



# Article

# Moldboard Plowing with Direct Seeding Improves Soil Properties and Sustainable Productivity in Ratoon Rice Farmland in Southern China

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**Abstract:** Several tillage and planting methods have been proposed to enhance the soil bulk density, biological community, and grain yield of rice. In this work, we present the impact of plowing methods with different rice crop establishment approaches, i.e., moldboard plowing with mechanical transplanting (MPMT), rotary tillage with mechanical transplanting (RTMT), moldboard plowing with direct seeding (MPDS), and rotary tillage with direct seeding (RTDS), on soil bulk density, microbial community, enzymatic activities, and grain yield of ratoon rice (RR). The results showed that MPDS improved soil bulk density in 0–30 cm depth in both years and both harvesting times (1H: 1<sup>st</sup> harvest and 2H: 2<sup>nd</sup> harvest). The results also showed that microbial community significantly improved under MPDS compared to the other treatments in both years and in 1H and 2H. Additionally, enzymatic activities showed a positive effect under MPDS in both years and in 1H and 2H. MPDS subsequently improved rice grain yield by 18.05% and 17.27% in 2017 (1H and 2H), and 14.86% and 18.64% in 2018 (1H and 2H), respectively. In conclusion, MPDS appears to be a more suitable approach to obtaining high soil eminence and health, as well as sustainable RR production.

**Keywords:** enzymatic activity; direct seeding; microbial community; moldboard plowing; ratoon rice yield

# 1. Introduction

Rice (*Oryza sativa* L.) is one of the most important crops, accounting for 21% of worldwide consumption of calories [1]. China is the leading producer of rice worldwide, accounting for an average yearly rice production of 210 million metric tons, or 28% of global production (FAO 2014–2016 Food and Agriculture Organization of the United Nations) [2]. Main factors in the improvement in yield in preceding years include growing adoption of the use of commercial fertilizers, pesticides, machinery, and better-quality breeds [3,4]. Nevertheless, new farming methods have also led to damaging influences on the environment and increased farming cost [5,6]. Therefore, there is a need for methods that can help increase output while reducing ecological impacts and guaranteeing cost-effectiveness.

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Ratoon rice (RR) is the system whereby the subsequent harvest is realized from tillers initiating from the stubble of the formerly harvested crop (main crop). Relating to doubled-season rice (DR), the RR practice does not need extra work for reseeding the subsequent rice crop. RR is an old ricecropping practice, widely adopted since 1950 in China [7]. The RR-cropped area swiftly increased from 6667 ha in 1988 to 73,000 ha in 1994 in the Hubei Province due to governmental policy and change in farming methods [8,9]. Nevertheless, RR area rapidly decreased afterwards, with a remaining 7000 ha of RR in 2010 in the Hubei Province. Explanatory factors for the decrease in RR area include: (a) Dearth of appropriate rice breeds for RR practices, (b) reduced and/or less reliable yields compared to other rice practices, and (c) increased work force necessity in RR compared to middle-season rice [9–11]. New rice breeds with improved ratooning aptitude, combined with improved crop and water practices that permit mechanized harvesting of the main crop [9,11,12], have caused growers to readopt RR, resulting in an RR area of 153,000 ha in the Hubei Province in 2017.

Currently, the foremost crop planting method approach for the main-season rice in RR practice is old-style transplanted rice (TSR) [13]. Nevertheless, TSR uses high energy and labor inputs [14]. Direct seeding rice (DSR) has been recommended as another rice cultivation approach, as it lessens water use and labor necessities but increases system output and resource use effectiveness [15,16]. DSR is the method of growing rice from seeds sown directly in the field rather than by transplanting seedlings in the field [17]. Direct seeding as a rice crop establishment approach instead of transplanting has become common in Asia due to labor shortage and a development of direct seeding know-how [18]. Direct seeding rice–ratoon rice (DSR–RR) combines the transferred merits of DSR and RR, which expects to be a promising approach in central China and possibly other places in Asia. Dong et al. [19] observed that DSR–RR is another rice establishing approach to traditional transplanted ratooning rice (TTR–RR) in central China, and similar RR yields of DSR–RR and TTR– RR were observed.

Machine-driven transplanting of rice is the system of transplanting young rice seedlings—which have been raised on a tray in a nursery—using a paddy transplanter. Seedlings are transplanted at the optimal age (14–18 day old seedlings).

Tillage systems have direct impacts on rice crop establishment approaches. Different kinds of plowing methods have various plowing intensities and capacities to modify soil bulk density and biological indicators that influence the crop output and soil health [20]. Soil bulk density is significantly influenced by different tillage practices [21]. Tillage methods disrupt the natural state of the soil. Tillage damages the soil aggregate stability and pore continuity, resulting in soil dispersal, erosion, and surface hardening. Tillage also increases fuel consumption. Reduced tillage practices have positive impacts on soil health such as aggregate stability [22,23], as well as infiltration, hydraulic conductivity, and aeration. The practice of moldboard plowing needs special attention, since it is the most common system of primary plowing adopted in conventional agricultural soil management systems. Therefore, the general aim of the work was to assess the effects of plowing methods with different RR crop establishment approaches on soil bulk density, microbial community, and the grain yield on Stagnic Anthrosols of Yi-Yang in the Hunan province of China, in order to develop an innovative approach for soil management and sustainable production that will help achieve sufficient food production to feed the growing world population.

## 2. Materials and Methods

## 2.1. Site Description

A two-year field experiment was established in 2017 and 2018 in Yi-Yang County (29°07″40′N, 112°25″25′E, 27 m of altitude) in the Hunan province of Southern China. The region has a subtropical monsoon climate with average temperatures of 18.4 °C and 18.5 °C for 2017 and 2018 respectively. At the study site, the annual precipitation (1613.29 mm and 1440.59 mm), sunshine hours (1373.2 h and 1608.9 h), wind speed (22.5 m·s<sup>-1</sup> and 23.38 m·s<sup>-1</sup>), and relative humidity (923.9% and 912.98%) were recorded for 2017 and 2018. The average monthly climatic condition and experimental location of the

study site are shown in Figure 1 and 2. The predominant soil at the study site is classified as Stagnic Anthrosol according to the United States Department of Agriculture Soil Classification (USDA), and is developed from the Quaternary Red Earth [24]. The site had soil N, P, and K contents of 100 kg·ha<sup>-1</sup>, 8.5 kg·ha<sup>-1</sup>, and 112 kg·ha<sup>-1</sup>, respectively, with pH values ranging between 6.5 and 7.5. In all, a total of 36 soil samples were collected from the entire experimental field, with each treatment field sampled three times at depth increments of 0–10, 10–20, and 20–30 cm. The basic soil conditions of the considered parameters at the depth of 0–30 cm are shown in Table 1.



**Figure 1.** Average monthly precipitation (mm), wind speed (m·s<sup>-1</sup>), temperature (°C), relative humidity (%), and sunshine hours (h) from the study site between January to December for 2017 and 2018.

Sand (%)	Silt (%)	Clay (%)	Soil Textural Class	Bulk Density (g·cm <sup>-3</sup> )			
57	9	34	Sandy clay loam	1.1	1.16		
Bacteria	Fungi	Actinomycetes	Catalase	Phosphatase	Urease		
(×10 <sup>5</sup> cfu·g <sup>-1</sup>	$(\times 10^3  cfu \cdot g^{-1})$	(×10 <sup>4</sup> cfu·g <sup>-1</sup> dry	[0.1NKMnO4	[P2O5 (mg·kg-	[NH4+-N		
dry soil)	dry soil)	soil)	$(mL \cdot g^{-1})]$	<sup>1</sup> )]	(mg·kg-1)]		
2.79	0.08	5.41	43.39	159.66	1211.50		

Table 1. Basic soil condition of the study site.

## 2.2. Treatment and Experimental Design

The experiment included four treatments: (i) Moldboard plowing with mechanical transplanting (MPMT); (ii) rotary tillage with mechanical transplanting (RTMT); (iii) moldboard plowing with direct seeding (MPDS); (iv) rotary tillage with direct seeding (RTDS). The moldboard plow and the rotary tillage were set respectively to 30 cm soil depth. The experimental area measured 10,990 m<sup>2</sup> with subdivided plots: (a) MPMT: Moldboard plowing with mechanical transplanting (57 m × 35 m), (b) RTMT: Rotary tillage with mechanical transplanting (57 m × 35 m), (c) RTDS: Rotary tillage with direct seeding (100 m × 35 m), and (d) MPDS: Moldboard plowing with direct seeding (100 m × 35 m), as shown in Figure 2.



Figure 2. Experimental location of Hongshuo Farm, Yi-Yang City, Hunan Province, China.

The regenerative rice variety used throughout the study was "Huanghuazhan", which was sown using the direct hill-drop method using MPDS and RTDS by a 2BDCSP Precision Rice Hill-Drop Drilling Machine (Figure 3a) on April 12, 2017 and March 30, 2018 at a dropping space of 25 cm × 15 cm with 4–6 seeds per hill. Mechanical transplanting using MPMT and RTMT was done with a YANMAR VP7D25 Rice Transplanter (Figure 3b) 15 days after germination/sprouting at a transplanting space of 25 cm × 15 cm with 4–6 seedlings per hill.



**Figure 3.** (a) Direct rice seeding using 2BDCSP Precision Rice Hill-Drop Drilling Machine; (b) mechanical transplanting using YANMAR VP7D25 Rice Transplanter.

The supply of water to the treatment fields was the ditch irrigation system. All treatment plots were uniformly applied with the same amount of urea (N content 46%) and formula fertilizer (25-11-15) before transplanting on April 22 and April 25 in 2017 and 2018, respectively. The basic formula fertilizer was applied at 15 kg·hm<sup>-2</sup>, urea was applied at 10 kg·hm<sup>-2</sup> at the tillering stage, and additional formula fertilizer at 15 kg·hm<sup>-2</sup> at the booting stage. Early season rice was harvested on August 25 and August 18 in 2017 and 2018 respectively, and the ratoon rice received urea at 10 kg·hm<sup>-2</sup> before the heading stage, followed by urea at 10 kg·hm<sup>-2</sup> application after full heading. Ratoon rice was harvested on October 20 in both years. The low amount of fertilizer application in late seasons was mainly due to the short growth season in the ratoon season, less accumulated dry matter, and less required amount of fertilizer.

## 2.3. Measurement of Soil Bulk Density

Soil bulk density is used as an important index of differences in the soil structure and moisture retentive measurements [25], and was measured from 50 mm diameter cores at 0–10, 10–20, and 20–30 cm; soil cores were weighed wet, desiccated in an oven at 105 °C for 48 h, and measured once more to determine the soil moisture content and bulk density [26].

2.4. Measurement of Biological Activity

A total of 10 g of soil was soaked in 90 mL deionized water, and the sample was shaken for 10 minutes and left standing for 5 minutes. Supernatant solution of 1 mL was diluted at a temperature of 30 °C. The measurements were done in triplicate, and were used for determining soil bacteria, actinomycete, and fungal levels.

Examinations of viable microbial levels were done by the normal procedure of sequential dilution and the pour plating process. Counting of bacteria and fungi levels was undertaken in soil extract agar medium [27]. Actinomycetes levels was counted by Kenknight's agar medium method [28]. Bacteria, fungi, and actinomycetes colonies were enumerated and their number per gram of dry weight of soil [written as colony-forming units (cfu)] was calculated. An automated calorimetric procedure was used to determine the soil urease [29]. A volumetric procedure method was followed to determine the soil catalase [30]. A continuous assay for acid phosphatase by means of phenyl phosphate sodium colorimetric procedure was used to determine the soil phosphatase [31].

#### 2.5. Measurement of Ratoon Rice Grain Yield

At the maturity stage, rice grain yield was measured from six- and five-unit sampling areas (1 m<sup>2</sup>) from each treatment plot for 1H and 2H (1H: 1<sup>st</sup> harvest and 2H: 2<sup>nd</sup> harvest) respectively and then threshed by machine at 13.5% moisture content. A FUQIANG 4LZ-427 Full-Fill Grain Combine Harvester was used to harvest the remaining plot. Rice grain yield was then calculated in tons per hectare.

## 2.6. Statistical Analysis

Data from each of the two years was analyzed separately to understand the soil management methods and crop establishment approach on soil bulk density, microbial community, enzymatic activities, and rice yield. IBM SPSS 23.0 was used to analyze the data. Analysis of variance (ANOVA) was done to test whether soil bulk density, microbial community, enzymatic activities, and rice yield were significantly different. Mean values were compared using Duncan's Multiple Range Test (DMRT) at a 5% probability level.

## 3. Results

## 3.1. Soil Bulk Density

Soil bulk densities in 2017 and 2018 were both significantly (p < 0.05) affected by tillage methods (Figure 4). The averages of soil bulk density calculated from 0–30 cm soil depth decreased significantly by 17.17, 11.54, and 10.48% under MPDS, RTDS, and MPMT, and 3.57, 2.65, and 0.86% under MPDS, RTDS, and RTMT, respectively, for 2017 (1 and 2H). Subsequently, in 2018 (1 and 2H), bulk density decreased significantly by 17.17, 14.88, 7.41, and 2.59% under MPDS, RTDS, MPMT, and RTMT and 11.54, 5.45, and 2.65% under MPDS, RTDS, and MPMT, respectively, compared to the initial bulk density value on Table 1. Comparatively, the bulk density under MPDS in 2017 (1H) and 2018 (1H) did not differ; however, bulk density for 2018 (2H) was 7.97% lower than for 2017 (2H).



**Figure 4.** Soil bulk density as affected by different plowing and planting methods. MPMT: Moldboard plowing with mechanical transplanting, RTMT: Rotary tillage with mechanical transplanting, MPDS: moldboard plowing with direct seeding, RTDS: Rotary tillage with direct seeding. Figures in columns with common letter(s) do not differ significantly at 5% level of Duncan's Multiple Range Test (DMRT). (1H: 1\* harvest, and 2H: 2<sup>nd</sup> harvest).

## 3.2. Soil Biological Activities

Tillage methods significantly (p < 0.05) affected the soil bacteria (Table 2). Means of soil bacteria recorded in the 0–30 cm soil depth decreased significantly by 70.69 and 30.84% under RTMT and 330.43 and 318.31% under MPMT for 2017 (1 and 2H), compared to a significant decrease of 4.21 and 18.80% under MPDS and 45.59 and 77.84% under RTDS for 2017 (1 and 2H). Additionally, soil bacteria decreased significantly by 57.98 and 23.75% under RTMT and 318.31 and 301.23% under MPMT for 2018 (1 and 2H), compared to a significant decrease of 4.58 and 5.69% under MPDS and 40.09 and 65.92% under RTDS for 2018 (1 and 2H). Comparatively, soil bacteria for 2018 (1H) reduced by 13.11, 12.71, and 7.09% respectively under RTDS, RTMT, and MPMT compared with in 2017 (1H). However, 2017 (1H) recorded 0.37% reduction compared to 2018 (1H) under MPDS. Subsequently, soil bacteria for 2018 (2H) reduced by 12.12, 17.08, 11.92, and 5.5% respectively under RTMT, MPMT, RTDS, and MPDS compared to 2017 (2H).

Soil fungi were significantly (p < 0.05) affected by tillage methods (Table 2). Averaged over 0–30 cm soil depth, a significant increase of 175.00 and 125.00% under MPDS and 137.50 and 62.50% under RTDS of soil fungi was recorded for 2017 (1 and 2H), compared to 12.50 and 0.00% under MPMT and 25.00 and 12.50% under RTMT for 2017 (1 and 2H). Subsequently, in 2018 (1 and 2H), soil fungi increased significantly by 200.00 and 127.50% under MPDS and 200.00 and 112.50% under RTDS, compared to 25.00 and 12.50% under MPMT and 37.50 and 37.50% under for 2018 (1 and 2H). Comparatively, soil fungi for 2018 (1H) reduced by 25.00% under MPDS and 12.5% respectively under MPMT, RTMT, and RTDS compared with 2017 (1H). However, soil fungi for 2018 (2H) decreased by 12.50, 25.00, 50.00, and 62.50% respectively under MPMT, RTMT, RTDS, and MPDS for 2017 (2H).

Table 2.	Soil bacteria,	fungi, ar	nd actinomycetes	as	affected	by	different	plowing	and	planting
methods.										

Soil Depth	Plowing Methods	E (×10 <sup>5</sup> cfr	Bacteria u∙g⁻¹ Dry Soil)	Fu: (×10³ cfu Sc	ngi 1·g <sup>-1</sup> Dry iil)	Actinomycetes (×104 cfu·g-1 Dry Soil)		
		2017 (1H)	2017 (2H)	2017 (1H)	2017 (2H)	2017 (1H)	2017 (2H)	
	MPMT	3.61c	0.61c	0.14b	0.14c	2.84d	6.56c	
0.10	RTMT	2.37d	1.81c	0.09b	0.13c	4.50c	7.07b	
0–10 cm	MPDS	5.40a	2.67a	0.35a	0.35a	6.39a	7.84a	
	RTDS	4.96b	2.64a	0.28a	0.22b	5.81b	7.09b	
	MPMT	1.90b	0.73d	0.08b	0.08b	1.99d	3.88c	
10.20	RTMT	1.74c	1.13c	0.08b	0.08b	2.27c	3.42d	
10–20 cm	MPDS	2.08a	1.83a	0.17a	0.14a	5.03a	5.23a	
	RTDS	1.78c	1.32b	0.16a	0.09b	2.39b	4.86b	
	MPMT	1.29a	0.72d	0.06b	0.09a	0.84d	2.69d	
20–30 cm	RTMT	1.12b	0.83c	0.08b	0.08a	1.01c	3.21c	
	MPDS	1.07b	1.63a	0.14a	0.09a	3.24a	3.99a	
	RTDS	0.75c	1.04b	0.09b	0.08a	2.43b	3.86b	
			Bacteria	F	ungi	Actinomycetes		
		(×10 <sup>5</sup>	cfu∙g-¹ dry soil)	(×10 <sup>3</sup> cfu	·g-1 dry soil)	(×10 <sup>4</sup> cfu·g <sup>-1</sup> dry soil)		
		2018	2018 (2H)	2018	2018	2018	2018	
		(1H)	2010 (211)	(1H)	(2H)	(1H)	(2H)	
	MPMT	3.89c	0.76c	0.15b	0.16c	2.89d	6.73c	
0-10  cm	RTMT	2.62d	1.85b	0.10b	0.16c	4.80c	7.16b	
0–10 cm	MPDS	5.15b	2.75a	0.40a	0.45a	6.49a	7.87a	
	RTDS	5.73a	2.74a	0.31a	0.34b	5.85b	7.22b	
	MPMT	1.94b	0.73d	0.09b	0.09b	2.01c	3.93c	
10–20 cm	RTMT	1.86b	1.15c	0.09b	0.08b	2.46b	3.46d	
	MPDS	2.12a	1.89a	0.18a	0.16a	5.25a	5.35a	
	RTDS	1.86b	1.44b	0.18a	0.09b	2.48b	4.88b	
20–30 cm	MPMT	1.38a	0.65d	0.07b	0.08a	0.88c	2.73c	
	RTMT	1.17b	0.87c	0.08b	0.08a	1.11c	3.41b	
	MPDS	1.24b	1.73a	0.15a	0.10a	2.50b	4.05a	
	RTDS	0.83c	1.18b	0.09b	0.09a	3.65a	3.89b	

MPMT: Moldboard plowing with mechanical transplanting, RTMT: Rotary tillage with mechanical transplanting, MPDS: Moldboard plowing with direct seeding, RTDS: rotary tillage with direct seeding. Figures in columns having common letter(s) do not differ significantly at 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

The averages of soil actinomycetes recorded from the soil depths of 0–30 cm decreased significantly by 186.24 and 108.88% under MPMT and 23.52 and 18.38% under RTMT for 2017 (1 and 2H), compared to 52.82 and 10.63% under RTDS and 2.66 and 5.18% under MPDS for 2017 (1 and 2H). Also, soil actinomycetes significantly increased by 180.31 and 93.91% under MPMT and 21.30 and 15.60% under for 2018 (1 and 2H), compared to 35.59 and 13.89% under RTDS and 1.50 and 6.47% under MPMT for 2018 (1 and 2H), as shown in Table 2. Comparatively, soil actinomycetes for 2017 (1H) increased by 17.23, 14.97, and 5.93% respectively under RTDS, RTMT, and MPMT compared with 2018 (1H). MPDS in 2018 (1H) increased by 3.26% compared with 2017 (1H). Also, soil actinomycetes in 2017 (2H) increased by 2.78, 2.22, and 1.16% respectively under RTMT, MPMT, and RTDS compared with 2018 (2H). MPDS in 2018 (2H) increased by 1.29% compared with 2017 (2H).

Soil catalase was significantly (p < 0.05) affected by tillage methods (Table 3). Averages of soil catalase recorded in the 0–30 cm soil depth increased significantly by 3.69 and 0.65% under MPDS and significantly reduced by 75.88 and 74.33% under RTDS for 2017 (1 and 2H), compared to a significant reduction of 6.37 and 4.23% under MPMT and 102.95 and 95.36% under RTMT recorded for 2017 (1 and 2H). In addition, soil catalase increased significantly by 7.63 and 3.94% under MPDS

and was significantly reduced by 71.37 and 69.23% under RTDS for 2018 (1 and 2H), compared to a significant reduction of 3.90 and 2.36% under RTMT, and 97.86 and 89.64% under MPMT in 2018 (1 and 2H). Comparatively, soil catalase for 2017 (1H) was increased by 2.47 and 1.87% respectively under RTMT and MPMT compared with 2018 (1H), while 2018 (1H) was increased by 3.94 and 3.29% under MPDS and RTDS compared with 2017 (1H). However, soil catalase for 2017 (2H) was increased by 5.72, 5.09, 5.10, and 4.51% respectively under MPMT, RTMT, RTDS, and MPDS compared with 2018 (2H).

Mean soil phosphatase measured in the 0–30 cm soil depth increased significantly by 39.95, 38.12, 35.43, and 35.41%, compared to a significant reduction of 9.89, 20.59, 36.18, and 37.42% respectively under MPDS, RTDS, RTMT, and MPMT for 2017 (1 and 2H). Also, soil phosphatase increased significantly by 41.54, 38.21, 38.05, and 34.99%, compared to a significant reduction of 9.38, 19.63, 34.93, and 36.26% respectively under MPDS, RTDS, RTMT, and MPMT, and MPMT for 2018 (1 and 2H), as shown in Table 3. Comparatively, soil phosphatase for 2018 (1H) was increased by 2.62, 1.59, and 0.09% respectively under RTMT, MPDS, and RTDS compared with 2017 (1H), while 2017 (1H) was increased by 0.42% under MPMT compared with 2018 (1H). However, soil phosphatase for 2017 (2H) increased by 1.25, 1.16, 0.96, and 0.51% respectively under RTMT, MPMT, RTDS, and MPDS compared with 2018 (2H).

Tillage methods significantly (p < 0.05) affected the soil urease (Table 3). Averages of soil urease in the 0–30 cm soil depth decreased significantly by 120.47, 115.14, 110.36, and 85.85% and 32.89, 25.49, 16.52, and 9.42% respectively under RTMT, MPMT, RTDS, and MPDS for 2017 (1 and 2H). Also, a significant decrease in soil urease of 119.85, 115.70, 102.45, and 91.20% and 32.72, 25.24, 16.36, and 9.24% were recorded respectively under RTMT, MPMT, RTDS, and MPDS for 2018 (1 and 2H). Comparatively, soil urease for 2018 (1H) was increased by 5.35 and 0.56% respectively under MPDS and MPMT more than 2017 (1H), compared to 2017 (1H), which recorded 7.91 and 0.62% reduction more than 2018 (1H) respectively under MPDS and MPMT. However, soil urease for 2018 (2H) was increased by 0.28, 0.18, 0.17, and 0.16% respectively under MPMT, MPDS, RTMT, and RTDS compared with 2018 (2H).

	Soil Donth (cm)	2017 (1H)				2017 (2H)			
	Son Depui (ciii)	MPMT	RTMT	MPDS	RTDS	MPMT	RTMT	MPDS	RTDS
Catalase	0-10	46.99c	45.06d	51.56a	50.18b	22.22d	24.31c	26.95a	26.25b
[0.1NKMnO4 (mL·g <sup>-1</sup> )]	10-20	42.84c	41.19d	46.56a	44.14b	22.80c	20.39d	24.79b	26.40a
	20-30	35.06c	36.13d	36.86a	36.69a	21.62c	19.44d	22.28a	22.04b
Phosphatase	0-10	216.06d	220.84c	224.23a	222.84b	172.46d	177.94c	204.71a	197.71b
	10-20	211.94b	217.09ab	223.70a	217.67ab	116.04c	109.95d	144.42a	121.47b
[F2O5(mg·kg·)]	20-30	220.66a	210.68b	222.42a	221.09a	60.03c	63.84c	86.74a	78.01b
Urease	0-10	860.64b	1021.80a	1013.48a	876.08b	1446.58b	1242.64c	1558.58a	1543.30a
	10-20	476.14d	518.10c	648.18a	587.86b	926.26c	978.08b	1157.36a	988.34b
[INFIA'-IN (Ing·kg·)]	20-30	352.54a	108.66d	293.92b	263.80c	523.34c	514.18d	605.68a	587.46b
			2018 (1H)		2018 (2H)				
		MPMT	RTMT	MPDS	RTDS	MPMT	RTMT	MPDS	RTDS
Catalase	0-10	47.84b	45.80b	53.10a	51.54a	23.46c	24.99b	27.53a	26.97b
[0.1NI/MaO (m.L. ~1)]	10-20	43.40c	42.13d	48.70a	45.63b	23.21c	20.93d	25.20b	26.97a
[0.11NKIVINO4 (mL·g··)]	20-30	35.93b	37.36ab	38.30a	38.12ab	21.96b	19.88c	23.25a	22.99b
Phosphatase	0-10	219.87c	222.08bc	225.25a	224.13ab	173.45d	178.74c	205.58a	198.93b
[P <sub>2</sub> O <sub>5</sub> (mg·kg <sup>-1</sup> )]	10-20	219.74a	218.81a	227.75a	219.30a	117.13c	111.15d	145.19a	122.65b
	20-30	221.62a	212.22b	224.96a	222.03a	60.94c	65.09b	87.15a	78.79b
Urease	0-10	861.49b	1024.09a	1016.41a	879.05b	1448.34b	1243.47c	1560.10a	1545.29b
[NH4+-N (mg·kg-1)]	10-20	470.28d	519.30c	589.18b	651.01a	928.73c	979.79c	1158.21a	990.08b
	20-30	353.22a	109.81d	295.26b	265.18c	525.05c	515.11d	607.28 a	588.11b

Table 3. Soil catalase, phosphatase, and urease as affected by different plowing and planting methods.

MPMT: Moldboard plowing with mechanical transplanting, RTMT: Rotary tillage with mechanical transplanting, MPDS: Moldboard plowing with direct seeding, RTDS: Rotary tillage with direct seeding. Figures in columns having common letter(s) do not differ significantly at 5% level of DMRT. (1H: 1<sup>st</sup> harvest, and 2H: 2<sup>nd</sup> harvest).

3.3. Ratoon Rice Grain Yield

As shown in Figure 5, different plowing and planting methods affected rice grain yield significantly. The highest grain yield was recorded by MPDS and RTDS in both years and harvesting times. However, there was no significant difference between MPDS and RTDS in 2017 (1H). Moreover, 2017 (2H), 2018 (1H), and 2018 (2H) recorded some levels of significant differences between MPDS and RTDS.



**Figure 5.** Ratoon rice grain yield as affected by different plowing and planting methods. MPMT: Moldboard plowing with mechanical transplanting, RTMT: Rotary tillage with mechanical transplanting, MPDS: Moldboard plowing with direct seeding, RTDS: Rotary tillage with direct seeding. Figures in columns having common letter(s) do not differ significantly at 5% level of DMRT. (1H: 1st harvest, and 2H: 2nd harvest).

## 4. Discussion

## 4.1. Soil Bulk Density

Plowing and planting methods conducted between 2017 and 2018 established that MPMT, RTMT, MPDS, and RTDS had an impact on soil bulk density, microbial indicators, and on ratoon rice grain yield. Almost all kinds of inverse tillage practices decrease soil bulk density [32]. The resultant reduction in soil bulk density (Figure 4) under MPDS after the two-year study was largely ascribed to the high incorporation of preceding rice crop residues and fewer soil disturbances after plowing for the direct rice seed drill. In addition, moldboard plowing loosens soils, resulting in lower soil bulk density, which may be due to the traffic for the secondary operation (during transplanting of seedlings).

#### 4.2. Soil Biological Indicators

Soil biological parameters are acknowledged to show variations in soil management quicker and with a larger degree than either soil organic carbon or soil total nitrogen concentrations [33]. The tillage practice had a substantial impact on the soil biological indicators. Bacteria concentration, as shown in Table 2, was greater under MPDS, which may be due to the high build-up and incorporation of crop residue [34], as well as the impact of the tillage practice type and the accessible substrates which in turn influenced the soil bacteria profusion. However, the decrease in bacteria under MPMT and RTMT could be a result of less accumulation of rice straw on the soil after tillage application and the high soil compaction produced during transplanting of seedlings. Soil fungi, as shown in Table 2, were significantly greater under MPDS due to the putrefaction of organic matter ensuing from the

high incorporation of rice crop residue and the augmented soil infiltration. Also, minimal disturbance of the soil resulted in an upsurge in soil fungi after the rice establishment.

However, MPMT and RTMT led to greater soil compaction after ration rice transplanting, which had a devastating impact on fungi profusion. Soil actinomycetes—shown in Table 2—under MPDS augmented significantly, which could be a result of greater accumulation of rice straw on the soil surface, as actinomycetes are characteristically greater in high organic matter soils.

Soil enzymes play a crucial role in soil nutrient cycling, which is affected by tillage practices [35,36]. Plowing and planting methods significantly affected the enzymatic activities of the soil. Soil catalase (Table 3) was greater under MPDS, which may be due to less/no soil disturbance after DSR establishment, leading to soil enhanced substrates. The augmented catalase activity in less-disturbed soils by MPDS before the rice seed establishment is in agreement with Jin et al. [37], who recorded greater catalase activity in shallow tillage practices. Catalase is an intracellular enzyme involved in the microbial breakdown in the cell and is a significant oxidoreductase that occurs in virtually all aerobic and facultative anaerobic microorganisms, shielding cellular processes and breakdowns from oxidative pressure by hydrogen peroxide [38,39]. MPDS positively impacted soil phosphatase (Table 3) compared to the other treatments. Urease and phosphatase enhanced under MPDS; this might be due to the incorporation of crop residue, leading to a greater decomposition of soil organic matter. The greater the microbial community, the greater the enhanced profusion of soil enzymes (e.g. catalase, urease, and phosphatase).

## 4.3. Ratoon Rice Grain Yield

Our two-year (2017 and 2018) study on tillage methods with different rice crop establishment approaches in Stagnic Anthrosols showed that MPDS significantly increased grain yield compared to the other treatments. The highest rice grain yield was recorded under the MPDS (Figure 5). Higher yield was attributed to good crop condition and more availability of nutrients. In addition, less soil disturbance enhanced the soil bulk density for root proliferation to aid in soil nutrient and moisture accessibility. The result is in agreement with [40–43], as they reported greater yield in DSR compared with flooded transplanting. Work done by [14,44–46] also recorded a greater grain yield in rice under direct seeding compared to that of transplanted rice. The lower yield recorded under RTMT and MPMT could be due to nutrient deficiency after the flooding of the field, resulting in nutrient leaching from the root zones during the transplanted seedlings' establishment, as well as less buildup of crop residue, leading to less putrefaction of soil organic matter.

## 5. Conclusion

This study examined the effects of different tillage methods and the ratoon rice establishment approach on soil properties and grain yield in Southern China. Results from the study showed that moldboard plowing with a direct seeding approach leads to enhancement in soil bulk density, microbial community, and enzymatic activities in the soil (0–30 cm), and results in sustainable increase in grain yield. In conclusion, moldboard plowing soil management with a direct RR seeding (MPDS) establishment approach appears to be a more suitable approach to obtaining high soil eminence and health, and sustainable ratoon rice (RR) production.

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