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Rotational Tillage: A Sustainable Management Technique for Wheat Production in the Semiarid Loess Plateau

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Abstract: Rotational tillage could be an advisable attempt to overcome some of the adverse impacts of mono conservation tillage, and it is necessary to assess the feasibility of adoption of rotational tillage for sustaining productivity in the long run. Data from an 8-year site-specific field study conducted on the Loess Plateau were used to estimate the long-term effect of rotational tillage on soil water dynamic, soil properties and winter wheat (*Triticum aestivum* L.) productivity. Three mono-tillage (No tilling (NT), subsoiling (ST) and ploughing (PT)) and three rotational tillage (NT/ST (NT and ST performed alternately), ST/PT, PT/NT) methods were applied after wheat harvest. Results showed the mean grain weight in the three rotational tillage treatments was 4.5% to 16.9% greater than in NT, and water use efficiency (WUE) was 5.0% to 18.8% greater over the 8 years. Rotational tillage could overcome the increased bulk density and nutrition stratification caused by NT and soil degradation due to PT. NT/ST was the best rotational tillage pattern with the highest grain yield and WUE, best soil property and relatively low mechanical cost in the present study. Here, we demonstrate that rotational tillage can improve wheat yield, WUE and soil properties compared with long-term no tilling and recommend using NT/ST as the optimal tillage pattern in similar ecological regions.

Keywords: subsoiling; no tillage; ploughing; yield; water use efficiency; soil property

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1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple crops worldwide, providing food for more than 40% of the world's population [1]. More food needs to be produced to meet the growing demand for food mainly caused by the increasing population. However, wheat production is strongly affected by climate change and land degradation [2]. With the increasing global food demand and decreasing availability of well-watered arable lands, the better use of existing agricultural land with a limited water supply in rain-fed area becomes more important in a future expected to be even drier [3,4]. To achieve this goal, on the one hand, improving the harvest, storage, retention and use of limited and unpredictable precipitation is necessary for high crop yields and resource use efficiency [5]. On the other hand, improving soil properties and preventing soil erosion and overuse of groundwater is appropriate for sustainable development and ecosystem services, especially in ecologically vulnerable zones such as Loess Plateau [6]. Wheat is the major food crop in Loess Plateau. Limited precipitation mainly occurs from July to September and is not synchronized with wheat growth (during the summer fallow). Almost no irrigation was applied in wheat due to the low economic benefit and high ecological cost. Thus, increasing precipitation use efficiency is the key for wheat yield improvement in this area. New technologies including mulching, ridging and conservation tillage systems have been developed to achieve this goal [7–9]. Among these technologies, conservation tillage has received increased attention over the last years due to its positive effects on resources use efficiency, economic and ecological benefits.

Conservation tillage represents the direct planting of crops with minimum soil disturbance, combined with crop residue retention and crop rotation, and holds much promise to help address global food security challenges with reduced external inputs and minimal environmental impacts [10,11]. Previous studies have reported that conservation tillage maintains soil and water, increases soil moisture content and improves soil fertility and crop yields, which are beneficial to the sustainable development of agricultural production in dryland [12–14]. However, long-term no tillage/minimum tillage probably results in soil compaction, shallow plough layers, the enrichment of nutrients and carbon near the soil surface, buildup of diseases, insect pests and herbicide-resistant weeds [15–17]. Thus, the same as ploughing, mono conservation tillage might be unable to support sustainable crop production in a long run, too.

It is possible to manage some of the specific issues emerging in conservation tillage systems and achieve goals of increasing WUE, reducing external inputs and environmental impacts, and improving soil porosity synchronously by the reasonable use of different tillage measures. Rotational tillage, which is constituted by different tillage measures, is a considerable method to overcome the defects of long-term mono-tillage practices.

The primary objective of this study was to evaluate the potential of rotational tillage as an alternative to contemporary conservation tillage for wheat production in semiarid areas. For this purpose, we conducted an 8-year site-specific field study and assessed soil moisture dynamics, soil properties, grain yields and WUE in response to various tillage measures. These results might help to optimize the selection of tillage measures for rain-fed wheat with an insufficient water supply, as well as elucidate the ecological mechanisms of soil productivity improvement.

2. Materials and Methods

2.1. Site Description

Long-term experiments with rotational conservation tillage were conducted at Ganjing Dryland Agricultural Experiment Station (35.33° N, 110.08° E, altitude 870 m) of Northwest A&F University in Heyang county, Shaanxi province, China, from 2007–2015. The research area is located in the Loess Plateau. The test field is dryland with no irrigation, and the cropping system is winter wheat with a summer fallow system.

The soil of the test field is Cumuli-Ustic Isohumosols (Chinese Soil Taxonomy), which contain 27% clay, 39% silt and 34% sand and has weak cohesion, good water storage capacity and negligible drainage below 2 m. The soil properties were measured at the beginning of the field experiments. The soil pH was 8.1 and contained 12.6 g kg^{-1} organic matter, 0.8 g kg^{-1} total N, 18.4 mg kg^{-1} available P and 210.6 mg kg^{-1} available K at the 0–40 cm tillage layer.

The mean annual rainfall during the experiment was 547.2 mm, and more than 60% of the rainfall occurred during the rainy season from July to September. The precipitation fluctuated widely between years, with a standard deviation of 93 mm. The 2009–2010 and 2013–2014 production season (from July to next June, including the fallow and nest wheat growth season) were dry with, precipitation of only 409 and 417 mm, respectively. However, 2007–2008 and 2011–2012 received precipitation of only 611 and 685 mm, respectively. The other production seasons were normal, with precipitation ranging from 551 to 591 mm.

2.2. Experimental Design

In this experiment, the winter wheat cultivars Jimai47 and Chang6359 were used for the 2007–2013 and 2014–2015 seasons, respectively, and were sown manually in 20 cm wide rows at a seeding rate of 225 seeds m^{-2} in late September each year and harvested on mid-June the following year. The experiment field was prepared in a randomized block design with 3 replicates. Plot size was 112.5 m^{2} (5 m wide by 22.5 m long). Prior to initiation of the experiment, the tillage system was conventional plow tillage with winter wheat for a long time. The experiment was conducted from 2007 to 2015 with six tillage pattern treatments, which were pairwise combined with no tillage (NT), subsoiling (ST) and ploughing (PT) after wheat harvest every year (Table 1).

Table 1. The soil tillage treatments in 2007–2015.

Tillage Treatments	Year							
	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015
NT	NT	NT	NT	NT	NT	NT	NT	NT
ST	ST	ST	ST	ST	ST	ST	ST	ST
PT	PT	PT	PT	PT	PT	PT	PT	PT
NT/ST	NT	ST	NT	ST	NT	ST	NT	ST
ST/PT	ST	PT	ST	PT	ST	PT	ST	PT
PT/NT	PT	NT	PT	NT	PT	NT	PT	NT

NT, ST and PT stand for no tillage, subsoiling and ploughing tillage, respectively. NT/ST stand for NT and ST performed alternately.

In the NT treatment, all the wheat straw residues after harvest were chopped, flattened and covered on the soil surface. The ST treatment was completed to a 35–40 cm depth, with an interval of a 40–60 cm width after wheat harvest with the deep loosening machine, and all the wheat straw residues returned and covered the soil. The PT involved complete soil inversion and burial of all the wheat straw residues to a depth of 22–25 cm. All the tillage patterns received 150 kg N ha^{-1}, 120 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1} before sowing, and herbicide was sprayed to control weeds within the summer fallow period and growing season of winter wheat.

2.3. Soil Water Storage

Soil samples were taking in 20 cm increments from 0 to 200 cm depth. Fresh weight of the soil samples was determined, and then these samples were oven dried at 105 °C for 8 h. Soil water content (SWC) was expressed as g water g^{-1} dried soil. Soil water storage (SWS) was calculated as SWC × soil profile depth × soil bulk density. Soil bulk density (BD) was determined by the ring cutting method in 0–60 cm layer with 20 cm intervals. The BDs of 60–200 cm depths were considered the same as for 40–60 cm layers due to the small variations for deep soils. The soil water profile is the variation of water content in the 0–2 m soil layer on spatial and temporal scales and is produced using the matrix contour plot function of Origin 2018.

2.4. Soil Properties

Soil samples at 0–60 cm were collected with 20 cm intervals after the wheat harvest in 2015. Soil bulk density was determined using the core method. Three samples were collected at random from each plot. Soil organic matter content was measured using the external heating potassium dichromate oxidation method ($K_2Cr_2O_7$-H_2SO_4) [18]. Total nitrogen (N) was measured using the Kjeldahl method [19] by a nitrogen/protein determinator. The wet sieving method of Elliott [20] was used to determine aggregate stability. Then, the soil was sieved through a sieve with mesh size of 2 mm. The macro aggregates proportion was water stable aggregates that were >2 mm.

2.5. Grain Yield and WUE

Wheat grain yield was valued at maturity each year. Three random rectangular areas covering 1 m^2 were sampled to measure wheat yield. Grain yield was calculated with 13% water content. Water use efficiency (WUE) for yields was defined as: WUE = yield/ET. ET is the evapotranspiration or water consumption over the whole growth season, and calculated as the equation [21]: ET = P + SW, where P is the amount of rainfall during the growth season (mm), and SW is the SWS change (mm) from sowing to maturity.

2.6. Statistical Analysis

Data were subjected to ANOVA to determine the difference between treatment means using IBM SPSS statistic package v.20.0 (SPSS Inc., Chicago, IL, USA). The differences between treatment means were considered significant by Fisher's protected LSD at the 0.05 level.

3. Results

3.1. Dynamics of Water Regime, Yield and WUE

Most of the precipitation was received during summer fallow, and the potential evaporation (as well as the supposed plant evaporation) was higher at later growth stages of wheat (Figure 1A). Thus, soil water storage at 0–200 cm depth progressively declined during the wheat growth period and then was restored during fallow. The various degrees of precipitation and evaporation among seasons led to drastic fluctuations in soil water storage. The soil water storage of NT treatment tended to be slightly higher than the other treatments (Figure 1A).

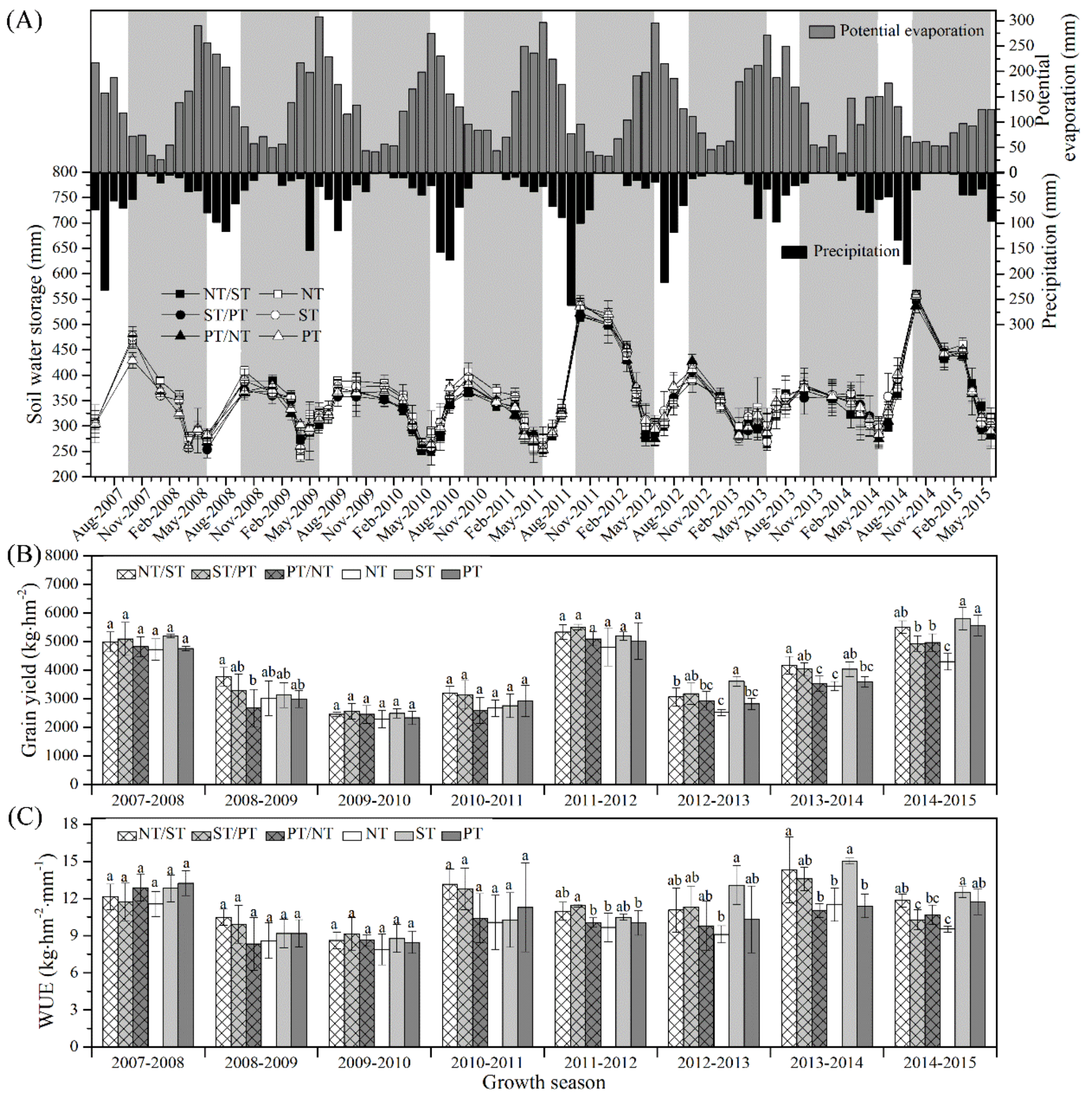

Figure 1. Soil water storage at 0–200 cm depth, precipitation and potential evaporation (**A**), wheat grain yield (**B**) and water use efficiency (**C**) from 2007 to 2015. The gray background in (**A**) represents the period of wheat growth. Different lowercase letters mean a significant difference at the 0.05 level among treatments.

The NT treatment tended to result in lower grain yields, and this became more pronounced as the duration of the experiment increased. Little differences in wheat grain yields among various tillage treatments were observed in the first five years. However, NT and PT/NT greatly decreased grain yields after five years. The highest yields were mostly obtained under treatments with subsoiling involvement, and its yield advantage compared with conventional tillage (PT) was more obvious in dry years (Figure 1B). The change in WUE was parallel with grain yields (Figure 1C). Grain yields also fluctuated with years, and the change roughly paralleled the soil water regime (Figure 1B).

3.2. Mean Grain Yield, Water Consumption and WUE

The mean grain yield and WUE across the eight seasons were significantly modified by tillage and year (Figure 2A,C). NT significantly decreased grain yields and WUE compared with other treatments. NT/ST, ST/PT and ST were beneficial to grain yields and WUE improvement. The highest mean grain yield and WUE both were achieved under NT/ST, which were 8.8% and 16.9%, and 8.3% and 8.1%, greater than NT and PT, respectively (Figure 2A,C). No remarkable effect of tillage on water consumption during the growth period was found (Figure 2B). There were likewise no significant interactions between the year and tillage on grain yields, water consumption and WUE (Figure 2).

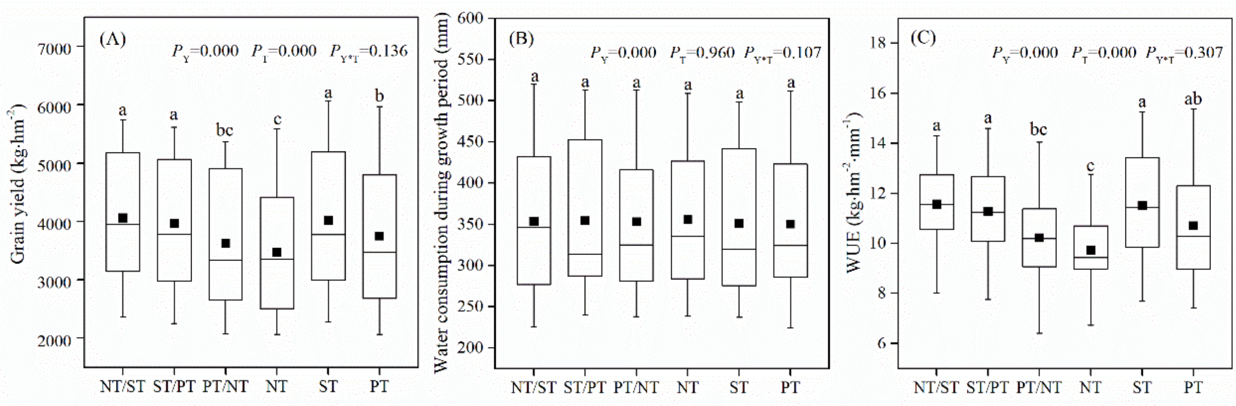

Figure 2. Wheat grain yield (**A**), water consumption during wheat growth period (**B**) and water use efficiency (WUE) (**C**) over eight seasons from 2007 to 2015. Different lowercase letters mean a significant difference at the 0.05 level among treatments.

3.3. Soil Water Retention

The mean SWS at the beginning of fallow across the 8 experimental years was 4.6% to 5.0% higher in NT than those in rotational tillage treatments. SWS at the end of fallow was 4.3% to 5.1% greater (Figure 3A,B), but no significant effects of tillage on the water storage rate during fallow were observed (Figure 3C). SWS and the water storage rate were more affected by the year than tillage (Figure 3).

3.4. Soil Water Profile

As shown in Figure 4, the variation of soil moisture spatially in the 0–2 m soil layer and on the 2010–2015 time scale constitutes the spatial-temporal profile of soil water. PT treatment tended to store more water in the 0–20 cm soil layer during the wet season, but water evaporation was also faster thereafter. ST treatments facilitated water infiltration and retention in the deep soil layer. NT was not conducive to soil water infiltration, but water evapotranspiration was also lower. Rotational tillage appeared to alleviate the deficiencies in soil water storage and use of each monoculture tillage practice.

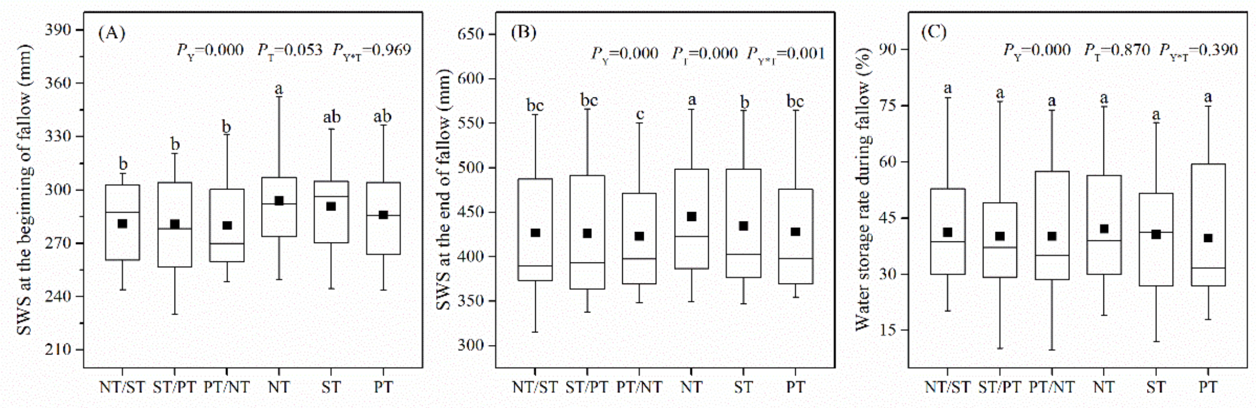

Figure 3. Soil water storage (SWS) at the beginning (**A**) and the end (**B**) of fallow, and the water storage rate during fallow (**C**) over eight seasons from 2007 to 2015. Different lowercase letters mean a significant difference at the 0.05 level among treatments.

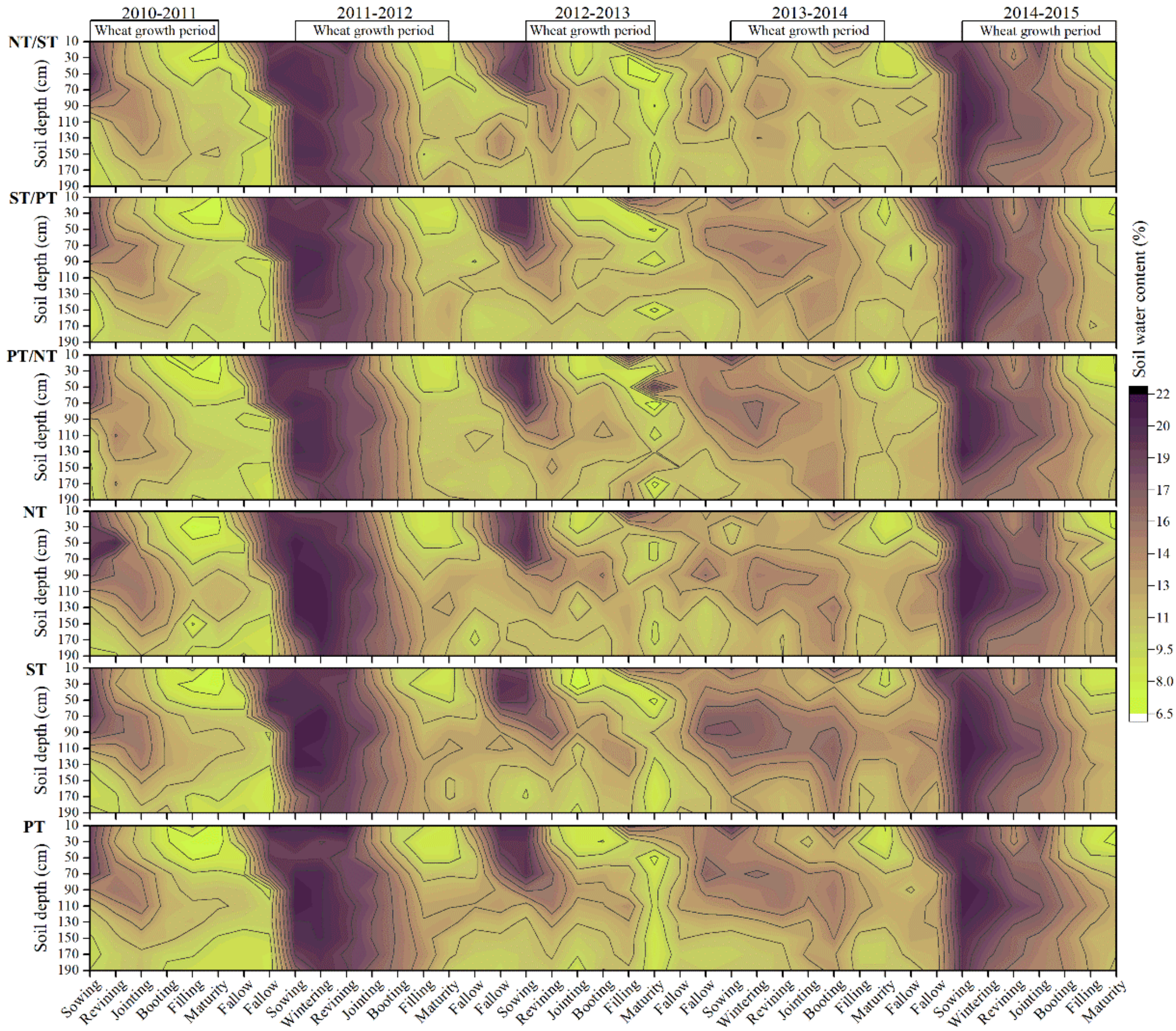

Figure 4. Soil water profile in 0–200 cm soil layer from 2010 to 2015.

Soil water content usually was less than 13% (about 50% of field capacity) during later growth periods even in the rainy season, especially in the 0–60 cm soil layer. The soil water deficit during later growth periods seemed be more severe in PT. Precipitation was hardly able to replenish soil moisture in depths >200 cm, expect in an extremely rainy season.

3.5. Soil Property

Soil properties at the 0–40 cm depth were significantly modified by 8-year tillage (Table 2). Rotational tillage, NT and ST tended to improve soil properties compared with PT, expect for the significantly increased bulk density observed in NT. The mean organic matter content across the 0–60 cm layer was 11.6%, 3.4%, 0.7%, 5.7% and 5.9% greater in NT/ST, ST/PT, PT/NT, NT and ST than that in PT, respectively, and the total N content was 12.9%, 3.6%, 9.3%, 6.2% and 7.2% greater. Organic matter and nitrogen content were reduced with the deeper soil layer. The difference between organic matter and nitrogen content in 0–20 cm and 20–40 cm was at its maximum in NT. The lowest bulk density was observed in PT. NT significantly increased the soil's bulk density, especially at 20–40 depth. PT led to a significantly decreased macroaggregates proportion, which was 2.1%, 1.1%, 0.6%, 1.2% and 0.9% less than that in NT/ST, ST/PT, PT/NT, NT and ST, respectively.

Table 2. Soil property after 8 years of tillage treatment at depths of 0–20 cm.

Soil Properties	**Depth (cm)**	**Tillage Treatments**					
		NT/ST	**ST/PT**	**PT/NT**	**NT**	**ST**	**PT**
Organic matter Content ($g\ kg^{-1}$)	0–20	16.9a	16.1ab	15.2b	16.1ab	16.0ab	15.2b
	20–40	10.6a	9.6b	10.3a	9.1b	10.6a	9.3b
	40–60	8.2ab	7.4bc	6.7c	8.8a	7.4bc	7.6bc
Total N content ($g\ kg^{-1}$)	0–20	0.9b	0.9c	0.9c	1.0a	0.8c	0.9c
	20–40	0.7a	0.6b	0.7a	0.5c	0.7a	0.6bc
	40–60	0.6a	0.5b	0.6b	0.5bc	0.6b	0.5c
Bulk density ($g\ cm^{-3}$)	0–20	1.4b	1.4b	1.4b	1.4a	1.4b	1.4b
	20–40	1.5ab	1.5ab	1.5b	1.6a	1.5ab	1.5b
	40–60	1.4a	1.5a	1.4a	1.5a	1.4a	1.4a
Macroaggregates proportion (%)	0–20	7.3a	6.0b	5.3bc	6.1b	5.8b	4.8c
	20–40	4.5a	3.7b	3.5b	4.0b	3.6b	2.8c
	40–60	-	-	-	-	-	-

Mean followed by the same letter within a year and a row are not significantly different according to LSD0.05. Macroaggregates proportion was water stable aggregates that were >2 mm.

3.6. Relationship between Soil Water Content and Precipitation with Yield

There was no significant correlation between grain yield with precipitation during fallow or during the whole grown season. (Figure 5A,B). While analyses of the relationship indicated a positive correlation between grain yields and soil water storage at sowing under all six tillage treatments (Figure 5C), simple linear regression analysis suggested grain yields increased linearly with the increased sum of soil water storage at sowing and precipitation during the growth period. In addition, the slope and intercept for NT were smaller than that for the other treatment (Figure 5D).

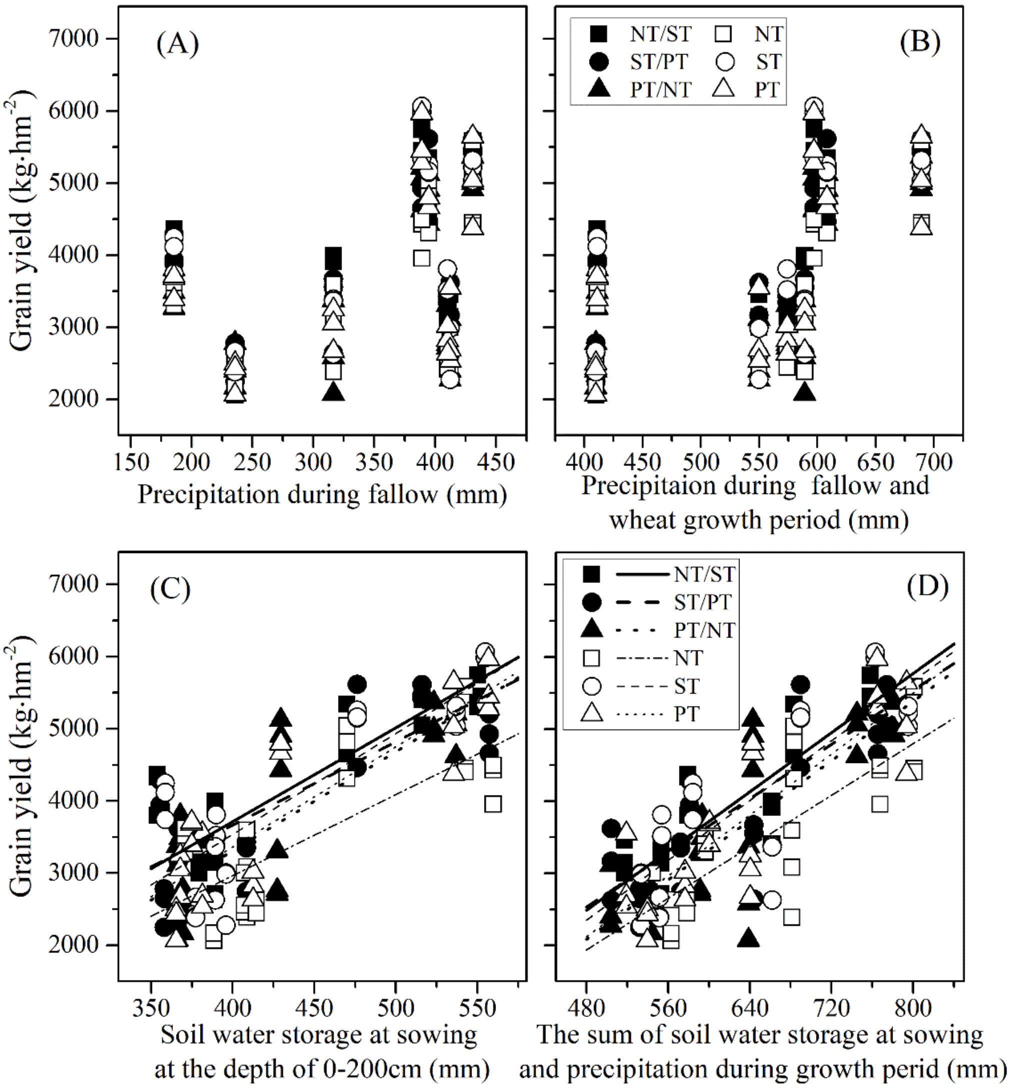

Figure 5. The relationship between wheat grain yield with precipitation during fallow (**A**), precipitation during the whole growth season (**B**), soil water storage at sowing (**C**) and the sum of water storage at sowing and precipitation during growth period (**D**).

4. Discussion

The main goal of this study was to explore the effect of rotational tillage on rain-fed wheat production and verify if it could manage some of the specific issues emerging in mono-tillage systems. Our data revealed changes in grain yield, water use efficiency, soil moisture reserves, soil nutrition and physical properties in response to different tillage management methods. These results partly confirm our hypothesis.

4.1. The Shortcomings of Mono-Tillage

No tillage, as one of the principles of conservation tillage, is viewed as a sustainable management method to improve water retention, soil property and productivity [22]. However, in the last few years, many studies found that the potential contribution of no tillage to the sustainable intensification of agriculture is more limited than is often assumed [12,15,23]. Similarly, in the present study, we found that the yield loss was significant under continuous no tillage (NT) compared with ploughing (CT) (Figure 2), despite the simultaneous application of straw cover. The soil moisture reserve was slightly improved by NT compared with the other tillage measures (Figure 3), but water consumption during the growth period was not affected, and WUE was decreased as the grain yield lowered

(Figure 2). Soil compaction and stratification of nutrients and carbon also were noted in NT (Table 2). These results demonstrated that the narrow advantage of soil water retention was unable to compensate for the adverse effects on soil properties under NT for wheat yields. Although the machinery input is the minimum in NT farming systems, a build-up of diseases, pests and herbicide-resistant weeds led to more chemical inputs and related environmental and health concerns [15]. Ploughing and subsoiling both can ameliorate soil's functional physical properties and be conducive to weed control [24–26]. In this research, wheat grain yields and WUE were higher in PT and ST than those in NT, being more pronounced in ST (Figure 2). This is probably related to the lower bulk density and the notably decreased macroaggregates proportion in PT, which is adverse for soil water and nutrient retention. Nevertheless, excessive soil disturbance and machinery input cannot adapt to sustainable crop production.

4.2. The Effects of Rotational Tillage on Yield and Soil Workability

Less aggressive tillage practices, such as reduced tillage [27], strategic or occasional tillage [15,28–30] and rotational tillage [31], have been developed around the world to solve the above problems without losing the advantages of conservation agriculture. Our data showed that rotational tillage (NT/ST, ST/PT) significantly increased wheat grain yields and WUE compared with NT and PT (Figure 2). NT/ST could increase organic matter content, total nitrogen content and the macroaggregates proportion compared with PT and overcome soil compaction that is caused by no tillage (Table 2). What is more, machinery inputs were well controlled with increased yields, WUE and soil properties. Reduced tillage or occasional strategic tillage in no tillage farming systems have been used as a means to manage difficulties in soil workability have received more attention in recent years [17,23,28,32], and the machinery input was obviously less than rotational tillage in the present study as the lower tillage frequency. However, the impact of contrasting soil properties, the timing of tillage and the prevailing climate exert a strong influence on the success of reduced tillage or occasional strategic tillage [15]. "*It's difficult for smallholder to adapt the implementation and frequency of tillage. Additionally, inverting and tillage of soil previously under long-term no-tillage has little and/or short-lasting effect on soil composition and functional physical properties*" [33]. In order to further decrease external inputs and soil disturbance with considerable agricultural outcomes, it is worth it to explore more rotational tillage schemes, such as NT/NT/ST or lower but fixed tillage frequencies incorporated into no tillage [34].

4.3. The Relationship between Water Regime Variation and Grain Yields

Water deficits are the main limitation to wheat production in semi-arid areas. As most precipitation was accepted during the fallow, previous studies suggested the precipitation during fallow could be a good producer for wheat grain yields [35,36]. However, we found there was no significant relationship between wheat grain yields and precipitation (Figure 5). "*Increasing water infiltration into the soil profile to increase plant available soil water storage is paramount to grains production in semi-arid regions where crop production depends more on stored soil water than in-season rainfall*" [15]. Grain yields were increased linearly with increased soil water storage at sowing in our study (Figure 5), which was affected by not only the amount but also the distribution of precipitation during the fallow. Precipitation that occurred later in the fallow was more efficient for soil water reserves, due to the high potential evaporation during the fallow (Figure 1). There was no significant effect of the tillage pattern on water infiltration (Figure 4). As soil water storage measurement is not accessible for smallholders, the estimation of the relationship between soil water with precipitation and potential evaporation will be more useful for wheat grain yield forecasting adaptation.

4.4. The Influence of Tillage on Crop Production under Varied Rainfall Conditions

Many previous studies have evaluated the impacts of tillage on rain-fed crop production based on various rainfall conditions, such as it being a dry, wet or normal year [7,24,31]. In this research, the year or rainfall conditions had a much greater effect on grain yields, WUE and soil water content than tillage treatment (Figures 2 and 3). However, there was almost no interaction between the year and tillage on wheat production and soil water dynamics, except for soil water storage at the end of fallow (Figures 2 and 3). Further analysis found that the difference in soil water storage at the end of fallow between various tillage techniques was greater in dry years than that in normal and wet year (Figure 1). In addition, the advantage in water retention of NT was more obvious in dry years. The same result also has been found in many previous studies [23,24], but its positive effect on grain yields was limited in the present study (Figure 2).

5. Conclusions

In this work, we have evaluated the effects of rotational tillage on wheat production, water retention and soil properties in the long run under rain-fed conditions in semiarid areas. Treatments with subsoiling involvement could increase rain-fed wheat yields and WUE compared with NT and PT in the long run. NT could increase soil water retention, but at the cost of reduced yields and WUE. Compacted soil structure and nutrition enriching in the top soil layer caused by NT and soil degradation caused by PT could be overcome by rotational tillage, and the NT/ST treatment has the best soil improvement effect. Mono-tillage measures of subsoiling did not cause obvious adverse effects on soil quality, but its soil improvement effect was not as good as rotational tillage with subsoiling involvement. In conclusion, the adoption of rotational tillage could manage the constraints emerging in mono-tillage systems without losing the advantages of conservation tillage, and is a potential alternation to no tillage to support the sustainable development of conservation agriculture. It is agreed that the effects of rotational tillage on wheat yields and soil properties may be site-dependent and determined by the specific conditions. Additional work is required to investigate crop rotation, soil type and the interaction in rotational tillage systems under different precipitation areas; machinery and labor inputs and greenhouse gas emissions should also be considered, thus helping to reveal the physiological and ecological mechanisms for productivity improvements and ecosystem services.

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References

1. Miransari, M.; Smith, D. Sustainable wheat (*Triticum aestivum* L.) production in saline fields: A review. *Crit. Rev. Biotechnol.* **2019**, *39*, 999–1014. [CrossRef] [PubMed]
2. Lobell, D.B.; Schlenker, W.; Costa-Roberts, J. Climate Trends and Global Crop Production Since 1980. *Science* **2011**, *333*, 616–620. [CrossRef] [PubMed]
3. Haddad, N.; Oweis, T.; Bishaw, Z.; Rischkowsky, B.; Hassan, A.A.; Grando, S. The potential of small-scale rainfed agriculture to strengthen food security in Arab countries. *Food Secur.* **2011**, *3*, 163–173. [CrossRef]
4. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20260–20264. [CrossRef] [PubMed]

5. Medrano, H.; Tomas, M.; Martorell, S.; Escalona, J.-M.; Pou, A.; Fuentes, S.; Flexas, J.; Bota, J. Improving water use efficiency of vineyards in semi-arid regions. A review. *Agron. Sustain. Dev.* **2015**, *35*, 499–517. [CrossRef]
6. Li, Z.; Liu, W.-z.; Zhang, X.-c.; Zheng, F.-l. Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *J. Hydrol.* **2009**, *377*, 35–42. [CrossRef]
7. Su, L.; Wang, S.; Zhang, Y.; Li, J.; Wang, X.; Wang, R.; Lyu, W.; Chen, N.; Wang, Q. Conservation agriculture based on crop rotation and tillage in the semi-arid Loess Plateau, China: Effects on crop yield and soil water use. *Agric. Ecosyst. Environ.* **2018**, *251*, 67–77.
8. He, G.; Wang, Z.; Li, F.; Dai, J.; Li, Q.; Xue, C.; Cao, H.; Wang, S.; Malhi, S.S. Soil water storage and winter wheat productivity affected by soil surface management and precipitation in dryland of the Loess Plateau, China. *Agric. Water Manag.* **2016**, *171*, 1–9. [CrossRef]
9. Gan, Y.T.; Siddique, K.H.M.; Turner, N.C.; Li, X.G.; Niu, J.Y.; Yang, C.; Liu, L.P.; Chai, Q. Ridge-Furrow Mulching Systems-An Innovative Technique for Boosting Crop Productivity in Semiarid Rain-Fed Environments. *Adv. Agron.* **2013**, *118*, 429–476.
10. Derpsch, R.; Franzluebbers, A.J.; Duiker, S.W.; Reicosky, D.C.; Koeller, K.; Friedrich, T.; Sturny, W.G.; Sa, J.C.M.; Weiss, K. Why do we need to standardize no-tillage research? *Soil Tillage Res.* **2014**, *137*, 16–22. [CrossRef]
11. Araya, T.; Nyssen, J.; Govaerts, B.; Deckers, J.; Sommer, R.; Bauer, H.; Gebrehiwot, K.; Cornelis, W.M. Seven years resource-conserving agriculture effect on soil quality and crop productivity in the Ethiopian drylands. *Soil Tillage Res.* **2016**, *163*, 99–109. [CrossRef]
12. Rusinamhodzi, L.; Corbeels, M.; van Wijk, M.T.; Rufino, M.C.; Nyamangara, J.; Giller, K.E. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agron. Sustain. Dev.* **2011**, *31*, 657–673. [CrossRef]
13. Wang, X.B.; Cai, D.X.; Hoogmoed, W.B.; Oenema, O.; Perdok, U.D. Developments in conservation tillage in rainfed regions of North China. *Soil Tillage Res.* **2007**, *93*, 239–250. [CrossRef]
14. Thierfelder, C.; Matemba-Mutasa, R.; Rusinamhodzi, L. Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in Southern Africa. *Soil Tillage Res.* **2015**, *146*, 230–242. [CrossRef]
15. Dang, Y.P.; Moody, P.W.; Bell, M.J.; Seymour, N.P.; Dalal, R.C.; Freebairn, D.M.; Walker, S.R. Strategic tillage in no-till farming systems in Australia's northern grains-growing regions: II. Implications for agronomy, soil and environment. *Soil Tillage Res.* **2015**, *152*, 115–123. [CrossRef]
16. Nichols, V.; Verhulst, N.; Cox, R.; Govaerts, B. Weed dynamics and conservation agriculture principles: A review. *Field Crops Res.* **2015**, *183*, 56–68. [CrossRef]
17. Soane, B.D.; Ball, B.C.; Arvidsson, J.; Basch, G.; Moreno, F.; Roger-Estrade, J. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil Tillage Res.* **2012**, *118*, 66–87. [CrossRef]
18. Bao, S. *Soil Agrochemical Analysis*; China Agriculture Press: Beijing, China, 2000.
19. Parkinson, J.A.; Allen, S.E. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. *Commun. Soil Sci. Plant Anal.* **1975**, *6*, 1–11. [CrossRef]
20. Elliott, E.T. Aggregate Structure and Carbon, Nitrogen, and Phosphorus in Native and Cultivated Soils1. *Soil Sci. Soc. Am. J.* **1986**, *50*, 627–633. [CrossRef]
21. Sun, M.; Ren, A.X.; Gao, Z.Q.; Wang, P.R.; Mo, F.; Xue, L.Z.; Lei, M.M. Long-term evaluation of tillage methods in fallow season for soil water storage, wheat yield and water use efficiency in semiarid southeast of the Loess Plateau. *Field Crops Res.* **2018**, *218*, 24–32. [CrossRef]
22. Somasundaram, J.; Reeves, S.; Wang, W.; Heenan, M.; Dalal, R. Impact of 47 years of No-tillage and stubble retention on soil aggregation and Carbon distribution in a Vertisol: Impact of No till, stubble retention on soil aggregation and Carbon. *Land Degrad. Dev.* **2017**, *28*, 1589–1602. [CrossRef]
23. Pittelkow, C.M.; Liang, X.; Linquist, B.A.; van Groenigen, K.J.; Lee, J.; Lundy, M.E.; van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **2015**, *517*, 365–368. [CrossRef] [PubMed]
24. Bogunovic, I.; Pereira, P.; Kisic, I.; Sajko, K.; Sraka, M. Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). *Catena* **2018**, *160*, 376–384. [CrossRef]
25. Pires, L.F.; Borges, J.A.R.; Rosa, J.A.; Cooper, M.; Heck, R.J.; Passoni, S.; Roque, W.L. Soil structure changes induced by tillage systems. *Soil Tillage Res.* **2017**, *165*, 66–79. [CrossRef]
26. Renton, M.; Flower, K.C. Occasional mouldboard ploughing slows evolution of resistance and reduces long-term weed populations in no-till systems. *Agric. Syst.* **2015**, *139*, 66–75. [CrossRef]
27. Lopez-Garrido, R.; Madejon, E.; Leon-Camacho, M.; Giron, I.; Moreno, F.; Murillo, J.M. Reduced tillage as an alternative to no-tillage under Mediterranean conditions: A case study. *Soil Tillage Res.* **2014**, *140*, 40–47. [CrossRef]
28. Celik, I.; Gunal, H.; Acar, M.; Acir, N.; Barut, Z.B.; Budak, M. Strategic tillage may sustain the benefits of long-term no-till in a Vertisol under Mediterranean climate. *Soil Tillage Res.* **2019**, *185*, 17–28. [CrossRef]
29. Quincke, J.A.; Wortmann, C.S.; Mamo, M.; Franti, T.; Drijber, R.A. Occasional tillage of no-till systems: Carbon dioxide flux and changes in total and labile soil organic carbon. *Agron. J.* **2007**, *99*, 1158–1168. [CrossRef]
30. Stavi, I.; Lal, R.; Owens, L.B. On-farm effects of no-till versus occasional tillage on soil quality and crop yields in eastern Ohio. *Agron. Sustain. Dev.* **2011**, *31*, 475–482. [CrossRef]

31. Wang, S.L.; Wang, H.; Zhang, Y.H.; Wang, R.; Zhang, Y.J.; Xu, Z.G.; Jia, G.C.; Wang, X.L.; Li, J. The influence of rotational tillage on soil water storage, water use efficiency and maize yield in semi-arid areas under varied rainfall conditions. *Agric. Water Manag.* **2018**, *203*, 376–384. [CrossRef]
32. Brouder, S.M.; Gomez-Macpherson, H. The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. *Agric. Ecosyst. Environ.* **2014**, *187*, 11–32. [CrossRef]
33. Reichert, J.M.; Brandt, A.A.; Rodrigues, M.F.; da Veiga, M.; Reinert, D.J. Is chiseling or inverting tillage required to improve mechanical and hydraulic properties of sandy clay loam soil under long-term no-tillage? *Geoderma* **2017**, *301*, 72–79. [CrossRef]
34. Zhang, Y.; Wang, R.; Wang, S.; Wang, H.; Xu, Z.; Jia, G.; Wang, X.; Li, J. Effects of different sub-soiling frequencies incorporated into no-tillage systems on soil properties and crop yield in dryland wheat-maize rotation system. *Field Crops Res.* **2017**, *209*, 151–158. [CrossRef]
35. Hu, Y.; Hao, M.; Wei, X.; Chen, X.; Zhao, J. Contribution of fertilisation, precipitation, and variety to grain yield in winter wheat on the semiarid Loess Plateau of China. *Acta Agric. Scand. Sect. B—Soil Plant Sci.* **2016**, *66*, 406–416. [CrossRef]
36. Wang, E.; McIntosh, P.; Jiang, Q.; Xu, J. Quantifying the value of historical climate knowledge and climate forecasts using agricultural systems modelling. *Clim. Chang.* **2009**, *96*, 45–61. [CrossRef]