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Effects of Seven Diversified Crop Rotations on Selected Soil Health Indicators and Wheat Productivity

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Abstract: Diversified cropping systems can enhance soil condition and increase system productivity worldwide. To reduce the negative effects that accompany the continuous winter wheat–summer maize (WM) double-cropping in the North China Plain (NCP), diversified crop rotation (DCR) needs to be considered. The objective of this study is to evaluate the effect of DCR on soil health and wheat productivity as compared to a continuous WM double-cropping. A field experiment (37°41′ N, 116°37′ E) was established in the NCP including a traditional WM double-cropping as a baseline. During 2016/2017–2017/2018, the control is winter wheat–summer maize→winter wheat–summer maize (WM→WM) and seven DCRs as follow: fallow→winter wheat–summer maize (F→WM); spring maize→winter wheat–summer maize (Ms→WM); winter wheat→winter wheat–summer maize (W→WM); sweet potato→winter wheat–summer maize (Psw→WM); spring peanut→winter wheat–summer maize (Pns→WM); winter wheat–summer peanut→winter wheat–summer maize (WPn→WM) and potato–silage maize→winter wheat–summer maize (PMl→WM). Our results indicated that DCRs significantly changed certain soil health indicators in 2016/2017 compared with the control, where F→WM rotation significantly decreased soil pH by 2.7%. The DCRs, especial Psw→WM and Pns→WM rotations showed a potential positive effect on soil health indicators at the end of the second year (2017/2018) compared with the control, where sweet potato increased soil organic carbon (SOC), total nitrogen (TN), available phosphorus (AP), urease activity (UA) and alkaline phosphatase activity (APA) in 2017/2018 by 5.1%, 5.3%, 13.8%, 9.4%, and 13.5%, respectively. With the spring peanut, TN, AP, and soil APA were increased by 2.1%, 13.2%, and 7.7%, respectively. Although fertilizer and irrigation input of DCRs were lower than the control, no significant decrease was observed on actual wheat yield as compared to the control (7.79 Mg/ha). The finding of this study highlights the value of DCRs, especially, Psw→WM and Pns→WM rotations over WM double-cropping in the NCP.

Keywords: diversified crop rotation; soil physical indicators; soil chemical indicators; soil enzymes activities; wheat productivity; winter wheat–summer maize double cropping

1. Introduction

Meeting the growing food demand of the increasing population with limited agricultural resources is a major challenge on national and global scales [1,2]. The world population is forecasted to reach about 9.6 billion by 2050, while the world's cultivated land area has increased by only 12% [3,4]. Meanwhile, there is a shortage of good quality soil to meet the increase in world food production [5]. Soil health, or soil quality is critically important to maintain the capacity of agricultural productivity, including plant and animal productivity [6]. The adaption of soil via improved management for sustainable agriculture is essential to achieving food security [5]. As one of the most important agricultural regions in a developing country, the North China Plain (NCP) has a similar but larger challenge to sustain soil health and guarantee food security. Since the 1960s, a winter wheat (*Triticum aestivum* L.)–summer maize (*Zea mays* L.) cropping system has dominated the NCP because of its high productivity [7,8]. Especially, the NCP contributes 2/3 of the nation's grain of wheat, which is the third leading crop in China [7,9,10]. However, the cereal-based practice has been found to have negative impacts on the soil health [11], especially worse under excessive fertilizer-input and lower nutrients-use efficiencies in the NCP [12]. Soil health determines the quantity and quality of food derived from soil-based agriculture [13]. Therefore, the traditional WM double cropping in the NCP not only needs to be modified to meet the increasing food demand of the 1.3 billion Chinese population [5,9], but also needs to be improved to maintain soil health and food security [12].

To reduce the negative impact of the cereal-based system, some research is needed on diversifying cropping systems. There are some significant benefits to the diversifying cropping system that have been documented worldwide. For example, a diversified cropping system in which cereals and broadleaf crops increases the water use efficiency [14], and grain yield [15,16]. Moreover, the rotation of wheat with pulse crops can improve soil conditions, including soil physical and chemical properties [17] and increase in system productivity [18]. In addition, some published research confirmed that diversifying cropping systems with plus crops is beneficial to enhance soil water conservation and improve soil nitrogen availability [19]. According to two global analyses, diversifying crop rotation or enhanced crop rotation has always been linked to increasing soil organic carbon (SOC) compared with monoculture [20,21]. Soil enzyme activities are soil health indicators that reflect changes in soil biogeochemical cycling potential, which can be more responsive to management practice like crop rotation [22]. The different quantity, quality, and distribution of crop residues from the crop rotations system generally leads to higher soil enzyme activity compared with a monocropping system [23]. It is well-known that high-quality soil condition plays an essential role in crop productivity [5]. In the NCP, compared with a conventional intensive WM system, diversified crop rotations decreased the carbon footprint [18,24] and increased economic water use efficiency [25] and biomass and economic output [24], but has no documentation on their effects on soil health. Considering the limited research in the NCP, there is a need to document the effect of diversified crop rotations compared to a WM double cropping on soil health.

Therefore, a long-term study using the continuous WM double cropping as a baseline was established to explore the effect of diversified crop rotations which aim to improve soil health and maintain crop productivity in the NCP. We included cereal, tuber, pulse crops, and fallow with WM to form seven new DCRs, considering the suitability, productivity, and sustainability. Specifically, sweet potato (*Ipomoea batatas* L.) has been included due to its importance in the Chinese economy, of which its high yield and widely used in various industries [26]. Peanut (*Arachis hypogea* L.) is an important oil, food and feed crop of the world [27]. Spring maize (*Zea mays L.*) showed the potential to use groundwater in balance and sustainably in the NCP [28,29]. The potato (*Solanum tuberosum* L.) tuber is an important food crop with nutrient and bioactive compounds for human health [30]. The importance of maize silage (*Zea mays* L.) as a feed component in cattle feed has substantially increased [31]. The objective of fallow is to rejuvenate the soil fertility and disrupt pests and diseases [32]. Based on the continuous WM double cropping (one year per cycle), we added the one season crop, or two-season crops, or fallow for another year to build a new two-year cycle. According to the previous researches [33,34], three broad categories of physical, chemical and biological soil health indicators and wheat productivity indicators will be evaluated. The objectives of this study were: (i) evaluating the seven diversified crop rotation (DCR) effects on soil health in the first two years of the establishment, and (ii) determining the seven DCR effects on wheat productivity. Our hypotheses are: (1) diversifying crop rotations can significantly affect selected soil health indicators at the end of the rotation-year compared with traditional rotation, and (2) wheat productivity among the DCRs will maintain stability or decrease slightly with lower fertilizer and irrigation input compared with the control.

2. Materials and Methods

2.1. Experiment Site

A new eight crop rotations experiment established in October 2015 at Wu Qiao Experiment Station (37°41′ N, 116°37′ E) of China Agricultural University, Hebei province, Northern China. The station is in warm, semi-humid and continental temperature monsoon zone, with an annual average temperature of 12.9 °C and an annual average rainfall of 562 mm, which concentrated during June to August and a 201 day frost-free period. The soil at the experiment site is classified as Calcaric Fluvisol [35] with a sandy clay loam texture. The baseline soil samples were collected in September 2016 for 0–20 cm depths, which include: soil bulk density (1.40 Mg/m^3), soil pH (8.13), soil organic carbon stock (13.49 Mg/ha), and soil total nitrogen stock (2.29 Mg/ha). Prior to the establishment of the study, the typical continuous double-cropping is winter wheat→summer maize (WM) with one-time conventional chisel plow tillage per year before winter wheat sowing.

2.2. Experiment Design

During 2016/2017–2017/2018 (Figure 1, Table 1), the control is winter wheat–summer maize→winter wheat–summer maize (WM→WM) and seven DCRs as follow: fallow→winter wheat–summer maize (F→WM), spring maize→winter wheat–summer maize (Ms→WM), winter wheat→winter wheat–summer maize (W→WM), sweet potato→winter wheat–summer maize (Psw→WM), spring peanut→winter wheat–summer maize (Pns→WM), winter wheat–summer peanut→winter wheat–summer maize (WPn→WM), potato–silage maize→winter wheat–summer maize (PMl→WM). The experiment includes wheat and maize planted in 2017/2018 (Table 1) and other crops mentioned above planted in 2016/2017 (Table 1) in three replications (n = 3) in 30 m^2 experiment plot size in a complete randomized block design. The growing crop and corresponding season of each year and different rotation, fertilizer and irrigation requirements for each crop in this study were summarized from October 2016 to October 2018 (Table 1). During the experiment, we used chisel plow tillage before the first crop sowing in that year. After crop harvest, crop residue is incorporated into the topsoil of each plot using chisel plow tillage except for silage maize, which is removed for livestock use.

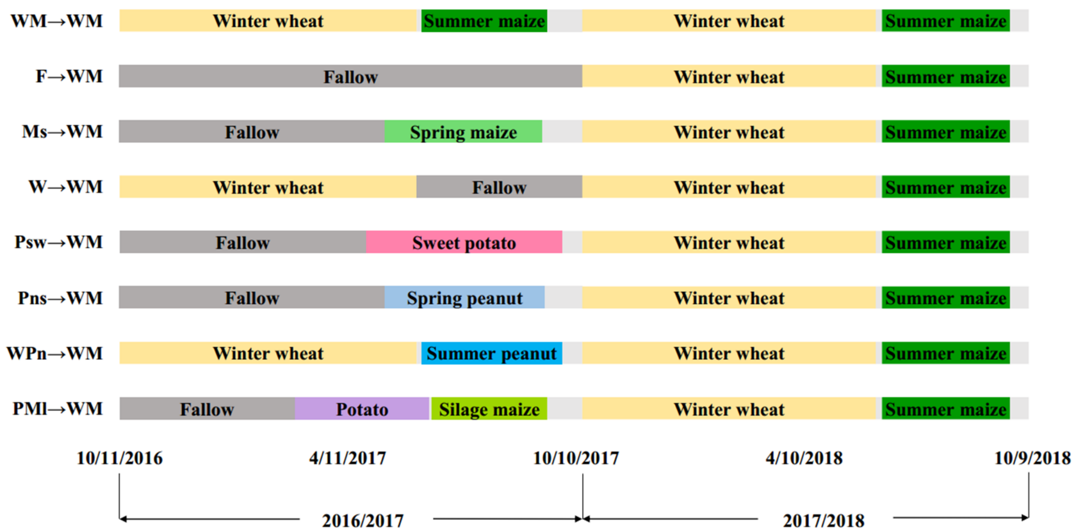

Figure 1. The timeline of the control (WM→WM, winter wheat–summer maize→winter wheat–summer maize) and seven diversified crop rotations in two years of this study.

Table 1. Fertilizer and irrigation applied to each crop of eight rotations in the first two-year the experiment.

Rotation	Growing Crop	Growing Season	Urea (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Irrigation (mm)
2016/2017 (October 2016–October 2017)						
WM→WM	winter wheat	October 2016–June 2017	225	112.5	225	225
	summer maize	June 2017–October 2017	180	103.5	112.5	75
F→WM	fallow	October 2016–October 2017	0	0	0	0
Ms→WM	spring maize	May 2017–October 2017	240	75	90	75
W→WM	winter wheat	October 2016–June 2017	225	112.5	225	225
Psw→WM	sweet potato	April 2017–October 2017	54	138	225	50
Pns→WM	spring peanut	May 2017–October 2017	172	172.5	150	75
WPn→WM	winter wheat	September 2016–June 2017	225	112.5	225	225
	summer peanut	June 2017–October 2017	172	172.5	150	75
PMl→WM	potato	February 2017–June 2017	180	120	300	155
	silage maize	June 2017–October 2017	180	103.5	112.5	75
2017/2018 (October 2017–October 2018)						
Eight Rotations	winter wheat	October 2017–June 2018	225	112.5	225	225
	summer maize	June 2018–October 2018	180	103.5	112.5	75

WM→WM, winter wheat–summer maize→winter wheat–summer maize; F→WM, fallow→winter wheat–summer maize; Ms→WM, spring maize→winter wheat–summer maize; W→WM, winter wheat→winter wheat–summer maize; Psw→WM, sweet potato→winter wheat–summer maize; Pns→WM, spring peanut→winter wheat–summer maize; WPn→WM, winter wheat–summer peanut→winter wheat–summer maize; PMl→WM, potato–silage maize→winter wheat–summer maize.

2.3. Soil Sampling and Measurements

Soil samples were collected from all crop rotations prior to harvest in September 2017. Additional soil samples were collected from all rotations in mid–June 2018 prior to the winter wheat harvest. Soil samples were collected using a metal ring for the top 0–20 cm soil depth. Soil gravimetric water content (GWC) was determined by weighing the wet and dry soil samples, which were oven-dried at 105 °C overnight [36]. Soil samples for bulk density (BD) were taken with a metal ring and weighed wet, then dried and weighed again to determine soil bulk density [37,38]. Soil pH was determined with an FE20-K pH meter (FiveEasy, Shanghai, China) by mixing 10 g of soil with 25 mL of water (China agricultural standard, NY/T 1377-2007). Soil organic carbon (SOC) concentration was measured by Schellenberger method and soil samples were treated with H_2SO_4 to remove inorganic C from soil [39]. Soil total N (TN) concentration was measured by the semi-micro Kjeldahl method [40] using automatic nitrogen analyzer (Foss Kjeldahl sampler 8400, Shanghai China). Soil available P (AP) concentration was measured by the Olsen method [41]. Soil organic carbon concentration was multiplied by depth (m) and soil bulk density (Mg/m^3) to be presented as soil organic carbon stocks (Mg/ha), and soil nitrogen concentration was multiplied by the same way to get soil nitrogen stocks (Mg/ha) [42]. Soil enzymatic activities such as sucrose and urease determined as soil biological indicators for soil health. Sucrase and urease activities determined by a modified method described by [42], and Ge et al. [43] to measure sucrase and urease activities in their research. Additionally, alkaline phosphatase activity was determined by using a method described by [44]. The same measurement was done by Liu et al. [45].

During five different wheat growth periods, which are: emerged, jointing, flowering, milky stage, and turning stage (152, 179, 194, 215, and 235 days after winter wheat emerged) of the growing season, samples of winter wheat were collected using a frame of 20 cm long by 15 cm wide of one row and taken to the laboratory for measurements. Then all the plant samples were dried at 65°C, then weighed for the total above-ground biomass dry weight [46]. Grain dry weight, spikes per plant, kernels per spike, and the weight of kernel were recorded at harvest time. Plants were hand-harvested by cutting them at ground level. Spikes and kernels were counted by hand, and grain was threshed with a single thresher. The kernels were dried and weighed with an electronic scale [47].

2.4. Data Analysis

The statistical analysis was done using the IBM SPSS.25. One-way analysis of variance (ANOVA) was employed to test the significance of mean differences (at p value of 0.05). A significant effect determined at $p < 0.05$ and means were separated using Duncan multiple–range procedure. The means of selected soil health indicators in 2016/2017 and 2017/2018 were analyzed using statistical analysis. The results summarized in Tables 2 and 3. Furthermore, in order to explore the effect of diversified crop rotations on soil health indicators, we calculated the rate of change of these indicators as compared to the control (WM→WM) in two years (Figure 2).

Table 2. Selected soil health indicators of eight rotations in the two years at 0–20 cm soil depth.

Indicators		Year	Rotation							
			WM→WM	**F→WM**	**Ms→WM**	**W→WM**	**Psw→WM**	**Pns→WM**	**WPn→WM**	**PMl→WM**
Physical	BD	2016/2017	1.38ab	1.40ab	1.39ab	1.38ab	1.42a	1.37ab	1.31b	1.35ab
		2017/2018	1.38a	1.43a	1.37a	1.41a	1.38a	1.36a	1.34a	1.36a
	GWC (%)	2016/2017	10.19bcd	10.82bc	13.02a	9.22cd	9.06cd	8.00d	8.13d	11.54ab
		2017/2018	8.14a	8.19a	6.85a	8.26a	8.14a	7.25a	6.93a	7.04a
Chemical	pH	2016/2017	8.48a	8.25b	8.29ab	8.29ab	8.32ab	8.39ab	8.34ab	8.47a
		2017/2018	8.17a	8.11a	8.16a	8.14a	8.25a	8.15a	8.16a	8.30a
	SOC (Mg/ha)	2016/2017	16.31a	16.62a	16.01ab	14.74ab	13.43b	16.65a	14.84ab	14.93ab
		2017/2018	15.55a	15.64a	15.91a	15.84a	16.35a	15.44a	14.92a	14.62a
	TN (Mg/ha)	2016/2017	2.10a	2.06ab	2.08ab	2.09a	1.71b	2.22a	2.07ab	2.04ab
		2017/2018	2.58ab	2.87a	2.53ab	2.61ab	2.72ab	2.64ab	2.60ab	2.46b
	AP (Mg/ha)	2016/2017	52.98a	50.15a	38.18ab	44.78ab	29.85b	54.97a	38.84ab	43.45ab
		2017/2018	33.03a	32.40a	26.01a	33.94a	37.60a	37.40a	34.73a	26.21a
Biological	SA (mg glucose g soil^{-1} d^{-1})	2016/2017	7.79a	6.28bc	7.42ab	7.50ab	5.58c	7.16ab	6.74abc	6.80abc
		2017/2018	8.21a	8.24a	8.74a	8.60a	8.17a	8.22a	7.46a	7.73a
	UA (mg NH_3-N g soil^{-1} d^{-1})	2016/2017	6.26ab	4.91c	5.33bc	6.04abc	5.70abc	6.48ab	6.61a	5.51abc
		2017/2018	5.73a	4.43a	4.82a	5.17a	6.27a	5.30a	5.41a	4.62a
	APA (mg phenol g soil^{-1} d^{-1})	2016/2017	0.15a	0.14a	0.14a	0.16a	0.13a	0.14a	0.12a	0.13a
		2017/2018	0.13a	0.12a	0.12a	0.13a	0.14a	0.13a	0.12a	0.13a

Values are means (n = 3). Values within a column followed by different lowercase letters are significantly different ($p < 0.05$). WM→WM, winter wheat–summer maize→winter wheat–summer maize; F→WM, fallow→winter wheat–summer maize; Ms→WM, spring maize→winter wheat–summer maize; W→WM, winter wheat→winter wheat–summer maize; Psw→WM, sweet potato→winter wheat–summer maize; Pns→WM, spring peanut→winter wheat–summer maize; WPn→WM, winter wheat–summer peanut→winter wheat–summer maize; PMl→WM, potato–silage maize→winter wheat–summer maize. *** BD, bulk density; GWC, soil gravimetric water content; SOC, soil organic carbon stocks; TN, total nitrogen stocks; AP, available phosphorus stocks; SA, surcease activity; UA, urease activity; APA, alkaline phosphatase activity.

Table 3. Eight rotations effect on yield components and grain yield of 2017/2018 winter wheat.

Rotation	Number of spikes (m^{-2})	Kernels per spike	1000-Kernel weight(g)	Grain Yield § (Mg ha^{-1})
WM→WM	682.2ab	28.18a	38.74d	7.79ab
F→WM	705.6ab	29.00a	42.12ab	7.54ab
Ms→WM	713.3ab	28.05a	40.80bcd	7.88ab
W→WM	627.8b	27.80a	39.48cd	7.24b
Psw→WM	821.1a	29.73a	43.39a	7.87ab
Pns→WM	765.6ab	28.03a	42.68ab	7.80ab
WPn→WM	806.7a	29.15a	41.23abc	7.73ab
PMl→WM	703.3ab	27.05a	41.24abc	8.04a

WM→WM, winter wheat–summer maize→winter wheat–summer maize; F→WM, fallow→winter wheat–summer maize; Ms→WM, spring maize→winter wheat–summer maize; W→WM, winter wheat→winter wheat–summer maize; Psw→WM, sweet potato→winter wheat–summer maize; Pns→WM, spring peanut→winter wheat–summer maize; WPn→WM, winter wheat–summer peanut→winter wheat–summer maize; PMl→WM, potato–silage maize→winter wheat–summer maize. § This represents actual harvest yield at the end of the season.

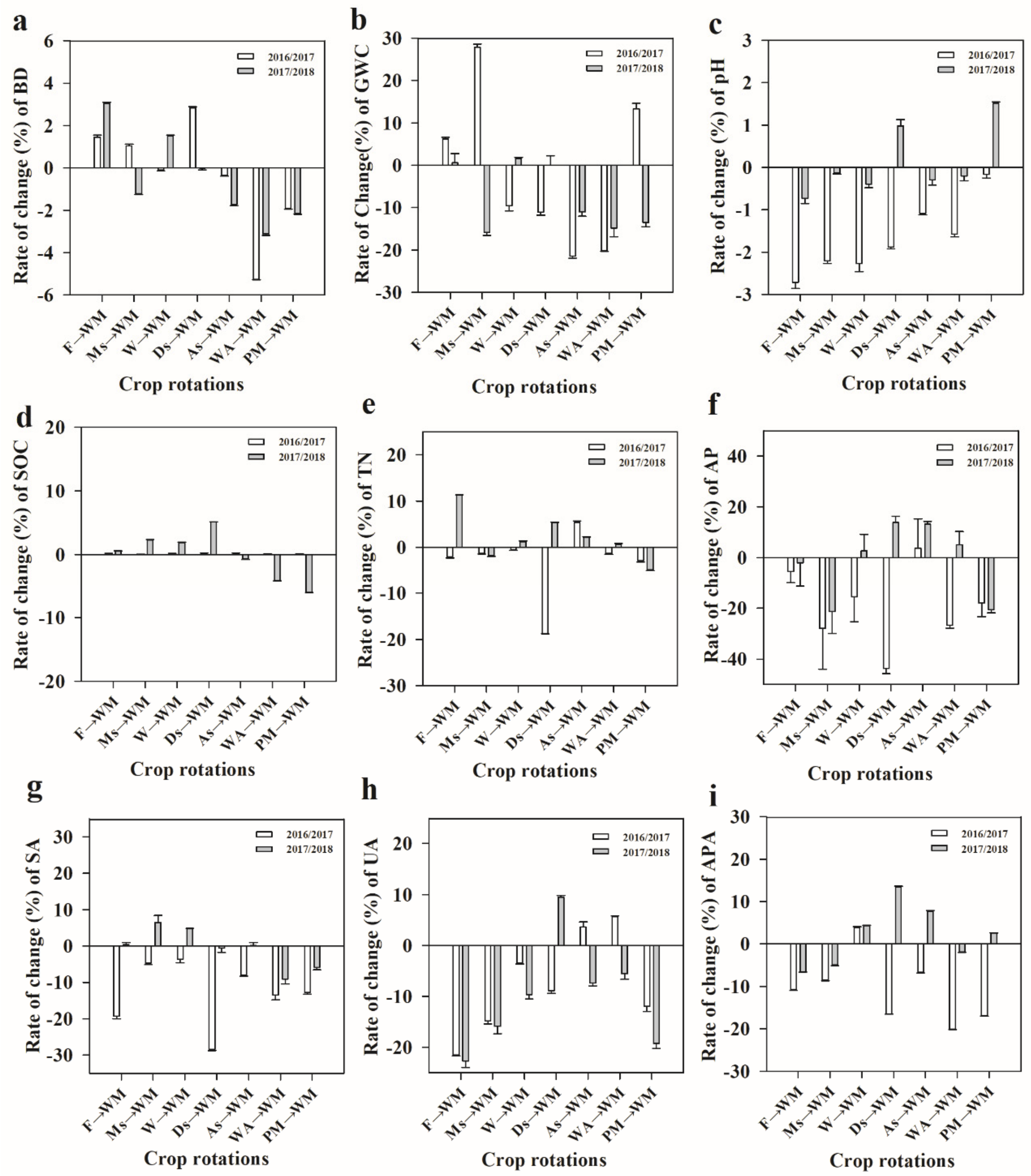

Figure 2. Rate of change of selected soil health indicators as influenced by different crop rotations compared with WM→W rotation as a baseline. WM→WM, winter wheat–summer maize→winter wheat–summer maize; F→WM, fallow→winter wheat–summer maize; Ms→WM, spring maize→winter wheat–summer maize; W→WM, winter wheat→winter wheat–summer maize; Psw→WM, sweet potato→winter wheat–summer maize; Pns→WM, spring peanut→winter wheat–summer maize; WPn→WM, winter wheat–summer peanut→winter wheat–summer maize; PMl→WM, potato–silage maize→winter wheat–summer maize. (**a**) BD, bulk density; (**b**) GWC, soil gravimetric water content; (**c**) pH, soil pH; (**d**) SOC, soil organic carbon stocks; (**e**) TN, total nitrogen stocks; (**f**) AP, available phosphorus stocks; (**g**) SA, surcease activity; (**h**) UA, urease activity; (**i**) APA, alkaline phosphatase activity.

3. Results

3.1. Soil Physical Properties

No significant effect of DCRs was observed on selected physical soil properties, BD and GWC, neither in 2016/2017 nor 2017/2018 with one exception. The only exception was Ms→WM rotation in the 2016/2017, in which GWC increased 27.8% than that in the control (WM→WM) (Table 2).

According to the analysis of the BD and GWC rate of change compared with that of the control in 2017/2018 (Figure 2a), the growth trend is limited. For example, Ms→WM, Pns→WM, WPn→WM, and PMl→WM rotations decreased soil bulk density by 1.2%, 1.7%, 3.1%, and 2.1%, respectively. The GWC in F→WM, W→WM, and Psw→WM rotations all increased by less than 2% compared to that in the control in 2017/2018 (8.1%) (Table 2 and Figure 2b).

3.2. Soil Chemical Properties

Diversified crop rotations had significant effects in 2016/2017, compared with the control on soil chemical indicators (Table 2). F→WM rotation (soil pH = 8.25) caused soil pH to decrease by 2.7% (Table 2). Among all seven DCRs, Psw→WM rotation was the only one had significantly lower soil SOC, TN, and AP in 2016/2017 compared with the control, with a rate of decline of 17.6%, 18.7%, and 43.7%, respectively (Table 2). However, no significant changes in the above indicators were observed in 2017/2018 (Figure 2) among seven DCRs.

All DCRs had a positive impact on one or more selected soil chemical indicators in 2017/2018, where F→WM, WF→WM, Psw→WM, and Pns→WM rotations had affected over half of the indicators. Soil pH of all seven DCRs decreased in 2016/2017 compared with the control (pH = 8.48) (Table 2 and Figure 2c). The following DCRs, Ms→WM and Psw→WM rotations had increased soil organic carbon by 2.3% and 5.1% compared with the control (15.55 Mg/ha). Moreover, soil TN was increased with F→WM, Psw→WM, Pns→WM rotations by 2.1–11.3% in 2018 (Figure 2f). In 2017/2018, AP increased by 2.8–13.9% among W→WM, Psw→WM, Pns→WM, and WPn→WM rotations compared with the control (Figure 2f).

3.3. Soil Biological Properties

In this study, most of the soil enzymes activities showed no significant change among all the rotations in two years with two exceptions in 2017/2018 (Table 2). The F→WM and Psw→WM rotations caused a significant decrease in SA in 2016/2017 by 19.3% and 28.4%, respectively, compared to the control (Table 2). In F→WM rotation, UA was 4.91 mg NH_3-N g soil^{-1} d^{-1} in 20116/2017, which was significantly lower than that in the control, 6.26 mg NH_3-N g soil^{-1} d^{-1} (Table 2).

Except for WPn→WM rotation, all other DCRs increased certain selected soil chemical indicators, soil pH, SOC, TN, and AP in 2017/2018, and W→WM, Psw→WM, and Pns→WM rotations had two out of three increases among SA, UA and APA. Although no significant change occurred in 2017/2018, Ms→WM and W→WM rotations increased SA by 6.5% and 4.8% over control (Figure 2g). UA decreased in most DCRs compared with the control (Figure 2i). In addition, W→WM, Psw→WM, Pns→WM, and PMl→WM rotations had greater APA than that in the control in 2018, with rate of increase: 4.3%, 13.5%, 7.7% and 2.6%, respectively.

3.4. Wheat Productivity

Diversified crop rotations showed no significant difference in the aboveground biomass production of winter wheat during different growth stages as compared to the control (Figure 3), while some significant differences observed in wheat yield parameters (Table 3). The control has the significantly lowest kernel weight, 38.74 g per 1000-kernel compared to the other seven rotations, which range from 39.48–43.39 g per 1000-kernel. In other words, it means enhancing crop species diversity has beneficial potential for wheat productivity (Table 3). There were no significant differences in the final winter wheat yield among the other rotations compared with the control (Table 3).

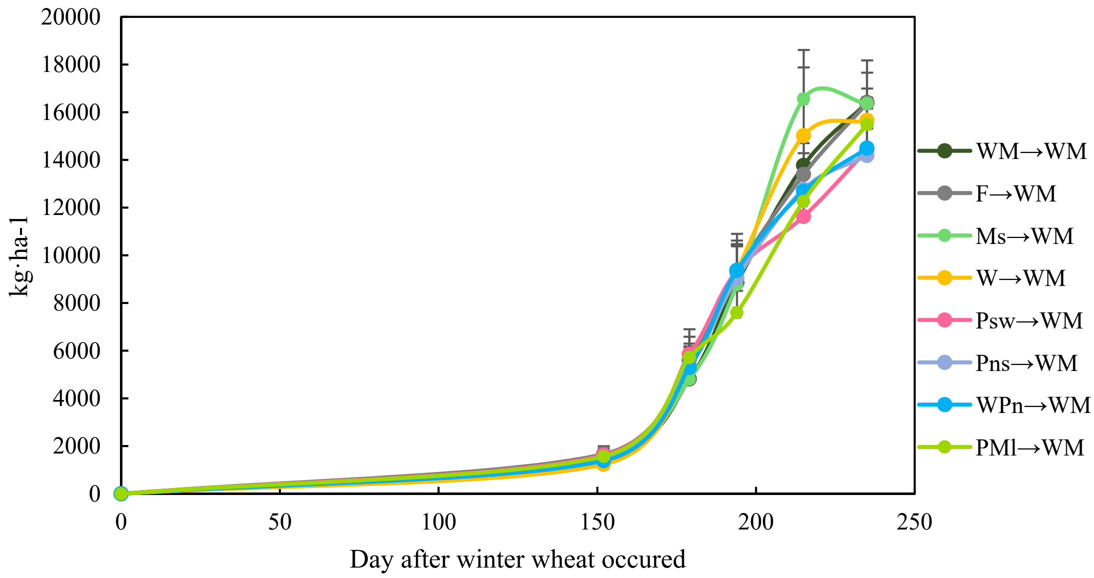

Figure 3. Aboveground biomass of 2017/2018 winter wheat growing season over time within each rotation. WM→WM, winter wheat–summer maize→winter wheat–summer maize; F→WM, fallow→winter wheat–summer maize; Ms→WM, spring maize→winter wheat–summer maize; W→WM, winter wheat→winter wheat–summer maize; Psw→WM, sweet potato→winter wheat–summer maize; Pns→WM, spring peanut→winter wheat–summer maize; WPn→WM, winter wheat–summer peanut→winter wheat–summer maize; PMl→WM, potato–silage maize→winter wheat–summer maize.

4. Discussion

4.1. Soil Health Indicators

Some significant changes in soil health indicators caused by crop rotations in 2016/2017 were observed at the end of that year. For instance, F→WM rotation significantly decreased soil pH by 2.7% compared to the control in the NCP, where lower soil pH is beneficial to crops in the NCP. The use of urea ($CO(NH_2)_2$) in this study shows no significant effect on soil pH [48,49]. In another research, it was found that soil pH of fallow–maize is lower than that of soybean–maize and cowpea–maize rotations [49]. Based on the analysis above, the use of the fallow system was beneficial in lowering soil pH in this study. In addition, Psw→WM rotation decreased SOC, TN, AP, and SA in this study in 2016/2017 as compared with the control in the short-term. In general, the soil SOC, TN, and AP under Psw→WM rotation were significantly lower than that in the control in 2017/2018. This can be attributed to the potential removal of considerable amount of nutrients from soil by sweet potato in the Psw→WM rotation [50]. However, the majority of these nutrients were returned into the soil after the sweet potato residues (leaves) were incorporated in the soil with plow tillage. This result concurs with the findings reported that returning crop straw increased soil total nitrogen and available phosphorus significantly at soil depth of 0–20 cm [20,51]. Therefore, it is reasonable to find that Psw→WM rotation had the significantly lower soil nutrients content and soil enzymes than the control.

Diversifying crop rotations had an effect on certain soil health indicators at the end of 2017/2018 compared with the traditional control, which is similar to other research results. More than half of the selected soil health indicators (physical, chemical or biological) were improved by the end of 2017/2018 under F→WM, W→WM, Psw→WM, and Pns→WM rotations in this study. For instance, F→WM, W→WM, and Psw→WM rotations showed higher SOC than that with the control in 2017/2018. Other studies documented that adding crop species improved the SOC [20,21]. Nonetheless, the SOC with PMl→WM rotation was always lower than that of the control. This may be attributed to maize biomass removal for animal feed instead of it returning it back to the field [31]. The DCRs showed a potential to decrease urease activity compared with the control. The TN with F→WM, W→WM, Psw→WM, Pns→WM, and WPn→WM rotations were higher than that in the control, WM rotation. Other studies documented similar findings with DCR [19].

4.2. Wheat Yield and Diversified Crop Rotation

Although the control had the lowest kernel weight than other DCRs, no significant wheat yield differences were observed among the seven DCRs as compared with the control. Based on this study's findings, our hypotheses regarding crop rotations effects in stabilizing wheat productivity with lower fertilizer and irrigation input of the seven DCRs as compared with control is supported by the findings of this study. However, other studies reported that diversifying crop rotations were beneficial in increasing the grain yield system productivity [15,16,18]. The potential reason is enhancing crop diversity has a potential benefit to improve wheat productivity that may occur in the long–term experiment. The compensation of cereals, i.e., to take advantage of favorable conditions throughout the crop life cycle, may form a particular balance among the yield components [52], which can lead to the significant different kernel weight, while being insignificant in the actual wheat yield in 2017/2018.

In this study, it has been demonstrated that there is a potential positive impact by DCR on selected soil health indicators and wheat productivity maintenance. These findings are similar to other studies, which show that DCRs are not only beneficial to soil health, but also to crop yield [33,52–54]. However, further definitive evidence was lacking due to the experiment being in the early stage of the long-term period. Long-term observations under DCR are needed to document in greater detail the long-term impact of such rotations on soil health indicators and crop productivity.

5. Conclusions

The findings of this study demonstrated the potential positive impact of DCR on selected soil health indicators and wheat productivity, by using different crop species included in different rotations in the NCP. Diversified crop rotations significantly affected certain soil health indicators at the end of the first year (2016/2017) compared with the control, especially, F→WM and Psw→WM rotations. The majority of the seven DCRs, especially Psw→WM and Pns→WM rotations, showed potential effect at the end of the second year (2017/2018) of the study as compared with the control. The DCRs showed an upward trajectory for improving soil health indicators, such as, GWC, BD, SOC, SA, UA and APA during the early years of establishment of this study. These indicators are essential to improve the main crop productivity such as wheat in the North China Plain, which is seriously short of water and has decreased soil fertilizer condition.

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