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Research Article

Effects of Water Saving Materials on Soil Physical Characters and Maize Yield in Loess Plateau

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Abstract: In this study, the comparison of soil aggregates, soil bulk density and total porosity, soil water content and maize yield were made among four water saving materials in Qingshuihe County of Inner Mongolia, the results showed that all the four water saving materials can change soil aggregates, increase soil total porosity, soil water content and maize yield, the order of their effects is treatment A (using PAA) >treatment B (using PAM) >treatment D (using bentonite) >treatment C (using humic acid). And in the 0-20 cm soil layer, the content of soil aggregates of >0.25 mm of A, B, C and D increased by 20.60, 15.95, 9.70 and 11.27%, respectively than that of CK, the soil bulk density of treatment decreased by 7.14, 5.00, 2.35 and 2.86%, respectively, the soil porosity increased by 6.91, 4.84, 2.07 and 2.76%, respectively. The water content of A, B, C and D of 10-20 cm in seedling stage increased by 43.26, 38.10, 5.91 and 17.20%, respectively than that of CK. The grain yield increased by 19.48, 15.22, 2.64 and 7.82%, respectively. So four water saving materials all had the effects of improving soil physical characters and crop yield, they can play important roles in improving soil quality of Loess Plateau, but the effects of PAA and PAM were better than the other two in the Loess Plateau.

Keywords: Correlation, maize, soil physical characters, water saving materials, yield

INTRODUCTION

In China, the status of soil and water loss are serious, the total area of soil and water loss has reached 3673 ha which is the 38.2% of the total land area (Tang, 2000). Loess Plateau includes Shanxi, Inner Mongolia, Henan, Shanxi, Gansu, Qinghai and Ningxia, the total area is 626800 km^2 (Yang and Yu, 1992). Loess Plateau is the main grain production area, it has rich light resources, but the rainfall is short and unevenly distributed, the shortage of water has become the main factor which affects the agricultural production and ecological environment. In this area the area of slope land is 71.3% of the total cultivated area. And with the long-term unreasonable human activities, the ecological has become deteriorated, soil structure has been damaged and the soil and water loss has become more and more serious (Jiang *et al*., 1997), the erosion modulus can reach 5000 to 10000 t/km^2, even 20000 to 30000 t/km^2, this is the highest of the world (Wu *et al*., 2004). And according to the investigation, the surface erosion in Helingeer and Qingshuihe County of Inner Mongolia of Loess Plateau can be 1 cm.

For a long time, researchers have done much works on decreasing soil and water loss with the increasing of yield, studies of soil improvement and increasing of soil anti-erosion ability have been an important aspect in the field of soil and water conservation in Loess Plateau. Xie and Fan (2004) put forward that good soil structure can increase soil infiltration capacity, decrease soil and water loss amount. Recent years, some studies have showed that water saving materials can decrease the loss of water and fertilizer, regulate the condition of soil water, fertilizer, air and heat and improve soil structure. Xuefeng Bai and his coworkers (Bai *et al*., 2004) had used the peat to improve soil water condition, it showed that peat can decrease soil bulk density and increase soil porosity and water content. The study of Fusheng Chen and his coworkers (Chen *et al*., 2003) had showed weathered coal and peat can improve soil physical and chemical characters obviously and then increase soil productivity. At the same time, many polymer materials have been used as water saving materials, some studies showed, polymer materials can increase the content of soil water stable aggregate (Wu *et al*., 2003), increase soil infiltration rate (Zhang, 2001), decrease the amount of soil erosion (Huang *et al*., 2002), protect plough layer and prevent the fertilizer from losing (Xiao, 2000). In order to decrease the soil loss of cultivated land in Inner Mongolia of Loess Plateau, improve soil structure, decrease water evaporation, improve soil quality and increase land output, this research chooses four water saving materials, including two natural water saving materials (humic acid and bentonite) and two polymer water saving materials (PAA and PAM), to study the effects of them on soil aggregates, soil bulk

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density and total porosity, soil water content and maize yield, compare the effects of them on soil physical characters and the increasing of yield and at last provide the theoretical basis for the choosing of suitable water saving materials used to soil improvement.

MATERIALS AND METHODS

The experiment was studied in Qingshuihe County of Inner Mongolia, the land area is 2859 km^2, land area for agriculture is 6.87 km^2 and more than 97% of the land is dry sloping land. It belongs to Loess Hilly-gully Region, the landform is complex, the average elevation is 1373.6 m, the average annual temperature is 7.1°C, the accumulated temperature ≥10°C is 2370.2°C, frostless period is 140 days, annual sunshine hours is 2914 h, the average number of gale day (the instantaneous speed is 17 m/s) is 19 days, the total annual solar radiant is 570.6 kJ/cm^2, the aridity is 3.94. The climatic characteristics are dry and windy in spring, cold, less rainfall and large evaporation in winter. It is semi-arid region of mid-temperate zone with continental monsoon climate. The experimental soil is loessial soil and the soil total porosity is 43.65%, soil aggregate is 118.8 g/kg, organic matter is 10.96 g/kg, total nitrogen is 0.49 g/kg, total phosphorus is 0.43 g/kg, available nitrogen is 35.10 mg/kg, available phosphorus is 4.55 mg/kg and available potassium is 118.90 mg/kg.

Materials:
Experimental maize variety: Zhedan 7
Experimental water saving materials: PAA (Potassium Polyacrylate), PAM (Polyacrylamide), humic acid and Bentonite

Experimental design: The experiment was conducted during April to September in 2011, there all had five treatments, including CK (no-using of water saving materials), A (using 75 kg/hm^2 PAA), B (using 75 kg/hm^2 PAM), C (using 1500 kg/hm^2 humic acid) and D (using 18000 kg/hm^2 bentonite). The four water saving materials were scattered in the surface of land equably, then through rotary tillage to put them into the soil. The experiment was by randomized block design and repeated three times. The area of each plot was 4×5 m = 20 m^2. The sowing, fertilization and field management were all according to the local planting habits, the planting density was 45000 plants per hectare. The time of using water saving materials and sowing were both 25 April.

Determined indexes and methods: Soil bulk density and total porosity: after the harvest of maize, using cutting ring method to determine soil bulk density of different soil layers (0-20, 20-40 and 40-60 cm, respectively), repeated three times. Calculation formula is d = m/V, d is soil bulk density (g/cm^3), m is amount of dry soil (g), V is the volume of cutting ring (cm^3). The calculation formula of soil total porosity (P %) is that, P% = 93.947-32.995d.

Soil aggregates: After the harvest of maize, taking soil sample of different soil layers (0-20, 20-40 and 40-60 cm, respectively), repeated three times. And then through natural air drying in the laboratory and then using mechanical sifting method to determine the soil aggregates.

Soil water content: In the seedling stage, jointing stage, heading stage, filling stage and mature stage of maize, taking the soil samples of different soil layers (0-10, 10-20, 20-40, 40-70 and 70-100 cm, respectively) by aluminum boxes. Then taking them back to the laboratory and drying them. Calculation formula is:

$$w = (S_w - S_d) / S_d \times 100\%,$$

where,
w : Soil water content (%)
S_w : The amount of wet soil (g)
S_d : The amount of dry soil (g)

Data processing: Date processing used the SPASS 18.0 to do the analysis of variance and correlation.

RESULTS AND ANALYSIS

Effects of water saving materials on soil particle size compositions. Soil composition of grain diameters have the effect on the change of soil hydraulic characteristics, fertility condition and soil erosion, it is one of the important soil physical characters (Giménez *et al*., 1997; Huang and Zhang, 2005; Montero, 2005). The four water saving materials all had effects on soil particle size compositions and the degrees were different. From Fig. 1, under different treatment, the soil particle size compositions showed consistent trend and from the soil particle content of <0.05 to >2 mm showed a first increasing, second decreasing and then increasing trend. The soil particle content of 0.05-0.1 mm was the most; this was determined by the soil characteristics of itself. In different soil layers, with the deepening of soil depth, the soil particle content of <0.25 mm increased, the content of >0.25 mm increased and the effects of water saving materials on the soil particle size compositions decreased with the deepening of soil depth. In the 40-60 cm soil layer, there were lowest or no difference among different treatments. And taking the 0-20 cm soil layer as example, the soil particle content of <0.05, 0.05-0.1 and 0.1-0.25 mm all showed CK>C, D>A, B. The content of 0.25-0.5, 0.5-0.1, 1-2 and >2 mm all showed A>B>D>C>CK. So using water saving materials can promote the soil micro-aggregates of <0.25 mm to form soil aggregates of >0.25 mm and the effects of using

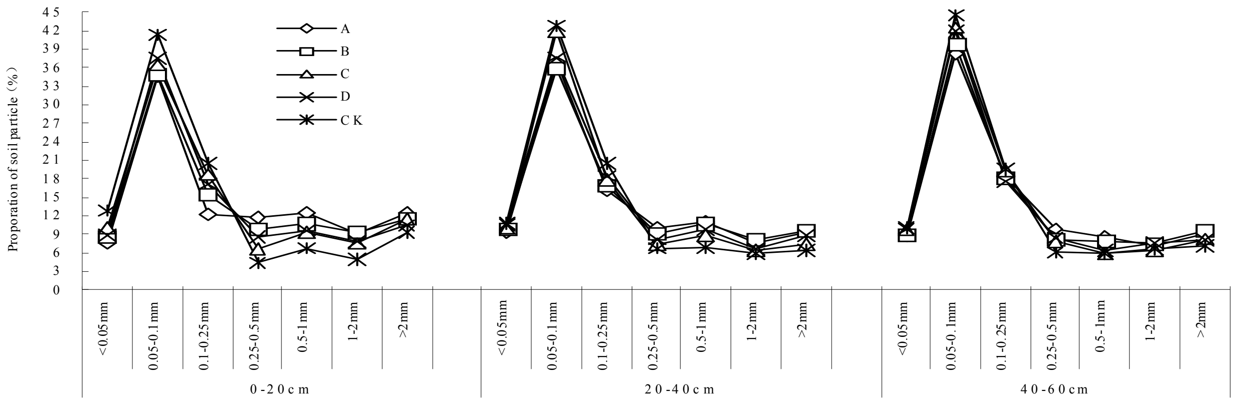

Fig. 1: Proportion of soil particle in different soil layers

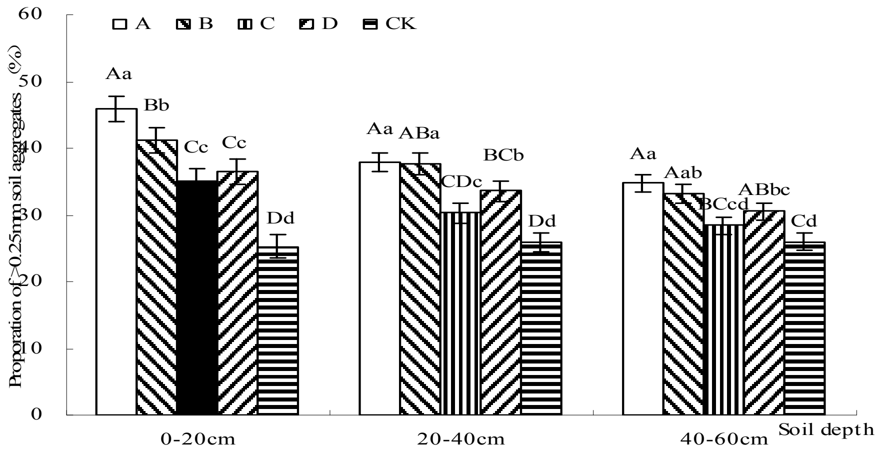

Fig. 2: The proportion of >0.25 mm soil aggregate content in different soil layers
The majuscule and minuscule in the figure stand for the significant difference in 0.01 and 0.05 levels

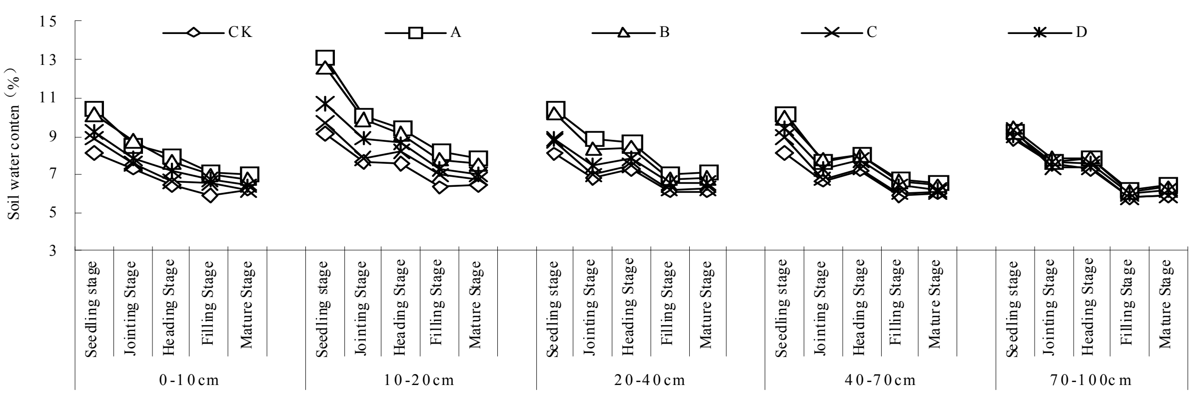

Fig. 3: The dynamic change of soil water content in different soil layers

PAA (A) and PAM (B) were better than that using bentonite (D) and humic acid (C).

Effects of water saving materials on soil aggregates of >0.25 mm. Soil fertility is one of the important indexes to evaluate soil quality; soil structure determines the effects of soil fertility and the water permeability and soil aeration. The soil particle content of >0.25 mm has the important effects on soil agronomy value (Liu *et al*., 2006). From Fig. 2, in different soil layers, the soil particle content of >0.25 mm of the four treatments used water saving materials were all higher than that of CK. The order of soil particle content of >0.25 mm in different soil layers all showed A>B>D>C>CK and with the deepening of soil depth, the content decreased. And with the deepening of soil depth, the differences among different treatments decreased; there were biggest difference in 0-20 cm soil layer. In 0-20 cm soil layer, the content of A, B, C and D increased by 20.60, 15.95, 9.70 and 11.27%, respectively than that of CK, in 20-40 cm soil layer, the content of A, B, C and D increased by 12.07, 1.79, 4.41 and 7.77%, respectively than that of CK. So the effects of increasing soil particle content of >0.25 mm of using PAA (A) and using PAM (B) were better than that of using humic acid (C) and using bentonite (D).

Effects of water saving materials on soil water content in maize growth period. In Fig. 3, the water content of 100 cm soil depth during growth period was showed. From the figure, with the going of growth period, water content of each treatment all showed a decreased trend, this mainly because that with the going of growth period, the performance of water holding of water saving materials decreased gradually and the rainfall was less, evaporation was big, so the soil water content showed a decreased trend. In the 0-20 cm soil layers, except the water content of treatment C was lower than CK in the jointing stage, the water content of other treatments were all higher than CK in the whole growth period, this mainly because the using of PAA, PAM and bentonite can increase soil water conservation ability and decrease the water evaporation. In the 20-40 cm, the increasing of soil water content of treatment A and B was obviously, the treatment C and D were crisscrossed with CK, this indicated that PAA and PAM had effects on soil water content in 20-40 cm, humic acid and bentonite had little or no effects on soil water content in 20-40 cm. In 40-100 cm soil layers, four water saving materials all were crisscrossed with CK, so the using of water saving materials had little effects on soil water content in deep soil layers. And in 0-100 cm soil layers, there existed biggest differences among five treatments in 10-20 cm soil layer; this may because the water saving materials was put into 10-15 cm of soil. In the different growth period, water saving materials had the biggest effects on soil water content in seedling stage; there were biggest difference in the seedling stage among different treatment. Taking the 10-20 cm soil layer in seedling stage for example, the water content of A, B, C and D increased by 43.26, 38.10, 5.91 and 17.20% than that of CK, respectively. So the effects of increasing soil water content showed that A>B>D>C. The using PAA and PAM had better effects on conserving soil water content.

Effects of water saving materials on soil bulk density and total porosity. From Table 1, under different treatments, the trend of soil bulk density and total porosity showed the same trend, with the deepening of soil depth, soil bulk density increased, soil total porosity decreased and the soil bulk density all showed 40-60>20-40>0-20 cm, soil total porosity showed 40-60<20-40<0-20 cm. And in the three soil layers, the

Table 1: The change of soil bulk density and total porosity in different soil layers

	Soil bulk density (g/cm^3)			Soil total porosity (%)		
Treatment	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
CK	1.40Aa	1.45Aa	1.49Aa	47.75Cd	46.10Bb	44.78Bc
A	1.30Dd	1.37Bb	1.46Abc	51.05Aa	48.74Aa	45.77ABab
B	1.33CDc	1.39Bb	1.45Ac	50.06ABb	48.08Aa	46.10Aa
C	1.37ABb	1.44Aa	1.49Aabc	48.74BCc	46.76Bb	44.78ABbc
D	1.36BCb	1.44Aa	1.48Aab	49.07BCc	46.76Bb	45.11ABbc

The majuscule and minuscule in the same row of the table stand for the significant difference in 0.01 and 0.05 levels

Table 2: Comparison of maize yield traits

Treatment	Ear length (cm)	Ear diameter (cm)	Grain number per spike	Spike grain weight (g)	100-grain weight (g)	Grain yield (kg/hm^2)	Biological yield (kg/hm^2)
CK	17.56Ccd	4.47ABa	438Cc	99.46De	23.71De	4475.70De	17282.46De
A	19.93Aa	4.53Aa	486Aa	119.30Aa	27.56Aa	5368.50Aa	19936.85Aa
B	19.13Bb	4.53Aa	461Bb	114.60Bb	26.86Bb	5157.05Bb	19271.56Bb
C	17.47Cd	4.37Bb	458Bb	102.09Dd	24.19Dd	4594.05Dd	17691.30Dd
D	17.83Cc	4.51Aa	465Bb	107.24Cc	25.21Cc	4825.80Cc	18491.37Cc

The majuscule and minuscule in the same row of the table stand for the significant difference in 0.01 and 0.05 levels

Table 3: The correlation analysis between soil physical characteristics and maize yield

Index	>0.25 mm soil aggregates	Soil bulk density	Soil total porosity	Soil water content	Grain yield
>0.25 mm soil aggregates	1				
Soil bulk density	-0.978^{**}	1			
Soil total porosity	0.978^{**}	-1.000^{**}	1		
Soil water content	0.885^{*}	-0.958^{*}	0.958^{*}	1	
Grain yield	0.937^{*}	-0.981^{**}	0.981^{**}	0.990^{**}	1

**: Stands for the significant correlation in 0.01 level; *: Stands for the significant correlation in 0.05 level soil bulk density of four treatments used water saving materials were lower than CK, in the 0-20 cm soil layers, the soil bulk density of treatment A, B, C and D decreased by 7.14, 5.00, 2.35 and 2.86%, respectively the soil porosity increased by 6.91, 4.84, 2.07 and 2.76%, respectively. Through the variance analysis, in the 0-20 cm soil layers, except for treatment C, the soil bulk density and total porosity of the other three treatments all had very significant difference ($p<0.01$) with CK. In the 20-40 and 40-60 cm soil layers, except the treatment A and B had significant differences ($p<0.05$) with CK in soil bulk density and total porosity, the other two treatments had no significant differences with CK.

Effects of water saving materials on maize yield traits. From Table 2, compared with CK, the increasing of ear length of treatment A showed the most significant, the treatment B also very significantly increased the ear length, but treatment C and D had not significantly increased ear length. Except that treatment C decreased ear diamenter, the other three treatments had no significant effects on ear diamenter. Four treatments of water saving materials all can increase grain number per spike, they all showed very significant difference with CK, but there were no significant difference among treatment B, C and D, the effects of treatment A was biggest. Treatment C had no significant difference with CK in increasing spike grain weight, the other three treatments all had very significant difference with CK and the biggest was A, then B, last was D. The effects of water saving materials on 100-grain weight, grain yield and biological yield showed the same with effects on spike grain weight. The effects of water saving materials on yield traits showed A>B>D>C, taking grain yield as example, treatment A, B, C and D increased by 19.48, 15.22, 2.64 and 7.82%, respectively this all indicated that four water saving materials can increase maize yield in different degrees.

Correlation analysis between soil physical characters in 0-20 cm soil layer and maize grain yield. From Table 3, in 0-20 cm soil layer, the soil aggregates content of >0.25 mm had significant positive correlation ($r = 0.937^{*}$) with maize grain yield, total porosity and soil water content had very significant positive correlation ($r = 0.981^{*}$ and $r = 0.990^{**}$) with maize grain yield, but soil bulk density had the very significant negative correlation ($r = -0.981^{**}$) with maize grain yield. So the increasing of soil aggregates of >0.25 mm, soil total porosity and soil water content, the decreasing of soil bulk density all can promote the increasing of maize grain yield.

CONCLUSION AND DISCUSSION

PAA, PAM, humic acid and bentonite all have some effects on the improvement of soil structure, they all have good water absorption and can effectively decrease surface runoff, increase rainfall infiltration and soil water content, the using of water saving materials can increase soil aggregates of >0.25 mm and soil total porosity, promote the formation of soil water stable aggregate (Aase *et al*., 1998), then there are many “small reservoir” formed in the soil and the soil ability of conserving water is increased. This can provide a better soil environment for the growth of crop and then promote the increasing of yield. But there exists differences in the effects of water saving materials, in this study, we found that water saving materials can change the soil particle size compositions, increase the content of >0.25 mm soil aggregates, soil total porosity and soil water content, decrease soil bulk density and last achieved the increasing of crop yield. Through the above analysis, we can make the following conclusion:

- Four water saving materials had different effects on the soil particle size compositions, the order was using PAA (A) >PAM (B) >bentonite (D) >humic acid (C), from the soil particle content of <0.05 mm to >2 mm in different treatments all showed a first increasing, second decreasing and then increasing trend.
- In different soil layers, the content of >0.25 mm soil aggregates of four water saving materials were all higher than that of CK. With the deepening of soil depth, the differences among different treatments decreased, there were biggest difference in 0-20 cm soil layer. In 0-20 cm soil layer, the content of A, B, C and D increased by 20.60, 15.95, 9.70 and 11.27%, respectively than that of CK.
- The change trend of soil bulk density and total porosity under four water saving materials was same. Soil bulk density of four treatments used water saving materials were lower than CK, in the 0-20 cm soil layers, the soil bulk density of treatment A, B, C and D decreased by 7.14, 5.00, 2.35 and 2.86%, respectively the soil porosity increased by 6.91, 4.84, 2.07 and 2.76%, respectively.
- The soil water content of different treatments showed A>B>D>C in the 0-20 cm. In the 20-40 cm, the increasing of soil water content of treatment A and B was obviously, the treatment C and D were crisscrossed with CK. In 40-100 cm soil layers, four water saving materials all were crisscrossed with CK. There existed biggest differences among five treatments in 10-20 cm soil layer, in different growth period; the biggest effects appeared in seedling stage. The water content of A, B, C and D of 10-20 cm in seedling stage increased by 43.26, 38.10, 5.91 and 17.20%, respectively than that of CK.
- The maize yield traits and yield all showed A>B>D>C>CK, the grain yield of treatment A, B,

C and D increased by 19.48, 15.22, 2.64 and 7.82%, respectively than that of CK. And there were better correlation between soil physical characters and crop yield.

On the basis of the above analysis, four water saving materials all had the effects of improving soil physical characters and crop yield, but there were differences in effects, using PAA had the best effects on improving soil structure, decreasing soil bulk density, increasing soil total porosity, soil water content and maize yield, the effects of PAM was secondly, then was the bentonite and the last was the humic acid.

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