Effects of sub-soiling on soil physical quality and corn yield

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Abstract: Soil compaction and water scarcity are two major issues concerning agricultural production in North China Plain. In order to increase the utilization of natural rainfall in the dry farmland in the semi- arid area, break up plough pan, achieve the purpose of water conservation and increase the crop production. The effects of two treatments, i.e. sub-soiling and local rotary tillage on soil physical properties and yield of maize were compared in Jining from 2011 to 2013. The experiment was designed as a randomized complete block and ANOVA was used to assess the treatment effects. The results showed that: Except the surface soil layer (0-15 cm), the values of soil bulk density and penetration resistance are significantly (P<0.05) lower than those of rotary tillage during all growth period, especially during silking stage. What's more, the values of water content of sub-soiling at 25-35 cm soil layer were significantly (P<0.05) higher than those of rotary tillage by 9.45% (2012) and 8.64% (2013) during siliking stage. However, maize yield is significantly (P<0.05) increased by 6.08%-7.23% while the effect of thousand seed mass is closing between two treatments. In conclusion, this experiment has important value in extending sub-soiling management practices which may be a more sustainable approach to farming in North China Plain.

Key words: soils; crops; cultivation; bulk density; penetration resistance; water content; yield
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0 Introduction

In recent years, soil compaction resulting from farm machinery below the normal tillage depth presents a unique problem. Naeem Ahmad et al. [1] pointed out that compaction was caused by the use of heavy machinery, pressure from wheels, tillage equipment and ploughing at the same depth for many years. Many studies showed that wheel traffic of normal farming operations could compact the soil to a 45-50cm depth [2]. For example, Satendra Kumar et al. concluded that intense mechanization involving traffic of heavy machinery could deteriorate soil physical condition to compact the soil to 30 cm depth[3].

The main objective in agriculture production, so far, focused mostly on the increase of yield and production [4]. However, soil compaction has long been known to cause root restriction and yield reduction in many crops[5]. In the west Rolling Pampas region of Argentina, Botta et al. [6] reported subsoil compaction caused changes to the root system that affected shoot growth and crop yields, and Abu-Hamdeh[7] found corn yield was reduced by 26.8% and 14.5% in 2000 and 2001 as a result of compaction loads.

The reasons that variables measured in this experiment were bulk density, penetration resistance, water content and maize yield can be listed as follows. Compaction can result in the changes of soil parameters such as increased bulk density, water storage capacity and impedes of root penetration [3]. Berisso[8](2012) found the measurements of penetration resistance and bulk density clearly showed the persistence of subsoil compaction, and the level of soil compaction increases as the maximum bulk density attains a higher level and at a lower water content level.

With a given soil, soil bulk density is described to affect the soil structural conditions, such as soil

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moisture and particle-size[9]. In addition, many researchers suggested bulk densities from 1.3 to 1.7 mg/m^3 may limit root growth and decrease plant yield[10]. Haytham[11] thought that in most soil layers, tillage practice can improve bulk density and cone index in the order: ZT>RT>MT>CT (zero tillage, ZT; reservoir tillage, RT; minimum tillage, MT; and conventional tillage, CT).

Penetrometers have been a widely used technique to measure the soil resistance and developed for determining soil properties in the fields [12]. What's more, the data provided can be analyzed easily. It has been suggested by many researchers that high penetration resistance may limit root growth, thus decreasing plant yield. Through the data of rotating penetrometer, it can be suggested that relatively moist soils (matric potential as high as -100 kPa) can provide high mechanical impedance to root elongation[13], and low soil strength (0.5 to 0.8 kPa) in the loosened zone provided an impedance free zone for the root to proliferate[14]. Bengough and Mullins [15] reported that the maximum axial pressure that a root can exert is between 0.9 MPa and 1.3 MPa, whereas root elongation stops in soil with penetrometer resistance of 0.8-5.0 MPa depending on plant species and soil types. In addition, Materechera[16] had been measured soil penetrometer resistance in the profiles of four adjacent fields with maximum penetrometer resistance over 14 years and found that the unploughed and untrafficked soil profile had the largest soil water content and the least penetrometer resistance.

Some studies showed that sub-soiling can be used to remove a compacted layer if yield is limited due to compaction. Many experiments have been done to explore how sub-soiling effects soil physical quality and yield over the world. Subsoil tillage is suggested as adverse soil compaction that results in improved conditions for crop growth, which can increase water holding capacity, crop production and decrease the impedance to root penetration[14]. For instance, Michael[18] found that increased soil moisture and temperature is related to more rapid movement of water which is determined by subsoil tillage. It suggested that subsoil tillage may be useful in alleviating compacted subsoil layers. If compaction problem are not evident, sub-soiling does not result in better yields or better soil moisture availability and tractor traffic of machinery in secondary tillage may cause soil compaction[19].

In North China, shallow plough layer, solid plough pan and low soil productivity resulted from the application of rotary tillage in successive years and the problem has generated an interest in the possible benefits that could be obtained from a deep tillage such as sub-soiling. This study was conducted to explore the effects of sub-soiling on soil physical properties such as bulk density, penetration resistance and water content and to evaluate effects on maize yield compared with rotary tillage. The objective of the study is to find whether sub-soiling is a more suitable method in North China Plain.

1 Materials and Methods

1.1 Experimental Site

This study (2011-2013) was carried out in Shandong Province, which has a temperate and monsoonal climate with four clearly distinct seasons. The weather conditions such as the average annual precipitation and average annual accumulative temperature are summarized in Table 1.

Tabel 1 Meteorological factors at the site of experiment area

Characteristics	Value
Average annual precipitation/mm	707.1
Average annual accumulative temperature/℃	5 076.7
Average annual sunshine hours/hr	2 406.8
Growth period precipitation/mm	435
Growth period accumulative temperature/℃	2 630
Growth period sunshine time/hr	850

The experimental site was located in Jining City (34°25′-35°55′N and 115°54′-117°06′E) which is 38m above sea level in North China. Soil samples were collected at the depth of 0-30 cm to determine soil type which was classified as a yellow cinnamon soil. Some soil chemical properties of the experimental site before test are shown in Table 2.

Tabel 2 Some soil chemical properties of experiment site

Characteristics	Value
Soil type	yellow cinnamon soil
Organic matter content/%	1.35
Total N/(mg·kg^{-1})	850
Total P/(mg·kg^{-1})	700
Total potassium/(mg·kg^{-1})	18 570
pH value	7.01

1.2 Experimental method

The experiment was conducted with two treatments as follows, (T1): sub-soiling + flat planting, and (T2): ordinary rotary tillage + flat planting. According to Wang et al.[19] subsoiling depth should be in the range 20-30 cm, therefore working depth of subsoiler in the T1 treatment was more than the determined critical depth was 30 cm. Working depth of ordinary rotary tillage in the T2 treatment was

15 cm. Deep-digging machine was used for experiment in maize planting area.

The experiment was carried out in randomized complete block design and replicated in two blocks. Each plot was 12 m wide and 160 m long with an inter row spacing of 0.6 m distance. All field operations (planting, spraying, harvesting, etc.) were done on a regular schedule as permitted by weather conditions. Corn was planted in the experiment field after the soil was tilled. After emergence of seedling, the plant rows were harrowed with row harrower for fertilizing and watering for all trails. Fertilizer amounts were supplied based on soil fertilizer test.

1.3 Measured parameters

1.3.1 Bulk density (BK) and water content (WC)

Soil bulk density and water content were determined on an oven-dry basis by the core method. The undisturbed soil cores of 100 cm^3, 5 cm diameter were taken between rows from 0-15 cm, 15-25 cm and 25-35 cm soil depth. Samples were transported to the laboratory and then oven dried at 108ºC for 8 hours to determine dry-basis gravimetric soil water content and bulk density.

1.3.2 Penetration resistance (PR)

Before tillage and after tillage, the penetration resistance of soil was measured at random sites in each plot, using a recorder penetrometer. This instrument recorded the values at 5 cm increments from soil surface to 35 cm deep; penetrometer had a 30° cone as angle and a base of diameter 11.28 mm.

1.3.3 Yield

Maize yields and thousand seed mass were determined by manual harvesting, threshing and air-drying grain to 14% moisture content from 20m lengths of two rows taken randomly from each of the replicated treatments.

1.3.4 Statistical analysis

Mean values were calculated for each of the measured variables, and ANOVA was used to assess the treatment effects. Statistical analyses were conducted with SPSS 19.0.

2 Results and discussion

2.1 The effect of sub-soiling on soil properties

2.1.1 Bulk density (BD)

In 2011, the values of bulk density of T1 were significantly higher than those of T2 at 0-15 cm soil layer during seeding stage and silking stage. However, T1 can significantly decrease bulk density values at 15-35 cm soil layer compared with T2 during all growing stages, particularly in the 15-35 cm soil layer where bulk density of T1 had decreased by 4.79%-8.16%(2012) and 4.93%-6.58% (2013) in comparison with T2. In addition, the highest percentage reduction between two treatments was 8.16% at 15-25cm during silking stage in 2012.

The gap of bulk density values between T1 and T2 was rapidly closing, the reasons may the soil sedimentation and rainfall during maize growing stages.

Table 3 Mean bulk density at 0-35cm for T1 and T2 during different growing stages from 2011 to 2013

$g \cdot cm^{-3}$

Year	Treatments	Seeding Stage/cm			Silking Stage/cm			Ripe Stage/cm		
		0-15	>15-25	>25-35	0-15	>15-25	>25-35	0-15	>15-25	>25-35
2011	T1	1.34^a	1.41^a	1.49^a	1.35^a	1.42^a	1.50^a	1.35^a	1.46^a	1.50^a
	T2	1.23^b	1.37^b	1.50^a	1.27^b	1.39^a	1.50^a	1.31^a	1.42^a	1.49^a
2012	T1	1.30^a	1.35^b	1.42^b	1.32^a	1.35^b	1.45^b	1.34^a	1.39^b	1.46^b
	T2	1.28^a	1.44^a	1.52^a	1.33^a	1.47^a	1.53^a	1.35^a	1.46^a	1.55^a
2013	T1	1.27^a	1.33^b	1.37^b	1.30^a	1.35^b	1.42^b	1.30^a	1.35^b	1.41^b
	T2	1.26^a	1.39^a	1.46^a	1.28^a	1.44^a	1.52^a	1.29^a	1.42^a	1.50^a

Note: Values within a column in the same year followed by the same letters are not significantly different and letter *b* means significantly different at 0.05 level ($P<0.05$). T1: sub-soiling + flat planting, and T2: ordinary rotary tillage + flat planting, the same as below.

2.1.2 Penetration resistance (PR)

As it can be seen from the Table4, T2 had lower values of penetration resistance at 0-15 cm soil layer during all growing stages compared with T2 in 2011. However, the changes in PR were consistent with the positive changes in bulk density during the next two years. PR of T1 treatment had significantly ($P<0.05$) decreased by 12.07%-21.78% in 2011 and 11.17%-16.95% in 2012 at 15-35cm soil layer in comparison with PR of T2. The highest percentage reduction was 21.78% at 25-35 cm during silking stage in 2012. These results reflected that sub-soiling can break up hardpans.

2.1.3 Water content (WC)

Based on the statistical analyses, water content in sub-soiling plots was lower than that of rotary tillage at 0-15 cm soil layer during seeding stage, because sub-soiling treatment easily lost soil water in shallow soil layers at early stage. During the silking stage, it was found that the water content of T1 at >25-35 cm soil layer was significantly ($P<0.05$) higher than those of T2 by 9.45% (2012) and 8.64% (2013), which indicated the effect of sub-soiling on moisture content mainly at deep soil layer (>25-35 cm). In summary, the use of subsoiler can rupture the hard pan and facilitated precipitation infiltration and water storage in the soil.

Table 4 Penetration resistance at 0-35 cm for T1 and T2 during different growing stages from 2011 to 2013

kPa

Year	Treatments	Seeding Stage/cm			Silking Stage/cm			Ripe Stage/cm		
		0-15	>15-25	>25-35	0-15	>15-25	>25-35	0-15	>15-25	>25-35
2011	T1	20.04[a]	31.08[a]	39.86[a]	22.72[a]	32.58[a]	41.36[a]	27.54[a]	36.58[a]	45.36[a]
	T2	16.92[b]	31.04[a]	41.98[a]	17.18[b]	32.44[a]	42.60[a]	19.46[b]	31.77[b]	43.47[a]
2012	T1	18.28[a]	28.71[b]	36.30[b]	20.07[a]	28.93[b]	37.31[b]	19.46[a]	31.77[b]	43.47[a]
	T2	17.40[a]	32.65[a]	43.18[a]	19.08[a]	33.06[a]	47.70[a]	21.94[a]	37.26[a]	46.34[a]
2013	T1	23.90[a]	30.78[a]	35.60[b]	25.06[a]	31.66[b]	36.06[b]	24.32[a]	29.42[b]	35.14[b]
	T2	22.24[a]	35.00[a]	42.38[a]	25.70[a]	35.78[a]	43.42[a]	25.54[a]	33.12[a]	40.00[a]

Note: Values within a column in the same year followed by the same letters are not significantly different and letter *b* means significantly different at 0.05 level ($P<0.05$). T1: sub-soiling + flat planting, and T2: ordinary rotary tillage + flat planting, the same as below.

Table 5 Water content at 0-35cm for T1 and T2 during different growing stages from 2011 to 2013

%

Year	Treatments	Seeding stage/cm			Silking stage/cm			Ripe stage/cm		
		0-15	>15-25	>25-35	0-15	>15-25	>25-35	0-15	>15-25	>25-35
2011	T1	17.80[a]	18.33[a]	20.33[a]	20.41[a]	19.85[a]	21.60[a]	19.20[a]	18.38[a]	19.35[a]
	T2	17.21[a]	19.13[a]	20.84[a]	20.56[a]	20.49[a]	21.77[a]	18.16[a]	18.63[a]	19.42[a]
2012	T1	16.96[a]	18.58[b]	20.08[b]	12.03[a]	12.41[a]	14.71[b]	15.21[a]	17.11[b]	17.05[a]
	T2	17.18[a]	17.76[a]	18.42[a]	12.16[a]	12.59[a]	13.44[a]	14.91[a]	16.15[a]	16.63[a]
2013	T1	18.99[a]	20.80[a]	21.88[a]	18.08[a]	19.86[b]	21.26[b]	15.09[a]	16.86[b]	17.84[a]
	T2	19.16[a]	19.99[a]	20.80[a]	17.87[a]	18.81[a]	19.57[a]	15.18[a]	15.61[a]	17.10[a]

Note: Values within a column in the same year followed by the same letters are not significantly different and letter *b* means significantly different at 0.05 level ($P<0.05$). T1: sub-soiling + flat planting, and T2: ordinary rotary tillage + flat planting.

2.2 The effect of sub-soiling on crop yield

The soil force of corn plants measured by corn seed yield (Table6) was monitored from 2011 to 2013 at experimental fields. Treatments effects on thousand seed mass were not significantly different and the average increasing range was just about 2.35%. Average maize yields under T1 were 2.08 kg/hm^2-2.76 kg/hm^2 higher than under T2, which translated to an average increment of 2.09%-2.55% from 2011 to 2013.The yield of T1 was found to be higher than that of T2. Average maize yields from 2011 to 2013 under T1 were 6.48% higher than under T2 treatments while the highest increase amplitude was 7.27%.

Maize yield of the next year was observed to be less than that recorded during the previous year, which was attributed to SBPH (small brown plant hopper).

Table 6 Increasing range and percentage change on seed yield between T1 and T2 from 2011 to 2013

Year	2011	2012	2013
T1/(kg·hm^{-2})	36.29	45.97	40.73
T2/(kg·hm^{-2})	34.21	43.33	37.97
Increasing range	2.08	2.64	2.76
Percentage change/%	6.08	6.09	7.27

Note: T1: sub-soiling + flat planting, and T2: ordinary rotary tillage + flat planting.

3 Conclusions

The study conducted from 2011 to 2013 demonstrated that sub-soiling is associated with a substantial improvement in soil properties and yields in those areas affected by soil compaction resulting from ploughing at the same depth in successive years compared with rotary tillage. Data indicated that:

1) Compared with T2, T1 can significantly ($P<0.05$) decrease bulk density and penetration resistance values and the highest percentage reduction was 8.16% (2012) at 15-25 cm and 21.78% (2012) at 25-35 cm soil layer during silking stage, respectively. Sub-soiling can break up plough pan and decrease the values of soil bulk density and penetration resistance to a suitable level for crop growth.

2) The water content values of T1 at 25-35cm soil layer was significantly ($P<0.05$) higher than those of T2 by 9.01% (2012) and 8.01% (2013), which indicated that sub-soiling can facilitate precipitation infiltration and water storage in the soil.

3) No significant difference was found among thousand seed mass within different treatments while sub-soiling increased maize yield by 2.09%-2.55% from 2011 to 2013.

4) Marked effects of sub-soiling were mainly at

deep soil layer (25-35 cm) during silking stage. In summary, sub-soiling may be a more suitable method in North China Plain.

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[References]

[1] Naeem Ahmad, Fayyaz-ul-hassan, Ghulam Qadir. Effect of subsurface soil compaction and improvement measures on soil properties[J]. International Journal of Agriculture and Biology (IJAB), 2007, 9(3): 509－513.

[2] Al-Adawi S S, Reeder R C. Compaction and subsoiing effects on corn and soybean yields and soil physical properties[J]. Transactions of the American Society of Agricultural and Biological Engineers, 1996, 39(5): 1641－1649.

[3] Satendra Kumar, Saini S K, Amit Bhatnagar. Effect of Subsoiling and Preparatory Tillage on Sugar Yield, Juice Quality and Economics of Sugarcane (Saccharum species hybrid) in Sugarcane Plant-Ratoon Cropping System[J]. Society for Sugar Research & Promotion, 2012, 14(4): 398－404.

[4] Sessiz A, Alp A, Gursoy S. Conservation and conventional tillage methods on selected soil physical properties and corn (Zea May L.) yield and quality under cropping system in turkey[J]. Bulgarian Journal of Agricultural Science, 2010, 16(5): 597－608.

[5] Ingrid G Martínez, Christian Prat, Carlos Ovalle, et al. Subsoiling improves conservation tillage in cereal production of severely degraded Alfisols under Mediterranean climate[J]. Geoderma, 2012, 189/190(11): 10－17.

[6] Botta G F, Jorajuria D, Balbuena R et al. Deep tillage and traffic effects on subsoil compaction and sunflower (Helianthus annus L.) yields [J]. Soil & Tillage Research, 2006, 91(1):164–172.

[7] Abu-Hamdeh N H. Compaction and subsoiling effects on corn growth and soil bulk density[J]. Soil Science Society of America Journal, 2003, 67(4): 1213－1219.

[8] Berisso F E,Schjnning P, Keller T, et al. Persistent effects of subsoil compaction on pore size distribution and gas transport in a loamy soil[J]. Soil & Tillage Research, 2012, 122(6): 42－51.

[9] Mora J L, Lazaro R. Seasonal changes in bulk density under semiarid patchy vegetation the soil beats[J]. Geoderma, 2014, 235/236(12): 30－38.

[10] Houlbrooke D J, Thom E R, Chapman R, et al. A study of the effects of soil bulk density on root and shoot growth of different ryegrass lines[J]. New Zealand Journal of Agricultural Research, 1997, 40(4): 429－435.

[11] Haytham M Salem, Constantino Valero, Miguel Ángel Muñoz, et al. Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield[J]. Geoderma, 2015, 237/238(1): 60－70.

[12] Mome Filho, Edison Aparecido, Silva, et al. Compared performance of penetrometers and effect of soil water content on penetration resistance measurements[J]. Revista Brasileira de Ciência do Solo, 2014, 38(3): 744－754.

[13] Whalley W R, Leeds Harrison P B, Clark L J, et al. Use of effective stress to predict the penetrometer resistance of unsaturated agricultural soils[J]. Soil and Tillage Research, 2005, 84(1): 18－27.

[14] Thiyagarajan R, Jayashree G C, Mohankumar A P, et al. Performance evaluation of cone penetrometer device for measuring the subsoil compaction in mulched plots[J]. International Journal of Agricultural & Biological Engineering, 2013, 6(3): 19－27.

[15] Bengough A G, Mullins CE. Mechanical impedance to root growth: A review of experimental techniques and root growth responses[J]. Soil Sci, 1990, 41: 341－358.

[16] Materechera S A. Tillage and tractor traffic effects on soil compaction in horticultural fields used for peri-urban agriculture in a semi-arid environment of the North West Province, South Africa[J]. Soil and Tillage Research, 2009, 103(1): 11－15.

[17] Michael E Copas, Alvin J Bussan, Michael J Drilias, et al. Influence of Compaction and Subsoil Tillage on Soil Conditions and Pink Eye[J]. American journal of potato research, 2008, 85(5): 342－352.

[18] Heidari Soltanabadi M, Miranzadeh M, Karimi M, et al. Effect of subsoiling on soil physical properties and sunflower yield under conditions of conventional tillage[J]. International Agrophysics, 2008, 22(4): 313－317.

[19] Wang Ruili, Qiu Lichun, Li Baofa. Study on inter-row subsoiling machine for conservation tillage field [C]. In: The Proceedings of Session IV of 2004-CIGR International Conference, October 11-14, 2004, Beijing, 153－155.

深松对土壤特性及玉米产量的影响

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摘 要：土壤压实和缺水成为制约华北平原作物产量的 2 个重要因素，为了提高半干旱地区旱地对自然降水的利用率，打破犁底层，达到节约用水、提高作物产量的目的，该文于 2011 年至 2013 年，在济宁进行了深松和当地旋耕 2 种耕作方式对土壤物理性质和玉米产量影响的试验研究。试验采用随机化完全区组设计，并采用方差分析评价不同耕作方式的耕作效果。试验结果表明，除了表层土（0～15 cm），在作物的所有生长时期，深松耕作下的土壤容重和紧实度明显小于旋耕，尤其是玉米吐丝期。另外，在玉米吐丝期，深松下的 25～35 cm 土层含水量比旋耕高出 9.45%（2012 年）和 8.64%（2013 年）。深松能显著提高玉米产量达 6.08%～7.23%，但 2 种耕作方式对玉米的千粒质量影响相差不大。该研究对为华北平原提供一种更可持续的耕作方式—深松耕作具有重要意义。

关键词：土壤；作物；耕种；容重；坚实度；含水量；产量