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Research Article

Effects of Different Tillage Measures on Soil Temperature and Humidity and Photosynthetic Capacity of Soybean

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In this study, we investigated the effects of different tillage measures on soil environment and soybean yield. We chose a combination of eight tillage treatments using Heihe 43 as the test variety in order to correlate the yield with tillage practices. Our study design involved tilling and rototilling as primary treatments in combination with the following secondary treatment methods: advance deep loosening, advance cultivation, conventional deep loosening, and conventional cultivation. We investigated the effects of the above tillage treatments on soil physicochemical properties and soil biological activity. We also analyzed how tillage treatments impacted the morphology, photosynthetic characteristics, and yield of soybean. Our results indicated that tilling was more beneficial than rototilling in terms of increase in soil water content; the water content at the seedling stage increased from 5.80% to 17.13% in the 0–5 cm soil layer which was subjected to tilling. Under tilling conditions, the Pn, Tr, and Gs values of soybean plants were higher compared to those of soybean cultivated in soil subjected to rototilling. However, Ci values of soybean were higher in rototilled soil. In 2018, we observed an increase in the number of pods and grains per plant in PT1 and PT2 of tilling compared to that of RT1 and RT2 of rototilling. PT1 and PT2 showed a percentage increase of 9.12% and 7.33%, respectively. T1 and T2 both increased the number of pods and grains per plant of soybean under the same tillage conditions, which in turn increased the yield.

1. Introduction

Drought is one of the major factors limiting the sustainable development of agriculture. Improvement of proper utilization of water resources is an important research topic in the country and the world over. Water is an integral part of the soil; soil is the source of life for crops as well as an indispensable part of the natural water cycle. The content and spatial distribution characteristics of water in the soil influence soil erosion as well as the hydrological cycle, which in turn affects agricultural fields and the growth of crops.

With the occurrence of extreme weather in recent years, water shortage in China has aggravated. Soil water content is one of the most important indicators utilized in irrigation technology. There is therefore considerable emphasis on research in agricultural irrigation technology as well as water conservation technology in China. With respect to crop cultivation, soil water content is influenced by the types of tillage practices, which in turn affect agricultural productivity [1, 2]. No-till farming can provide sufficient water for crop growth by reducing water loss from surface evaporation and runoff, thereby maintaining the soil surface water content. However, timely tillage is critical for dryland areas in northern China. Intercropping regulates soil moisture during the initial stages of crop growth. Changes in soil moisture directly affect the chemical and physical properties of the soil; this is regulated by temperature and promotes fertility of the soil, which in turn affects the growth and yield of plants.

Soil temperature is one of the important ecological factors affecting crop growth; it directly influences moisture content and air in the soil and significantly affects root function and photosynthesis in leaves of crops [3, 4]. Optimal temperatures facilitate the growth and development of crops. Soil temperature is influenced by a host of factors such as atmospheric temperature, near-surface spatial thermobalance characteristics, soil water holding status, and solar radiation [5, 6]. Tillage practices affect the soil heat capacity and thermal conductivity by altering the organic matter, bulking, agglomerate contact, and water content, further affecting thermal diffusivity, all of which influence soil temperature. With conventional tillage, soil temperature is unstable because the land is bare. Under solar radiation, the soil surface temperature rises sharply, which accelerates the evaporation of water, eventually affecting the growth and development of crops. Guo et al. [7] believe that tillage increases the surface area of contact between the soil and the atmosphere and that tillage has better insulation properties than no-till; Chen et al. [8] indicated that crop residues on the soil surface in conservation tillage systems can reduce the rate of change in soil temperature. This is attributed to the residues on the soil surface which increase the reflectance of solar radiation and insulate the soil surface from the warmer (or colder) atmosphere. The residues provide a stable temperature by preventing the soil from becoming too hot or too cold. In contrast, however, Zhang et al. [9] observed that soil temperatures are lower in the no-till straw mulch layer. The higher water retention capacity and increased heat capacity of no-till soils are not conducive to early spring temperatures and hence hinder crop root development. Therefore, a moderate reduction in the amount of plant residue on the ground may increase the soil temperature in conservation tillage. Zhang et al. [9] pointed out that deep loosening tillage helps mitigate the adverse effects of low temperatures on seedling stage crops, optimizes the soil hydrothermal environment, and stabilizes soil temperature [10].

The effects of tillage measures combined with other techniques on soil environment and crop yield have been widely reported by domestic and foreign researchers. In particular, there was a lot of research on soil microorganism, soil enzyme activity, soil physical and chemical properties in conservation tillage measures, and soil protection. However, there are few researches on the intertillage mode after traditional tillage combined with sowing.

The present study focused on the effects of different tillage methods combining intercropping measures on soybean yield and soil environment by setting up two tillage methods (tilling and rototilling) with additional deep loosening and/or soil lifting. We undertook this study in order to understand the following: (1) the effect of different tillage measures on soil temperature and humidity, (2) the effect of the same tillage method and different intercropping methods on photosynthetic index and yield of soybean, and (3) tillage and intercropping measures suitable for the area based on the effect of different tillage measures on soil temperature and humidity and on soybean yield.

We studied the influence of soil environment and the yield of soybean on field preparation method combined with an intertillage method, to investigate the effects of tillage methods on the physical and chemical properties of soil, photosynthetic parameters, morphology, and yield of soybean. The purpose is to seek out the best combination of soil preparation and cultivating way. It provides important theoretical basis and technical support for soybean energy saving and efficient production.

2. Materials and Methods

2.1. Site Location and Characteristics. The experiment was carried out in Heshan Farm, Heihe City, Heilongjiang Province (48°43′N-49°03′N, 124°56′E-126°21′E). The area is continental monsoon climate zone and rainfall concentrated in the summer; the local rainfall of 2017-2019 is shown in Figure 1. The annual effective accumulative temperature is from 2000 to 2300°C, the annual average temperature is ≥10°C, and the period of frost-free is 115-120 days. The soil of plots is black soil, and the physical and chemical properties of black soil are shown in Table 1.

2.2. Field Experiment. The experiment was conducted in the 2017-2019; adopt split plot experiment design. The main treatment is the farming methods; set the tilling (P) and rotary tillage (R). The four different cultivating measures was set under the two farming methods. The cultivating measures were designed by different deep scarification and earthing up time, different deep scarification and earthing up number, and different depths of deep scarification. As given in Table 2, we designed a total of 8 treatments. In soil treatment, three times of earthing inter-tillage are set as contrast (CK), and it was a common mode in rural areas. In large ridging, the width of the cultivator earthing knife is 110~120°. In midridging, the width of the cultivator earthing knife is 80-90°. In small ridging, the width of the cultivator earthing knife is 20-30°.

Soybean variety is Heihe 43 as the main product soybean variety. Each experimental plot was 468 m^2, the width of row was 65 cm, with 8 rows in each area, repeated 3 times, and the harvest time occurred on September 28, 2018 and October 1, 2019. The corn was the preceding crop, and the fertilization level was consistent with the local fertilization amount. There were 54 kg·hm^{-2} of pure nitrogen fertilizer, 67.5 kg·hm^{-2} of pure P_2O_5, and 30 kg·hm^{-2} of pure K_2O.

2.3. Capacitive-Based Soil Indicator Determination. In soil volumetric moisture content and temperature measurement, the volumetric water content of the soil was monitored by the temperature and humidity meter (model: NZ99-TWS-3) of Nanjing Nengzhao Technology Co., Ltd. The instrument was placed on the fourth row of each treatment, and the probe was inserted into 5.15 and 25 cm layers, respectively. The temperature and water content of the soil were monitored in real time and recorded hourly. The 1-day average temperature and water content of soil in each treatment layer were analyzed by selecting the average data of continuous 7 days after soybean entered the seedling stage, pod setting stage, and maturity stage.

2.4. Photosynthesis Index Determination. The chlorophyll content was measured with SPAD-502 chlorophyll meter, and three blade leaves were selected for measurement. The

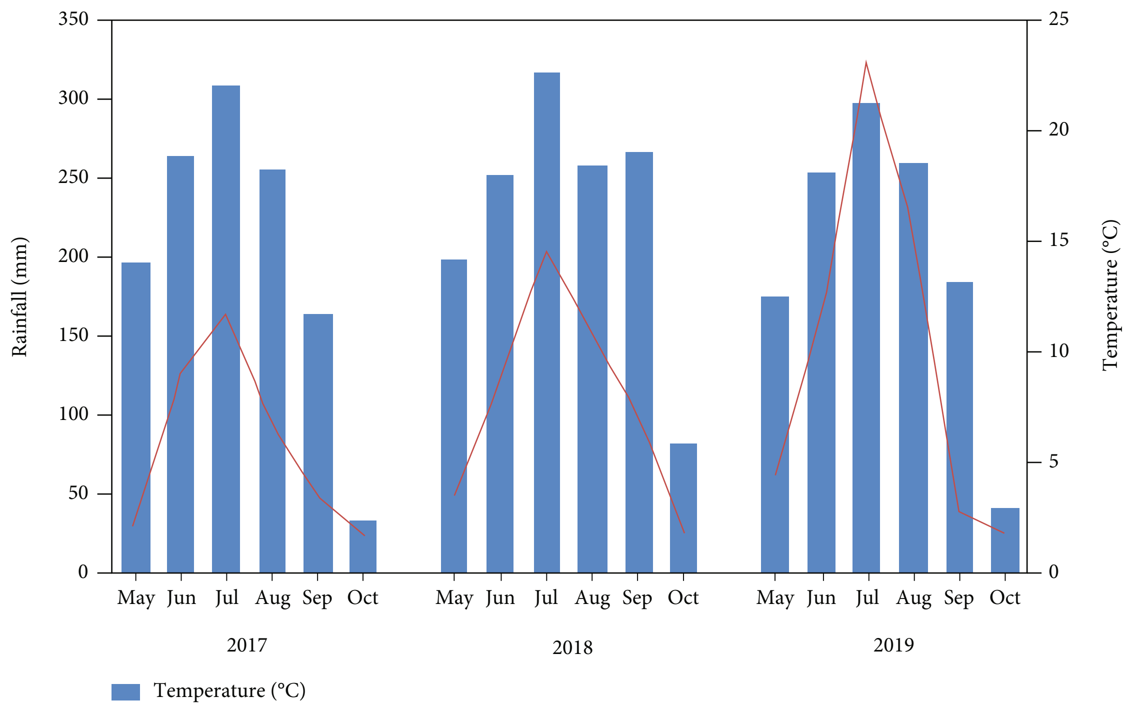

Figure 1: The monthly mean precipitation (mm) and mean temperature (°C) in 2017, 2018, 2019, and 2017–2019 (May to October) at the weather station during the growing season in the experimental site.

Table 1: Basic physical and chemical properties of the soil of the test site.

Year	Bulk weight ($g \cdot cm^{-3}$)	Available nitrogen ($mg \cdot kg^{-1}$)	Available phosphorus ($mg \cdot kg^{-1}$)	Available potassium ($mg \cdot kg^{-1}$)	Organic matter ($g \cdot kg^{-1}$)	pH
2018	1.19	138.9	20.79	179.35	14.3	6.25
2019	1.21	137.8	20.35	180.16	22.1	6.26

Table 2: Different tillage methods.

Tillage measures	Treatments	Stage			
		4-5 days after the broadcast	V2-V3 stage	V4-V5 stage	V6-V7 stage
Ploughing	PT1	Soil dressing		Middle ridging	Large ridging
	PT2			30-35 cm subsoiling+midridging	Large ridging
	PT3	25-30 cm subsoiling	25-30 cm subsoiling		Large ridging
	PCK		Soil dressing	Mid-ridging	Large ridging
Rotary tillage	RT1	Soil dressing			Large ridging
	RT2			30-35 cm subsoiling + mid-ridging	Large ridging
	RT3	25-30 cm subsoiling	25-30 cm subsoiling		Large ridging
	RCK		Soil dressing	Mid-ridging	Large ridging

photosynthetic index of soybean was measured by LI-6400 Photosynthetic Analyser (LI-COR) in the pod stage of soybean. The third leaf from the bottom was measured starting from 8 a.m. in the sunny day, and the measurement indexes are Pn, Ci, GS, and Tr. Each treatment was repeated for three times.

2.5. Production Determination. During both soybean cropping seasons (2018/2019), harvests were performed by hand from 4.5 m^2 per plot, each processing pick at 1 m^2 representative plants; repeat 3 times. Grain number per plant, number of pods per plant, and number of main stem section were determined. Soybean grain was dried to constant weight at 80°C, and determine the soybean grain weight per plant and grain weight; repeat 3 times each process.

2.6. Statistical Analysis. All statistical analyses are completed by SPSS 17.0, and the plotting adopts Origin 2018. Data

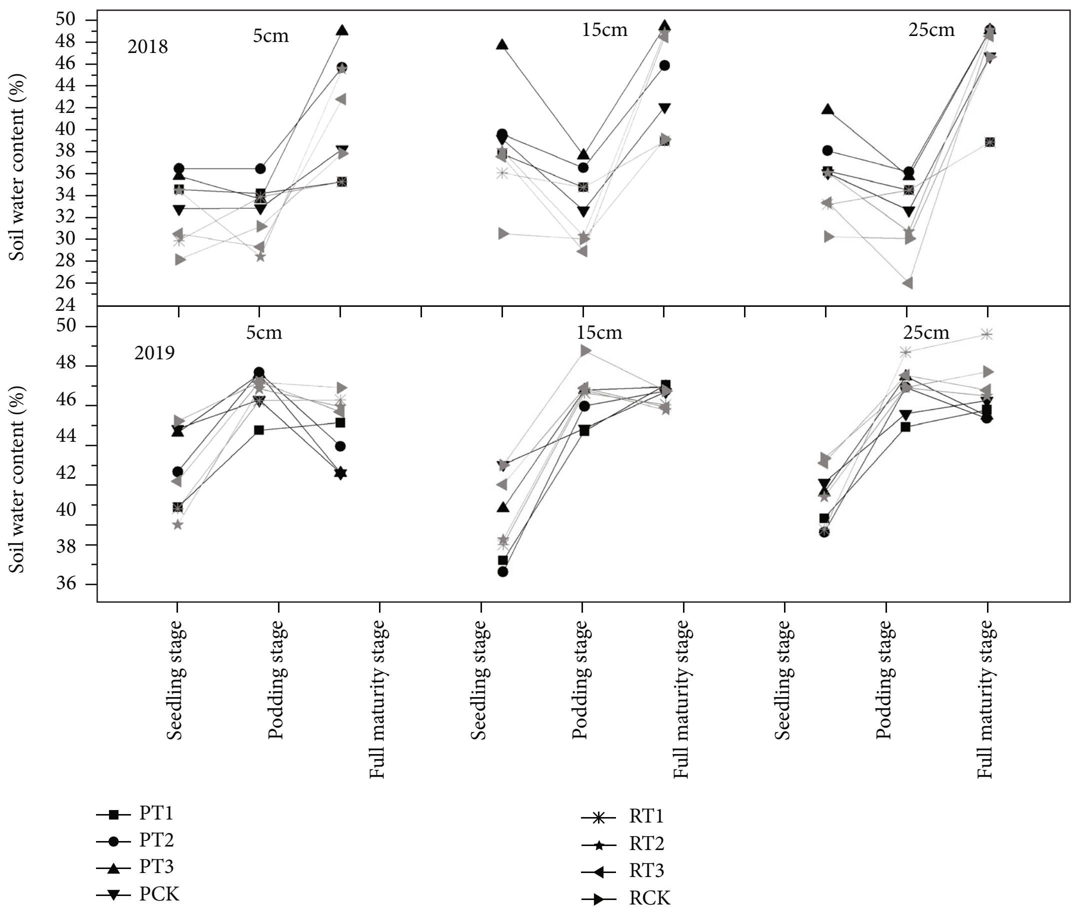

Figure 2: Effects of different tillage measures on soil moisture content.

processing was conducted by Excel 2010, and the effects that each treatment has on the microbial quantity and enzymatic activity of soil are compared using Duncan's.

3. Results

3.1. Weather Conditions for Field Experiments in 2017 and 2019. In 2017, the precipitation was 484.8 mm during the soybean growing season (May–October), considerably better the many years (2006–2016) average of 357 mm for the same period of the year. The average temperatures of air for the 2017 and 2018 rowing seasons were 14.6°C and 16.4°C, respectively, both below the long-term (2006–2016) average of 16.9°C (Figure 1). The precipitation in 2018 was 651.6 mm, above the same term average (Figure 1).

3.2. Soil Moisture Content in Different Tillage Measures. Different tillage measures have great influence on soil water content (Figure 2). In 2018, the soil water content of each layer depth in ploughing treatment was higher than that of rotary tillage treatment in each period. The water content of each soil layer under ploughing tillage was higher than that under rotary tillage at seedling stage of soybean, and the water content in the soil layer of 0-5 cm, 5-15 cm, and 15-25 cm was increased by 5.80%~17.13%, 3.82%~28.07%, and 5.60%~25.17%, respectively. In the podding stage, the water content of each soil layer under ploughing tilting was also increased compared with that under rotary tillage, and the PT2, PT3, and PCK under ploughing tilting were significantly increased compared with RT2, RT3, and RCK under rotary tillage, which were increased by 28.10%, 14.76%, and 5.34% in the 5-15 cm soil layer, respectively. In the maturity stage, the difference becomes smaller, and the overall difference is not significant.

Under the same tillage measures in 2018, the water content of each treatment in each period of ploughing tillage conditions had a tendency to increase compared with that of PCK (except PT1). At the seedling stage, the water content of PT1, PT2, and PT3 in 0-5 cm and 15-25 cm soil layers was higher than that of PCK, and in the 0~5 cm soil layer, the rate of increase was 5.36%, 11.12%, and 9.02%, respectively, and reached a significant level ($P < 0.5$) compared with PCK. In the podding stage, the water content of PT1, PT2, and PT3 in each layer of soil was higher than that of PCK, and the water content of 5~15 cm and 15~25 cm in soil layers was significantly increased by 6.37%, 11.75%, and 15.20% and 5.61%, 10.70%, and 9.38%, respectively. In the mature stage, the water content of PT2 and PT3 in each layer of soil was higher than that of PCK, while the water content of PT1 is lower than that of PCK. The variation trend of rotary tillage was basically the same as that of ploughing tillage, but the difference was that the soil water content of RT3 was lower than that of RCK in all soil layers at the podding stage.

In 2019, the water content of the 5-15 cm and 15-25 cm soil layers in ploughing tillage treatment showed a trend of decrease compared with rotary tillage at the seedling stage, except for the fact that the water content of the 0-5 cm soil layer had a trend of increase compared with rotary tillage. In the podding stage, the water content of each soil layer under ploughing tillage tended to decrease compared with rotary tillage, especially in the 5-15 cm and 15-25 cm soil layers, and it decreased by 0.23%-8.65% in the 5-15 cm soil layer. At the mature stage, the water content of 0-5 cm and 15-25 cm soil layer under ploughing tillage was lower than that under rotary tillage, with a drop of 2.67%-9.85% and 2.63%-8.24%, respectively.

Under the same tillage measures in 2019, the water content of each treatment in each period of ploughing tillage was lower than that of PCK, and the decrease was the most significant in 5-15 cm, which was 12.14%, 13.60% and 5.55% compared with PCK, respectively. In the podding stage, the water content of PT2 and PT3 in all layers of soil was higher than that of PCK, and the water content of 5~15 cm and 15~25 cm soil layers increased by 2.71% and 4.67% and 3.17% and 4.44%, respectively, compared with that of PCK, while PT1 showed an opposite trend. In the mature stage, the water content of all treatments increased in the 0-5 cm and 5-15 cm soil layer compared with that of PCK, but the water content of PT1 significantly increased by 6.48% in the 0-5 cm soil layer compared with that of PCK, and the difference was not significant in other treatments. In the 15-25 cm soil layer, the opposite trend was shown, but there was not significant difference ($P < 0.05$). In rotary tillage, the water content of RT1 significantly increased by 4.10% and 4.26% compared with RCK in 15-25 cm soil layer during pod and mature stage. Compared with RCK, the water content of each soil layer in all stages of other treatments was lower than that of RCK. And the water content in 0-5 cm soil layer of RT1, RT2, and RT3 at the seedling stage significantly decreased by 10.54%, 12.46%, and 7.24%, respectively.

3.3. Soil Temperature of Different Tillage Measures. In 2018, the temperature of 0-5 and 15-25 cm soil layers at the seedling stage of ploughing tillage tended to increase compared with that of rotary tillage (Figure 3), especially in the 15-25 cm soil layer, which significantly increased by 16.58% to 28.17% compared with that of rotary tillage. The soil temperature of other treatments in all stages tended to decrease compared with that of rotary tillage, but the difference was not significant.

Under the same ploughing tillage measures in 2018, the temperature of tilting PT3 (conventional deep loosening treatment) at the soil layer of 0-5 cm and 5-15 cm was significantly lower than that of PCK at the seedling stage. During the pod setting stage, the temperature of each treatment in each soil layer was not significantly different, but the temperature of deep loosening treatments (PT2 and PT3) was lower than that of soil cultivation treatments (PT1 and PCK). Under rotary tillage, the temperature of 0-5 cm and 15-25 cm soil layer under deep loosening treatments (RT2 and RT3) was lower than that under soil cultivation treatments (RT1 and RCK) at seedling stage, but the difference was not significant. Entering pod setting stage, the temperature of RT2 and RT3 in each soil layer was higher than that of the soil cultivation treatments (RT1 and RCK).

Under the same ploughing tillage measures in 2019, there was no significant difference ($P < 0.05$) between the temperature of 0-5 cm and 5-15 cm soil layer in ploughing and that of rotary tillage in each period. Compared with rotary tillage, the temperature of 15~25 cm soil layer in ploughing tillage significantly increased at the seedling and maturity stage, with an increase of 4.15%-11.61%. However, under tilting condition, the soil temperature under PT1, PT2, and PT3 treatments at mature stage increased by 10.97%, 11.74%, and 7.82% compared with the soil temperature under RT1, RT2, and RT3 treatments.

In 2019, the temperature of PT1 and PT2 in 0-5 cm, 5-15 cm, and 15-25 cm soil layers under tillage increased compared with that of PCK at seedling stage, and the increase rates in 0-5 cm soil layers were 13.03% and 8.56%, respectively. In the podding stage, the temperature of deep loosening treatments (PT2 and PT3) in each soil layer tended to decrease compared with that of soil cultivation treatments (PT1 and PCK), and the temperature of PT2 and PT3 in the 15-25 cm soil layer was significantly reduced by 5.39% and 5.62% compared with that of PCK. In the mature stage, there was no significant difference in the temperature of 0~5 cm and 5~15 cm soil layers between all the treatments, but the temperature of PT1, PT2, and PT3 in the 15~25 cm soil layer was higher than that of PCK, and the temperature of PT2 was significantly increased by 11.63%. Under rotary tillage, the variation trend of temperature in each soil layer was basically the same as that under tillage at seedling stage. In the podding stage, the temperature of RT1, RT2, and RT3 treatments in the 0-5 cm and 5-15 cm soil layers was higher than that of RCK, and the temperature increases in the 5-15 cm soil layers were 3.35%, 2.24%, and 1.26%, respectively. The soil temperature of intertillage treatments (T1 and T2) in advance of seedling stage increased significantly among all treatments. The results showed that the combination of the two tillage measures had positive effect on the increase of soil temperature at the seedling stage, which was helpful for emergence and germination of soybean.

3.4. Photosynthetic Capacity of Soybean under Different Tillage Measures

3.4.1. Net Photosynthetic Rate (Pn). The net photosynthetic rate (Pn) was significantly affected by different tillage measures (Figure 4). The net photosynthetic rate of tillage was significantly increased by 8.22%~26.20% compared with rotary tillage in 2018. The net photosynthetic rate (Pn) of PT1, PT2, and PT3 under ploughing tillage condition was significantly increased by 6.55%, 11.00%, and 5.86% compared with that of PCK, respectively. The net photosynthetic rate (Pn) of RT1 and RT2 in rotary tillage increased by 1.35% and 6.45% compared with RCK.

The trend of the net photosynthetic rate (Pn) in 2019 is consistent with that in 2018. The net photosynthetic rate of

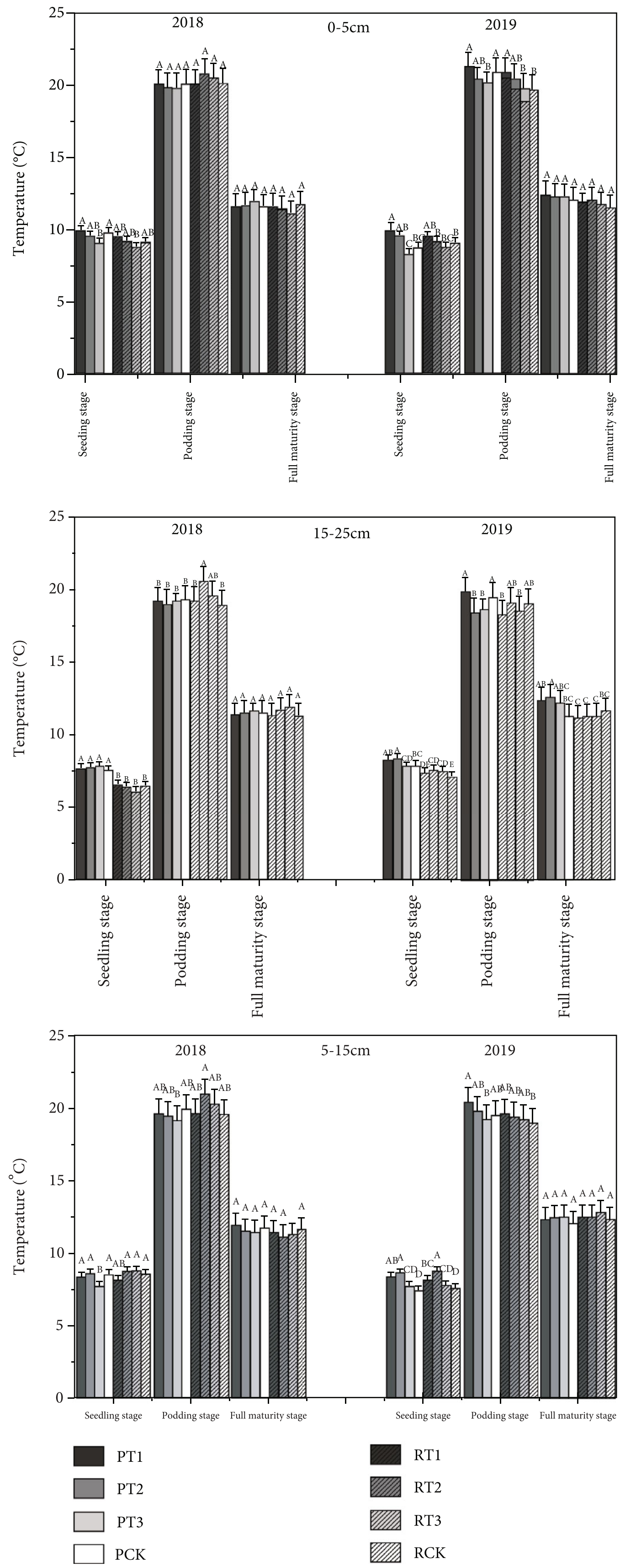

Figure 3: Effects of different tillage measures on soil temperature.

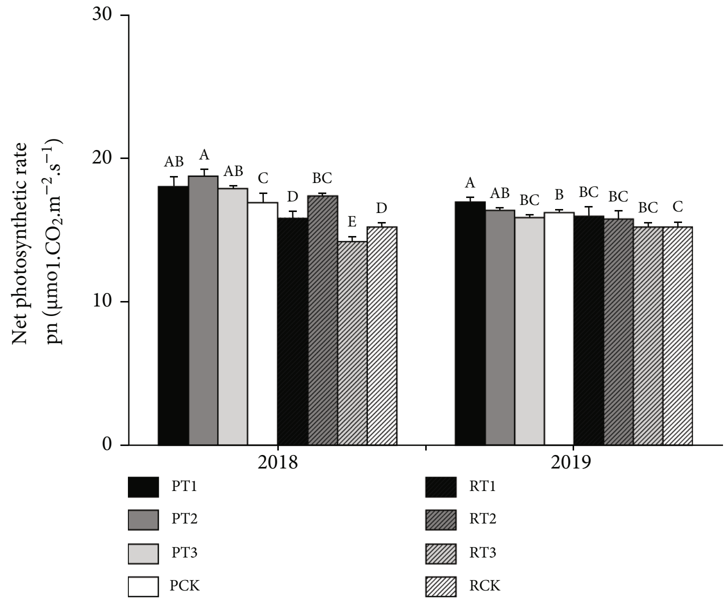

Figure 4: Effects of different tillage measures on net photosynthetic rate of soybean.

ploughing tillage was higher than that of rotary tillage, with an increase range of 3.66%-6.55%, and the net photosynthetic rate of PT1 and PCK significantly increased by 6.45% and 6.55% compared with the corresponding RT1 and RCK. The net photosynthetic rate (Pn) of PT1 and PT2 treatments increased by 3.91% and 13.92% compared with PCK under ploughing tillage condition. The net photosynthetic rate of RT1, RT2, and RT3 was increased by 4.76%, 4.18%, and 0.25%, respectively, compared with that of RCK under the rotary tillage. In particular, RT1 and RT2 reached significant levels ($P < 0.5$) compared with that of RCK.

3.4.2. Transpiration Rate. In 2018, the transpiration rate (Tr) was not significantly different between the PT2 under ploughing tilting and RT2 under rotary (Figure 5). The transpiration rate (Tr) of other treatments under ploughing tilting was significantly higher than that under rotary tillage, and PT1, PT3, and PCK significantly increased by 11.40%, 18.15%, and 18.34% compared with their corresponding RT1, RT3, and RCK. Under ploughing tillage condition, the transpiration rate of PT2 treatment was significantly increased by 6.62% compared with that of PCK, and the transpiration rate of RT2 under rotary tillage was significantly increased by 10.03% compared with RCK.

In 2019, the transpiration rate of ploughing tilting was increased by 1.03%-15.04% compared with that of rotary tillage. The transpiration rate of other ploughing tilting treatments was significantly higher than that of rotary tillage, except for no significant difference between PT2 and RT2. The transpiration rate of each treatment (PT1, PT2, and PT3) was increased by 6.71%, 34.12%, and 1.57%, respectively, compared with that of PCK under ploughing tillage, and the difference between PT1 and PT3 reached significant level ($P < 0.5$). In rotary tillage, transpiration rates of RT1, RT2, and RT3 treatments were increased by 5.12%, 9.90%, and 1.85% compared with RCK, respectively, and the difference between RT1, RT2, and RCK reached a significant level ($P < 0.5$).

3.4.3. Intercellular CO_2 Concentration. In 2018, the intercellular CO_2 concentration of PT1 and PT2 under tillage condition was significantly reduced by 5.19% and 6.42% compared with that of RT1 and RT2 (Figure 6). Compared with PCK, the intercellular CO_2 concentration of PT1 and PT2 under plowing was significantly decreased by 1.86% and 4.29%. In rotary tillage, the Ci of RT1, RT2, and RT3 increased by 4.80%, 3.56%, and 1.45% compared with RCK, and the difference between RT1 and RT2 reached a significant level ($P < 0.5$).

In 2019, the intercellular CO_2 concentration of ploughing tilling was significantly reduced by 1.55%-7.95% compared with that of rotary tillage. Under the same tillage measures, the CI of PT2 and PT3 under the ploughing tilling increased by 0.18% and 5.12% compared with that of PCK. In rotary tillage, the Ci of RT1, RT2, and RT3 were significantly reduced by 2.72%, 3.13, and 1.71% compared with RCK.

3.4.4. Stomatal Conductance (Gs). In 2018, compared with the corresponding rotary tillage, the stomatal conductance (GS) of PT3 and PCK under the ploughing significantly increased by 22.71% and 16.12% compared with that of the RT3 and RCK under the rotary tillage (Figure 7). Under the same rotary tillage measures, the stomatal conductance of RT1, RT2, and RT3 was significantly increased by 24.63%, 32.25%, and 10.52% compared with RCK, respectively.

In 2019, the stomatal conductance of other tillage treatments was significantly higher than that of rotary tillage treatments, with an increase of 5.80%~11.42, except that the stomatal conductance of PT3 and RT3 was not significantly different. Under the same rotary tillage measures, the stomatal conductance of RT1, RT2, and RT3 under

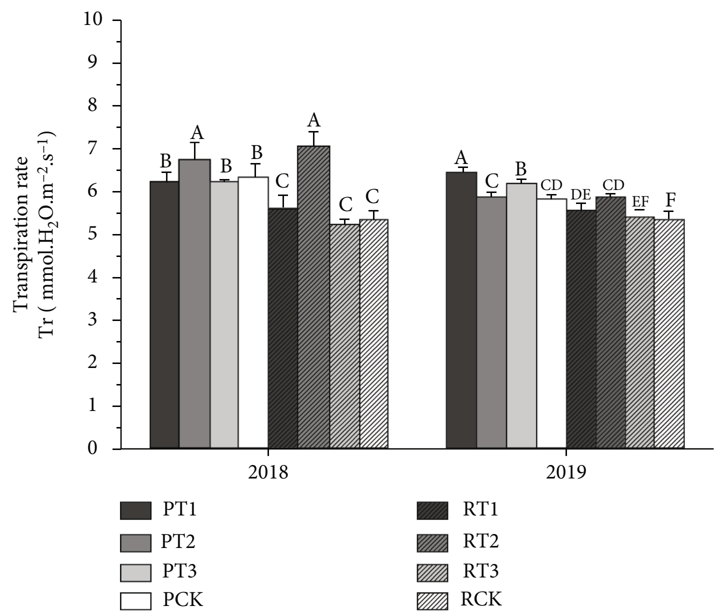

Figure 5: Effects of different tillage measures on soybean transpiration rate.

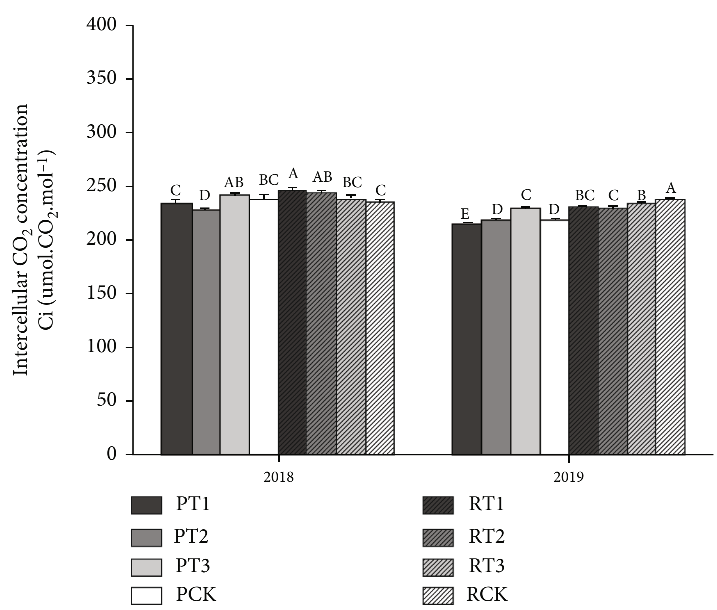

Figure 6: Effect of soybean intercellular CO_2 concentration under different tillage measures.

rotary tillage increased by 7.29%, 6.78%, and 3.87% compared with RCK, and the difference between RT1 and RT2 reached a significant level ($P < 0.5$).

3.4.5. Chlorophyll Content (SPAD). In 2018 (Figure 8(a), 2018), different tillage measures had significant effects on the leaf chlorophyll content (SPAD) of soybean at the flowering stage. The SPAD of rotary tillage was significantly increased by 2.60%-6.16% compared with that of ploughing tillage. There was no significant difference ($P < 0.05$) between the two tillage methods at the pod setting stage and the grain bulging stage, but the SPAD of rotary tillage was higher than that of ploughing tilling.

Under the ploughing tilling, the SPAD of PT1, PT2, and PT3 at flowering and granulation stages was higher than that of PCK, and the increase amplitude was 16.15%, 19.77%, and 3.83% and 11.25%, 11.52%, and 7.70% at the two stages, respectively. The chlorophyll content of PT1 and PT2 at flowering and granulation stages was significantly higher than that of PCK ($P < 0.5$). The SPAD of PT1 and PT2 was significantly increased by 11.37% and 14.86% compared with that of PCK at the podding stage. In rotary tillage, the change trend of each period is consistent, and the SPAD of RT1, PT2, and RT3 is higher than that of RCK. The SPAD of RT1, PT2, and RT3 at anthesis and bulging stages was significantly higher than that of PCK, which were increased by

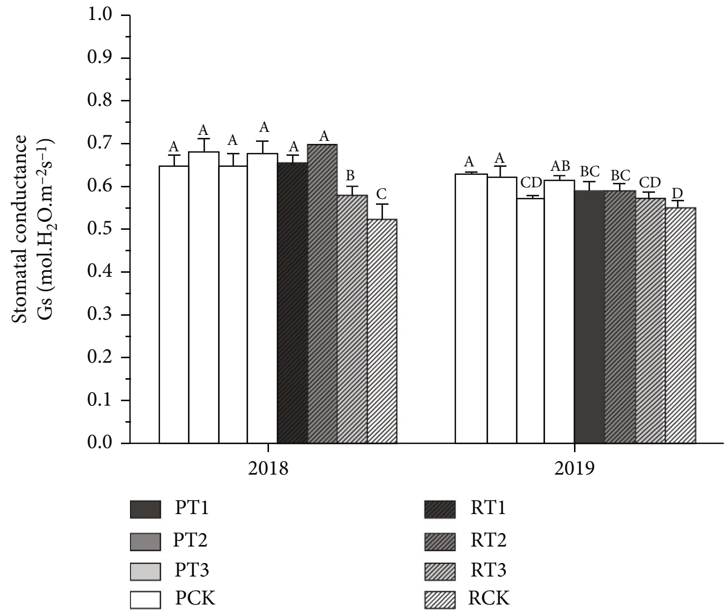

Figure 7: The stomatal conductance of soybean in different tillage measures.

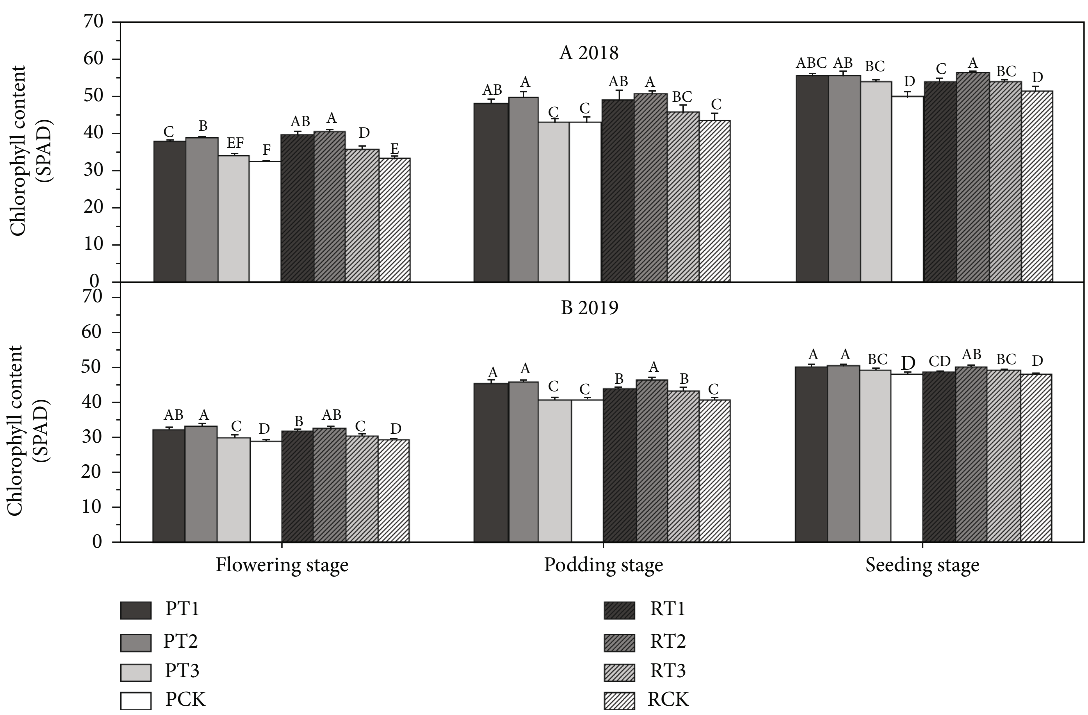

Figure 8: The chlorophyll content of soybean in different tillage measures.

18.91%, 20.52%, and 7.44% and 5.24%, 10.75%, and 6.03%, respectively. The SPAD of RT1 and Pt2 was significantly increased by 12.89% and 15.90% compared with that of RCK at pod setting stage.

In 2019 (Figure 8(b), 2019), the SPAD of ploughing tillage at the flowering stage was improved compared with that of rotary tillage. In the pod setting stage, the SPAD of PT1 under ploughing tilting was higher than that of RT1 under rotary tillage, and the SPAD of PT1 was significantly higher than that of RT1 under rotary tillage with an increase of 3.50% at the bulging stage.

Under the same ploughing tillage measures, the variation trend of SPAD of PT1, PT2, and PT3 at flowering stage and granulation stage and the increase rates of PT1, PT2, and PT3 were significantly higher than that of PCK, with increases of 12.09%, 15.12%, and 4.77% and 4.50%, 4.61%, and 2.08%, respectively. In the pod setting stage, the SPAD of PT1 and PT2 was also significantly increased by 12.50%

Table 3: Effects of different tillage measures on soybean yield and yield composition.

Year	Treatment	Pod number	Seed number	100-seed weight (g)	Seed weight (g)	Yield (kg·hm^{-2})
2018	PT1	28.39 ± 2.84^{a}	67.89 ± 9.76^{a}	21.41 ± 0.62^{a}	10.87 ± 1.42^{abc}	3279.08 ± 547.85^{a}
	PT2	29.42 ± 0.44^{a}	68.50 ± 6.78^{a}	21.58 ± 0.15^{a}	12.18 ± 0.83^{a}	3324.77 ± 306.82^{a}
	PT3	24.69 ± 1.36^{a}	61.49 ± 5.08^{a}	19.80 ± 0.19^{cd}	9.42 ± 0.9^{c}	3027.89 ± 241.18^{ab}
	PCK	24.99 ± 1.01^{a}	59.87 ± 2.19^{a}	18.67 ± 0.23^{e}	10.47 ± 0.56^{abc}	3059.32 ± 471.32^{ab}
	RT1	26.87 ± 3.93^{a}	66.62 ± 7.83^{a}	19.96 ± 1.25^{bcd}	10.57 ± 0.87^{abc}	3005.15 ± 513.49^{ab}
	RT2	27.43 ± 1.44^{a}	65.05 ± 4.15^{a}	21.14 ± 0.56^{a}	11.60 ± 0.92^{ab}	3097.76 ± 279.69^{ab}
	RT3	23.00 ± 1.80^{a}	61.26 ± 4.23^{a}	20.93 ± 0.60^{ab}	9.39 ± 1.45^{c}	2532.94 ± 214.42^{b}
	RCK	22.84 ± 6.74^{a}	60.27 ± 9.47^{a}	20.81 ± 0.44^{abc}	9.44 ± 0.87^{c}	2514.91 ± 62.97^{b}
2019	PT1	21.07 ± 0.31^{a}	51.73 ± 1.97^{a}	20.43 ± 0.37^{abc}	9.81 ± 0.17^{a}	3025.73 ± 102.36^{a}
	PT2	16.94 ± 0.26^{bc}	45.31 ± 0.50^{b}	20.08 ± 0.13^{cde}	8.18 ± 0.55^{bc}	2632.62 ± 53.06^{b}
	PT3	15.34 ± 0.94^{d}	41.50 ± 0.32^{c}	20.94 ± 0.19^{ab}	7.53 ± 0.39^{c}	2479.95 ± 27.36^{cd}
	PCK	16.22 ± 0.84^{bc}	40.48 ± 0.83^{c}	21.24 ± 0.38^{a}	8.24 ± 0.60^{bc}	2459.84 ± 53.94^{cd}
	RT1	15.09 ± 0.50^{d}	42.52 ± 1.00^{c}	19.44 ± 0.66^{e}	8.51 ± 0.40^{bc}	2380.05 ± 102.85^{d}
	RT2	18.59 ± 0.80^{b}	46.01 ± 2.19^{b}	20.33 ± 0.60^{bcd}	8.80 ± 0.60^{bc}	2639.84 ± 57.56^{b}
	RT3	16.08 ± 0.51^{bc}	45.47 ± 0.39^{b}	19.58 ± 0.49^{de}	8.34 ± 0.13^{b}	2570.51 ± 59.29^{bc}
	RCK	15.71 ± 1.22^{bc}	41.46 ± 0.52^{c}	20.63 ± 0.36^{abc}	8.24 ± 0.33^{b}	2384.83 ± 63.51^{d}

and 12.99% compared with that of PCK. In rotary tillage, the SPAD of RT1, RT2, and RT3 was higher than that of RCK at flowering and pod stage, with increases of 10.00%, 11.04%, and 4.25% and 7.69%, 14.89%, and 6.30%, respectively. At bulging stage, SPAD of RT2 and RT3 was also significantly increased by 4.31% and 2.85% compared with that of RCK.

3.5. Effects of Different Tillage Measures on Soybean Yield and Yield Composition. Table 3 Filled-pod number (m^{-2}), grain number (m^{-2}), hundred-grain weight (HGW, g), and grain yield (kg m^{-2}), in 2018 and 2019.

In 2018, the number of pods per plant, grain number per plant, 100-grain weight per plant and grain weight per plant treated of PT1 and PT2 under ploughing tilting conditions were all increased at a certain extent compared with that of RT1 and RT2 under rotary tillage, and finally, the yield was improved (Table 2). The yield of PT1 and PT2 was increased by 9.12% and 7.33%, respectively, compared with the corresponding RT1 and RT2, and the yield of PT3 and PCK was also increased compared with the corresponding RT3 and RCK, but the difference was not significant. In the same tillage measures, the yield components of PT1 and PT2 treatments were higher than those of PCK, and the yield of PT1 and PT2 was increased by 7.18% and 8.67%, respectively, compared to that of PCK. Similarly, in rotary tillage, the variation of yield components and the increasing trend of yield showed the same characteristics as under ploughing tilling conditions.

In 2019, except that the yield of tilting PT1 was significantly higher than RT1, there was no significant difference between ploughing tilting and the corresponding rotary tillage treatments. Under tillage condition, the soybean yield of PT1 and PT2 increased by increasing soybean pod number per plant and grain number per plant, and the yield of PT1 and PT2 increased by 23.00% and 7.02%, respectively, compared with that of PCK. Under rotary tillage, the yields of RT2 and RT3 were increased by 10.69% and 7.79%, respectively, compared with RCK, and the differences reached significant levels ($P < 0.5$).

4. Discussion

Soil moisture is not only an important component of soil but also an indispensable part of water cycle in nature [11], and the water content of soil seriously restricts the increase of crop yield. Soil water content is affected by topography, soil type, crops planted, and tillage methods, among which tillage methods undoubtedly have a significant effect on soil water content [12]. According to Haytham et al. [13], the greater hydraulic conductivity of traditional tillage is conducive to increase the soil moisture content. Liu et al. [14] believe that tillage can reduce soil compaction, and loose soil layer can reduce the bulk density and hardness of soil, which may increase the moisture content and water storage capacity of soil. Similarly, in this experimental study, each layer of soil is relatively loose under the ploughing tillage treatment in 2018, so the potential of tillage soil to receive rainwater is greater and the rainwater infiltration resistance is smaller. As a result, the soil water content of ploughing tillage was significantly more than that of rotary tillage.

There was more rainfall in the spring of 2019 (Figure 1), and the difference of soil water content between the two tillage practices became smaller. As a whole, the soil water content of ploughing tillage was higher than that of rotary tillage, which further indicated that ploughing tillage was better to increase the soil water content than rotary tillage. Deep loosening can effectively break the soil plough bottom and reduce soil compactness, thus reducing soil bulk density and increasing soil total porosity. Deep loosening also facilitates the movement and exchange of moisture and gas in different layers of soil, thus increasing moisture content and water storage of soil. In this study, the volumetric water content of deep loosening treatment in 2018 is significantly higher than that of soil cultivation treatment, mainly because deep loosening loosens the soil layer and reduces the bulk density of soil. The soil permeability improved and the ability to accept and store rainwater of soil [15] enhanced, which is similar to the research results of Liu et al. [16]. In 2019, the advance intertillage was conducive to increase the water content of soil. The water content of soil was increased greatly at advance intertillage treatments (T1 and T2), which was significantly higher than CK at 0-25 cm.

Soil temperature affects the transfer or transformation of water, air, and nutrients in soil. The research results of Zhou et al. [17] showed that straw returning under rotary tillage increased soil temperature compared with conventional straw returning and thus helped to improve the respiration rate of soil. However, Kuang et al. [18] believed that different tillage had different disturbance degrees on soil. Soil is often disturbed, leading to changes in void ratio, strengthening soil evaporation, and reducing soil moisture content, which leads to decreasing in soil heat capacity and thermal conductivity, thus increasing the temperature of soil. In this study, tillage treatment in 2019 makes the temperature of the 15-25 cm soil layer significantly higher than rotary tillage, because tillage works on the soil at a deeper depth than rotary tillage, which contributes to the increase of soil temperature. Early ploughing of the soil can increase the heat area of the soil and improve the three-phase ratio of soil, thus raising the soil temperature.

Different tillage measures affect the soil temperature and humidity and the content of available nutrients, which affect the growth of soybean. Soybean plant height, leaf area index, and leaf SPAD can all affect the photosynthetic characteristics of soybean, so different tillage measures can affect the photosynthetic strength of crops by changing the soil environment [19]. The study of Li et al. [20] showed that appropriate tillage can provide a better environment for improving the photosynthetic capacity of crops by improving the capacity of water storage, utilization, and the content of nutrients in soil. Xu et al. [21] showed that, compared with rotary tillage, ploughing tillage can increase the soil structure and promote the growth of crop and the uptake of nutrient, which have a positive impact on delaying the decline of chlorophyll and maintaining the photosynthetic capacity of crops. In this experiment, the net photosynthetic rate of at ploughing tilting treatment was higher than that of rotary tillage in two years, and the Tr and Gs showed a similar trend overall, but the Ci of tilting showed an opposite trend compared with that of rotary tillage. The increase of Pn, Tr, and Gs accelerated the assimilation of CO_2 in leaves and reduced the concentration of CO_2 between the cell pf leaves. At the flowering stage in 2018, the SPAD of ploughing tillage was significantly lower than that of rotary tillage, but the difference in other periods. There was not significant difference on the whole in 2019. Deep loosening can increase soil water content and remove the restriction of water deficit on photosynthesis [22], thus contributing to the improvement of photosynthetic characteristics of crops. It is found in our study that Pn, Tr, and Gs of advanced deep loosening (T2) treatment are increased compared with other treatments in the year of relatively suitable precipitation in 2018. However, soil planting in advance increased Pn, Tr, and GS of soybean in 2019 with more rainfall. Early deep loosening soil can maintain a suitable hydrothermal environment in the years with appropriate rainfall, which makes the leaf area wider and improves SPAD, thus improving the photosynthesis of soybean. In the case of heavy rainfall, the furrows formed by soil cultivation not only facilitate drainage but also increase the heated area, so that the moisture content of soil is not too high and the suitable hydrothermal environment can be maintained, and thus, the photosynthesis of soybeans can be improved, and finally, the yield can be increased.

In this experiment, both PT2 and PT1 treatments had the highest yields in two years. It indicated that early intertillage was conducive to the improvement of soil temperature and humidity in this region, activated soil nutrients, and provided a better environment for soybean growth and development, thus increasing the yield.

5. Conclusions

Compared to rotary tillage, we found that the 2-year tillage was more effective in plowing to loosen the soil at a certain depth, which resulted in a reduction in soil bulk and hard compactness and increase in porosity; this further improved the soil hydrothermal environment. Compared to rototilling, tilling improved the soil environment and promoted overall soybean growth and development. Tilling promoted dry matter accumulation and biomass transfer to seeds, which increased soybean yield by increasing soybean photosynthesis. When compared with rototilling, we observed that tilling caused a significant improvement of soil environment. Tilling also promoted soybean growth and development, as we observed a significant increase in plant height at flowering stage and an increase in the leaf area index (LAI) during both the years. The increase in soybean plant height and LAI facilitated an increased light capture by the leaves. As a result, the Pn, Tr, and Gs showed an elevated trend in the plants under tilling treatment; in contrast, Ci showed the opposite trend, where plants under rototilling showed an increase in Ci. In the soil subjected to tilling, the increase in photosynthesis of soybean further facilitated the accumulation of dry matter and the transfer of biomass to seeds, which increased the yield of soybean. This was observed particularly with the combination of tilling and early intercropping; PT1 and PT2 treatment combinations in 2018 had the greatest yield increase, whereas the PT1 combination in 2019 maintained a better soil hydrothermal environment and ultimately increased the yield by 23.00% compared to PCK.

Data Availability

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

Conflicts of Interest

The authors do not have any possible conflicts of interest.

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References

[1] X. Wa, Z.-j. Xu, Y.-j. Qi, and W. Cun-xiang, "Effects of tillage and straw returning on soybean yield and soil physicochemical properties in Yellow-Huai-Hai Rivers Valley," *Chinese Journal of Oil Crop Sciences*, vol. 39, no. 6, pp. 834–841, 2017.

[2] Z. K. Peng, L. L. Li, J. H. Xie et al., "Effects of conservation tillage on moisture characteristics of dry farmland in central Gansu," *Journal of Applied Ecology*, vol. 29, no. 12, pp. 1–11, 2018.

[3] G. O. Iremiren, "Effect of soil temperature on the growth and yield of corn," *International Agriculture*, vol. 40, no. 2, pp. 54–56, 1988.

[4] Y. L. Zhao, H. B. Guo, Z. W. Xue, X. Y. Mu, and C. H. Li, "Effects of tillage and straw returning on microorganism quantity, enzyme activities in soils and grain yield," *Journal of Applied Ecology*, vol. 26, no. 6, pp. 1785–1792, 2015.

[5] Q. Ye and W. Xuan, "Effects of tillage patterns on soil moisture and soybean yield in sloping fields," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 34, no. 22, pp. 128–137, 2018.

[6] S. Lili, L. Yajie, X. Wenxiu et al., "Effects of tillage methods on soil physical and chemical properties and yield of summer soybean," *Agricultural Research in the Arid Areas*, vol. 35, no. 3, pp. 43–49, 2017.

[7] Q. Guo, L. L. Yu, and J. R. Han, "Effects of conservation tillage on soil respiration and water use efficiency in corn fields," *Journal of Irrigation and Drainage*, vol. 11, pp. 57–62, 2018.

[8] Y. Chen, S. Liu, H. Li et al., "Effects of conservation tillage on corn and soybean yield in the humid continental climate region of Northeast China," *Soil and Tillage Research*, vol. 115-116, no. 2, pp. 56–61, 2011.

[9] B. W. Zhang, Y. M. Yang, J. L. Li et al., "Effects of continuous subsoiling on the characteristics of hydrothermal enzymes and bacterial communities in black soil," *Journal of Ecology*, pp. 1–13, 2018.

[10] B. Huang, M. Wang, X. Jin, Y. Zhang, and G. Hu, "Effects of different tillage measures on soil microbes and enzymatic activity," *Nature Environment and Pollution Technology*, vol. 19, no. 4, pp. 1443–1452, 2020.

[11] F. F. Haghighi, M. Gorji, and F. Sharifi, "Temporal variability of soil water content and penetration resistance under different soil management practices," *Journal of Soil and Water Conservation*, vol. 74, no. 2, pp. 188–198, 2019.

[12] S. Andreas, G. Br, S. Peter, G. D. Buchan, and W. Loiskandl, "Temporal dynamics of soil hydraulic properties and the water-conducting porosity under different tillage," *Soil & Tillage Research*, vol. 113, pp. 89–98, 2011.

[13] M. S. Haytham, V. Constantino, M. Á. Muñoz, M. G. Rodríguez, and L. L. Silva, "Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield," *Geoderma*, vol. 237-238, pp. 60–70, 2015.

[14] L. J. Liu, H. W. Gao, and H. W. Li, "Experimental study on a corn-wheat two-cropping protective tillage system," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 3, pp. 70–73, 2004.

[15] V. Nele, F. Isabelle, and G. Bram, "Conservation agriculture, improving soil quality for sustainable production systems," in *Food Security and Soil Quality*, pp. 137–208, CRC Press, Boca Raton, 2010.

[16] Z. D. Liu, K. Zhang, C. Huang et al., "Effects of different tillage and irrigation methods on photosynthetic characteristics of maize," *Journal of Soil and Water Conservation*, vol. 33, no. 4, pp. 213–220, 2019.

[17] Z. Peng-Chong, Y. Shen, X. Jiao-Jiao, H. Hui-Fang, N. Tang-Yuan, and L. Zeng-Jia, "Contribution of winter wheat field root respiration to soil respiration under long-term positioning tillage," *Journal of Agricultural Resources and Environment*, vol. 36, no. 6, pp. 766–773, 2019.

[18] E. J. Kuang, F. Q. Chi, J. M. Zhang et al., "Effects of different tillage methods and organic materials on the main characteristics of soil," *Soil and Crops*, vol. 8, no. 4, pp. 395–404, 2019.

[19] J. H. Li, Z. W. Tan, X. W. Luo et al., "The effect of farming and mulching methods on dryland sugarcane production," *Transactions of the Chinese Society of Agricultural Machinery*, vol. 5, pp. 70–73, 2004.

[20] Y. Li, J. Wu, M. Huang et al., "Effects of different tillage methods on photosynthetic characteristics and water use efficiency of wheat flag leaves," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 22, no. 12, pp. 44–48, 2006.

[21] H. D. Xu, J. H. Tang, L. L. Su et al., "Effects of farming methods on photosynthetic characteristics and yield formation of summer soybeans," *Journal of Xinjiang Agricultural University*, vol. 39, no. 1, pp. 45–49, 2016.

[22] J. Pu, D. M. Shi, Y. B. Lou, T. Duan, and G. Song, "Effect of different tillage depth on soil properties of ploughing layer in slope cultivated land of red soil," *Journal of Soil and Water Conservation*, vol. 33, no. 5, pp. 8–14, 2019.