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Research Article

Effects of Puddling Types and Rice Establishment Methods on Soil Characteristics and Productivity of Rice in Southern China

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Puddling 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 a 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 pregerminated seeds were hill-seeded with direct seeding machine (PD), puddling the land twice with rotary tiller and pregerminated 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 effects of puddling and rice establishment method 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 grain yield showed a higher productivity increase of 7.65 $t \cdot ha^{-2}$ (31.25%) and 3.93 $t \cdot ha^{-2}$ (13.91%) for 1H and 2H (1H: 1st harvest and 2H: 2nd harvest), respectively, in PD compared with the lowest of 5.76 $t \cdot ha^{-1}$ and 3.45 $t \cdot ha^{-1}$ in 1H and 2H, respectively, under RT. Overall, PD was found to be the most suitable puddling type and rice establishment method for soil improvement and increasing rice yield.

1. Introduction

A preprint has previously been published [1]. 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 [2]. Consequently, enhancing and sustaining the cultivation of rice are indispensable for the global food security. Cultivation of rice in China is primarily thru mechanical transplanting and direct seeding in paddy fields. The impact of puddling on rice output varies according to soil indicators and environmental conditions [3]. 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 microaggregates and smaller particles [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 impede weed growth [5]. However, mechanical rice transplanting involves the practice of transplanting seedlings of young rice with paddy field transplanter which have been raised up in a climatic box in the nursery. Seedlings of rice between an 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 the transplanting process [8]. DS is done to save water, save labor, decrease cultivation cost, cause less damage to soil physical health, and less greenhouse gases production. The right puddling type combined with the appropriate rice establishment method can upshot positively on both the soil characteristics and the yield of rice, as an upsurge in rice grain yield is reliant on the improvement in the soil characteristics which will result from the management practices. This study therefore seeks to evaluate the effect of puddling types and rice establishment methods (i.e., direct seeding and mechanical transplanting) on soil characteristics and their influence on rice grain yield.

2. Materials and Methods

2.1. Site Description. The study was initiated in 2017/18 at the Zengcheng Experimental Station (23°13′N, 113°81′E, altitude 11 m, Figure 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 is 2660.09 mm and for 2018 is 2758.21 mm, annual wind speed for 2017 is 23.4 $m{\cdot}s^{-1}$ and for 2018 is 24.7 $m{\cdot}s^{-1}$, annual temperature for 2017 is 21.3°C and for 2018 is 22.8°C, annual humidity for 2017 is 728.3% and for 2018 is 713.8%, and the annual sunshine hours for 2017 is 1707.2 h and for 2018 is 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 rice field before the experiment are shown in Table 1.

2.2. Experimental Design and Farm Management. Two puddling types, plowing (P) and rotary (R) were adopted with two rice establishment approaches, direct seeding (D) and mechanical transplanting (T). The treatment description is as follows [10]:

(i) Moldboard plowing (at 30 cm depth) with direct seeding (PD): before planting, the land was puddled twice with a 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.

(ii) Rotary tiller (at 30 cm depth) with direct seeding (RD): before planting, the land was puddled twice with a rotary tiller. 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.

(iii) Moldboard plowing (at 30 cm depth) with mechanical transplanting (PT): before transplanting, the land was puddled twice with a 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.

(iv) Rotary tiller (at 30 cm depth) with mechanical transplanting (RT): before transplanting, the land was puddled twice with a rotary tiller. 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.

The experimental field measured 10,990 m^2, with subdivided plots: PD and RD (100 m × 35 m) and PT and RT (57 m × 35). Aromatic rice cultivar, Meixiangzhan-2, with a maturity period between 111 and 114 days and widely planted in South China, sown on the 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. The first harvest (1H) was done on August 25 and August 18 in 2017 and 2018, respectively, and the second harvest (2H) was done on October 20 in 2017 and 2018.

2.3. Soil Sampling and Analysis. Presoil and after rice were harvested, soil samples were collected from three points on each of the treatment plot with an auger from 0–10, 10–20 and 20–30 cm and were mixed together to determine the physical, chemical, and biological properties. Soil samples collected were sealed in aluminum lunch boxes for laboratory analysis.

2.3.1. Soil Bulk Density Measurement. Soil bulk density was used as a significant indicator of changes in the 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°C for 48 h, and weighed again to measure the soil bulk density [12].

2.3.2. Soil Chemical Characteristic Measurements (pH, SOC, Available NPK, and Total NPK). Soil pH was determined using the combined glass electrode method [13, 14]. SOC was determined by the 0.5 mol/L potassium sulfate extraction-high temperature external thermal potassium dichromate oxidation-volume method [15]. Available N was determined by the alkali solution diffusion method [15]. Available P was determined by the Bray no. 1 extract method [16]. Available K was determined by the colorimetric method [15]. Total N was determined by the Kjeldahl distillation method [15]. Total P was determined by the sodium hydroxide melting-molybdenum antimony colorimetric method [15]. Total K was determined by the alkali fusion-flame photometer or atomic absorption spectrophotometer method [15].

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, and T K: total potassium.

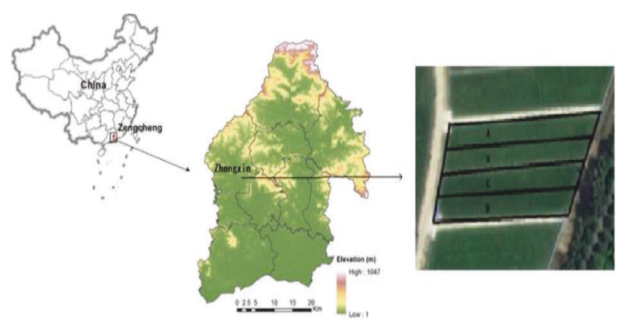

Figure 1: Site location of South China Agricultural University Research Station, Zhongxi Town, Zengcheng District, Guangzhou City, Guangdong Province.

2.3.3. Soil Biological Characteristic Measurements (Bacteria, Fungi, Actinomycetes, Urease, Catalase, and Phosphatase). Culturable bacteria, fungi, and actinomycetes were determined by the plate inoculation method [15], soil urease was by the automated calorimetric method [15], soil catalase by the volumetric method [14, 15], and soil phosphatase by the phenyl phosphate sodium colorimetric method [15].

2.4. 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.

2.5. 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.

3. Results

3.1. Soil Bulk Density as Affected by Puddling Types and Rice Establishment Methods. Soil bulk density values in 1H and 2H were affected by puddling types and rice crop establishment methods (Figure 2). Significant differences of 1.55, 1.52, 1.39, and 1.46 $g\cdot cm^{-3}$ for RT, PT, PD, and RD, respectively, in 1H were recorded among all the puddling types and rice establishment approaches. Similarly, 1.58, 1.54, 1.39, and 1.49 $g\cdot cm^{-3}$ were also recorded under RT, PT, PD, and RD, respectively, in 2H. Comparatively, PD recorded a lower bulk density of 1.39 $g\cdot cm^{-3}$ in both 1H and 2H resulting to 15.11% decrease in the depth of 0–30 cm compared to the initial value in Table 1.

3.2. Soil pH and SOC as Affected by Puddling Types and Rice Establishment Methods. Soil pH varied considerably among puddling types and rice crop establishment methods. The results showed that the pH was in the range of 5.74 to 6.37 and 6.34 to 6.96 for 1H and 2H, respectively. However, the highest pH of 6.11 and 6.93 in 1H and 2H, respectively, was recorded under PD (Figure 3(a)). SOC was significantly different in 1H compared to 2H. The highest value 13.30 $g\cdot kg^{-1}$ and 14.26 $g\cdot kg^{-1}$ in 1H and 2H, respectively, resulting in an increase of 32.47% and 42.03% were recorded under PD (Figure 3(b)).

3.3. Available NPK as Affected by Puddling Types and Rice Establishment Method. PD resulted in the highest activity of available N of 45.43 $mg\cdot kg^{-1}$ in 1H and 64.07 $mg\cdot kg^{-1}$ in 2H which markedly increased by 14.95% and 62.12%, respectively (Table 2). The available P content was significantly varied among puddling types and rice crop establishment methods. The highest 13.51 $mg\cdot kg^{-1}$ in 1H and 14.05 $mg\cdot kg^{-1}$ in 2H resulting in an increase of 1.43% and 5.48%, respectively, of available P were observed under PD (Table 2). The highest available K 41.09 $mg\cdot kg^{-1}$ in 1H and 51.68 $mg\cdot kg^{-1}$ in 2H resulting in an increase of 31.74% and 65.69%, respectively, were recorded under PD (Table 2).

3.4. Total NPK as Affected by Puddling Types and Rice Establishment Methods. 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

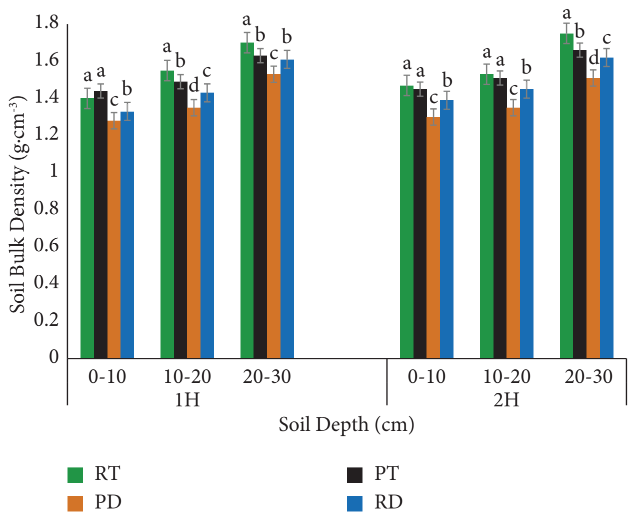

Figure 2: Puddling types and rice establishment methods on soil bulk density (two years average). PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and RT: rotary tiller with mechanical transplanting. Different letters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

RD, PT, and RT in the growing seasons. PD recorded highest of 0.61 $g{\cdot}kg^{-1}$ resulting in an increase of 22% in 1H and 0.74 $g{\cdot}kg^{-1}$ resulting in an increase of 48% in 2H (Table 3). Total P was significantly different in both growing seasons under puddling types and rice crop establishment methods; however, the highest values statistically were 0.30 $g{\cdot}kg^{-1}$ and 0.34 $g{\cdot}kg^{-1}$ resulting in an increase of 15.38% and 23.53% in 1H and 2H, respectively, were recorded under PD (Table 3). The highest total K 15.19 $g{\cdot}kg^{-1}$ and 22.28 $g{\cdot}kg^{-1}$ resulting in an increase of 0.60% and 47.55% in 1H and 2H, respectively, were recorded under PD (Table 3).

3.5. Culturable Bacteria, Fungi, and Actinomycetes as Affected by Puddling Types and Rice Establishment Methods. The bacteria content was significantly varied among puddling types and rice crop establishment methods. The highest 2.55 ($\times 10^5$ $cfu{\cdot}g^{-1}$ dry soil) and 2.78 ($\times 10^5$ $cfu{\cdot}g^{-1}$ dry soil) resulting in an increase of 15.38% and 25.79% in 1H and 2H, respectively, were observed under PD (Table 4). PD resulted in the highest activity of fungi of 1.66 ($\times 10^3$ $cfu{\cdot}g^{-1}$ dry soil) and 1.77 ($\times 10^3$ $cfu{\cdot}g^{-1}$ dry soil) which markedly increased by 37.19% and 46.28% in 1H and 2H, respectively, (Table 4). The highest actinomycetes of 3.19 ($\times 10^4$ $cfu{\cdot}g^{-1}$ dry soil) and 3.32 ($\times 10^4$ $cfu{\cdot}g^{-1}$ dry soil) resulting in an increase of 13.93% and 18.57% in 1H and 2H, respectively, were recorded under PD (Table 4).

3.6. Catalase, Phosphatase, and Urease Activity as Affected by Puddling Types and Rice Establishment Methods. Puddling types and rice crop establishment methods had a significant effect on 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 the highest catalase of 1.72 (0.1NKMnO$_4$ ($mL{\cdot}g^{-1}$)) and 1.71 (0.1NKMnO$_4$ ($mL{\cdot}g^{-1}$)) resulting in an increase of 6.83% and 6.21% in 1H and 2H, respectively (Table 5). The highest phosphatase of 73.26 (P_2O_5 ($mg{\cdot}kg^{-1}$)) and 79.52 (P_2O_5 ($mg{\cdot}kg^{-1}$)) resulting in an increase of 6.13% and 15.20% in 1H and 2H, respectively, were recorded under PD (Table 5). PD resulted in the highest activity of urease of 49.33 (NH_4^+-N ($mg{\cdot}kg^{-1}$)) and 50.18 (NH_4^+-N ($mg{\cdot}kg^{-1}$)) which markedly increased by 3.85% and 5.64% in 1H and 2H, respectively (Table 5).

3.7. Grain Yield Analysis. Puddling types and rice establishment methods had a significant effect on rice grain yield (Figure 4). PD recorded the highest increase in both harvesting times, whilst RT recorded the lowest. PD recorded an increase of 31.25% and 13.91% in 1H and 2H, respectively, than under RT.

4. Discussion

Environmental 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 the soil bulk density when combined with direct seeding [6].

The results showed that PD has a tendency to improve the 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 which may be 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 to higher SOC by P, this confirms the study done by Xue et al. [19]. Available and total NPK improved under PD due to decomposition of carbon-based matter and conversion of the 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 P could be more effective in increasing soil fertility in deeper soils

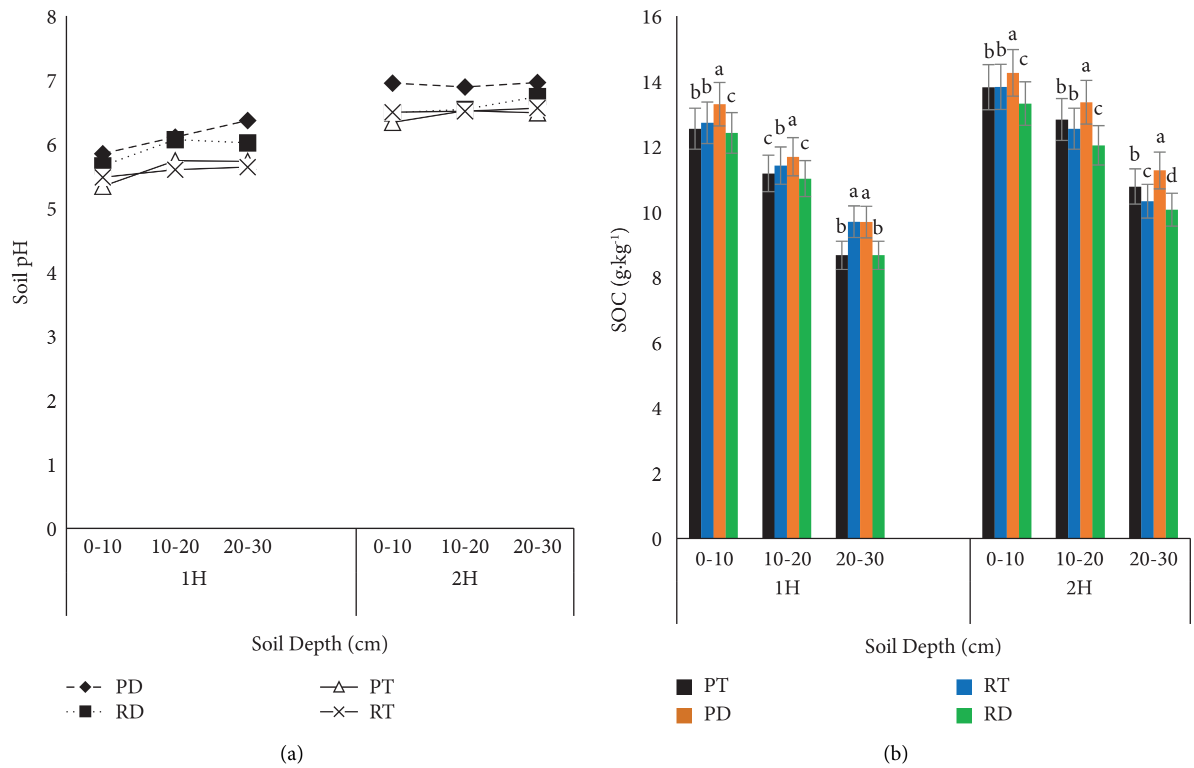

Figure 3: Puddling types and rice establishment methods on soil (two years average): (a) soil pH and (b) soil organic carbon. PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and RT: rotary tiller with mechanical transplanting. 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 types and rice establishment methods (two years average).

Soil depth	Treatments	Available nitrogen ($mg{\cdot}kg^{-1}$)		Available phosphorus ($mg{\cdot}kg^{-1}$)		Available potassium ($mg{\cdot}kg^{-1}$)	
		1H	2H	1H	2H	1H	2H
0–10 cm	PD	54.38a	69.33a	14.34a	15.78a	45.19a	55.46a
	RD	51.69b	66.36b	14.02b	15.39b	42.97b	52.34b
	PT	50.41c	62.93c	13.77b	14.80c	39.89c	49.24c
	RT	49.87d	61.48c	13.45b	14.26d	38.47c	48.34c
10–20 cm	PD	46.38a	75.57a	13.98a	13.97a	42.28a	51.85a
	RD	44.41b	49.32b	12.76b	13.66ab	39.24b	48.46b
	PT	41.75c	48.19b	12.46b	12.77c	37.73bc	44.19c
	RT	39.57d	44.66c	12.42b	11.00d	34.98c	41.83 cd
20–30 cm	PD	35.52a	47.31a	12.22a	12.39a	35.81a	47.74a
	RD	31.65b	40.59b	10.41b	11.26b	34.20b	44.28b
	PT	30.86c	38.30b	8.13c	10.63c	30.56c	42.77b
	RT	30.16d	36.61b	7.71d	9.30d	30.07 cd	38.97c

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and 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).

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].

Soil enzymes play a critical role in nutrient cycling of the soil, which results from puddling practices [22]. Puddling and rice cultivation modes had a considerable effect on the soil biological properties. PD observed high culturable bacteria resulting from the high buildup and amalgamation of the rice crop residue [6, 23], 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.

Table 3: Total NPK condition as affected by puddling types and rice establishment methods (two years average).

Soil depth	Treatments	Total nitrogen ($g\cdot kg^{-1}$)		Total phosphorus ($g\cdot kg^{-1}$)		Total potassium ($g\cdot kg^{-1}$)	
		1H	2H	1H	2H	1H	2H
0–10 cm	PD	0.67a	0.92a	0.33a	0.39a	16.38a	17.31a
	RD	0.64b	0.89a	0.32a	0.35b	15.95b	16.14b
	PT	0.64b	0.84b	0.31a	0.34b	15.75b	16.05b
	RT	0.64b	0.84b	0.29a	0.30c	15.37c	15.60c
10–20 cm	PD	0.63a	0.71a	0.29a	0.33a	15.32a	15.87a
	RD	0.61a	0.70a	0.28a	0.30b	15.06b	15.31b
	PT	0.60a	0.58b	0.28a	0.30b	15.00b	14.78c
	RT	0.56b	0.55b	0.25b	0.27c	14.84c	13.99d
20–30 cm	PD	0.54a	0.58a	0.27a	0.29a	13.86a	15.66a
	RD	0.48b	0.56a	0.26a	0.28a	13.74a	13.94b
	PT	0.47b	0.54a	0.24b	0.26a	13.35b	13.63c
	RT	0.46b	0.52b	0.23b	0.26a	13.30b	13.06d

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and 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 4: Culturable bacteria, fungi, and actinomycetes condition as affected by puddling types and rice establishment methods (two years average).

Soil depth	Treatments	Bacteria ($\times 10^5$ $cfu\cdot g^{-1}$ dry soil)		Fungi ($\times 10^3$ $cfu\cdot g^{-1}$ dry soil)		Actinomycetes ($\times 10^4$ $cfu\cdot g^{-1}$ dry soil)	
		1H	2H	1H	2H	1H	2H
0–10 cm	PD	2.64a	2.77a	0.99a	1.14a	2.69a	2.81a
	RD	2.44b	2.59b	0.92a	0.99b	2.42b	2.54a
	PT	2.38b	2.50b	0.89a	0.93b	2.29c	2.37b
	RT	1.53c	1.35c	0.83a	0.78c	2.20c	2.30b
10–20 cm	PD	3.40a	3.79a	1.38a	1.47a	3.29a	3.45a
	RD	3.20b	3.47b	1.27b	1.37a	3.20a	3.34a
	PT	2.87b	2.95c	1.20b	1.27b	3.17b	3.32a
	RT	2.62b	2.61c	1.10c	1.23b	3.10b	3.24b
20–30 cm	PD	1.62a	1.77a	2.60a	2.69a	3.60a	3.71a
	RD	1.57b	1.65a	2.21b	2.31b	3.36b	3.48a
	PT	1.42c	1.41b	2.18b	2.21b	3.20b	3.42b
	RT	1.35d	1.33c	2.07b	2.19b	3.18b	3.34b

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and 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 5: Catalase, phosphatase, and urease activity as affected by puddling types and rice establishment methods (two years average).

Soil depth	Treatments	Catalase (0.1NKMnO_4 ($mL\cdot g^{-1}$))		Phosphatase (P_2O_5 ($mg\cdot kg^{-1}$))		Urease (NH_4^+-N ($mg\cdot kg^{-1}$))	
		1H	2H	1H	2H	1H	2H
0–10 cm	PD	1.71a	1.76a	88.43a	95.12a	55.89a	56.63a
	RD	1.58a	1.56b	82.91b	92.11b	54.45b	55.38a
	PT	1.37b	1.46c	79.26c	90.56c	53.92b	54.64b
	RT	1.34b	1.45c	77.68d	86.42d	51.46c	52.62c
10–20 cm	PD	1.88a	1.90a	74.44a	78.72a	47.51a	48.73a
	RD	1.78a	1.85b	71.00b	73.15b	45.84a	46.64b
	PT	1.58b	1.82b	66.88c	68.96c	44.94b	45.66b
	RT	1.44c	1.72c	65.09c	67.55d	44.23b	44.72c
20–30 cm	PD	1.58a	1.48a	56.90a	64.72a	44.62a	45.17a
	RD	1.46b	1.40a	54.02b	62.35b	43.91b	44.30a
	PT	1.34c	1.30b	52.88c	59.62b	43.28b	43.85a
	RT	1.29c	1.22c	50.99d	56.09c	42.56b	43.19a

PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and 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).

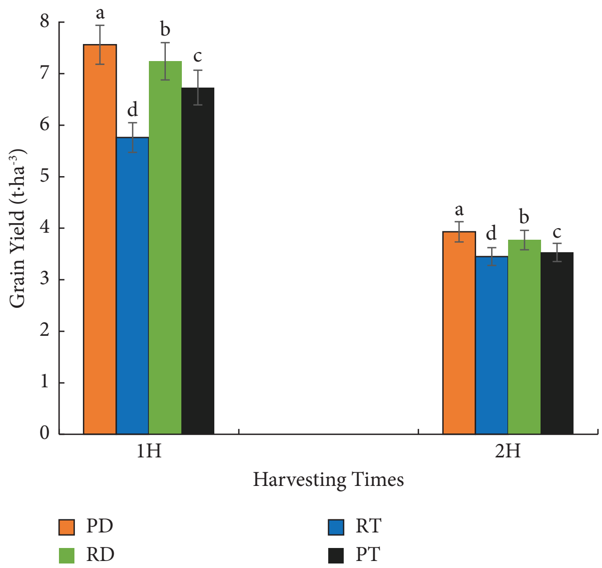

Figure 4: Puddling types and rice establishment methods on rice grain yield (two years average). PD: moldboard plowing with direct seeding, RD: rotary tiller with direct seeding, PT: moldboard plowing with mechanical transplanting, and RT: rotary tiller with mechanical transplanting. Different letters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

Culturable 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 the disturbing effect on fungi abundance [6]. PD improved culturable 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 activity by enhancing the substrates, which is in agreement with the work done by Jin et al. [24], who observed higher catalase activity in shallow tilling practices. PD treatment improved soil urease and phosphatase activity as likened to the other treatments, this result is in support of the findings from Asenso et al. [6], who observed the increase in urease and phosphatase population under P 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 the work done by Gupta et al., San-oh et al., Tabbal et al., and Ali et al. [25–28], who observed higher grain yield under DS rice as likened to flooded rice transplanting. Also, higher grain yield of rice has been recorded under DS compared to that of transplanted rice [6, 29–31].

5. Conclusion

On the basis of the current study, it may be concluded that among all the treatments, moldboard plowing combined with direct seeding (PD) improved the soil bulk density, chemical properties (SOC, pH, total NPK, and available NPK), and biological properties (bacteria, fungi, actinomycetes, urease, catalase, and phosphatase). PD also resulted in highest rice grain yield of 7.65 t·ha^{-1} and 3.93 t·ha^{-1} in 1H and 2H respectively compared with the lowest 5.76 t·ha^{-1} and 3.45 t·ha^{-1} in 1H and 2H respectively under RT. Therefore, PD should be adopted as a suitable combined management practices to obtaining good soil productivity and achieving sustainable rice grain yield under the prevailing climatic conditions.

Data Availability

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

Additional Points

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 the present study were provided by the College of Agriculture, South China Agricultural University, and we have permission to the seeds. Meixiangzhan-2 (Lemont × Fengaozhan) was bred by the 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/.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Li Jiuhao conceptualized the study and responsible for project administration and supervised the study. Evans Asenso performed formal analysis and investigation, wrote the original draft, and responsible for submission. Zhimin Wang performed data processing. Tian Kai performed data processing and analysis. Lian Hu reviewed and edited the manuscript and was responsible for project administration. All authors read and approved the final manuscript.

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