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Review

The effects of no-tillage practice on soil physical properties

Zhang Fengyun[1,2], Wu Pute*, Zhao Xining[1] and Cheng Xuefeng[2]

[1]Institute of Soil and Water Conservation, Chinese Academy of Science and Ministry of Water Resources, Yangling, 712100 Shanxi, China.
[2]Department of Resources and Environment Science, Heze University, Shandong, 274000 Heze, China.

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No-tillage (NT) is now widely recognized as a variable concept for practicing sustainable agriculture. The objectives of this study were to summarize the effects of no-tillage on soil physical properties and outline the environment capability of no-tillage practice. The effect of no-tillage on soil bulk density was a debated question, and in order to make it comparable, the study conditions (soil texture, climate conditions, planting system, straw covering conditions on soil surface, soil water content and the no-tillage practiced period) were first addressed. Total porosity, a measure of the porous space left in the soil for air and water movement, was inversely related to bulk density. When the conventional tillage practices were used, the volume of soil macropores (>0.05 cm) was higher than that under no-tillage practice. With time, it decreased greatly, but the conventional tillage treatment still kept the lead. As a result of soil agitation, the soil aggregate rate under conventional tillage cropland was generally lower than that under the no-tillage practiced cropland. The studies of no-tillage on soil temperature and on crop yield also have conflicting results because of the absence of systemically long term monitoring, and there was little information on the effects of no-tillage on crop quality. Therefore, future perspectives of no-tillage research were put forward.

Key words: No-tillage, conventional tillage, soil physical property, yield.

INTRODUCTION

Serious soil erosion from arable land has been a major concern over the past centuries, resulting in the reduction of soil productivity and waste of resources. Conversation tillage, especially no-tillage practice has long been known to curtail erosion and dust as compared to conventional tillage practices which make the soil surface deficient in plant residues and always leave the soil vulnerable to erosion. For this reason, no-tillage, which is considered as the most promising conservation tillage, becomes one of the important topics in the cropping system research field.

No-tillage is a complex system which is highly related to the physical, chemical and biological factors, agricultural machines and no-tillage technology, etc. How to harmonize these factors is a major task, but there are still many disputations at different effects of no-tillage on soil and crop. In this study, the different studies were addressed and the reasons that led to them were analyzed.

NO-TILLAGE AND ITS CURRENT STATUS IN THE WORLD CONTEXT

No-tillage farming (NT) involves planting seeds in a narrow slot, trench or band opened by the planter with minimal disturbance of the surface crop residue and no additional tillage is done for seedbed preparation. Additional soil and residue disturbance is limited to fertilizer and pesticide placement and possible cultivation for weed control, if necessary. It can also be described as the introduction of seeds into unplowed soil in narrow

*Corresponding author. E-mail: gjzwpt@vip.sina.com. Tel: 86-02987082802.

Abbreviations: NT, No-tillage.

slots, trenches or bands with sufficient width and depth for seeds coverage and soil contact. There are four princi-ples for no-tillage practice: maintaining soil cover with plant residues, reducing mechanical soil disturbance by tillage, restricting in-field traffic to permanent wheel tracks, and using crop rotations and cover crops to foster soil fertility. No-tillage today appears to be relevant to the large commercial producer as well as the smaller farmers producing food and fiber for their family, and the principles of no-tillage crop production apply equally well to both of them. Retrenchment of cost and time and reduction of energy use, whether it is fossil fuel or manpower, will remain an important consideration in the future, with specific implications for the spread of no-tillage to all parts of the world.

It was estimated by the United Nations Food and Agricul-tural Organization (FAO) that no-tillage was practiced on more than 74.8 million ha worldwide until 2002. Approxi-mately, 52% of no-tillage was practiced in the U.S. and Canada, 44% in Latin America, 2% in Australia and 2% in the rest of the world, including Europe, Africa and Asia. There was a very big potential to bring this soil conserving technology to these parts of the world, although, limiting climatic and socio-economic factors have to be taken into account. USA is the country that has the largest area under no-tillage (22.41 million ha), while Paraguay is the leading country in terms of percentage of no-tillage accounting for all cropland (in USA, no-tillage practiced arable land accounts for only 19.7% and in Paraguay it accounts for about 60%) and it is not easy to get infor-mation about the spread of no-tillage in Asia, Africa and in the East European countries (Benites et al., 2003).

In China, the development of no-tillage is also very fast. No-tillage management is now practiced on more than 300,000 ha of cropland in ten provinces of northern China. The Ministry of Agriculture is planning to adopt no-tillage for the entire northern China in the coming 7 to 10 years (Gao et al., 2003).

Though, no-tillage is an important practice in terms of achieving efficient and sustainable land use, there is a requirement for scientists, landholders and farming-industry stakeholders to demonstrate that there is no ill-effect of removing tillage from the agriculture system. However, the concept of not disturbing the soil still clashes strongly with most farmers, who for years have disturbed the soil to obtain a soft medium for better crop growth. For the farmers, undisturbed soil seems to be harder and more resistant to root penetration than tilled soil. In fact, high soil strength has been proven to reduce and even stop root growth (Atwell, 1993). Measurements are needed to determine whether or not reduction or suppression of tillage can increase soil strength, disturbing root and plant growth.

To date, there has been an assumption that soil conditions generally improved with no-tillage, but it is important for this assumption to be supported by proof, both soil and crop, in order to fully support the future promotion and adoption of no-tillage as part of a broader set of conservation agriculture practices.

THE EFFECTS OF NO-TILLAGE ON SOIL PHYSICAL PROPERTIES

The effect of no-tillage on soil bulk density

Soil bulk density is one of the most common variables used to assess soil physical properties, which influences soil total porosity, size distribution and the penetration resistance of root, and further influences water and nutrient content, air conditions, temperature and the situation of root development in the soil.

The optimal soil bulk density for plant growth changes greatly in different soils. In general, low soil bulk density (high porosity) leads to poor soil-root contact, and high soil bulk density (low porosity) reduces aeration and increases penetration resistance (PR), limiting root growth (Cassel, 1982). Bulk density is related to natural soil characteristics such as texture, organic matter, soil structure (Chen et al., 1998) and gravel content (GC) (Franzen et al., 1994). It varies over the year due to the action of several processes: freezing and thawing (Unger, 1991), settling by desiccation and kinetic energy of rainfall, and loosening by root action and animal activity. Crop operations, especially tillage, may also alter soil bulk density. However, numerous experiments performed to compare the soil bulk density under no-tillage with that under conventional tillage systems have given different results and this part has always been the most contro-versial topic in no-tillage practice affecting soil properties. Some experiments demonstrated that bulk density were greater under no-tillage (Tebrugge et al., 1999; Wander et al., 1999; Hill, 1990; Vyn et al., 1993; Logsdon et al., 2000). Although, some experimental findings suggested a conflict between these conclusions, the decreased bulk density in no-tillage system was also indicated (Croretto, 1998; Dao, 1996; Shaver et al., 2002). In a third group, no differences in bulk density were also reported between tillage systems (Ferreras et al., 2000; Hammel, 1989; Mohammad et al., 2003).

All of the debated conclusions were based on the difference of soil texture, climate conditions, straw covering conditions on soil surface, soil water content, and the period of no-tillage implementation. The greater bulk den-sity when compared with conventional tillage which created a soft tilth layer might be produced by the lack of soil tillage, hardened soil and rain compaction, especially in the early years. While the lower soil bulk density when compared with the traditional methods by the end of the growing season may be derived from the more intense plant root operation, soil organism movement and the function of soil freeze and melt, as well as the well known increased soil water content and increased crop residue amounts, would also decrease bulk density in the 0 to 5cm soil layer.

For the fact that the factors that influence soil bulk density are interrelated, and only parts of using these variables may lead to misleading results, to make the results comparable, the factors should be combined when they are addressed, and long-term experiments are needed in order to study the influence of no-tillage on different soil types. It is important to continue research for more than three years after the no-tillage practice is introduced (Hammel, 1989; Mohammad et al., 2003).

The effect of no-tillage on soil porosity

Pore geometry and size distribution control water transmission and storage, and provide air and space for root growth. Internal and external stresses cause pore structure to be dynamic (Oades, 1993). A primary goal of soil management is the development and maintenance of an optimal pore structure for crop production. Sustaining crop productivity in agricultural soils requires a high degree of pore stability. Thus, describing soil structure in terms of stable pores is very important (Lynch et al., 1985).

Agricultural management affects pore-size distribution as well as pore continuity and tortuosity. When the conventional tillage practices were used, the volume of soil macropores (>0.05 cm) increased and was about 65% higher than that under no-tillage practice. After the jointing stage, the quantity of macropore under different tillage treatments all decreased, but the conventional tillage treatment still kept the lead (Zhang, 2003). Nevertheless, it was not good for soil water maintenance because of serious water evaporation, which has negative influences on the crop absorbing water due to the restriction of water reservation when the precipitation was adequate and of water transportation and effective water usage by the crop in the dry year. While it was also reported that the percentage of cylindrical macropores account for soil macropores and the quantity of micropore, porosity increased especially with the increase of no-tillage duration (Vanden Bygaart et al., 1999; Perfect et al., 1998). The increase of the micropore between 0.025 and 0.01 cm will inevitably lead to the resultant decrease of smaller micropores, and it is well known that the water in these smaller micropores is invalid to crop. This micropore character will be of benefit to water reservation in soil profile and can improve effective soil water holding capacity that will help improve the water absorption of crop.

Except the cases discussed in the foregoing, soil using no-tillage management would also show a greater number of horizontally oriented elongated macropores in the top 5 to 15 cm due to the combination of no-tillage and freezing-thawing, and these macropores will be of benefit to soil water holding and root absorbing. This phenomenon was proved by Vanden Bygaart et al. (1999).

The effect of no-tillage on soil aggregate

Soil aggregate is the pool of soil nutrient and is influenced by agricultural practices, such as tillage, cropping systems, the types of fertilizers applied, etc. To some degree, its content in a kind of soil can reflect the ability of soil application or reserving nutrients.

Aggregate-size distribution is significantly impacted by tillage. When no-tillage practices were used, different sizes of water-stable aggregates were formed under the influence of natural conditions due to the absence of artificial destruction, which implied that soil aggregate rate under no-tillage practice was greatly higher than that under conventional practices. It is explained that the conventional tillage practices disturb the soil structure, and soil aggregate is broken mechanically at this process which results in the rapid mineralization of soil organic materials and the decrease of the content of organism-inorganism compounded colloid in the cultivated layer. All the factors addressed in the foregoing lead to the reduction of the binding-force between soil particles and the decrease of water-stable aggregate. On the other hand, the annual input of residues in continuously cropped soils can increase the quantity of water stable aggregates relative to soils with a fallow phase in the crop rotation (Unger et al., 1998).

Studies carried out by West et al. (1992) indicated that the water-stable aggregate in the soil under no-tillage practice was 50% to 67% higher than that under conventional tillage. The result presented by Bear et al. (1994a, b) revealed that the micro-aggregate (<2.5 mm) in the soil under conventional tillage was unstable and much less than that under no-tillage practice. The result also showed that the micro-aggregate in no-tillage practiced cropland was 21% to 65% higher than that in conventional practiced one. Wei et al. (1990) reported that the soil aggregate of 0.01 mm in the topsoil of no-tillage practiced farmland was 4.4% higher than that in conventional prac-ticed cropland. He drew the conclusion that no-tillage was advantageous to the formation of water-stable aggregate in soil. Bruce (1990) indicated that the stability of soil aggregate of 0 to 10 mm under no-tillage increased significantly when compared with that under conventional tillage. Unger (1994) also pointed out that the diameter of water-stable aggregate under no-tillage could increase by 0.5 mm if conventional tillage was taken as the controlled object.

Aggregate stability is strongly controlled by the soil organic matter level (Oades, 1984; Haynes et al., 1996), which can, in turn, be influenced by tillage and stubble management practices (Chan et al., 1992). The state of aggregate is a function of aggregate formation and degradation processes and therefore may be expected to vary during a season. Temporal changes in aggregate stability have been reported on a range of soil types (Perfect et al., 1990). Studies also showed that the temporal fluctuation in soil structural stability within each of the cropping and tillage treatment was as large as, or larger than the changes observed between treatments (Chan et al., 1992; Perfect et al., 1990). Chan et al. (1994) found that no-tillage practice resulted in higher stability and lower seasonal fluctuation as far as soil aggregate was concerned. Furthermore, the extent of fluctuation varied with different cropping treatments. Perhaps, soil water content variation during the season was the most significant factor associated with the observed seasonal fluctuation in aggregate stability. Therefore, when the aggregate stability was investigated, soil water content was measured synchronously.

The effect of no-tillage on soil temperature

Soil temperature influences most physical, chemical and biological processes that occurred in soil. Many studies showed that soil temperature under no-tillage with straw mulch was higher in winter than under conventional tillage (Unger et al., 1998; Zhou et al., 1997). Proper reasons were also given that the reflective and insulative properties of straw mulched on surface decreased as it became dark from weathering, while lower temperature (Ren et al., 2002; Carter et al., 1985) and the decreased accumulated temperature of the tilth layer (Xiao et al., 1996; Li et al., 1995; Wang et al., 2002) under no-tillage were also reported when compared with that under conventional tillage during the first period of spring wheat growth, which was not good for crop production.

The slow recovery of soil temperature in early spring which postponed sowing and influenced seed germination and seedling development in the early growth period was one of the main shortcomings under the no-tillage for spring crops in north China; although, it was good for the tropical area and summer crop because the decrease of soil temperature could cut down the harms of high temperature on crop and effectively control water evaporation and improve the soil water content. Therefore, it is important to consider the promotion of conservation tillage where mean annual temperature was low, and cold-resistant crops would be the best choice when no-tillage practice was put into practice. Also, from the research conditions, the past research of the effects of no-tillage on soil temperature mainly focused on a period of monitoring. The result which showed that the soil temperature under no-tillage was higher than that under conventional tillage was mostly induced from the morning and evening soil temperature study, while the other result might be received by studying daytime soil temperature. In view of this situation, soil temperature monitoring during the whole year is badly needed.

THE EFFECTS OF NO-TILLAGE ON CROP GROWTH

A great deal of research (Ding et al., 2002; Deng et al., 2003) showed that no-tillage could generally get higher or equivalent crop yield when compared with conventional tillage, but there were still other results.

Kapusta et al. (1996) reported that farming system had little effects on corn yield in a consecutive 20-years-experiment and Ike (1986) also reported that the yield of cotton and maize had no difference between no-tillage and conventional tillage. Like the results demonstrated by most experiments, Tisdall et al. (1986) approved that the maize under no-tillage with straw mulch had yield increasing tendency when compared with conventional tillage. On the other hand, there were many other studies that had contrary result. Shad et al. (1986) pointed out that rice yield was decreased with the decrease of tiller number under conventional, reduced and no-tillage, which reduced consequently. Ogunremi et al. (1986) indicated that rice yield under no-tillage decreased by 35% when compared with that under conventional tillage, while Jiang et al. (2005) reported that the effects of no-tillage on crop yield had great relations with the growth stage of the experimental crop. These results might be having some relationships with soil water content, in that many researches reported that the effects of no-tillage increased as the soil water content was reduced. Also, those paradoxical results might be influenced by the different no-tillage periods and other factors, such as mulched straw quantity. On spring crop, most of the researches showed that lower soil temperature was found to be the restrictive factor. The lower soil temperature led to the lower rate of emergence which reduced lower yield in the end, but on summer crop, no-tillage led to higher crop yield. As a result of the increased soil water content at the crop growth period which accelerated the grain milk and increased grain weight, and the soil organic matter and other nutrients' content which resulted in melioration of soil physical, chemical and biological effects, the favorable soil conditions then led to well growth and significant crop yield improvement.

Maintaining good crop quantity is particularly important all over the world; however, the study about the effects of no-tillage on crop quality was very unusual up to date.

FUTURE PERSPECTIVES OF NO-TILLAGE RESEARCH

Along with the research of past decades, it is clear that the study of no-tillage has achieved rapid development. The influences of no-tillage on soil properties have also been widely reported, although, the effects of no-tillage on some soil physical properties need further research. From the standpoint of the present situation and the problems that need to be solved in the near future, we can see the emphasis of future study in the following areas:

1) There is still a debate on whether or not no-tillage practice would improve soil property. Farming system has significant effects on soil property in the layer that is tilled

for farmland ecosystem, and the change of farming system would lead to great changes on soil water, nutrient, thermodynamic properties, root growth and the activity of microbe which would, in some degree, affect the soil property. Also, samples were mainly collected in 0 to 30 cm soil layer, which would also affect soil properties through the complex effects from the outside environment. Therefore, the factors, such as soil types, cropping system, etc., should be considered when estimating the effects of no-tillage on soil physical properties.

2) The improvement of soil surface stubble after no-tillage practice leads to the increase of pesticide leaching and is absorbed by soil micro-aggregate or is combined to soil colloid. As the soil aggregate rate under no-tillage is higher, the quantity of pesticide that is absorbed by soil under no-tillage is greater which results in the more pesticide that is absorbed by crop; thus, it causes the pollution of products. Also, because the agricultural production of pollution could be directly reduced by the decreased use of pesticide, biological pesticide could be transmitted into no-tillage system. The mechanism of pesticide remains and transformation in soil and the relief of ecologically preventing and killing disease and pests will be one of the emphases in no-tillage practice research in the future.

3) Yield effects under no-tillage system maybe greatly related to soil operation such as straw mulching style, straw quantity and straw mulched time, and soil factors such as water content, nutrient and temperature. As the effects of no-tillage on crop growth are studied, all the environmental conditions should be taken into consideration to enhance the comparability between different results under different conditions. Improving the quantity of agriculture product is also one target of agriculture production. For the fact that the high yield and high quality is negatively correlated, how to harmonize them under no-tillage conditions as well as the whole agricultural system becomes one of the problems that need to be resolved. Currently, the research in China is focused on yield effects and there are little reports on the relationship between crop quality and no-tillage that lead to the negative effects on the increase of the economical benefit.

4) No-tillage consists of no-tillage machine, the technology of seeding, fertilizer application, straw mulching, ridging, pests and weeds' control, etc. How to combine the components in order to attain the optimal is one of the contents for no-tillage system research in the future.

5) At present, no-tillage technique in China had no standardization and criterion. Efforts should be made to consolidate no-tillage system, production safety and organic agriculture to further improve the standardization of no-tillage and improve crop yield and crop quality.

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