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EFFECTS OF DIFFERENT TILLAGE MANAGEMENT ON THE GROWTH AND YIELD OF MAIZE (*ZEA MAYS* L.)

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Keywords: Tillage treatments, Plant height, Chlorophyll, Aboveground biomass, Crop yield, Soil compaction

Abstract

Effects of different tillage management on the growth and yield of maize were studied from early June to September 2017. The experiment was set up with three tillage treatments: traditional shallow moldboard plow tillage with straw removal (MT), sub-soiling/ plow tillage /sub-soiling rotation with straw mulch (ST) and no-till/sub-soiling/no-till rotation with straw retention (NT). The soil compaction of different soil layers, plant height, chlorophyll content, above-ground biomass and yield were determined through the three tillage practices. Results showed that NT and ST treatments helped to reduce soil compaction, and had a positive effect on maize root growth and development, plant height and chlorophyll content compared to the MT treatment. The chlorophyll value in early growth period under NT and ST increased by 31.8 and 24.6%, respectively, and the plant height was increased by 20.2 and 15.9% compared with MT, respectively. The size order of soil compaction was MT > NT > ST, and the soil compaction value was the maximum at 20 cm under MT treatment, which was 1007 kPa. Meanwhile, NT and ST also increased the plant above-ground biomass and yield of maize. Compared to MT treatment, the dry weight of plants for the NT and ST treatments significantly increased by 24.3 and 15.7%, respectively, and the grain yield significantly increased by 11.9 and 14.9%, respectively ($P < 0.05$). NT and ST tillage treatments are effective measures to improve structure of soil, contribute to plant growth and development and thereby increase in yield.

Introduction

The healthy and sustainable development of soil is affected by agricultural tillage, planting, management practices, and other activities. The purpose of soil tillage practice is to improve soil physico-chemical properties and performance through mechanical and other human activities, and coordinate conditions such as soil water storage and fertilizer retention , so as to create a suitable soil ecological conditions for plant growth and development (Shi *et al.* 2006, Vita *et al.* 2007, López and Pardo 2009). In recent years, continuous shallow ploughing for many years has led to the compaction of the soil subsurface and the deterioration of soil permeability. In addition, the application of organic fertilizers has become less and less, which affects the growth, development and physiological functions of plants, resulting in stagnant grain yields in farmland, and the economic benefits are not obvious (Lupwayi *et al.* 2006, Calonego and Rosolem 2010, Song *et al.* 2019). Therefore, finding a suitable tillage management system have an important role in improving soil structure, promoting crop growth and development, and ensuring stable and high yields.

Studies had shown that long-term shallow moldboard plow tillage causes damage to the stability of topsoil structure and the quality of aggregates, aggravate the compaction and degradation of the topsoil in farmland, and affect the growth and development of plant roots and crop yields (Gozubuyuk *et al.* 2014). The conservation tillage measures represented by no-tillage,

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less tillage, deep loosening, and straw returning can effectively optimize soil physical structure, improve the soil's water supply and fertilizer supply capacity, and promote crop root growth and nutrient absorption, thereby increasing crop yield and forming suitable soil (Blanco-Moure *et al.* 2012, Dairon *et al.* 2017, Nunes *et al.* 2018). These conservation tillage measures will solve a series of problems of soil and plant health and sustainable development brought about by long-term single tillage measures. Physiological growth indicators such as plant height and chlorophyll are the key physiological growth indicators reflecting the growth process and health of plants, and play an extremely important role in the formation of crop yields (Ki-Hong *et al.* 2003). Therefore, studying and comparing the effects of different tillage management practices on soil compaction, plant physiological growth indicators and yield can provide theoretical basis and technical support for improving soil quality and promoting crop growth and development.

Materials and Methods

The experimental site is located at the Qinling Field Monitoring Center Station (34°09'N, 107°52'E) in Shangwang Village, Tangyu Town, Meixian County, Shaanxi Province, China. The terrain is mainly Qinling Mountains, which is a warm temperate continental semi-humid climate. The annual average temperature, annual average sunshine hours, annual average precipitation and frost-free period are 12.9°C, 2015.2 hrs, 609.5 mm and 218 days, respectively. The natural conditions basically needs for the normal growth of plants. The test plot is the available arable land formed by the reclamation of the abandoned bare rock and gravel. The soil maturity and structure are poor. Therefore, it is used to investigate effects of different rotary tillage modes and comprehensive remediation techniques such as straw returning on the soil structure and plants physiological growth indicators of the newly added arable land.

The experiment started maize planting at the long-term observation and examination station of Qinling from June to September 2017. A total of 3 tillage management methods were set up in the experiment: traditional shallow moldboard plow tillage with straw removal (MT), sub-soiling/ plow tillage /sub-soiling rotation with straw mulch (ST) and no-till/sub-soiling/no-till rotation with straw retention (NT). A random block design was adopted, each treatment was designed with 3 replicates, and each tillage treatment plot was 6 m long and 5.5 m wide, with a total area of about 297 square meters, and the specific tillage treatment measures are shown in Table 1.

Table 1. Description of specific measures about different tillage treatments.

Tillage treatments	Description of practical measures
MT	Use a single plowshare to plough 10-20 cm shallowly, remove all straws after the crops are harvested, and leave the ground bare on the winter slack period.
ST	All crop straws are crushed to cover the ground after the crops are harvested under ST, and the depth of single subsoiling shovel is 30-35 cm and the width is 40-60 cm. The subsoiling and ploughing are rotated before the crops are planted, so as to keep the straw covered over the ground on the winter slack period.
NT	All crop straws are crushed to cover the surface without other mechanical rolling operations after the crops are harvested. No-tillage and subsoiling are rotated before crops are planted, and keep the surface covered with straw on the winter slack period.

Soil compaction was measured by SC900 soil compaction instrument, which was measured in the 0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, and 20 cm soil layers; three representative plants were selected from each plot for the determination of plant height and chlorophyll content. After the maize matures, the aboveground biomass, 1000-grain weight and crop yield were measured by weighing methods. The aboveground corn plants were sun-dried, bagged and dried in an oven to a constant weight and the plant yield was calculated and recorded after the grains were dried in an oven (Wang *et al.* 2021).

SigmaPlot10.0 software was used to draw and generate graphics. Significant statistical analysis was performed on the test data by IBM SPSS Statistics 22.0 using the LSD method, and the significance test level was $P < 0.05$.

Results and Discussion

With the increase of soil depth, soil compaction under different tillage treatments showed an overall trend of first increasing, then decreasing, then increasing and finally decreasing (Fig. 1). Under 3 rotational tillage systems, the variation range of soil compaction for the NT and ST treatments was smaller than that under conventional MT, and the variation of soil compaction in different soil layers for the MT treatment was higher. The maximum value was 1007 kPa at the 17.5~20 cm soil layer, and the soil compaction under MT treatment was greater than that under NT and ST treatments. At the different growth stages in maize, it was found that the soil compaction under the MT treatment showed an increasing trend, and the soil compaction under the NT and ST treatments tended to be stable and no longer increased (Fig. 1). These results

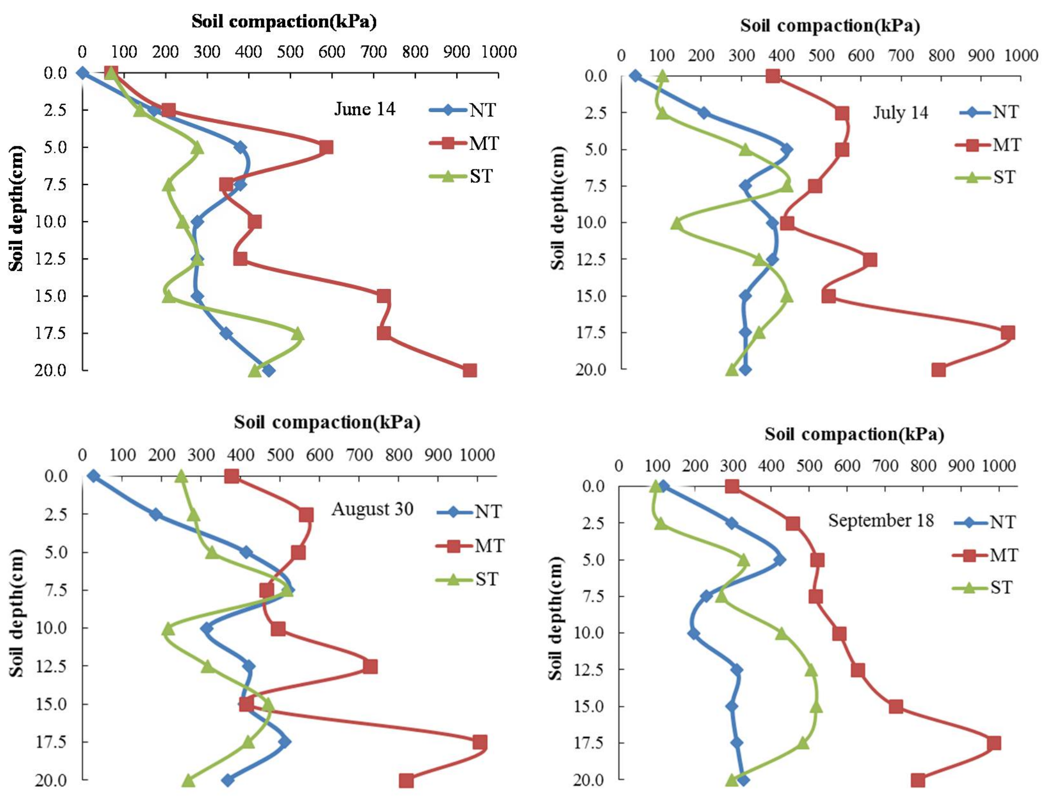

Fig. 1. Soil compaction under different tillage treatments and different time periods. MT: traditional shallow moldboard plow tillage with straw removal; ST: sub-soiling/ plow tillage /sub-soiling rotation with straw mulch; NT: no-till/sub-soiling/no-till rotation with straw retention.

showed that in appropriate tillage practices could cause soil particles to migrate and settle, reduce the number and structural stability of aggregates, disrupt surface vented pores and decrease retention and transmission of water and solutes, resulting in the compaction of subsurface soil and the formation of plough pan layer (Zhou *et al.* 2009). Previous studies on soil compaction on plant root growth have showed that the cell turgor pressure of plant root was generally about 700~1200 kPa. If the soil compaction was higher than the cell turgor pressure value of plant root, plants will be mechanically stressed, which will affected the growth and nutrient absorption of plant roots (Mari *et al.* 2008, Shi *et al.* 2016). Therefore, at the 0-20cm soil layer, the soil compaction and maize root system will be greatly affected due to the settlement of soil particles and the formation of plough pan in conventional MT treatment, which hindered the growth and development of maize. However, the NT and ST treatments under the conservation tillage method help to break the plough pan layer, reduce the soil compactness and buffer the drastic changes of soil compaction, and are beneficial to the growth and development of the maize root.

Plant height is an important indicator in the process of crop growth and has an important impact on crop yield in later stages. Among the three tillage treatments, the plant height values for the NT and ST were higher than those under MT treatment. With the passage of time, the plant height of maize showed a trend of rapid growth at first and then tended to be stable, and the crop height under NT treatment was the highest (Fig. 2). On June 23, the plant height of maize under NT and ST increased by 20.2 and 15.9%, respectively, compared to the MT treatment, and the difference between the NT and ST treatments and the MT was significant ($P < 0.05$). On September 14, the plant height of maize for the NT and ST increased by 8.6 and 1.9% compared to the MT treatment, respectively, and the difference between NT and MT was significant. These results showed that compared with conventional MT treatment, NT and ST have a positive effect

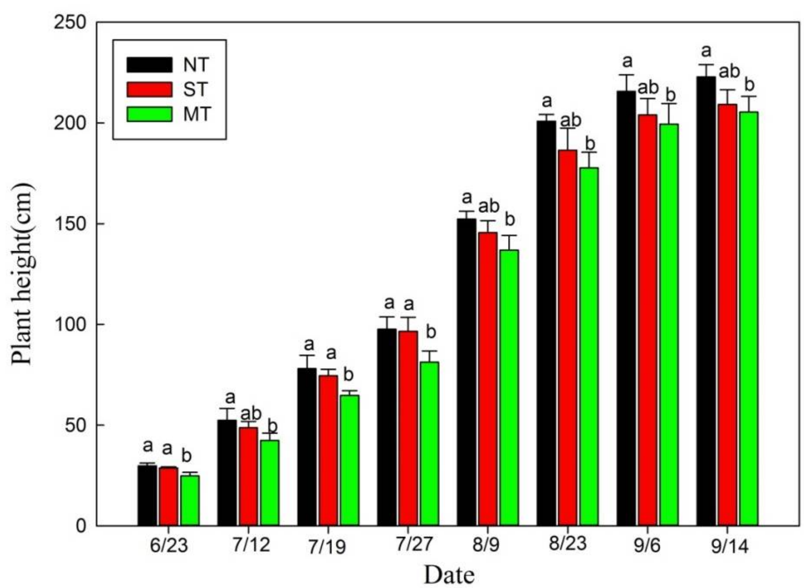

Fig. 2. Plant height under different tillage treatments at different growth stages (month/day). MT: traditional shallow moldboard plow tillage with straw removal; ST: sub-soiling/ plow tillage /sub-soiling rotation with straw mulch; NT: no-till/sub-soiling/no-till rotation with straw retention. Different lowercase letters indicate significant differences about plant height for the different tillage treatments at the same growth period.

in improving the plants growth and development, which were more favorable for the maize growth at the early stage, and the effect of plant height growth under NT treatment was the most obvious. Due to the different effects of different rotation tillage practices on soil compactness and water and fertilizer conservation characteristics, effects of maize roots on soil water and nutrient uptake were also different (Karlen and Rice 2015). Conventional shallow tillage increased the compactness of the subsurface soil, reduces the water and fertilizer retention properties of the soil, and accelerates the mineralization and consumption of nutrients, thus affecting the growth and later yield of maize (Blanco-Canqui and Ruis 2018).

Chlorophyll is an important substance for photosynthesis of higher plants. It is a key pigment that plants participate in photosynthesis to capture, transmit, and convert light energy to the reaction center. It plays an extremely important role in regulating the healthy growth of plants and the formation of crop yields (Wang *et al*. 2016). The chlorophyll content of maize for the NT and ST was higher than that for the MT treatment, and the chlorophyll value of maize increased rapidly in the early stage and tended to be stable in the later stage, which showed a similar trend with plant height (Fig. 3). On July 7, the chlorophyll content of maize for the NT and ST increased by 31.8 and 24.6%, respectively, compared to the MT treatment, and NT, ST treatment and MT treatment showed significant differences, respectively ($P < 0.05$). On August 28, the chlorophyll content of maize for the NT and ST increased by 15.9 and 8.1% compared to the MT, respectively, and the difference between NT and MT treatment was significant. The above results showed that different rotation tillage practices produced different effects on the chlorophyll value of plants, and the leaf color of plants for the NT and ST had better photosynthetic effect and greener leaf color than that under MT. The reason might be that the conventional MT treatment affected the compactness of the soil and the characteristics of water and fertilizer retention, which limited the absorption of soil water and nutrients by the maize root system to a certain extent, and the leaf color appeared yellowing and whitening, resulting in low chlorophyll content, which was not conducive to the healthy growth and high and stable yield of crops at the later stage.

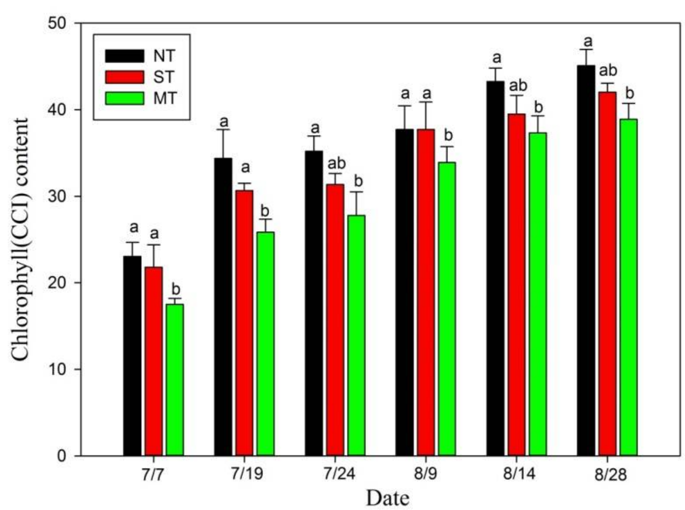

Fig. 3. The chlorophyll content of maize under different tillage treatments at different growth stages (month/day). MT: traditional shallow moldboard plow tillage with straw removal; ST: sub-soiling/ plow tillage /sub-soiling rotation with straw mulch; NT: no-till/sub-soiling/no-till rotation with straw retention. Different lowercase letters indicate significant differences about maize chlorophyll content for the different tillage treatments at the same growth period.

Different tillage treatments showed significant effects about the fresh weight, dry weight, 1000-kernel weight and yield of maize plants ($P < 0.05$), and NT and ST treatments under conservation tillage had improved effects on the aboveground biomass and yield of maize (Table 2). The fresh weight and dry weight of maize plants showed the order of MT< ST < NT. The dry weight of plants for the NT and ST treatments increased by 24.3 and 15.7%, respectively, compared to the MT, and the difference was significant. The 1000-kernel weight and yield of maize were in the order of ST > NT > MT, and the yield of maize for the NT and ST treatments was 11.9 and 14.9% higher than that of MT treatment, respectively. There were significant difference in maize yield for the NT, ST and MT treatments, and the yield was the highest under the ST treatment, but it was not significantly different from the NT treatment. In summary, due to conventional intensive shallow moldboard tillage and straw removal for the MT, it disturbs soil and fragments the tillage layer soil greatly, causes soil particles to migrate and settle, decreases the number of well-structured aggregates, disrupts the ventilation pores of the topsoil, decreases retention and transmission of water and solutes, and ultimately results in soil compaction and low soil moisture content. These effects further hindered root growth and water and fertilizer absorption, which ultimately affected plant growth and crop yield. However, the disturbance and impacts to natural soil was slight for the NT and ST with crop straw residues mulch, and increased soil moisture infiltration and retention capacity (Das *et al.* 2018). In addition, NT and ST help to disrupt the plough pan, promote the formation and stability of well-structured aggregates, and increase the SOM content and porosity, which were beneficial to reduce soil bulk density, optimize soil physical structure (Alam *et al.* 2017) , promote the increase of chlorophyll content and the growth and development of stalks, and increased maize yield.

Table 2. Aboveground biomass and yield of Maize under different tillage treatments.

Treatments	Plant fresh Weight (kg)	Plant dry Weight (kg)	Plant moisture content (%)	1000-kernel weight (g)	Theoretical yield (Kg /667m^2)
NT	0.34 ± 0.02 a	0.29 ± 0.02 a	15.67 ± 2.08 a	315 ± 1.13 b	567.51 a
ST	0.32 ± 0.01 a	0.27 ± 0.01 a	15.68 ± 0.58 a	326 ± 0.58 a	582.73 a
MT	0.27 ± 0.02 b	0.23 ± 0.02 b	14.67 ± 1.15 a	301 ± 0.86 c	507.05 b

MT: traditional shallow moldboard plow tillage with straw removal; ST: sub-soiling/ plow tillage /sub-soiling rotation with straw mulch; NT: no-till/sub-soiling/no-till rotation with straw retention. Different lowercase letters indicate significant differences about aboveground biomass and yield of maize for the different tillage treatments.

Based on the planting experiments of different tillage treatments on maize plant height, chlorophyll content, plant dry weight and soil compactness, it may be concluded that different tillage practices had different effects on soil compaction, maize physiological growth index and yield. Compared with conventional shallow moldboard plow tillage, the practice of no-till and subsoiling with straw retention help to reduce soil compaction, prevent the formation of plough bottom, and has a positive effect on nutrient uptake by maize roots, plant height and chlorophyll content. Meanwhile, the physiological growth index of maize was improved, and maize yield was increased. The maize yield for the NT and ST treatments increased by 11.9 and 14.9%, respectively, compared to the MT treatment. Therefore, NT and ST under conservation tillage are favourable measures to improve soil physical structure, increase plants height and chlorophyll content, and promote crop growth and yield.

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