Study on the structure of topsoil aggregates for Mu Us sandy land in China

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Abstract. It is significantly important to study the topsoil aggregates occurrence for land use, recovery at regional scale and protecting from topsoil sandification. Based on land sampling through experimental analysis and correlation statistics, this paper studies on the characteristics and the correlation of different habitat topsoil aggregates in Mu Us region. The results show: The soil aggregates are mainly micro aggregates in the range of 0.5~0.25mm in this area. The contents of soil aggregates are different in different depths which are 0cm>10cm>20cm respectively. The contents of soil aggregates are also different in different habitats, and the contents of >1mm soil aggregates are highest 4.27% and 3.55% in poplar woodland and Calamagrostis epigeios grassland sampled at the 0cm depth. After analyzing the stability of soil aggregates, the development of soil aggregates is not sufficient, and the stability of soil aggregates is poor. The soil structure is gradually optimized in the better area of vegetation protection or restoration.

Key words: Mu Us sandy land; Aggregates; Stability

1. Introduction
Mu Us sandy land is a region belonged to the tail-end of monsoon dry and little rain, the ecosystem environment was weak, the sandy land was large. And it is one of the much more serious areas of wind erosion and sandification in China. With the background of wind erosion and sandification, the wind erosion process by the action of wind force is also the deterioration process of topsoil structure. Therefore, studying on the structure of soil aggregates and the effects related factors, it has the
important significance not only in theory and practice, but on the very definition of wind erosion, the
influence in soil quality caused by soil degradation, and the related control.

Soil aggregates are glued by inorganic and organic matter, and their quantity and quality determine
the soil characteristics and fertility. Soil aggregates and organic matter is the base for keeping the soil
structure and fertility, they are integral while interacting, the former is the existence places for the later,
and meanwhile, the latter is also the exiting cementation substance of the former. The soil aggregate
stability and organic carbon characteristics have been paid much attention to studying in plantation
[1]. For the study of soil aggregate characteristics, Hessen has calculated the fractal dimension of soil
aggregates by the weight distribution and the relationship between the average particle size[2]. O
'Brien has thought that the accumulation speed of soil organic carbon is faster than the soil nitrogen
accumulation one. Soil C/N trend was not only going up with the increasing time but also the
condition of the same vegetation [3]; The soil development is relatively slow because of the harsh
natural environment in arid and semi-arid regions. Studying on soil aggregates is mainly concentrated
on the forest soils which remain comparatively in good conditions. At present, studying on the
formation and the stability of soil aggregates is less than wind erosion and desertification. Studying on
soil aggregates is mainly qualitative with structural destruction of soil by the wind erosion. The
reformative and rehabilitative structure has been put into effect by the measures of protecting
desertification soil[4,5]. The change of soil structure has been done after adding external modified
material in a certain sense[6,7,8]. And so has the effects of soil aggregates on different land-use
type[9,10,11]. In addition, the soil aggregates of often studying for desertification are mainly focused
on the study on soil crusts[12-15]. Fang Shi-bo has thought that the development of biological crust
can enhance the soil anti-scour ability and increase the time of soil crust anti-scour ability[16].
Gaohong-qian has also thought that the soil shows a trend of tapering with the biological crust
development in loess hilly-gully region, the amount of sand is reduced, and the silt is increased [17].
Some scholars have researched the distribution of soil aggregates in the area for different land use
[18-23]. Zhou Ping has analyzed soil granular structure with seven kinds of different ways of land use
in loess hilly-gully region, and the results show that the natural grass, shrubs and artificial terrace of
soil aggregate fractal dimension were lower than those of other land use types. The soil structure has
good aggregation condition, high stability, small damage rate, strong ability against resist erosion.
Improving soil fertility function is strong, and artificial grassland is the worst [19]. This paper studies
the characteristics and interdependency of different habitat topsoil aggregates in Mu Us sandy land
based on land sampling through experimental analysis and correlation statistics. Looking forward to
that it is helpful for the study on the mechanism of resistance against the wind erosion of soil
aggregates in Mu Us sandy land.

2. Overview of the studied area
The studied area is located in the center of Mu Us sandy land, Wu Shen Banner Erdos Inner Mongolia.
The Geographical position is 38°24′～39°02′N, 108°41′～109°42′E. The average altitude is about
1300 m. The climate is semi-arid and temperate continental. Annual mean temperature is 6.5°C, the
average annual cumulative temperature is 890°C, the annual precipitation is 360mm, mainly
concentrated in June-September, the average annual evaporation 2300mm. The average annual wind
speed is 3.3m/s, the annual sand windy and sand stormy days are 40～50, mainly concentrated in
Spring and Winter. Most of Mu Us sandy land is in chestnut soil steppe region, from northwest transition to brown soil semi-desert areas, from southeast transition to the loess plateau with warm Dark loessial soils area, it is just in a few transition regions of natural areas. In the studied area, the terrain is mainly the composition of flowing sand dunes, fixed sand dunes, semi fixed ones and dune bottomland in-between.

3. Materials and methods

3.1. Land investigation and sampling

As for Mu Us sandy land, nine samplings were got in different habitat soil. That’s exactly in different landscape areas of fixed sand dunes, semi-fixed ones and dune bottom land in-between, also in willow woodland and *Calamagrostis epigeios* grassland. Digging the soil profile to the 20cm point, sampling in top-down turn every 10 cm vertically. Keeping a soil sample after eliminating debris according to fourfold division, and taking back for lab test with fresh soil.

3.2. Experimental measurement and calculation

The analysis of soil aggregates is through the method of dry sieving and wet sieving [24], weighting each soil sample 50g, testing the content of soil aggregates. For soil organic carbon testing, adopted potassium dichromate volumetric method---the external heating method [25].And processed through the particular ways as follow:

Wet sieving: under the natural structure indoor, first, breaking into small lumps about 1 cm in diameter , and removing plant residues, small stones and other impurities. Then carrying on the processing of soil sample with wet sieving method: put the sample 50g into the vibrating scalper, deionized in water for 5 mins, moved up and down in the water carefully, and then, got the results from the sieves 1.0 mm,0.5mm and 0.25mm respectively. 4 kinds of soil samples were got as the result: particle size > 1.0 mm, 0.5 ~ 1.0 mm, 0.25 ~ 0.5 mm, < 0.25 mm, then tested the weight and calculated the weight percentage respectively. Made sure that the amplitude of the movements was 3 cm, the movement speed was about 25 times per minute, so was the time for 2 mins. Also took much care for the soil sample blending adequately and the drying after wards. And the four-point method is used to divide the sample preparation.

Dry sieving: drying the soil samples in laboratory air. When the soil moisture content is 22% - 25%, the sieve on shaking table of soil sample needed processing under the speed 270 r/min, the shock 2 mins (keep the soil particle size of aggregate separative enough ), repeating dry sieving twice, then isolated soil aggregate are > 1.0 mm, 0.5 ~ 1.0 mm, 0.25 ~ 0.5 mm, and < 0.25 mm.

3.3. Data processing

Stability of soil aggregates is expressed with Mean Weight Diameter [26](MWD). The calculating formula of MWD:

\[
MWD = \frac{\sum_{i=1}^{n} (X_i W_i)}{\sum_{i=1}^{n} W_i}
\]  

2.1
In the formula, $X_i$ expresses the average diameter of soil aggregates; $W_i$ is for the mass fraction of the corresponding $X_i$.

The calculating formula of the disruption rate on soil aggregates:

$$\text{Disruption rate on soil aggregates} = \frac{R - 1}{R} \times 100\%$$

In the formula, $R$ and $L$ indicate the mass fraction of which is not only for the mechanical stability of soil aggregates but for water stability on their particle size $>0.25$mm respectively. All the statistical analyses were performed using SPSS13.0 software.

4. Results and analysis

4.1. The composition characteristics of soil aggregates

4.1.1. The composition characteristics of soil aggregates in general. The Table 1 indicates the content of different soil aggregates by both dry sieving and wet sieving. As shown in Table 1, by dry sieving, the content of soil aggregates is obviously different, of which the particles size is $<0.25$mm sampled from the different studied areas. After calculation, the average content of soil aggregates is 44.74% using dry sieving with $<0.25$mm particles size. Then under the dry sieving, the proportion of soil aggregates is highest in the range of $0.5 \sim 0.25$mm, and the average content is 40.8%. Also by dry sieving, the average content of soil aggregates is 3.43% in the range of $1 \sim 0.5$mm, and the lowest average content is 0.49% when the particle size of soil aggregates is $>1$mm. Next even some soil samples do not contain soil aggregates with $>1$mm particle size. However, for the soil samples through the wet sieving, the content of the soil aggregates of every soil layers is 43.67%, that is not obviously reduced. The average content of soil aggregates is 0.13% when the particle size is $>1$mm, some are disappeared thoroughly. Next as for the soil aggregates with $1 \sim 0.5$mm particle size, the content is reduced to 2.24% sharply while for $0.5 \sim 0.25$mm particle size, the content of soil aggregates is 41.29%,and is slightly increased. In general, it shows that the particle size of the soil aggregates in Mu Us sandy land is mainly $0.5 \sim 0.25$mm, it is mainly the soil aggregates of small particles size, that is the soil aggregates of small particle size are more than the large ones.

4.1.2. The difference of soil aggregates content. Testing the content of soil aggregates in different soil profiles of 0cm, 10cm and 20cm respectively, for the soil aggregates with the particle size $>0.25$mm, the average content of soil aggregates is highest, while for the particle size $1 \sim 0.5$mm at the soil profile 0cm, the average content of soil aggregates is also highest. Moreover, for the particle size $0.5 \sim 0.25$mm at the soil profile 20cm, the content of topsoil aggregates was the highest in Mu Us sandy land. It showed that the nearer the topsoil got, the higher the content of larger aggregates was; also that the content of soil aggregates with big particle size was different when the surface characteristics were different. For example, by dry sieving, the content of $>0.25$mm soil aggregates was up to 4.27% and 3.55% sampled at the depth 0cm in the poplar woodland and Calamagrostis epigeios grassland. But above all, the effect was very great on the content of large soil aggregates in topsoil, if different habitats, and the average content of $>1$mm soil aggregates is 0.62% at the 0cm for other sampling lands.
4.1.3. The difference of soil aggregates stability. Compared dry sieving to wet sieving, analyze Mean Weight Diameter (MWD) of soil aggregates (as Table 2). Firstly, by wet sieving, the data of MWD is not significantly different, and it is among 0.38-0.5mm whatever different depths are for a single land or for different lands at the same depth. Secondly, by dry sieving, the data of MWD is always bigger in the top of the soil profile for the same land although there is a big difference with different soil lands. Especially in the windward slope of sand dunes, poplar woodland and Calamagrostis epigeios grassland, the data of MWD is higher than in other lands. Finally, compared to the data of MWD through dry sieving with wet sieving, discover that there is some differences with the MWD data of dry sieving soil aggregates occurred both in the top-down soil and the different types of sampling lands, however, for the wet sieving soil aggregates there is almost no differences with the MWD data. Therefore, it is that the development of soil aggregates is not fully sufficient, only the primary micro aggregates development exists based on fine sand level, so the stability of the soil aggregates is poorer.

Table 1. The analysis of aggregates in profiles.

| Sample Area Type                  | Depth /cm | Diameter (mm) Dry/Wet Sieving Aggregates Contents |                |
|-----------------------------------|-----------|--------------------------------------------------|----------------|
|                                   |           | >1                                               | 1~0.5          | 0.5~0.25 | <0.25 |
| Windward Slope of Sand Dune       | 0cm       | 2.07/0.29                                        | 2.96/0.77      | 46.28/46.88 | 51.3/47.94 |
|                                   | 10cm      | 0.32/0.08                                        | 1.77/0.66      | 45.27/45.88 | 46.62/46.62 |
|                                   | 20cm      | 0.04/0.01                                        | 1.41/0.57      | 42.97/43.29 | 44.42/43.86 |
|                                   | 0cm       | 0/0                                              | 0.32/0.1       | 35.3/35.07  | 35.62/35.17 |
|                                   | 10cm      | 0/0                                              | 0.54/0.09      | 45.94/45.93 | 46.48/46.02 |
|                                   | 20cm      | 0.02/0.07                                        | 0.25/0.07      | 30.42/30.3  | 30.69/30.37 |
| Leeward Slope of Sand Dune        | 0cm       | 1.45/0.06                                        | 2.09/0.44      | 54.87/56.38 | 58.41/56.82 |
|                                   | 10cm      | 0.02/0.05                                        | 1.03/0.55      | 67.95/67.29 | 69/67.84    |
|                                   | 20cm      | 0.01/0.07                                        | 1.21/0.61      | 74.08/74.2  | 75.37/74.8  |
| Inter-Sand-Dune Area              | 0cm       | 0.03/0.03                                        | 0.09/0.02      | 27.51/27.28 | 27.63/27.3  |
|                                   | 10cm      | 0.07/0.01                                        | 0.72/0.31      | 36.53/36.6  | 37.31/36.94 |
|                                   | 20cm      | 0.04/0.02                                        | 0.82/0.3       | 46.26/46.5  | 47.12/46.8  |
|                                   | 0cm       | 3.55/0.93                                        | 5.23/2.51      | 46.59/46.92 | 55.37/50.36 |
| Sand Dune Top Area                | 0cm       | 0.11/0.04                                        | 2.28/1.38      | 48.63/48.26 | 51.03/49.68 |
|                                   | 10cm      | 0.07/0.02                                        | 3.74/2.69      | 58.06/57.97 | 61.87/60.67 |
|                                   | 0cm       | 0.2/0.08                                         | 0.68/0.42      | 22.61/22.63 | 23.49/23.13 |
| Willow Area                       | 10cm      | 0.11/0.04                                        | 2.28/1.38      | 48.63/48.26 | 51.03/49.68 |
|                                   | 20cm      | 0.07/0.02                                        | 3.74/2.69      | 58.06/57.97 | 61.87/60.67 |
| Sand Willow Root Area             | 0cm       | 3.55/0.93                                        | 5.23/2.51      | 46.59/46.92 | 55.37/50.36 |
|                                   | 10cm      | 0.02/0.04                                        | 0.12/0.04      | 18.76/18.48 | 18.89/18.52 |
|                                   | 0cm       | 3.55/0.93                                        | 5.23/2.51      | 46.59/46.92 | 55.37/50.36 |
|                                   | 20cm      | 0.01/0.08                                        | 1.57/0.8       | 30.72/31.04 | 32.3/31.84  |
| Hedysarum Laeve Root Area          | 0cm       | 0.49/0.15                                        | 7.8/0.41       | 35.53/35.8  | 43.83/42.37 |
|                                   | 10cm      | 0.56/0.33                                        | 11.87/10.59    | 32.91/33.39 | 45.33/44.31 |
|                                   | 20cm      | 0.02/0.01                                        | 2.47/1.91      | 35.87/35.68 | 38.37/37.59 |
| Grassland Area                    | 0cm       | 0.09/0.01                                        | 2.28/1.65      | 35.51/35.6  | 37.88/37.25 |
|                                   | 10cm      | 0/0                                              | 1.73/1.26      | 23.05/23.28 | 24.78/24.54 |
As shown in Table 1, the content of soil aggregates is obviously decreased, of which the size is $>1$mm or $1\sim0.5$mm for every soil profile after wet sieving. The calculated destruction rate of soil aggregates in different depths (as shown in Table 2), the results show that the destruction rate is the biggest at 0cm, and then it is smaller and smaller at 10cm and 20cm respectively. It shows that in the topsoil of different surface characteristics in Mu Us sandy land, the content of large particle size soil aggregates is reduced with the depth increased. Viewing the data of soil aggregates destruction rate as a whole shows that the destruction rate is small. And shows that micro aggregates take the main part, and the surface damage rate is maximum from the vertical variation. In addition, the difference of the vertical variation is not obvious with the part sampling environment from the top to the down, and that is the protection and the recovery get well with vegetation. Therefore, it indicates that the soil structure is gradually optimized in both areas of the good vegetation protection and restoration.

**Table 2.** The analysis data of aggregates in different depths.

| Sample Area Type          | Depth(cm) | Wet Sieving Average Diameter MWD(mm) | Dry Sieving Average Diameter MWD(mm) | Aggregates Damaging Rate (%) | Organic Matter Content (g/kg) |
|---------------------------|-----------|--------------------------------------|--------------------------------------|-------------------------------|-----------------------------|
|                           |           |                                      |                                      |                               |                             |
| Windward Slope of Sand Dune | 0cm       | 0.38                                  | 1.61                                 | 6.60                          | 6.60                        |
|                           | 10cm      | 0.38                                  | 0.35                                 | 1.60                          | 1.90                        |
|                           | 20cm      | 0.38                                  | 0.66                                 | 1.30                          | 1.01                        |
| Leeward Slope of Sand Dune | 0cm       | 0.38                                  | 0.35                                 | 1.30                          | 0.79                        |
|                           | 10cm      | 0.38                                  | 0.34                                 | 1.00                          | 0.61                        |
|                           | 20cm      | 0.38                                  | 0.37                                 | 1.10                          | 0.59                        |
| Inter-Sand-Dune Area      | 0cm       | 0.38                                  | 0.44                                 | 2.70                          | 1.32                        |
|                           | 10cm      | 0.38                                  | 0.34                                 | 1.70                          | 0.91                        |
|                           | 20cm      | 0.38                                  | 0.34                                 | 0.70                          | 0.87                        |
| Sand Dune Top Area        | 0cm       | 0.38                                  | 0.65                                 | 1.20                          | 0.99                        |
|                           | 10cm      | 0.38                                  | 0.35                                 | 1.00                          | 0.89                        |
|                           | 20cm      | 0.38                                  | 0.34                                 | 0.70                          | 0.62                        |
| Willow Area               | 0cm       | 0.41                                  | 1.94                                 | 9.00                          | 12.62                       |
|                           | 10cm      | 0.39                                  | 0.86                                 | 2.60                          | 1.73                        |
|                           | 20cm      | 0.39                                  | 0.60                                 | 1.90                          | 1.50                        |
| Sand Willow Root Area     | 0cm       | 0.38                                  | 0.46                                 | 1.50                          | 1.07                        |
|                           | 10cm      | 0.38                                  | 0.59                                 | 2.00                          | 0.53                        |
4.2. The difference on the content of soil organic matter

With a comparative analysis of every land at 0 cm, 10 cm and the 20 cm profile of the soil organic carbon content respectively (shown Table 2). Organic carbon was highest at the 0cm sampling depth, and the contents of organic matter are all 3.57g/kg. Then for 9 lands sampling at the 10cm, the content of organic matter is 1.16g/kg, next at the 20cm, is 0.92g/kg. Therefore, shown as Table 2, the content of soil organic carbon is decreased successively for 9 lands at the 0cm, 10cm and 20cm respectively. Above all, the content of topsoil organic carbon is obviously different at the 0cm, 10cm and 20cm under the same environment of Mu Us sandy land, especially the content of organic carbon is the most obvious at the 0cm in the soil profile. As sampling soil from 9 different areas, their surface characteristics are different (shown as table 2), and the content of organic carbon is the highest in poplar woodland, and the content of organic carbon is all lower in other lands.

4.3. The correlation analysis among the characteristics value of soil aggregates

After taking the soil samples at different depth in MU Us sandy land, the soil aggregates are got through dry sieving and wet sieving (as shown in Table3). The correlation of the MWD, the damage rate and the content of soil organic carbon for the soil aggregates were analyzed by using SPSS 13.0 software. Firstly sampled at the 0cm by dry sieving aggregates, the result shows that the correlation coefficient is 0.914, and it is for MWD in 0.01 confidence interval and the content of soil organic carbon, that the correlation coefficient is 0.923 got with soil destruction rate. In a word, they are always significant correlation. However, by wet sieving aggregates, the correlation coefficient is 0.264 for MWD in 0.05 confidence interval and the content of soil organic carbon, and then the correlation coefficient is 0.415 with soil damage rate. The result is not correlative. Secondly sampled at the 10cm by dry sieving aggregates, the correlation coefficient is 0.123 for MWD in 0.05 confidence interval and the content of soil organic carbon while it is 0.926 for the content of organic matter and the damage rate of soil aggregates in 0.01 confidence interval. So it is not correlative. Also by wet sieving aggregates, the correlation coefficient is 0.493 for MWD and the content of soil organic carbon. It is not correlative either. Finally sampled at the 20cm by dry sieving aggregates, it is 0.572 for MWD and the content of soil organic carbon, and it is 0.274 for the damage rate and the content of soil organic carbon. Meanwhile, sampled at the 20cm by wet sieving aggregates, it is 0.228 for MWD and the content of soil organic carbon. Still it is not correlative. In conclusion, when using dry sieving on the one hand, the content of soil organic matter is significant correlation with both soil aggregates and the
damage rate. That is that soil organic matter is the important factor which affects the stability and aggregates occurrence of soil aggregates. On the other hand, the content of organic matter is not significant correlation with MWD of wet sieving aggregates, also means that the development of soil aggregates is in low level for this area, the content of organic matter is low. And the humus with high water stability and cohesion has not been differentiated; it has great relationship with the regional drought environment.

Table 3. The correlation on the characteristic value of soil aggregates in different depths and the content of soil organic matter.

|                | 0cm of the content of soil organic matter | 10cm of the content of soil organic matter | 20cm of the content of soil organic matter |
|----------------|------------------------------------------|------------------------------------------|------------------------------------------|
| MWD (mm) of wet sieving aggregates | 0.206                                    | 0.493                                    | 0.228                                    |
| MWD (mm) of dry sieving aggregates | .945**                                   | 0.123                                    | 0.572                                    |
| the damage rate of dry sieving aggregates (%) | .940**                                   | 0.534                                    | 0.274                                    |

Note: here, ** represent significance level at P < 0.01 (99% confidence interval)

5. Discussion and conclusions

(1) Wind erosion and arid environment are important constraint conditions and background for topsoil aggregates occurrence and evolution in the area. According to the study, the soil aggregates are mainly micro aggregates in the range of 0.5~0.25mm. The contents of soil aggregates are different in different depths. The contents of topsoil aggregates get smaller as 0cm>10cm>20cm respectively, this result is identical with which of SHenfangyu and Wang yongdong[27].

(2) The contents of soil aggregates are also different in different habitats as followed: the contents of more than 1mm soil aggregates are up to 4.27% and 3.55% in poplar woodland and *Calamagrostis epigeios* grassland at the 0cm.

(3) Moreover, after analyzing the soil aggregates stability, the development of soil aggregates is not sufficient, then the stability of soil aggregates is poor; the damage rate of aggregates is low. The data of soil aggregates destructive rate shows that the content of soil aggregates is small in the soil of this area. Viewing from the vertical variation, surface damage rate is maximum. It means that the soil structure is gradually optimized in the good vegetation protection and restoration, this result is identical with which of Gao xiaofei, Liu heping, Six J and Elliott E T, the content of > 0.25 mm air drying soil aggregates and water-stable aggregates, the content is higher, the greater the stability of the soil structure[28, 29].

(4) There is the synchronization between the content of soil organic matter and the change rule of structural system. Again analyzing the correlation on the characteristics value of soil aggregates, at the 0cm in 0.01 confidence interval, the result shows that the content of soil organic matter has significant
correlation not only with dry sieving aggregates but also the damage rate of soil aggregates. It indicates that soil organic matter is the important factor that affects the stability and aggregates occurrence of soil aggregates. Meanwhile, the content of organic matter does not have significant correlation with MWD by wet sieving aggregates, it shows clearly that the development of soil aggregates is lower in this area, it has great relationship with the regional drought environment. Yu Haiyan and Cha tonggang also thought that the soil organic carbon content is a downward trend with particle size decreasing.

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