Impact of Conservation Tillage on Some Soil Physical Properties and Soybean Yields(*Glycine max* L. Merrill)

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Abstract: The great challenge in north Songnen Plain, China is soil degradation and dry period and sandstorm attacking during soybean planting season. The objective of this work is to assess the effects of no-tillage and reduced tillage systems on soil temperature, soil water storage, soil compaction and its effects on soybean yields in a productive soil. The determinations were carried out in 2008. Notillage (NT) showed higher water storage than both reduced tillage (RT) and conventional tillage (CT) during the soybean planting season. Mean soil temperatures were lower under NT than under both RT and CT, and similar between RT and CT during the initial period. Thermal amplitude was lower under NT than under both RT and CT, and was similar between RT and CT during the first growing stage (June 4 to June 19). Bulk density was higher under NT than under CT at 5-20 cm depth, and no different between RT and NT at 10-20 cm soil depth. Penetration resistance performed differences between tillage systems, being higher under NT than under RT and CT at 0-20 cm depth. Grain yields showed no significant differences between tillage systems. Results suggested that application of NT/RT at local climatic and soil conditions could reduce soil water deficiency/sandstorm-attacking during soybean growing season without affecting soybean grain yields in short terms of conservation tillage.

Key words: Tillage; Soil water; Soil temperature; Soil physical properties; Soybean yields

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保护性耕作对土壤部分物理特性及大豆产量的影响

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摘 要:研究了免耕和少耕对松嫩平原地区农田土壤温度、土壤水分、土壤紧实性等物理特性和大豆产量的影响。结果表明:在春季大豆播种期,免耕处理(NT)土壤含水量高于少耕(RT)和传统耕作(CT)。在大豆生长前期,免耕条件下的土壤平均温度低于传统耕作和少耕,传统耕作和少耕接近,免耕模式的土壤温度日较差低于少耕和传统耕作。5~20 cm深度内,免耕条件下的土壤容重高于传统耕作,在10~20 cm深度内,免耕和少耕接近。不同模式间的土壤机械阻力表现出差异,在0~20 cm深度内,免耕高于少耕和传统耕作。不同耕作模式间的大豆产量差异不显著。短期保护性耕作试验结果表明:在当地气候和土壤条件下应用少免耕模式,能够减少春季播种期间土壤水分损失和沙尘暴侵袭造成的危害,同时对大豆产量并没有造成不利影响。

关键词:耕作;土壤水分;土壤温度;土壤物理特性;大豆产量

1 Introduction

Nen River Plain was an alluvial plain created by the sediment of Nen River (Fig. 1). Daxijiang State Farm is located at north Songnen Plain which is distributed largely in the area of Nenjiang County of Heilongjiang province and partly in Hongyan region, Inner Nongolia. The great challenges for local farming system is soil water deficiency, frequent sand storm-attack, and topsoil erosion during soybean planting season which can affect adversely soybean planting and seed germination. The introduction of conservation tillage could avoid or reduce soil erosion, reduce sand storm-attack and water evaporation from soil surface. No-till-

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age could leave most crop residues and maintain undisturbed surface soil layer so as to give rise to changes of soil chemical, biological, and physical properties. Soil water content, soil temperature, soil bulk density, and soil penetration resistance are some of soil physical properties affected by tillage systems. Changes in soil physical properties could be attributed to the adoption of conservation tillage related to the factors of weather conditions, management history, and soil types, etc.

Soil water content is a factor affected by tillage systems. Several authors found water content in soil was greater on zero-tillage compared to conventional-tillage plots[1-3]. Some authors indicated that no-tillage resulted in higher steady state infiltration rate and higher soil water storage as compared to moldboard plowing and chisel plowing[4-5].

The decrease in soil temperature is due to the influence of surface residue by reflecting solar radiation and insulating the soil surface[6-7]. Ma et al[8] found that the soil temperature under whole covering straw + minimum tillage was still the lowest. Low soil surface temperatures can adversely affect emergence, and seedling growth under no-tillage in mid-latitudes[9]. Bulk density is considered to be a measure of soil quality due to its relationships with other properties[10] (e. g., porosity, soil moisture, hydraulic conductivity, etc.). Bulk density greatly influences air-water relations and potential productivity of a soil[11]. Conservation tillage practices can also impact soil physical properties, such as bulk density, total porosity, hydraulic conductivity and aggregate stability, both positively and negatively[10]. Some authors found greater bulk density under conservation tillage than under conventional tillage[12-13], however, some others did not find differences as for soil bulk density between tillage systems[14-15].

Soil penetration resistance was consistent with soil bulk density[15]. Ferreras et al [16] found greater mechanical resistance values under no-tillage than under conventional tillage. Soil penetration resistance has been observed to be greater under no-tillage than under conventional tillage systems[17-18].

The objective of the this work is to evaluate the effects of no-tillage and reduced tillage systems on soil water storage, soil temperature, soil bulk density and penetration resistance and its effects on soybean yields in a productive soil in short term, and in the end, to conquer the big problems such as soil water deficiency and sand storm-attacks during soybean planting season in North Songnen Plain of China.

2 Materials and methods

2.1 Site descriptions and soil

The trial (Fig. 1) was established at Hongyan of Daxijiang state farm, Inner Mongolia (latitude:49°29′44″N, longitude: 125°59′07″E) in April, 2006 where no-tillage system has been carried out from 2005. Soil was a Udic Haploborolls (USDA, Soil Taxonamy) / Haplic Phaeozems(FAO Soil Classification) with a silt loam soil texture (silt: 59.27%, sand: 19.81%, clay: 20.92%). The crop sequence was wheat-wheat-soybean. The experiment designed for randomized block with 3 replications, consisted of three treatments with 18 m width and 300 m long for each plot. The experiment comprised of three tillage treatment: Conventional tillage (CT) for 20 years with moldboard plowing and subsoil plowing, Reduced tillage (RT) with 2200 Field Cultivator of John Deere Tiantuo Co. LTD plowing followed with tiny harrow, and No tillage (NT) with 1820 Air Seeder of John Deere Tiantuo Co. LTD sowing directly into the mulch of previous crop. All plots was used of herbicide weed control before soybean seedling emergence in application of acetochlor (2 000 mL · ha^{-1}), clomazone (1 000 mL · ha^{-1}), and thifensulfuron-methyl (20.0 g · ha^{-1}), sprayed by 4 720 sprayer. Soybean cultivar Kenjian 23 was planted on May 21, 2008 using a John Deere 1820 planter. Distance between rows was 38 cm and plant population was 40 seeds m^{-2}. Ground cover with wheat residue was approximately 65% for NT. Plots were fertilized with 56 kg P_2O_5 · ha^{-1} (Diammonium hydrogen phosphate) and with 41 kg N · ha^{-1} (urea) while soybean was planted. Soybean was harvested on September 17.

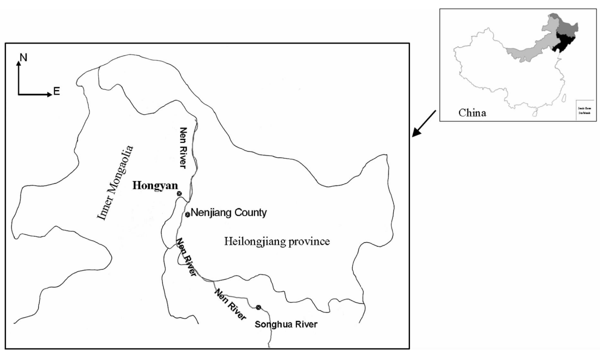


Fig. 1 Location of Hongyan site

2.2 Measurements

Measurement of soil moisture content was made using a TDR 100 Soil Moisture Meter on six occasions during soybean growing period at 10 cm increments from soil surface to 40 cm depth, and at 20 cm increments from 40 to 80 cm soil depth for each plot. The field measurement values of TDR100 were calibrated by User's Manual, Spectrum, Inc[19]. Soil volumetric water content was determined on May 21 (planting date), 3 developed trifoliolate leaves (V_3), full flowering (R_2), full pod (R_4), full size seed(R_6), and physiological maturity (PM), respectively. Soil water storage was calculated throughout soybean growing season according to volumetric soil water content accumulated into 0-80 cm soil depth considering the presence of a dense illuviation layer in the field.

Soil temperatures were recorded every one hour from June 4 to July 17 during soybean growing season with a temperature sensor (HOBO® RH8 Soil Temperature sensor, USA). 4 sensors were placed to 3-8 cm soil depth in inter-rows for each plot. The results were evaluated from soybean seedling emergence (June 4) to flowering period (July 17).

Penetration resistance (PR) was measured with 6101 Economy Soil Compaction Tester at 5 cm increments from soil surface to 30 cm depth. Measurements with ten replications were made at each depth interval for each plot from untracked inter-rows while the bulk density was determined, and the soil volumetric water content was 22.90% averagely.

Bulk density (BD) was determined on May 20, 2008. For each sample, soil cores (5.0 cm diameter and 5.0 cm height) were taken at 5.0 -10.0 cm, 10 -15 cm, and 15 -20 cm depth. Six soil cores were taken from random locations avoiding wheel tracked inter-rows in each soil depth of the plots.

2.3 Statistical analysis

ANOVA analyses were carried out to evaluate the values of water content, soil physical properties, soybean dry matter accumulation, and soybean grain yields (SAS procedures, SAS Institute Inc.). The results were graphed by Sigma Plot 10.0 (Systat Software Inc.).

3 Results and discussion

3.1 Weather conditions

It is a rain-fed agricultural region in Hongyan. The climate is semi-humid microthermal. The 29-year average annual precipitation is 508.0 mm. The distribution of annual precipitation (Fig. 2) was not uniform, and about 54.1% of it occurred in June and July, only 7.3% in May. Adequate rainfall in June and July can benefit soybean growth and reproduction. The three peak values appeared in early July, late July, and late August. There was a dry period from November of each year to April of the next year while the rainfall was near to zero level. As to the critical period for soybean planting in May, the average rainfall was below 10 (mm), and there were sandstorm attacks frequently in recent years which affected adversely on soybean seed germination and seedling emergence. Mean daily air temperature in mid May is suitable to soybean planting because the temperature below 10℃ occurred with the frequency of 62.0% in early May, and only 3.4% in mid May. Mean daily air temperature (19.97℃) in soybean growing season (from planting day to August 31) in 2008 was higher than the mean values (19.3℃) obtained from 1980-2008.

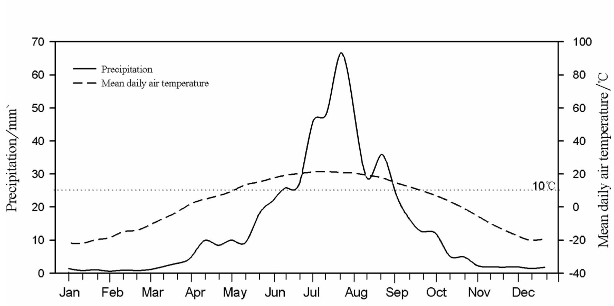
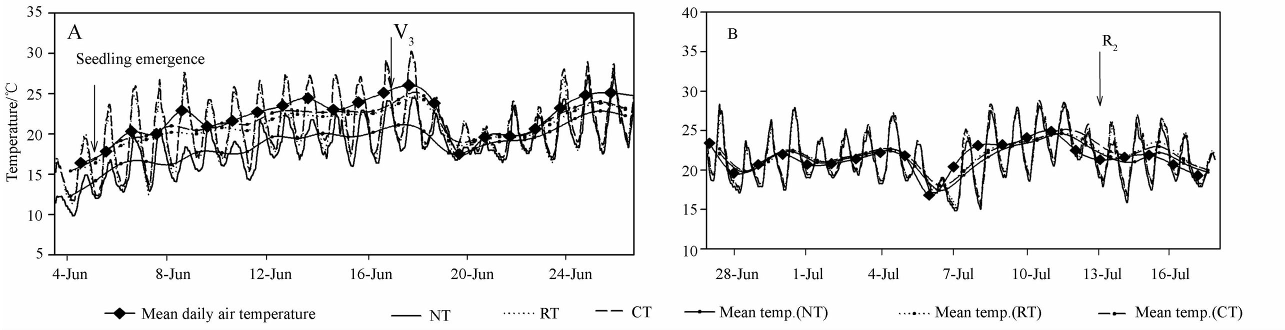


Fig. 2 Dynamics of average precipitation and mean daily air temperature from 1980 to 2008

3.2 Soil temperature

Mean soil temperature (Fig 3A, B) was lower under NT than under RT and CT at growing stage from June 4 to June 19 (vegetation growing stage). The results were similar to those published by Fabrizzi et al[20]. Differences between tillage treatments may be attributed to accumulation of the residue on the soil surface. High solar reflectivity and low thermal conductivity of the residues prevent an increasing temperature under NT[21]. Mean soil temperature was similar between different tillage systems at the advanced soybean growing stage from June 19 to July 16. Maximum temperature was lower under NT than under RT and CT and was similar between RT and CT at the initial growing stage from June 4 to June 19. However it was similar between different tillage systems at the advanced soybean growing stage. Minimum temperature was similar between tillage treatments during the first stage to advanced stage. Soil mean daily temperature averaged 2.5℃ lower under NT than under CT approximately, and was similar between RT and CT at first soybean growing stage. These results were due to the heating of bare soil in CT and RT. Thermal amplitude (Fig. 4) was higher under CT/RT than under NT at the initial growing period may be attributed to higher maximum soil temperature under CT/RT and similar minimum soil temperature between different tillage treatments. The bare soil cooled down more quickly than soil covered by residue during the night resulting different tillage treatments to reach similar minimum soil temperature values. These results were similar to those obtained by Fabrizzi et al[20], and Teasdale and Mohler[22].

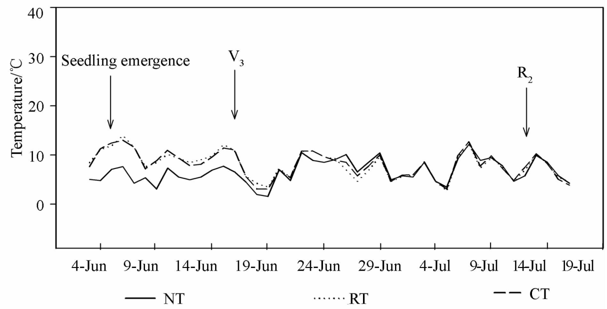


V_3 :3 developed trifoliolate leaves, R_2 :full flowering

Fig. 3 Soil temperature and daily mean temperature at 3-8 cm soil depth during soybean growing season under different tillage systems

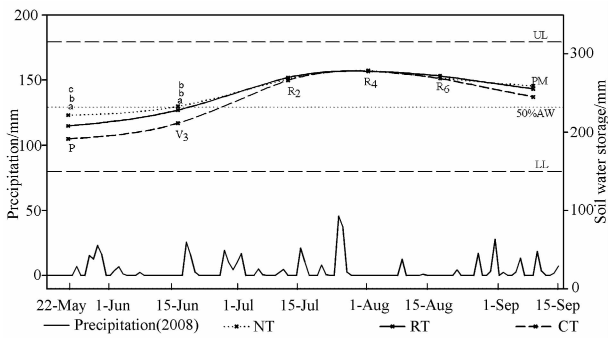
3.3 Soil water dynamics

Soil water storage (Fig. 5) was higher under NT than under RT and CT, higher under RT than under CT on soybean planting day and showed no differences between tillage treatments from R_2 stage to the end of soybean growing period. Soil water storage on soybean planting day under CT was below the threshold of 50% of available water and near to wilting point may due to its lower precipitation, and its bare and moldboard plowed soil which can give rise to higher soil water evaporation. Soil profile was recharged by adequate precipitation after V_3 stage and it was still above the threshold of 50% of available soil water from R_2 to PM stage attributed to the abundant rainfalls during this period. The differences between tillage treatments were similar to those obtained by Fabrizzi et al[20], and LI et al[3]. The results (Fig. 6) obtained from 0-30 cm soil depth on May 21 showed that soil water content was higher under NT than under RT and CT at 0-10 cm soil depth, attributed to its residue cover preventing the evaporation of soil water, and was the lowest at 0-30 cm soil depths under CT assigned to its moldboard plowing and sub-soiling practices benefiting the water evaporation from soil surface.



V_3 :3 developed trifoliate, R_2 :full fowering

Fig. 4 Soil thermal amplitude at 3-8 cm depth during soybean growing season

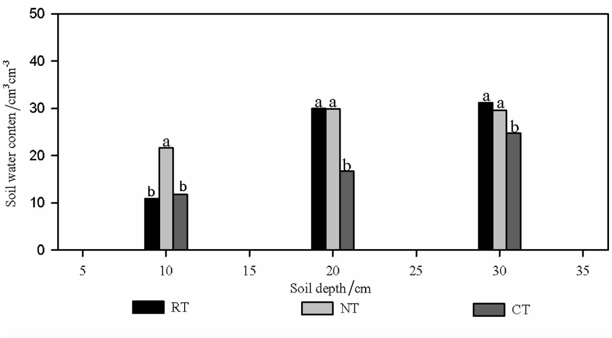


P: planting date, V_3: developed trifoliolate leaves, R_2: full bloom, flower in top 2 nodes, R_4: full, 3/4 in. pod in top 4 nodes, R_6: full size seed, in top 4 nodes, PM: physiological muturity, UL: upper limit of available soil water storage (field capacity), LL: lower limit of avialablesoil water storage (wilting point), 50% AW: 50% of available soil water storage. Letters above the 3 spline curves: differences beween tillage ($P < 0.05$)

Fig. 5 Soil water storage at 0-80 cm depth

3.4 Penetration resistance and bulk density

Tillage treatments had a significant effect on soil penetration resistance at 0-30 cm soil depth (Fig. 7a). Penetration resistance was higher under NT than under CT at 0-30 cm depth due to no tillage treat-



Letters above bars = differences between different tillage treatments ($P<0.05$)

Fig. 6 Soil water content($cm^3 \cdot cm^{-3}$) at planting date at 0-30 cm depth

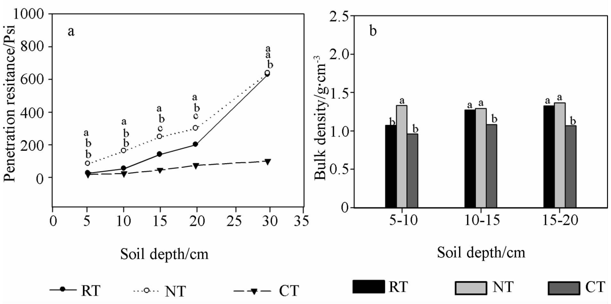
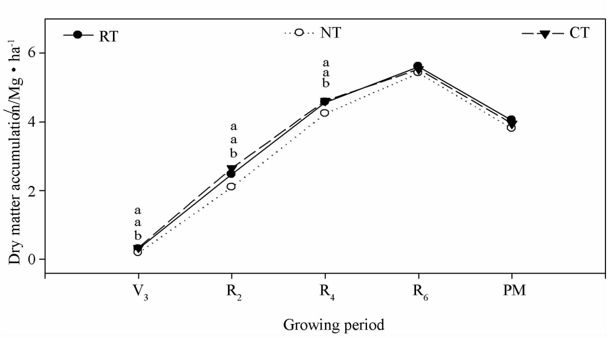


Fig. 7 a Penetration resistance at 0-30 cm soil depth, letters above 3 straight lines means differences between tillage treatments($P<0.05$); b Bulk density at 5-20 cm soil depth on May 20, letters above 3 bars means differences between tillage treatments($P<0.05$)

ment, was the lowest under CT at 0-30 depth attributed to its moldboard plowing and sub-soiling practices, and no differences were found between the values under RT and CT at 0-10 cm depth may due to the plowing practices. However, the values of penetration resistance under NT at 0 ~ 20 cm depth did not exceed the values of 2-3 MPa (290. 9-436. 4Psi) which is considered to be a threshold of root growth restriction[23-24]. The values at 20-30 cm depth under NT and RT exceeded the threshold of penetration resistance because of the existence of the plowing-pan, the dense subsoil layer. The results of differences between tillage treatments agreed with those obtained by O' sunbitan et al[13] and Fabrizzi et al[20]. Bulk density (Fig. 7b) under NT was the highest at 5-10cm depth, and was higher than CT at 0-20cm depth due to its no-till practices. The results agreed with those obtained by Baldev and Malhi[25] and did not agree with those obtained by Taboada et al[15], who claimed that Zero tillage did not affect bulk density under sandy loam and silty clay loam soils. However, the results did not exceed the value of 1.55 $g \cdot cm^{-3}$ which is considered to be the threshold of bulk density for restriction of root growth under silty loam soil[26]. The bulk density and penetration resistance were only measured at soybean sowing day in this experiment, the variation under different soil texture and precipitation should be determined and discussed next few years.

3.5 Dry matter accumulation and grain yields

Lower growth (fig. 8) under NT than under RT an CT was found from V_3 to R_4 due to its lower soil temperature at initial growing period and no differences of dry matter accumulation between different tillage treatments observed from R_6 may be attributed to similar soil temperature and adequate precipitation at advanced growing stage. The lower dry matter accumulation of corn and wheat under NT was reported by Fabrizzi et al[20]. Raji et al[27] reported that soybean growing on the CT plots had produced a substantially larger total plant dry biomass than those on NT plots, and the difference was maintained until R_6, and the grain yields were similar between CT and NT. Soybean grain yields in this experiment, however, were similar between different tillage systems (Table 1). Similar soil temperature between different tillage treatments during advanced growing period and dry matter accumulation after R_4 may be responsible for the grain yield performance.



Letters above the straight lines mean differences between tillage treatments($P<0.05$)

Fig. 8 Dry matter accumulation on during growing period under defferent tillage treatm ents

Table 1 Soybean grain yields

Treatments	Yields/kg · ha^{-1}
RT	2383.4 a
NT	2337.9 a
CT	2308.5 a
P- value	0.1716(>0.05)

Letters followed means of soybean grain yields show differences ($P<0.05$)

4 Conclusions

Soil water content was affected by precipitation throughout soybean growing season and was higher under NT and RT at 0-30 cm soil depth compared to CT adequate for soybean seed germination in soybean planting season. Soil temperature was lower under NT and affected soybean growth at its first growing stage. Soil thermal amplitudes were lower under NT than under both RT and CT, and were similar between RT and CT during the first soybean-growing stage. Soil bulk density and penetration resistance were higher under NT than under CT at 20 cm depth and did not exceed the threshold values indicated in the literature that could affect soybean growth and grain yields.

Soil water dynamics, soil temperature, and some other soil physical properties under short term conservation tillage, did not affect soybean grain yields significantly in Hongyan, North Songnen Plain. The introduction of conservation tillage (NT/RT) in the region may decrease soil water deficiency and sand-storm attack and increase soil water content in soybean sowing season without adverse affecting on its grain yields.

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