Soil Structure and Stability Features under Rotation Tillage

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Abstract. In order to improve the soil quality and soil environment, make crop grow ecologically and healthily, and reach the goal of increasing regional agricultural production and income, this paper studied the soil structure and stability under different rotation methods. The six treatments of rotation tillage were included: subsoiling-no tillage (N-S)T, subsoiling-tillage (S-C)T, tillage-notillage (C-N)T, notillage-notillage (N-N)T, subsoiling-subsoiling (S-S)T and tillage-tillage (C-C)T. Among them, tillage-tillage (C-C)T was regarded as the traditional method and control group. The result showed that: (1) compared with pre-experimental status and traditional measures, reasonable and scientific alternate farming measures were conducive to reduce soil bulk density, increase soil porosity, and improve soil permeability. In the 0-60cm soil layer, the effect of “no-tillage and subsoiling” treatment on the improvement of bulk density and porosity was the best. With pre-trial and conventional tillage as comparison, the soil bulk density decreased by 3.8% and 8.6%, and the soil porosity increased by 3.3% and 7.8%. (2) “No tillage - subsoiling” treatment can better improve soil stability in 0-40cm soil layer. The soil mechanical aggregate and the ratio of water-stable aggregate content can be increased by 11.4% and 5.2% in the layers beyond 0.25mm. Compared with the conventional tillage, the soil structure breaking rate and other factors were significantly decreased in rotation tillage. The effects of “no tillage-subsoiling” and “subsoiling-subsoiling” treatments on reducing the fractal dimensions of aggregates were significant.

1. Introduction
Soil structure was an important factor in determining soil quality and achieving high and stable crop yield, which mainly affects the distribution of gas, solid and liquid in soil and the transportation and preservation of soil nutrients [1]. The essential composition of soil was a kind of porous medium, which was arranged efficiently and orderly according to certain sequence and size [2]. The changes of soil bulk density, porosity and aggregate structure directly determine the quality and stability of soil structure. These three factors mainly affect the germination and growth of crops, thus finally affect the
yield of crops [3-5]. The mode of rotation tillage is mainly through organic combination of different conservation tillage measures, so as to realize effective rotation of tillage measures, periodic treatment of soil, so as to realize reform and improvement of soil physical properties [6]. The use of rotation tillage mode can provide a good seed bed and suitable growth conditions for crop growth. Through previous studies, it was found that there was a significant negative correlation between soil bulk density and porosity that was, bulk density increased and porosity decreased. The soil aeration characteristics were obviously improved with the decrease of bulk density. Soil with larger bulk density had a significant adverse effect on crop production performance. Rotation tillage model could decrease soil bulk density and increase soil porosity effectively, which not only increased porosity, but also obviously enhanced soil water retention function [7-8].

The aggregate structure of the soil constitutes the most basic unit of the soil, and its size and composition will affect the quality and stability of the soil [9]. The changes of distribution and characteristics of soil aggregates were significantly affected by different soil tillage methods. Soil aggregates were mainly comprehensively affected by different grain levels and different arrangement patterns, which also affect the distribution and continuity of soil pores, and then determine the hydraulic properties of soil. Soil aggregates were generally judged by the number and distribution of mechanical stability and water-stable aggregates [10]. With the deepening of the research, the evaluation of soil aggregates at this stage added the indexes such as mean geometric diameter, mean weight diameter and fractal dimension of aggregate and so on. That was, the mean weight diameter and mean geometric diameter were directly proportional to soil stability, and the larger the value of the two indexes, the better the soil stability. The fractal dimension was the opposite, the larger the fractal dimension, the worse the soil stability. It was of great significance for the selection of rotation tillage model and the organic combination of single tillage model to study the change of soil aggregate stability indexes under different rotation tillage models [11-12].

This study mainly studied the changes of soil bulk density, porosity, and the number of soil aggregate, distribution characteristics and relative stability indexes such as aggregate stability rate, mean weight/geometric diameter and fractal dimension in 0-40cm solum after spring maize harvest from 2007 to 2014. Try to find out the influence of different rotation tillage measures on soil structure, and provide scientific support for improving soil structure and improving its stability.

2. Materials and methods

2.1. Site description
The experimental site (35°19'N, 110°05' E, 900m H) was set in Ganjing Town, Heyang County, Weinan City, Shanxi Province, which was the area selected by Northwest University of Agriculture and Forestry Science and Technology in Weibei dryland with typical agricultural characteristics. The experimental years were 2007-2014. The mean rainfall in this area was 522.7 mm, the rainfall in the main growing period of the crops was about 392.8 mm, and the annual evaporation was 1832.8 mm.

2.2. Experimental design
The experiment began in 2007, and the long-term positioning experiment was carried out under the continuous cropping system of spring maize. The design treatment of the experiment was different tillage measures, and the experimental tillage treatment was divided into three types, respectively, ploughing (CT) No-tillage (NT) and deep loosening (ST), and choose the combination of different tillage or the same tillage in 3 tillage methods, the total number of combination tillage patterns selected is 6, as shown in Table 1. The location of the plot remained the same for many years during the experiment. In 2007, the tillage methods used in the experimental fields were all the traditional tillage methods. There are 21 test area in total, and the area of each test area is 22.5 m * 5 m = 112.5 m², and the total area is 0.27 ha.
Table 1. Sequence of soil rotational tillage systems from 2007 to 2014.

| Rotational system | Before treatment | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|-------------------|------------------|------|------|------|------|------|------|------|
| (N-S)T            | CT               | NT   | ST   | NT   | ST   | NT   | NT   |      |
| (S-C)T            | CT               | ST   | CT   | ST   | CT   | ST   | CT   |      |
| (C-N)T            | CT               | CT   | NT   | CT   | NT   | CT   | NT   |      |
| (N-N)T            | CT               | NT   | NT   | NT   | NT   | NT   | NT   |      |
| (S-S)T            | CT               | ST   | ST   | ST   | ST   | ST   | ST   |      |
| (C-C)T            | CT               | CT   | CT   | CT   | CT   | CT   | CT   |      |

2.3. Determination items and methods
Bulk density and porosity. In this paper, the key period of spring corn field, namely, before and after harvest of spring corn, was selected by using the general method of ring knife method. The soil samples were collected by using the standard ring knife of 5 cm in height and 5.04 cm in diameter for the determination of bulk density and porosity. Five sampling points were set up in each plot, the sampling depth and sampling interval were 60 cm and 20 cm, respectively. A total of 15 bulk density samples were taken in each plot, and the drying method was used [13].

\[ P = \frac{DS - W}{V} \]  \hspace{1cm} (1)

\[ SD = \left(1 - \frac{P}{SP}\right) \times 100 \]  \hspace{1cm} (2)

In the formula: P is soil bulk density (g cm\(^{-3}\)); DS is the total weight of drying soil and ring knife (g); W is ring knife mass (g); V is the ring knife volume (cm\(^3\)); SD is soil porosity (%); SP is soil specific gravity, generally 2.65 g cm\(^{-3}\).

Soil aggregate parameters. Affair determination of the stability of soil aggregates selection of harvest of spring corn in the experimental year, five sampling points were set up according to the method of soil diagonal sampling. The sampling depth and interval were 30 cm and 10 cm respectively. The samples collected from different solum were used to determine the relative indexes of soil aggregates. No backlog and no damage of the samples were brought back to the laboratory, and the stones and debris in soil samples were removed after natural air drying. Soil mechanical stability was determined by dry sieve method, and soil water stability was determined by wet sieve method [14-15].

\[ Wn = \frac{Wdn \ or \ Wwn}{200} \times 100\% \]  \hspace{1cm} (3)

\[ R_{0.25} = \sum_{n=1}^{i} (W_n) \]  \hspace{1cm} (4)

\[ MWD = \sum_{n=1}^{i} (\overline{X}_n \times W_n) \]  \hspace{1cm} (5)

\[ GWD = \sum_{n=1}^{i} (\overline{X}_n \times W_n) \]  \hspace{1cm} (6)

\[ WSAR = \frac{WSA}{MSA} \times 100\% \]  \hspace{1cm} (7)

\[ PAD = \frac{(DR_{0.25} - WR_{0.25})}{DR_{0.25}} \times 100\% \]  \hspace{1cm} (8)
\[
\frac{M(r < \bar{X}_n)}{M_t} = \left( \frac{\bar{X}_n}{X_{\text{max}}} \right)^{3-D}
\]  

In the formula: \(R_{0.25}\) is the aggregate content of the diameter > 0.25 mm aggregates,\%; \(M_{\text{WD}}\) is the mean weight diameter of aggregates, mm; \(G_{\text{MD}}\) is the geometric mean diameter of agglomerates, mm; \(X_n\) is the mean diameter of aggregates in a certain range, mm; \(W_n\) is the proportion of the mass of \(N\) particle aggregate, \%; both of dry sieve (\(W_{dn}\)) and wet sieve method (\(W_{wn}\)) can be calculated; \(M(r < X_n)\) is the weight of aggregates with diameter smaller than \(X_n\), g; \(M_t\) is the total weight of agglomeration, g; \(X_{\text{max}}\) is the maximum particle size of agglomerates, mm. D is the fractal dimension of aggregates.

2.4. Data analysis

Test data using SPSS (PASW Statistics 16.0) to make single factor analysis of variance (ANOVA), and EXCEL 2007 and Sigmaplo12.5 were used for data collation and mapping.

3. Results and Discussion

3.1. Effect on mean bulk density and porosity of soil in continuous cropping Field of Maize

Through the analysis of mean bulk density and porosity of 0-40 cm solum in spring maize continuous cropping field after the implementation of rotation tillage measure from 2007 to 2014, the results showed that the implementation of rotation tillage measure made the soil bulk density of spring maize continuous cropping field decrease obviously compared with that before the experiment. The bulk density of each treatment increased with the increase of solum. In 0-40 cm solum, the bulk density of each treatment was maintained at 1.24-1.42 g cm\(^{-3}\). With the difference of overyear tillage measures, the bulk density of each treatment is different. In the 0-60 cm solum, (N-S)T treatment had the smallest mean bulk density of 1.29 g cm\(^{-3}\); (C-C) T treatment had the highest mean bulk density of 1.40 g cm\(^{-3}\). In 0-20 cm solum, the soil bulk density of (N-S)T and (C-N)T were significantly improved compared with that before the test, and the decrease was 1.2% and 0.4%, respectively, and the soil bulk density was significantly different from that before the test (\(P<0.05\)). The mean value of soil bulk density in other soil rotation tillage models was higher than that before the test, and the increase was 1.0% to 9.8%. In the solum of 20-40 cm, the order of bulk density of each treatment is consistent with that of 0-20 cm. In 20-40 cm solum, the bulk density of soil was obviously higher than that of 0-20 cm solum, and there was no significant difference between pre-text and (C-C)T treatment, but there was significant difference between and other treatments (\(P<0.05\)). In the 20-40 cm solum, the mean bulk density of each treatment soil increased by 3.6% to 4.9% than that of 0-20 cm solum. The results show that the effects of three rotation tillage models on the mean bulk density of 0-40 cm solum were better than those of pre-text and the traditional tillage (C-C)T, which effectively reduces 1.8% to 3.8% and 6.8% to 8.6% respectively, and (N-S)T was the best, which was mainly because the organic combination of no-tillage and deep loosening could avoid excessive disturbance of soil and large mechanical compaction, and combined with timely soil loosening, so as to effectively achieved the improvement of soil structure. The soil bulk density increased slightly before the contrast experiment of three continuous tillage models, which was mainly related to the tillage treatments of the three continuous tillage model.

Rational rotation tillage model can effectively reduce soil bulk density, keep it at a lower level, and promote the overall loosening of soil and improve the composition of particle arrangement and structure within the soil [16-17]. The combination of no-tillage and deep loosening has the best effect, which was mainly because that the overyear deep loosening measures can effectively break the bottom of the plow, no-tillage can effectively avoid the rolling of the soil by the machine, and the rotation of the two measures every other year, which can achieve the goal of reducing the bulk weight and increasing the porosity.
3.2. Effects on the size of soil aggregates

After many years of research, many scholars no longer singly use more than 0.25 mm aggregate content to express the stability of soil structure, then calculation, they are treated with mechanical stability and water stable aggregate, respectively. Then the mean weight diameter and mean geometric diameter of soil aggregates are calculated to indicate the stability of aggregates [18]. The larger the mean weight diameter and the mean geometric diameter, the higher the cementation degree and agglomeration degree of the mean particle size of soil aggregates, the stronger the stability. By studying and analyzing the soil aggregate in 40 cm solum after maize harvest from 2008 to 2014, we found that the mean weight diameter and mean geometric diameter of mechanical stability aggregates were higher than those of water stable aggregates. The mean mass diameter and mean geometric diameter of mechanical stability increased with the increase of soil depth, and the two indexes of water stable aggregate decreased with the increase of solum, as shown in Figure 2. The mean weight diameters of (N-S)T, (S-C)T, (C-N)T, (N-N)T and (S-S)T treatment under dry sieve method in 40 cm solum were higher than those in traditional tillage (C-C)T by 25.6%, 22.8%, 5.1%, 16.5% and 12.4%, respectively, the difference of each treatment and (C-C)T was obvious (P<0.05). In 0-30 cm solum, the mean geometric diameter of (N-S)T treatment was the largest, and the mean geometric diameter of each treatment increase of (C-C)T was 5.3% to 32.4%. Under wet sieve, the mean values of mean weight diameter and mean geometric diameter of (N-S)T and (S-C)T treatment in 0-40 cm solum were higher than that of traditional tillage (C-C)T treatment increased by 21.4%, 23.1%, and 14.6%, 13.9%, respectively. In summary, (N-S)T treatment can effectively improve soil stability, that is, organic combination of no-tillage and deep loosening can improve soil structure. Many scholars had shown that maize field can effectively increased the content of water stable aggregates in surface soil under continuous no-tillage treatment [19-20]. The results of this study showed that the combination of no-tillage and deep loosening can effectively increase the grain size ratio of > 0.25 mm, improve soil mechanical stability and water stability, which was the best effect to improve soil structure.
Figure 2. MWD and GMD of dry and wet sieving under different tillages.
3.3. Effect on stability parameters of soil aggregates

Water stable aggregate stability rate and aggregate fragmentation rate can also better reflect the stability of soil. By analyzing the difference of soil aggregate quantity and distribution from 2008 to 2014 (Table 2), the stability of soil aggregates was significantly affected by different tillage methods. Under (N-S)T, (S-C)T and (S-S)T treatment, the stable aggregate rate of soil water decreased with the increase of solum, but the other three kinds of continuous tillage models were not obvious. In the 0-10 cm solum, the order of stability rate of water stable aggregates was following the order: (N-S)T>(S-S)T>(S-C)T>(N-N)T>(C-N)T>(C-C)T. In the 20-40 cm solum, mainly the stability of (N-S)T treatment was the highest, followed by that of (S-C)T treatment. A comprehensive study on the effect of soil water stability aggregate stability rate in 0-40 cm solum was carried out. The highest mean value under (N-S)T treatment was 19.2%, and the stability of other treatments was higher than that of traditional tillage treatment (18.4%-76.2%), and the difference between treatments was significant (P<0.05). Aggregate failure rate is also one of the indicators of soil stability, generally the damage rate of soil aggregate increases with the increase of solum. Because of the rotation of tillage methods, the index law does not show a significant rule. By analyzing the mean value of soil aggregate failure rate in 0-40 cm solum, (N-S)T treatment was the lowest by 81.3%. Each treatment was lower than that of traditional tillage(C-C)T by 1.8% to 8.4%. Through the analysis of the difference of stability index, the results show that the soil damage rate and stability can be reduced and improved respectively and obviously by each rotation tillage treatment, and (N-S)T treatment was the best.

Table 2. Effect of different tillage models on the stability parameter of soil aggregates.

| Index  | Treatment | Soil depth/cm |
|--------|-----------|---------------|
|        |           | 0–10          | 10–20         | 20–30         | 30–40         |
| (WSAR) | (N-S)T    | 21.86±0.38aA  | 18.02±0.54aA  | 17.79±0.75aA  | 17.09±0.18bAB |
|        | (S-C)T    | 18.98±0.31bAB | 17.57±0.76aA  | 15.56±0.99bB  | 13.18±0.60bB  |
|        | (C-N)T    | 18.00±0.23bBC | 12.51±0.39eC  | 10.71±0.33cC  | 11.99±0.45dC  |
|        | (N-N)T    | 14.99±1.41cC  | 12.04±0.38dC  | 12.52±0.67bBC | 10.28±0.71cD  |
|        | (S-S)T    | 21.79±0.30aA  | 16.05±0.52bB  | 13.36±0.90bB  | 12.39±0.23cC  |
|        | (C-C)T    | 14.06±0.83cC  | 11.59±0.65dC  | 7.99±0.18dD   | 10.02±0.86dD  |
|        | (PAD)     | 78.21±0.82dD  | 82.91±0.82cB  | 81.98±0.23dD  | 82.21±0.71cC  |
|        | (N-S)T    | 86.82±0.87aA  | 84.44±2.65bcB | 82.43±1.32dD  | 81.02±1.71dC  |
|        | (S-C)T    | 82.00±0.73cC  | 87.49±0.93aAB | 89.29±1.51bB  | 88.01±1.28bB  |
|        | (C-N)T    | 85.01±0.64bB  | 87.96±0.91aAB | 87.48±0.62cC  | 87.90±2.08bB  |
|        | (N-N)T    | 78.14±1.32dD  | 83.95±0.16eB  | 86.64±1.59cC  | 87.61±1.30aA  |
|        | (S-S)T    | 85.94±1.22bAB | 88.41±1.30aA  | 92.01±1.06aA  | 89.98±1.66aA  |

3.4. Effects on fractal dimension characteristics of soil aggregates

The fractal dimension of soil is a parameter that reflects the geometric shape of soil structure. The fractal dimension of particle size distribution of soil aggregates is an index to reflect the distribution of soil water stable aggregates and the influence of water stable aggregates on the structure and stability of soil, that is, the smaller the fractal dimension of aggregates, the more stable the soil, and the structure is better [21]. Figure 3 shows the distribution of fractal dimension of 6 different kinds of soil aggregates in 0-40 cm solum under dry and wet sieve treatments. The mean fitting R² of fractal dimension of aggregates treated by dry sieve method is 0.92. In 0-40 cm solum, the fractal dimension of soil aggregates decrease with the increase of soil depth, and show the same trend. The fractal dimension of soil aggregate was 2.26-2.58, and in 0-40 cm solum, the order of mean fractal dimension of each treatment was (N-S)T<(S-S)T<(N-N)T<(C-N)T<(S-C)T<(C-C)T. The mean fitting R² of fractal dimension of aggregates under wet sieve treatment was 0.86. The fractal dimension of soil aggregates decrease with the increase of solum, and the fractal dimension of aggregates was 2.93-2.96. Under wet sieve treatment, the trend of fractal dimension of soil aggregates was opposite to that of dry sieve method, and decreases with the
increase of solum, and the performance trend was same among the treatment, the fractal dimension of aggregates was 2.93 - 2.96 among which, the mean value of fractal dimension of 0-40 cm solum in (N-S)T treatment was the smallest.

4. Conclusion
Soil porosity decreases with the increase of soil depth. In this study, soil porosity was the largest in no-tillage and deep loosening rotation tillage models and soil aeration was the best. Therefore, it was beneficial to seed germination and growth, in which the combination of no-tillage and deep loosening was the best. Through the analysis of soil water stability rate, mean mass diameter, mean geometric diameter and fractal dimension and other related indexes, the model of no-tillage and deep loosening rotation tillage was the best, followed by the combination of deep loosening and continuous ploughing tillage and deep loosening and ploughing, and the lowest stability was traditional tillage and ploughing and continuous ploughing.

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