdot cm^{-3}$ respectively for RT, PT, PD and RD in 1H and 2H) were recorded among all the puddling and rice establishment approaches in 2017. Similarly, 1.44, 1.36, 1.29 and 1.37 $g\cdot cm^{-3}$ and 1.58, 1.53, 1.29 and 1.45 $g\cdot cm^{-3}$ were respectively recorded under RT, PT, PD and RD in 1H and 2H in 2018. Comparatively, PD recorded lower bulk density in 2017 (8.84% and 8.11% respectively for 1H and 2H) than in 2018 (24.03% respectively for 1H and 2H) compared to the initial value in Table 1.

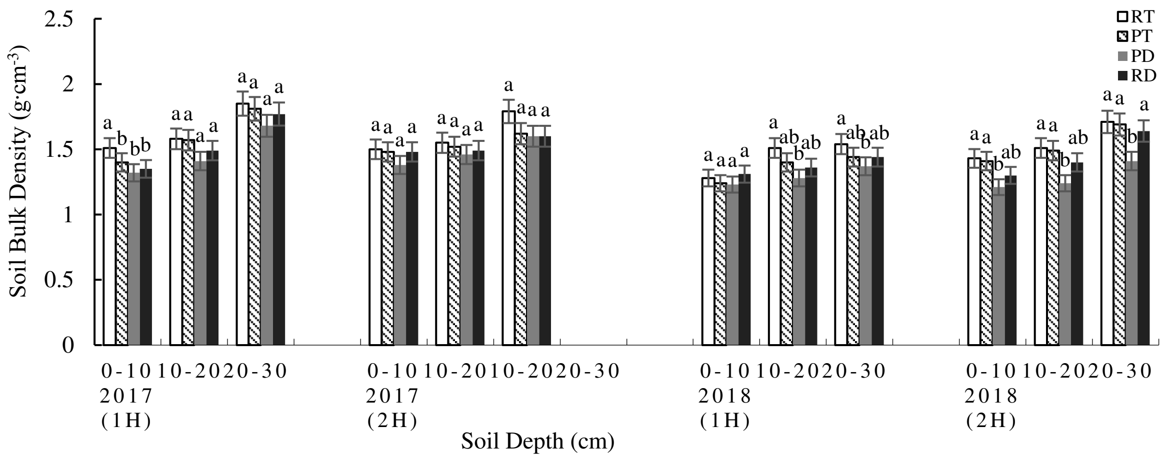

Figure 2. Puddling, direct seeding and mechanical transplanting on soil bulk density. PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Soil pH and SOC as affected by puddling and rice establishment approach

Soil pH varied considerably among puddling and rice crop establishment approaches. The results showed that pH was in the range of 5.74 to 6.41 and 5.23 to 7.73 respectively for 2017 and 2018, however, the highest pH of 6.14 and 6.27 (for 1H and 2H in 2017) and 6.11 and 7.60 (for 1H and 2H respectively in 208) was recorded under PD (Fig. 3a). SOC was significantly different in 2017 compared to in 2018; however, the highest value 11.47 and 13.12 $g \cdot kg^{-1}$ (for 1H and 2H in 2017), and 11.79 and 12.31 $g \cdot kg^{-1}$ (for 1H and 2H in 2018) statistically with highest increase of 14.24 and 30.68% (for 1H and 2H in 2017) and 17.43 and 12.31% (respectively for 1H and 2H in 2018) in 0-30cm soil depth were recorded under PD (Fig. 3b).

Available NPK as affected by puddling and rice establishment approach

PD resulted in highest activity of available N (47.45 and 58.41 $mg \cdot kg^{-1}$) which markedly increased by 20.29 and 47.80% in 2017 (for 1H and 2H respectively), and 43.31 and 56.53 $mg \cdot kg^{-1}$) resulting to an increase of 9.59 and 43.04% in 2018 for 1H and 2H respectively (Table 2). Available P content was significantly varied among puddling and rice crop establishment approach. The highest 13.42 and 13.86 $mg \cdot kg^{-1}$ resulting in an increase of 0.75 and 4.05% in 2017 (for 1H and 2H respectively), and 13.61 and 13.98 $mg \cdot kg^{-1}$ resulting in an increase of 2.18 and 4.95% in 2018 (for 1H and 2H respectively) of available P were observed under PD (Table 2). The highest available K (43.32 and 49.82 $mg \cdot kg^{-1}$) resulting in an increase of 38.89 and 59.73% in 2017 (for 1H and 2H), and 38.85 and 53.55 $mg \cdot kg^{-1}$ resulting in an increase of 24.56 and 71.69% in 2018 (for 1H and 2H respectively) were recorded under PD (Table 2).

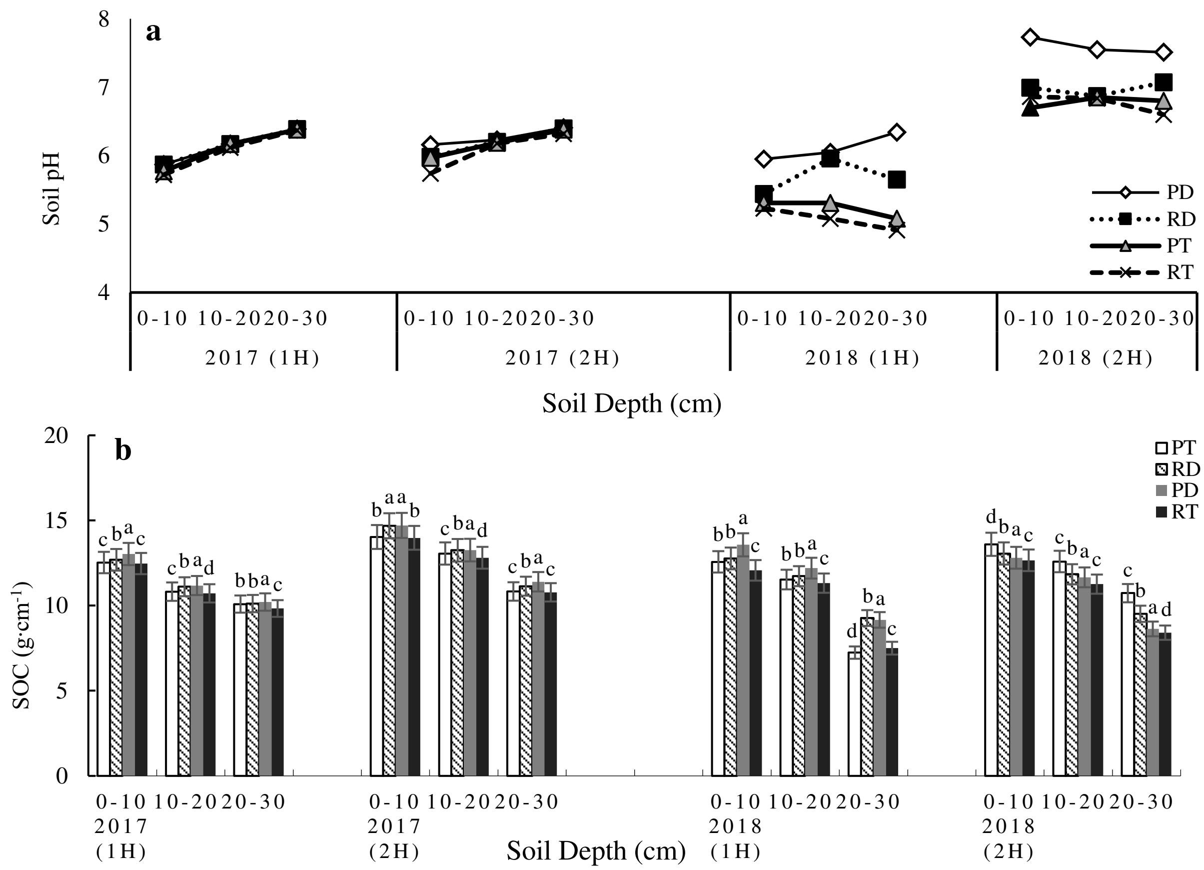

Figure 3. Puddling, direct seeding and mechanical transplanting on soil (**a**) soil pH and (**b**) soil organic carbon. PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Table 2 Available NPK condition as affected by puddling and rice establishment approach.

Soil Depth	Treatment	Available Nitrogen ($mg\cdot kg^{-1}$)		Available Phosphorus ($mg\cdot kg^{-1}$)		Available Potassium ($mg\cdot kg^{-1}$)	
		2017(1H)	2017(2H)	2017(1H)	2017(2H)	2017(1H)	2017(2H)
0-10cm	PD	56.32a	64.87a	14.70a	15.76a	48.68a	54.39a
	RD	54.91b	61.09b	14.51b	15.67ab	46.14b	52.00b
	PT	53.234c	60.06c	14.42b	15.59bc	43.58c	49.47c
	RT	52.49c	58.67d	14.37b	15.47c	43.00c	47.88d
10-20cm	PD	47.42a	60.40a	14.23a	14.33a	43.66a	49.94a
	RD	44.15b	54.41b	13.98b	14.18ab	42.51a	45.71b
	PT	42.04c	52.36c	13.71c	13.94bc	41.01b	42.41c
	RT	41.47c	51.78c	13.66c	13.87c	39.92b	40.86d
20-30cm	PD	38.88a	49.96a	11.33a	11.51a	37.63a	45.12a
	RD	38.49a	47.30b	11.21a	11.32ab	34.99b	40.52b
	PT	37.54b	43.58c	10.92b	11.26b	32.03c	38.83c
	RT	36.36c	42.79c	10.88b	11.20b	31.17d	36.84d
		Available Nitrogen ($mg\cdot kg^{-1}$)		Available Phosphorus ($mg\cdot kg^{-1}$)		Available Potassium ($mg\cdot kg^{-1}$)	
		2018(1H)	2018(2H)	2018(1H)	2018(2H)	2018(1H)	2018(2H)
0-10cm	PD	52.43a	73.79a	13.98a	15.80a	41.69a	56.53a
	RD	49.19b	71.63b	13.53b	15.00b	39.80b	52.67b

	PT	47.58c	65.80c	13.12c	14.00c	36.19c	49.00c
	RT	47.25c	64.29c	12.53d	13.04d	33.93d	48.80c
10-20cm	PD	45.33a	51.13a	13.73a	13.60a	40.89a	53.76a
	RD	44.66a	44.23b	11.53b	13.13b	35.97b	51.18b
	PT	41.46b	44.01b	11.20b	11.60c	34.44c	45.96c
	RT	37.54c	37.54c	11.18b	8.13d	30.04d	42.80d
20-30cm	PD	32.16a	44.66a	13.11a	13.27a	33.98a	50.35a
	RD	24.81b	33.87b	9.60b	11.20b	33.40a	48.03b
	PT	24.17b	33.01b	5.33c	10.00c	29.09b	46.70c
	RT	23.95b	30.42c	4.53d	7.40d	28.97b	41.10d

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Total NPK as affected by puddling and rice establishment approach

Puddling and rice crop establishment approach had a significant effect on total NPK during the growing season (Table 3). Total N under PD was higher than RD, PT and RT in the growing seasons. PD recorded highest of 0.63 g·kg^{-1} resulting and increase of 26% in 2017 (for 1H and 2H respectively), and 0.59 and 0.84 g·kg^{-1} resulting in an increase of 18 and 68% in 2018 for 1H and 2H respectively (Table 3). Total P was significantly different in both growing seasons under puddling and rice crop establishment approach, however, the highest values statistically 0.28 and 0.30 g·kg^{-1} resulting in an increase of 7.69 and 15.38% in 2017 (for 1H and 2H respectively), and 0.31 and 0.37 g·kg^{-1} resulting in an increase of 19.23 and 42.31% in 2018 for 1H and 2H respectively were recorded under PD (Table 3). The highest 14.95 and 16.52 g·kg^{-1} resulting in a decrease of 1% and an increase of 9.40% in 2017 (for 1H and 2H respectively), and 15.42 and 16.03 g·kg^{-1} resulting in an increase of 2.12 and 6.16% in 2018 for 1H and 2H respectively were recorded under PD (Table 3).

Table 3 Total NPK condition as affected by puddling and rice establishment approach.

Soil Depth	Treatment	Total Nitrogen (g·kg^{-1})		Total Phosphorus (g·kg^{-1})		Total Potassium (g·kg^{-1})	
		2017(1H)	2017(2H)	2017(1H)	2017(2H)	2017(1H)	2017(2H)
0-10cm	PD	0.68a	0.69a	0.33a	0.35a	15.94a	18.02a
	RD	0.66ab	0.67a	0.31b	0.32b	15.77b	17.34b
	PT	0.65b	0.67a	0.30bc	0.31bc	15.64bc	17.19b
	RT	0.65b	0.65b	0.29c	0.30c	15.55c	16.89c
10-20cm	PD	0.64a	0.65a	0.27a	0.30a	15.54a	15.93a
	RD	0.62b	0.63b	0.26a	0.28b	15.31b	15.86ab
	PT	0.62b	0.63b	0.26a	0.28b	15.29b	15.74ab
	RT	0.61b	0.61b	0.26a	0.27b	15.21b	15.67b
20-30cm	PD	0.56a	0.56a	0.24a	0.26a	13.38a	15.61a
	RD	0.54b	0.56a	0.23ab	0.24b	13.26b	15.59a
	PT	0.53bc	0.55b	0.22bc	0.22c	13.20bc	15.58a
	RT	0.52c	0.54b	0.21c	0.22c	13.12c	15.55a
		Total Nitrogen (g·kg^{-1})		Total Phosphorus (g·kg^{-1})		Total Potassium (g·kg^{-1})	
		2018(1H)	2018(2H)	2018(1H)	2018(2H)	2018(1H)	2018(2H)
0-10cm	PD	0.65a	1.14a	0.33a	0.43a	16.82a	16.59a
	RD	0.62b	1.10b	0.32ab	0.38b	16.13b	14.93b
	PT	0.62b	1.00b	0.31bc	0.36c	15.86c	14.91b

	RT	0.62b	1.03b	0.29c	0.29d	15.19c	14.30c
10-20cm	PD	0.61a	0.77a	0.30a	0.36a	15.09a	15.81a
	RD	0.59b	0.76a	0.30a	0.32b	14.80b	14.75b
	PT	0.57c	0.53c	0.30a	0.31c	14.71c	13.82c
	RT	0.51d	0.49d	0.29a	0.27d	14.46d	12.31d
20-30cm	PD	0.52a	0.60a	0.29a	0.32a	14.34a	15.70a
	RD	0.42b	0.56b	0.29a	0.31b	14.21b	12.28b
	PT	0.41c	0.53c	0.25b	0.29c	13.49c	11.68c
	RT	0.40d	0.49d	0.24c	0.29c	13.14d	10.56d

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, MT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Bacteria, fungi, and actinomycetes as affected by puddling and rice establishment approach

Bacteria content was significantly varied among puddling and rice crop establishment approach. The highest 2.35 and 2.65 [$\times10^5$ cfu·g^{-1} dry soil] resulting in an increase of 6.33 and 19.91% in 2017 (for 1H and 2H respectively), and 2.75 and 2.89 [$\times10^5$ cfu·g^{-1} dry soil] resulting in an increase of 24.43 and 30.77% in 2018 (for 1H and 2H respectively) of bacteria were observed under PD (Table 4). PD resulted in highest activity of fungi (1.60 and 1.74 [$\times10^3$ cfu·g^{-1} dry soil]) which markedly increased by 32.23 and 43.80% in 2017 (for 1H and 2H respectively), and 1.71 and 1.79 [$\times10^3$ cfu·g^{-1} dry soil] resulting to an increase of 41.32 and 47.93% in 2018 for 1H and 2H respectively (Table 4). The highest 3.16 and 3.34 [$\times10^4$ cfu·g^{-1} dry soil] resulting in an increase of 12.86 and 19.29% in 2017 (for 1H and 2H respectively), and 3.32 and 3.30 [$\times10^4$ cfu·g^{-1} dry soil] resulting in an increase of 15.35 and 17.86% in 2018 for 1H and 2H respectively were recorded under PD (Table 4).

Table 4 Bacteria, fungi and actinomycetes condition as affected by puddling and rice establishment approach

Soil Depth	Treatment	Bacteria ($\times10^5$ cfu·g^{-1} dry soil)		Fungi ($\times10^3$ cfu·g^{-1} dry soil)		Actinomycetes ($\times10^4$ cfu·g^{-1} dry soil)	
		2017(1H)	2017(2H)	2017(1H)	2017(2H)	2017(1H)	2017(2H)
0-10cm	PD	2.47a	2.61a	0.91a	1.06a	2.66a	2.86a
	RD	2.31b	2.53a	0.88a	0.92b	2.42b	2.58b
	PT	2.27b	2.39b	0.87a	0.90b	2.26bc	2.38c
	RT	1.66c	1.24c	0.83a	0.86b	2.18c	2.30d
10-20cm	PD	3.05a	3.68a	1.34a	1.47a	3.25a	3.46a
	RD	2.98ab	3.37b	1.24ab	1.37a	3.15ab	3.33ab
	PT	2.83b	2.81c	1.17bc	1.28a	3.11ab	3.31ab
	RT	2.54c	2.66c	1.08c	1.20a	3.07b	3.24b
20-30cm	PD	1.52a	1.66a	2.56a	2.68a	3.56a	3.71a
	RD	1.44ab	1.54a	2.14b	2.27b	3.31b	3.50b
	PT	1.43ab	1.35b	2.10b	2.19b	3.12c	3.41b
	RT	1.35b	1.27b	2.00b	2.16b	3.11c	3.34b
		Bacteria ($\times10^5$ cfu·g^{-1} dry soil)		Fungi ($\times10^3$ cfu·g^{-1} dry soil)		Actinomycetes ($\times10^4$ cfu·g^{-1} dry soil)	
		2018(1H)	2018(2H)	2018(1H)	2018(2H)	2018(1H)	2018(2H)
0-10cm	PD	2.80a	2.92a	1.07a	1.21a	2.72a	2.75a
	RD	2.57ab	2.64b	0.95b	1.07b	2.41b	2.49b
	PT	2.48b	2.60b	0.90bc	0.96bc	2.31c	2.36bc
	RT	1.39c	1.46c	0.83c	0.70c	2.22d	2.30c

10-20cm	PD	3.74a	3.89a	1.41a	1.47a	3.33a	3.43a
	RD	3.41b	3.56b	1.30b	1.37b	3.25ab	3.35ab
	PT	2.91c	3.08c	1.22c	1.26c	3.22ab	3.32bc
	RT	2.70d	2.72d	1.11d	1.25c	3.12b	3.23c
20-30cm	PD	1.71a	1.88a	2.64a	2.70a	3.63a	3.71a
	RD	1.69a	1.76b	2.27b	2.35b	3.41b	3.46b
	PT	1.40b	1.46c	2.25b	2.22c	3.28c	3.43b
	RT	1.35b	1.39c	2.14c	2.21c	3.24c	3.33c

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Catalase, phosphatase, and urease as affected by puddling and rice establishment approach

Puddling and rice crop establishment approach had a significant effect catalase, phosphatase, and urease during the growing season (Table 5). Catalase under PD was higher than RD, PT and RT in the growing seasons. PD recorded highest of 1.77 and 1.72 [0.1NKMnO$_4$ (mL·g^{-1})] resulting in an increase of 9.94 and 6.83 % in 2017 (for 1H and 2H respectively), and 1.67 and 1.70 [0.1NKMnO$_4$ (mL·g^{-1})] resulting in an increase of 3.73 and 5.59% in 2018 for 1H and 2H respectively (Table 5). The highest 70.43 and 66.14 [P$_2$O$_5$ (mg·kg^{-1})] resulting in an increase of 2.03% and a decrease of 4.37% in 2017 (for 1H and 2H respectively), and 76.08 and 92.90 [P$_2$O$_5$ (mg·kg^{-1})] resulting in an increase of 10.21 and 34.58% in 2018 for 1H and 2H respectively were recorded under PD (Table 5). PD resulted in highest activity of urease (48.85 and 49.97 [NH$_4^+$-N (mg·kg^{-1})]) which markedly increased by 2.84 and 5.20% in 2017 (for 1H and 2H respectively), and 49.82 and 50.38 [NH$_4^+$-N (mg·kg^{-1})] resulting to an increase of 4.88 and 6.06% in 2018 for 1H and 2H respectively (Table 5).

Table 5 Catalase, phosphatase and urease condition as affected by puddling and rice establishment approach

Soil Depth	Treatment	Catalase [0.1NKMnO$_4$ (mL·g^{-1})]		Phosphatase [P$_2$O$_5$ (mg·kg^{-1})]		Urease [NH$_4^+$-N (mg·kg^{-1})]	
		2017(1H)	2017(2H)	2017(1H)	2017(2H)	2017(1H)	2017(2H)
0-10cm	PD	1.68a	1.73a	85.18a	75.49a	55.49a	56.22a
	RD	1.63b	1.65a	76.45b	72.33ab	53.84a	54.61b
	PT	1.59c	1.63a	73.31c	70.47b	53.82a	54.25b
	RT	1.58c	1.61a	70.87d	69.41b	50.28b	51.18c
10-20cm	PD	1.87a	1.77a	69.21a	67.51a	46.8a	48.57a
	RD	1.83b	1.74a	67.02ab	62.98b	44.50ab	45.04b
	PT	1.74c	1.73a	65.29b	57.23c	43.53b	44.06c
	RT	1.66d	1.69a	64.40b	55.95c	43.06b	43.37d
20-30cm	PD	1.77a	1.65a	56.89a	55.42a	44.26a	45.13a
	RD	1.74ab	1.65a	54.44ab	52.64b	43.53a	43.57b
	PT	1.69bc	1.64a	53.35bc	52.30b	42.95a	43.56b
	RT	1.67c	1.53a	51.47c	51.16b	41.72a	42.27c
		Catalase [0.1NKMnO$_4$ (mL·g^{-1})]		Phosphatase [P$_2$O$_5$ (mg·kg^{-1})]		Urease [NH$_4^+$-N (mg·kg^{-1})]	
		2018(1H)	2018(2H)	2018(1H)	2018(2H)	2018(1H)	2018(2H)
0-10cm	PD	1.74a	1.78a	91.68a	114.74a	56.28a	57.04a
	RD	1.52b	1.46b	89.37a	111.88ab	55.06b	56.15b
	PT	1.14c	1.29c	85.21a	110.64b	54.01c	55.02c
	RT	1.09d	1.28c	84.49a	103.42c	52.63d	53.44d

10-20cm	PD	1.88a	2.02a	79.66a	89.93a	48.21a	48.88a
	RD	1.73b	1.95a	74.98b	83.32b	47.17b	48.24a
	PT	1.42c	1.91a	68.47c	80.68bc	46.34c	47.25b
	RT	1.22d	1.74b	65.77c	79.14c	45.40d	46.06c
20-30cm	PD	1.38a	1.31a	56.91a	74.02a	44.98a	45.21a
	RD	1.15b	1.15b	53.60ab	69.27b	44.28b	45.02a
	PT	1.02c	0.95c	52.41ab	66.94b	43.61c	44.14b
	RT	0.91d	0.91c	50.50b	61.01c	43.40c	44.10b

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Grain yield analysis

Puddling and rice establishment approach had a significant effect on rice grain yield (Fig. 4). PD recorded the highest increase in both years and harvesting times, whilst RT recorded the lowest. PD recorded an increase of 32.38 and 14.33% in 2017, and 33.28 and 13.22% in 2018 respectively for 1H and 2H than under RT.

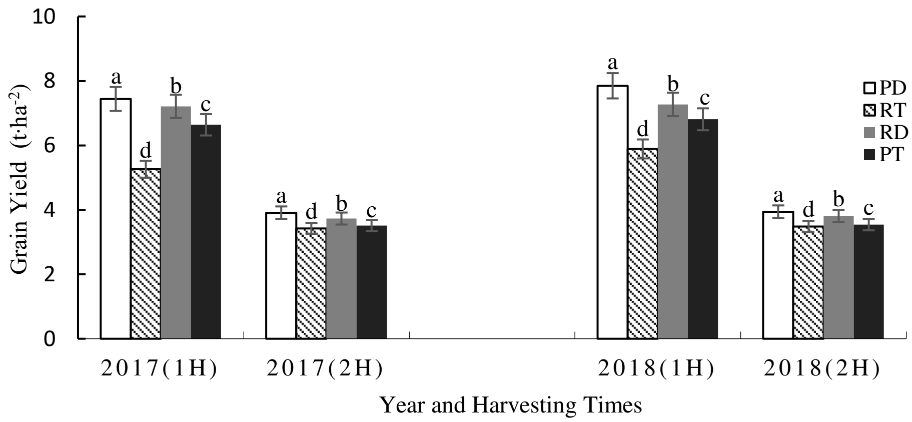

Figure 4. Puddling, direct seeding and mechanical transplanting on ratoon rice yield. PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, RT: rotary tiller with mechanical transplanting. Different letters within a column represent significant differences at the 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

Discussion

Environment issues and human activities can cause alteration in the soil physical properties (i.e., bulk density), which can be detrimental to crop output[17]. A significant reduction in soil bulk density was observed under PD. This resulted from the total overturn of the soil resulting from the plow. This process influences the soil aggregates steadiness, leading to soil deformation structure. There was also high incorporation of straw residue which resulted in buildup of adequate carbon-based matter in the soil medium, as the high buildup of carbon-based matter results in enhancement in soil aggregates ensuing in a reduction in soil bulk density. This result is consistent with a previous study in which moldboard plowing reduces soil bulk density when combined with direct seeding[6].

The results showed that PD has a tendency to improve soil pH compared to the order combination. The improved pH under PD was as a result of reduced water movement, which encouraged the retention of nutrients and hydrogen ions from the crop residue and the mineralization of inorganic materials. The slow response to crop and puddling and variable nature of SOC measurements requires a significant time before the direction of change can be assessed[18]. Generally, intensive puddling can lead to decline in SOC destroying soil structure, exposing soil aggregates and aggravating soil carbon-based matter putrefaction[19]. However, PD improved the SOC due to the high incorporation of rice straw into the soil as a result of reduction in soil disturbance and reduced conversion rate of soil carbon-based matter leading higher SOC by moldboard plow, this confirms study done[19]. Available and total NPK improved under PD, due to decomposition of carbon-based matter and conversion of nutrient induced by the crop residue and associated actions of beneficial microorganisms. Also, less loss in N through immobilization, volatilization, denitrification, and leaching[20], high SOC incorporation by crop residue as moldboard plowing could be more effective in increasing soil fertility in deeper soils caused an improvement in K and P as it was due to the redistribution of P and K at lower soil layers and also the contact between K and P and soil particles[21-23].

Soil enzymes play a critical role in nutrient cycling of the soil, which results from tillage practices[24]. Puddling and rice cultivation modes had a considerable effect on the soil biological properties. PD observed high bacteria resulting from the high build-up and amalgamation of the rice crop residue[25,6], also the available substrates which in turn influenced the soil bacteria profusion by the effect of the implement type[6]. However, less buildup of rice stover on the soil by RD and RT treatment, and the high compaction of the soil may have led in the decreased in bacterial population.

Soil fungi were improved under PD resulting from the putrefaction of carbon-based matter resulting from the high integration of rice stover and the augmented soil water. Also, less plow uproar of the soil lead to an improvement in the soil fungi. RD and RT lead to high compaction of the soil resulting from rice transplanting leading to disturbing effect on fungi abundance[6]. PD improved soil actinomycetes which may be a resultant of sufficient buildup of rice stover in the soil, as high carbon-based matter soils lead to improvement in actinomycetes population. Reduced soil uproar during direct seeding under PD improved catalase by enhancing the substrates, which is in agreement with work done by Jin et al.[26] who observed higher catalase activity in shallow tilling practices. PD treatment improved soil urease and phosphatase likened to the other treatments, this result is in support of findings from[6], who observed increase in urease and phosphatase population under moldboard plowing combined with direct seeding. This increase may result from the high integration of rice stover, resulting to a more putrefaction of soil carbon-based matter.

PD showed an increase in grain yield compared to the other treatments higher yield under PD resulted from good crop condition enhanced soil bulk density for root proliferation aiding to more accessibility of plant nutrients and soil moisture this result supports work done by[27,30] who observed higher grain yield under direct-seeding rice as likened with flooded rice transplanting higher grain yield has also been recorded under direct seeding compared to that of transplanted rice [31-34,6].

Conclusions

On the basis of current study, it may be concluded that among all the treatments, moldboard plowing combined with direct seeding improved the soil bulk density, chemical properties (SOC, pH, total NPK and available NPK), and biological properties (bacteria, fungi, actinomycetes, urease, catalase, and phosphatase) resulting in higher rice grain yield by 32.38 and 14.33% in 2017, and 33.28 and 13.22% in 2018 respectively for 1H and 2H (1H: 1st harvest, and 2H: 2nd harvest) compared with the other treatments. Therefore, PD should be accepted as a suitable combined management practices to obtaining good soil productivity and achieving sustainable rice yield under the prevailing climatic conditions.

Author Contributions

Conceptualization; Project administration and supervision: (Li Jiuhao), Formal analysis and investigation; Writing -original draft preparation: (Evans Asenso), Data processing: (Zhimin Wang), Writing - review and editing; Project administration and supervision; Submission: (Lian Hu). All authors read and approved the final manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability

The data used to support the findings of this study are available from the corresponding author upon request.

Statement of Permission or License to Use Rice Variety (*Meixiangzhan-2*)

We confirmed that the collection of the plant material in this study complies with relevant institutional, national, and international guidelines and legislation. The seeds of *Meixiangzhan-2* in present study were provided by College of Agriculture, South China Agricultural University, and we have permission to the seeds. *Meixiangzhan-2* (Lemont × Fengaozhan) was bred by Rice Research Institute, Guangdong Academy of Agricultural Sciences and is widely cultivated in South China. More information of this cultivar could be found in https://www.ricedata.cn/.

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