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IMPROVEMENT OF SANDY SOIL WITH WATER-CONSERVING MEMBRANE AND ITS EFFECT ON CROP GROWTH

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ABSTRACT: Water-conserving membrane is a new material of improving sandy soil. It is based on the rule that a compound with organic and inorganic components can produce colloid after its integrating with Ca^{2+} in soil. The water-conserving membrane will obstruct capillary and increase viscidity of sandy soil, so as to decrease leakage and evaporation in sandy soil. The water-conserving membrane contains polyacrylic acid (PAA) and bentonite. When PAA concentration and pH of solution are different, water-conserving membrane can be made in different depth of soil. This experiment shows that the solution with 0.2% PAA does not harm and poison the crops, on the contrary, promotes crop germination. The solution with 0.2% or 0.4% PAA can accelerate corn growth. Accordingly, different crops need the application of the different PAA concentrations in the cultivation. Therefore, on the basis of different vadose coefficient in sandy soil, the solution with different PAA concentration can improve sandy soil and increase its water-conserving competence very well. The solution can be used to improve sandy soil and control desert enlargement in arid, semi-arid and semi-humid areas.

KEY WORDS: water-conserving membrane; water-conserving capability; germination rate; crops

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1 INTRODUCTION

Arid, semi-arid, and semi-humid areas abound in sandy soil, which causes water to leak into deep soil or groundwater so that soil′s water-conserving capability becomes lower and water is used with low efficiency. Water is one of the important factors in sandy soil that affect crop growth greatly (Nanjing Institute of Soil, Chinese Academy of Sciences, 1987; LIU *et al*., 1992). There are several measures to increase water reserves in soil (CHEN, 1995). First, irrigation works are established to achieve water-saving irrigation. Second, soil structure is improved so that soil evaporation and leakage are decreased and soil′s water-conserving capability is increased as well. Third, chemical techniques are applied to reducing evaporation or transpiration. In addition, drought-enduring crops are planted to improve soil structure in the long term and help reduce evaporation. However, irrigation works need a large amount of investment and ample water resources. The disadvantage of chemical techniques is to pollute environment unavoidably. Drought-enduring crops usually have low yield and a few economic benefits. Therefore, to improve soil structure is comparatively more economical and efficient. Many experts and researchers around the world are researching on the improvement of soil structure. One kind of chemical macromolecule materials was applied to sandy soil, which helped improve soil characteristics, prevent sandy soil from being eroded by wind and restrain evaporation (PINI and GUINI, 1994). But this measure needs more funds, and is difficult to be applied widely. Researchers, from Lanzhou Desert Institute, Chinese Academy of Sciences, had buried plastic film in sandy soil to prevent water from leaking, and then planted rice on it in Horqin Sandy Land. Experience from the above measure has testified that plastic film can improve the water-conserving capability of sandy soil (LIU *et al*., 1995; HUANG *et al*., 1994). Since water and air can not penetrate the plastic film, the soil over the plastic film will salinize. Besides, it has two disadvantages. First, it needs more time and labor force to bury the plastic film in the soil. Second, mice

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can easily damage the plastic film in the soil. To apply manure (HE *et al*., 2002) or peat (JIN and YIN, 1995) to sandy soil can improve soil structure and water-conserving capability. But the improvement of soil structure can only be achieved through long-term and large-quantity application of manure or peat. Polyacryloamide and polyacrylic glycol were used to sandy soil to improve soil structure (PINI and GUINI, 1994), but the cost is high. Sulfite Spent Liquor was also applied in sandy soil to improve soil structure (LI *et al*., 2003; LONG *et al*., 2002). So far, the better measure to increase soil′s water-conserving capability is still under discussion.

Our research shows that polyacrylic acid (PAA) compounds with bentonite into a solution, and the solution can produce a colloid after its integrating with Ca^{2+} in soil, and the colloid is called water-conserving membrane (CUI, 1988). The membrane can improve water-conserving capability of sandy soil very well (CUI and LI, 2000). As an organic substance, PAA is a macromolecule material with carboxyl, and can dissolve in water. But as an inorganic substance and a kind of clay mineral, bentonite can increase viscous grains in sandy soil, and can increase soil′s water-conserving capability. This paper is to introduce the experimental result that water-conserving membrane can improve sandy soil′s water-conserving capability and influence crops growth.

2 MATERIAL AND METHODS

2.1 Solution Preparation

Solution forming water-conserving membrane is a compound that is composed of PAA and bentonite. The molecular weight of PAA is 2 600 000. The solution was diluted with distilled water and turned into three kinds of solution, i.e. 0.2% PAA concentration (0.2C), 0.4% PAA concentration (0.4C) and 0.6% PAA concentration (0.6C). In addition, distilled water is used as a check treatment (0C).

2.2 Experiment in Sandy Soil

Twelve glass tubes with a height of 1m and a diameter of 5cm were needed in the experiment, and they were divided into four groups. Every tube was filled with sandy soil, whose characteristics were showed in Table 1, to the height of 70cm. The first group of 3 glass tubes was filled with 0.2C solution, the second group of 3 glass tubes was filled with 0.4C solution, the third group of 3 glass tubes was filled with 0.6C solution and the forth group of 3 glass tubes was filled with 0C solution. The liquid in each tube reaches 2mL. Five hours later, 50mL of distilled water was filled into each tube. By observing the velocity and the quantity of water leakage, we could estimate whether water-conserving membrane had formed in the tubes or not. After taking out soil specimens in the glass tubes with a stainless steel tube, we could measure the quantity of carbon contained in the soil specimens by using plasma chromatogram technique, so that we could determine the depth of soil in which water-conserving membrane could form. Chemistry titration was used to find out the membrane by means of a spectrophotometer (Type 751).

Table 1 Characteristics of sandy soil

Humus (%)	Total N (%)	Total P_2O_5 (%)	Total K_2O (%)	pH
1.334	0.084	0.029	1.765	8.0

2.3 Effect of Solution on Crop Germination

Crops germinate in culture dishes under constant temperature (22℃) in laboratory. Four kinds of crops were used in the experiment, which were Fengyou 301 rice, Jilin 55 soybean, Jidan 180 corn and Aoza 1 broomcorn. The diameter of the culture dish is 15cm. Four kinds of solution, i.e. 0.2C, 0.4C, 0.6C and 0C, were filled into the culture dishes as culture medium. The height of the culture medium is 5mm. The seeds of each crop were planted on the culture medium respectively as a treatment. Each treatment needed to be repeated four times. In the course of the experiment, the culture dishes were not irrigated. The experiment lasted 10 days.

2.4 Effect of Solution on Corn Growth

Twenty plastic tanks with diameter of 1.2m and height of 1.2m were filled with sandy soil whose characteristics were showed in Table 1. These plastic tanks were divided into 4 groups. The first group of 5 tanks was filled with 0.2C solution, the second group of 5 tanks was filled with 0.4C solution, the third group of 5 tanks was filled with 0.6C solution and the last group of 5 tanks was filled with 0C solution. Humidity in soil of tanks is 75% when seeding. Water management in tanks is the same as precipitation. The seeds of Jidan 180 corn were planted in each plastic tank on April 30, 2000. During seedling, 5 individual seedlings were left in each plastic tank. We observed the height, the number of leaves, and the weight of each individual plant; as well as the weight of root, earing time, the yield of individual corn plant, and the field moisture capacity and the specific gravity of the sandy soil.

3 RESULTS AND DISCUSSION

3.1 Formation of Membrane

The PAA with carboxyl group can easily produce PAA-Na through its chemical reaction with NaOH. PAA-Na can react with metal cations, especially Ca^{2+}, to form colloid that is called water-conserving membrane. In the process of forming the membrane, Na^+ in PAA-Na is exchanged by Ca^{2+}. Because Na^+ valence is different from Ca^{2+} valence, the straight chains of two macromolecules (PAA-Na) will cross each other through Ca^{2+} (knots come into existence), which forms net. When a number of straight chains of macromolecules cross one another, the membrane is formed. In order to observe the factors that have effect on membrane forming, we conducted two experiments.

The first experiment was that three kinds of solution (0.2C, 0.4C, 0.6C) formed colloid under different pH. In Fig.1, the colloidizing curves vary with PAA-Na concentration of 0.2C, 0.4C, and 0.6C. The higher PAA-Na neutralization concentration becomes, the more Ca^{2+} is required in forming membrane. The increase of PAA-Na neutralization concentration means the decrease of pH. Least Ca^{2+} is required at 0.6C PAA-Na neutralization concentration, while more Ca^{2+} is needed at other PAA-Na neutralization concentration.

It is known that there are many kinds of salt in soil. If PAA-Na solution with certain concentration is poured on soil surface, Na^+ in PAA-Na is exchanged with Ca^{2+} in soil to form knots in macromolecule chains of PAA when the solution infiltrates down the soil. When the solution infiltrates down to a certain depth, and the Ca^{2+} knots reach certain number, the colloid (which is called membrane) will form. The membrane stays in soil porosity and prevents water from leaking and evaporating, thereby it is called water-conserving membrane. In semi-arid area and arid area, soil is usually sandy, has a little clay or lacks active colloidal particle, therefore, the field moisture capacity is lower. If PAA-Na solution is poured into sandy soil, water-conserving membrane can form automatically and the colloidal particle in soil increases, which can improve the physical characteristics of soil.

Another experiment is that certain concentration solution (0.4C) was mixed with different quantity of clay. In Fig. 2, the more clay there is in soil, the less Ca^{2+} is required in forming membrane. The adjustment of the quantity of clay in soil attributes to the control of the membrane forming. In addition, the cost of the adjustment is comparatively lower, which is possible for application of the membrane.

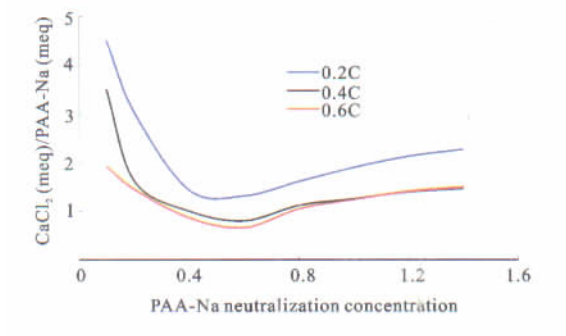

Fig. 1 Colloidizing carves of PAA-Na

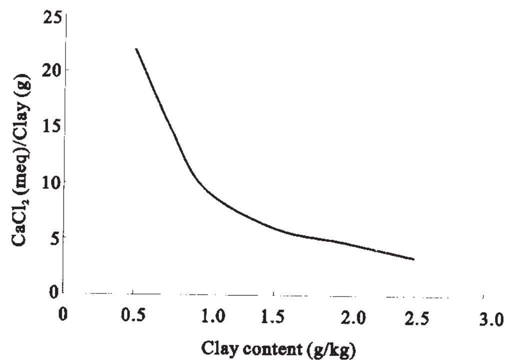

Fig. 2 Relation between clay content and Ca^{2+}

3.2 Formation of Membrane in Soil

Fig. 3 showed that the membrane formed in soil after certain concentration solutions (0.2C, 0.4C, and 0.6C) were poured into glass tubes. When soil pH was different, the depth in which the membrane formed would be different. Soil pH was lower, while the membrane was closer to the surface soil. Thus, it is possible to control the depth in which the membrane formed by means of adding NaOH or ammonia into the concentration solution so as to adjust pH in soil.

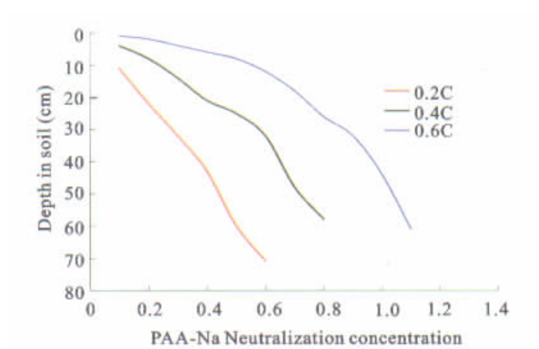

Fig. 3 Membrane depth in soil and neutralization concentration

3.3 Effect of Solutions on Crop Germination

The experiment showed that the membrane had effect on crop germination. Fig. 4 was the result of experiment with Fengyou 301 rice, Jilin 55 soybean, Jidan 180 corn and Aoza 1 broomcorn. In 0.2C solution, the germination percentage of rice is 2.06% more than that in 0C solution. In 0.4C solution, the germination percentage of the rice is 2.58% more than that in 0C solution. In 0.6C solution, the germination percentage of the rice is 2.06% less than that in 0C solution. This experiment shows that the 0.2C or 0.4C solution can help rice seeds germinate. Therefore, the 0.2C or 0.4C solution can be used in paddy field to improve soil. The 0.2C or 0.4C or 0.6C solution can help soybean germinate and their germination percentages are 13.29%, 20.43%, or 22.43% more than that in the 0C solution, which shows that all the solutions from 0.2C to 0.6C can be applied in soybean field to improve soil structure. In the 0.2C solution, however, the germination percentages of corn and broomcorn are 11.22% and 22.88% more than that in the 0C solution. In the 0.4C or 0.6C solution, the germination percentage of corn or broomcorn is less than that in the 0C solution. Therefore, the 0.2C solution can be applied in corn or broomcorn field to improve soil structure. The experiment is distinct by *F*-test. The experiment also shows that the solution of high concentration may impede crops germination while that of low concentration can promote crop germination. Since crop seed need air to germinate and the quantity of air needed varies with different crops, the solution with high concentration may cause soil to carry less quantity of air and can not meet the need of germination. Thus, different-concentration solution should be applied to different crops so as to promote germination and avoid disadvantageous factors.

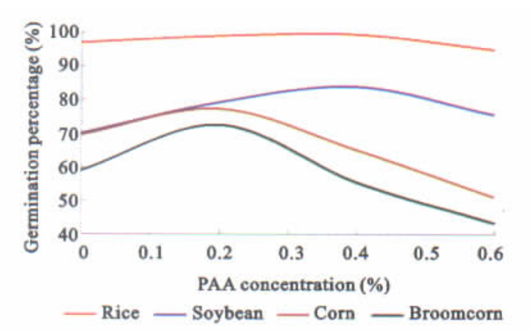

Fig. 4 Germination test

3.4 Effect of Different Treatments on Corn Growth

We started to observe corn growth 20 days after seeds planting. Table 2 shows that dry corn trunk weight and dry root weight treated in 0.2C, 0.4C, 0.6C solutions are heavier than that in check (0C) in the tanks; and the number of corn leaves in 0.2C, 0.4C, and 0.6C treatments is more than that in check; and in 0.2C or 0.4C treatment, trunk is higher than that in check. In 0.6C treatment, trunk is shorter than that in check. Therefore, the 0.2C or 0.4C treatment can promote corn growth greatly, because water-conserving membrane is formed in the soil treated by the above-mentioned solutions and soil′s water content is increased so as to meet the need of corn growth. The experiment is distinct by *F*-test.

Table 2 Effect of different PAA concentration on corn growth

Treatment	Trunk height (cm)	Number of leaves	Dry trunk weight (g)	Dry root weight (g)
0 C	13.43	3.33	0.13	0.050
0.2 C	13.45	3.68	0.14	0.066
0.4 C	14.35	3.63	0.19	0.075
0.6 C	13.35	3.63	0.17	0.070

Table 3 provides the result of earring time and corn yield. In the 0.2C and 0.4C treatments, male heading appears 7 days or 9 days earlier than that in check and female earring appears 6 days or 9 days earlier than that in check. In 0.6C treatment, ears appear as early as that in check. This experiment shows that the 0.2C or 0.4C treatment can promote corn propagation, early earring and blooming. Corn yield in 0.2C, 0.4C and 0.6C treatments is 13.53%, 14.77% and 7.88% respectively more than that in check (0C). The reason is that the treatment helps soil form water-conserving membrane and increase soil′s water-conserving capability so as to promote corn propagation. The experiment is distinct by *F*-test.

Table 3 Earring time and corn yield

Treatment	Male heading appearing time	Female earring appearing time	Yield (kg/ha)	Increment (%)
0 C	July 23	July 30	5403	0
0.2 C	July 15	July 24	6134	13.53
0.4 C	July 13	July 21	6201	14.77
0.6 C	July 23	July 30	5829	7.88

Fig. 5 shows that corn trunk grows faster than that in 0.2C and 0.4C treatments and slower in the 0.6C treatment than that in the check. This may be caused by the fact that more water-conserving membrane can be formed in the 0.6C treatment, so that air content in soil is reduced and corn growth is restrained.

Table 4 indicates the field moisture capacity of soil in tanks. Apart from soil surface (0–10cm), field moisture capacity increases in soil treated by the above-mentioned solutions. In the 10–20cm soil layer, field moisture capacity is the highest, so most water can be preserved in this soil layer. Besides, crop roots are mainly distri-

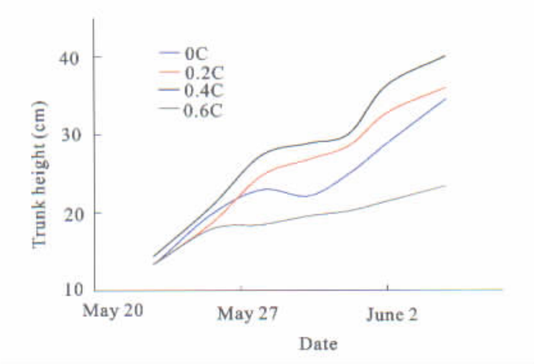

Fig. 5 Changes of trunk height of corn

buted in 0–20cm of soil layer. Water will be used most efficiently.

3.5 Effect of Different Treatments on Leakage

Water leakage is related to soil's physical characteristics. Water leakage quantity in sandy soil is 0.864–8.64m/d. Water leakage quantity in paddy field is usually 360–1440mm/d in the northern China (KOU and JIANG, 1995). Table 5 lists vadose coefficient of various soils.

Table 6 shows that the more clay content soil has, the better result water-conserving membrane can achieve in certain solution concentration. In addition, soil must have air permeability in the period of crop growth; so water-conserving membrane must keep a balance between water and air. The most proper clay content in water-conserving membrane is 2.0–2.5g/L.

Table 4 Effect of different PAA concentration on field moisture capacity (%)

Soil layer (cm)	0C	0.2C	Increment	0.4C	Increment	0.6C	Increment
10	13.95	13.96	0.01	13.75	–0.20	13.93	–0.02
20	11.08	14.00	2.92	14.13	3.05	14.65	3.57
30	11.69	11.77	0.08	12.61	0.92	12.54	0.85
40	13.53	14.12	0.59	14.47	0.94	15.68	2.15
50	16.50	16.83	0.33	17.98	1.48	17.93	1.43
60	15.71	16.05	0.34	17.34	1.63	17.99	2.28

Table 5 Vadose coefficient of soil (LI, 1996)

Soil type	Vadose coefficient		Soil type	Vadose coefficient	
	m/day	cm/s		m/day	cm/s
Clay	<0.005	$<6\times10^{-6}$	Coarse sand	20–50	2×10^{-2}–6×10^{-2}
Sub-clay	0.005–0.1	6×10^{-6}–1×10^{-4}	Homogeneous coarse sand	60–75	7×10^{-2}–9×10^{-2}
Light sub-clay	0.2–0.5	1×10^{-4}–6×10^{-4}	Round gravel	50–100	6×10^{-2}–1×10^{-1}
Loess	0.25–0.5	3×10^{-4}–6×10^{-4}	Boulder flint	100–500	6×10^{-2}–1×10^{-1}
Mealy sand	0.5–1.0	6×10^{-4}–1×10^{-3}	Unfilled boulder flint	500–1000	6×10^{-2}–10
Fine sand	1.0–5.0	1×10^{-3}–6×10^{-3}	Little fracture rock	20–60	2×10^{-2}–8×10^{-2}
Medium sand	5.0–20.0	6×10^{-3}–2×10^{-2}	Much fracture rock	>60	$>1\times10^{-2}$
Homogeneous medium sand	35–50	3×10^{-3}–6×10^{-2}			

Table 6 Clay content and vadose coefficient

Soil type	Content of clay (g/L)	Vadose quantity (mL/min)	Vadose coefficient (cm/s)
Coarse sand	0	31.0	2.86×10^{-2}
Coarse sand	0.5	25.0	2.30×10^{-2}
Fine sand	1.0	3.2	2.95×10^{-2}
Mealy sand	1.5	1.0	9.22×10^{-4}
Light sub-clay	2.0	0.5	4.60×10^{-4}
Sub-clay	2.5	0.1	9.22×10^{-5}

4 CONCLUSIONS

Water-conserving membrane is a new material used to improve sandy soil through obstructing capillary and increase viscidity particles so as to decrease water leakage in sandy soil. In different PAA-Na concentration, different water-conserving membranes are formed accordingly. As pH and PAA-Na neutralization concentration decreases, required Ca^{2+} increases. Least Ca^{2+} is required at 0.6C PAA-Na neutralization concentration. More PAA-Na concentration needs more Ca^{2+}, but required Ca^{2+} decreases with the increase of clay particles in soil. In practice, in different soils, the adjustment of pH and clay content can control the depth where water-conserving membrane is formed in soil.

Solution of 0.2C and 0.4C can promote rice seeds germination. All 0.2C, 0.4C and 0.6C solutions can promote soybean germination and the germination percentage is respectively 13.29%, 20.43% and 22.43% more than that of 0C. And 0.2C solution can help corn and broomcorn germinate. Therefore, 0.2C solution can be applied extensively in more crop fields. Solution of 0.2C or 0.4C can also help corn growth, propagation, early earring and yield increase. It can also increase field moisture capacity, especially in 10–20cm soil layer, with the increment of 27.5%.

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