Advance Journal of Food Science and Technology 5(6): 712-720, 2013
DOI:10.19026/ajfst.5.3153
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: January 22, 2013 Accepted: February 18, 2013 Published: June 05, 2013

Research Article

The Influence of Soil Particle on Soil Condensation Water

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Abstract: The experiment results showed that the indoor experiment formed from the volume of soil hygroscopic water increased gradually with decreasing size of soil particles. In the outdoor experiments, the results showed that the formed condensation water in medium sand was greater than it was in fine sand; the soil hot condensation water was mainly formed in the top layer of soil between 0-5 cm. We also found that covering the soil surface with stones can increase the volume of formed soil condensate water, reduce the evaporation and maintain relatively high moisture content in the top layer of soil.

Keywords: Arid and semi-arid regions, indoor experiments, soil condensation water, soil particle size, weighing method

INTRODUCTION

Many studies have been conducted to investigate the factors that influence the formation of soil condensation water. For example, (Guo and Liu, 2005; Hou *et al*., 2009; Zhuang and Zhao, 2008) reviewed that the literatures referring to soil condensation water and provided a detailed description about factors on the influence the formation of soil condensation water. They pointed out that the soil particle size could be the important factor, but lack of supports from the previous studies. Among limited number of studies: (Thomas, 1928) pointed out that soil moisture absorption ability increased with clay component. With a series of field soil condensation water (including hygroscopic water) test and experiment (Feng and Gao, 1995) concluded that the soil mechanical composition could be a major controlling factor, especially when the clay content less than 0.001 mm. (Hillel, 1998) pointed out that the moisture in air-dried soil largely depends on the soil mechanical composition and air humidity; (Guo and Han, 2002) concluded that daily average condensation volume of soil water in powder light clay, fine sand, sand gravel were 0.145 mm, 0.064 mm, 0.055 mm in freezing period, respectively, while the volumes were 26.1 mm, 11.5 mm, 9.9 mm separately in whole period. Li (2002) concluded that the condensation ability of fine sand, gravel, loess were 0.120 mm/d, 0.071 mm/d, 0.150 mm/d, respectively; (Fang and Ding, 2009) analyzed the relationship between grit size and condensation water formation and pointed out that at edge of desert oasis in Linze when powder sand size was <0.02 mm, it has the greatest condensation volume; the sandy loam took the second place; gravel has the smallest condensation volume when the particle sizes were in the range of 5.0-2.0 mm, 2.0-0.2 mm and 0.2-0.02 mm.

The soil condensation water experiments were primarily implemented in arid and semi-arid region, as water limited the development of these areas. Knowing the factor that influence the formation of soil condensation water is particularly important for the health of ecological systems. Field experiment and observation was the common method for studying the soil condensation water. Here we combined field observation with indoor experiment to study the impact of soil particle size on soil condensate formation. Compared with simply field observation experiment, the indoor control condition experiment could reduce the disturbing factors. We discussed the significance of our experimental results for development and utilization of soil condensation water, land moisture conservation, crop growth, soil improvement, desertification control of northwest area and improvement of ecological environment in north arid region.

EXPERIMENTAL APPARATUS AND METHOD

Study area: The field experimental site was located in the boundary of southeastern Mu Us Desert (N 39º16′40.49″, E 110 º 16′38.12″) and the north of Shenmu County. It was very close to the Inner Mongolia. The climate in the study area is continental

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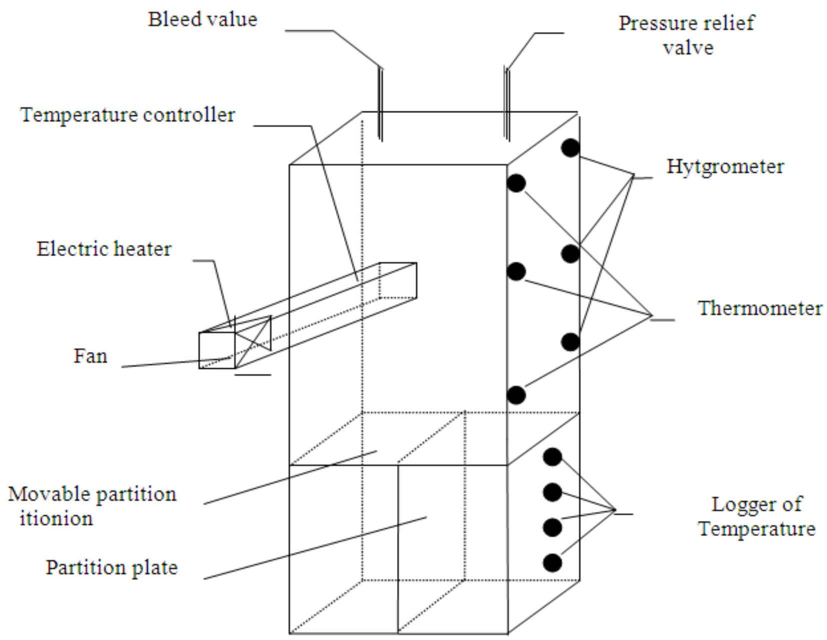

Fig. 1: Indoor experimental apparatus schematic diagram of soil condensation water

monsoon climate in a arid and semi-arid area. The winter in this region is long and cold, but summer is short and hot summer. The climate is dry with concentrated heavy rain, frequent sandstorm and dramatic daily temperature swings. Annual frost-free period is short which gets freeze in annual early October, freeze thaw out in March the following year. The annual mean temperature is 8.4ºC and the maximum and extreme minimum temperature are 38 ºC and -28 ºC, respectively. Annual mean rainfall is 441.2 mm, that the rainfall in 7, 8, 9 three months take accounts for about 70% of the whole year. Heavy rain and severe rainstorm occurs frequently. Annual mean evaporation is 2111.2 mm. Annual mean relative humidity is 55%. The mean wind speed is 2.2 m/s with a maximum wind speed of 25 m/s. Maximum frozen soil depth is 1.46 m. During the experiment period (2008.9.11-10.9), the maximum wind speed was 9.5 m/s, the range of atmospheric pressure was 61.1-88.7 KPa, the range of surface air relative humidity was 21% -100% and the range of surface temperature was 0.3-38.2 ºC.

The landscape in this area was mainly aeolian accumulation with sand dunes, long and sand beach staggered distribution. Vegetation included dry steppe type, deciduous broadleaf brush and desert vegetation and sandy plants. Sandy plants dominated the area that the coverage could attain 40-60% of the whole study area in the warm season.

Indoor experimental apparatus: The schematic diagram of indoor experimental apparatus is shown in Fig. 1. This device was an upper-lower interconnected cuboid. The length and width of the apparatus were both 40 cm. The height of upper part was 80 cm and the lower part was 40 cm. The upper and lower parts are separated by a movable bulkhead. The upper and lower parts can be separated completely by pushing the movable bulkhead into the box body and can be put together by pulling it out. The box is composed of three layers. The outside layer, middle layer and inner layer of the box were made of density board, insulation (in order to keep temperature constant when device is in sealing condition) and fireproof (in order to prevent fire from heating), respectively. The vent valve and safety valve were installed on the top side of the box to avoid the danger that could be triggered by too high pressure in box body. The quartz tube electric heater, fan and automatic temperature controller were installed on the upper side of the box. These apparatuses could help control the temperature and relative humidity inside the box. Quartz tube electric heater was used to heat up the air temperature inside the box and control the temperature in a required range. Fan can send the natural wind, cold wind and water vapor into box to adjust air temperature and humidity in upper part of the box. Automatic temperature controller was employed to keep temperature inside the box constant that when the air temperature is below the threshold value, the power of quartz tube electric heater was set on to heat the box up. Conversely, when the air temperature is higher than the threshold value, the power of the heater will be cut off by the automatic temperature controller. The six probes on the upside of the box were connected to hygrometer and thermometer separately to measure air relative humidity and temperature. The lower side of the box is divided into two parts by a clapboard that each part can be filled with different soil samples and micro-lysimeter which were used to conduct the soil condensate formation experiment. The clapboard in the middle part of the box can be taken out. The lower part of the box was used to place various types of soil. Temperature monitoring instrument inside the soil samples was employed to measure the soil temperature across the soil layers in different depths.

Indoor experimental scheme: Indoor experiment was designed to study the relationship between soil particle diameter and the soil hygroscopic water. In order to reduce the influence from other factors soil samples with different particle sizes were put into the micro-lysimeter which was placed at the lower side of the box. Doing this could guarantee the samples were under same experimental conditions. To prevent formation of hot condensation water, the relative humidity was controlled below 90% during the whole experimental process. The relative humidity in the upper box was set at 50, 70 and 90% respectively, for three experiments. Weighing method was employed in this study that the samples were weighted every 4 h by a weigh micro-lysimeter. The difference of weight in the weightings was considered as the amount of hygroscopic water or soil evaporation. The observation of soil temperature and air temperature and humidity were conducted concurrently. The soil temperature was observed by temperature inspecting instrument at depths of 0cm, 2cm, 5cm, 10cm, 15cm, 20cm, 30cm and 40cm, respectively. The soil temperature data were collected at a half-an-hour time step. Air temperature and humidity is measured by hygrometer and thermometer at an hour time step, respectively.

Field experimental apparatus: The apparatus used for measuring the soil condensation in the field observation was a self-made food-steamer-style micro-lysimeter. It was composed of multiple PVC steamers which were stacked successively from top to bottom. Each steamer is made of PVC tube of 9 centimeters inner diameter and the PVC tube were sealed by 400 nylon mesh. The stacked PVC steamers were put into a PVC barrel with a diameter of 11 cm (Fig. 2).

Field experimental scheme: The weighing method was also employed in the field experiment. The difference between the sequent two measured weights was considered as the volume of formed hygroscopic water or soil evaporation during this period. Same micro-lysimeters were employed for soil sample with different particle sizes. The weighting was conducted every 2 h to make sure the micro-lysimeter had enough

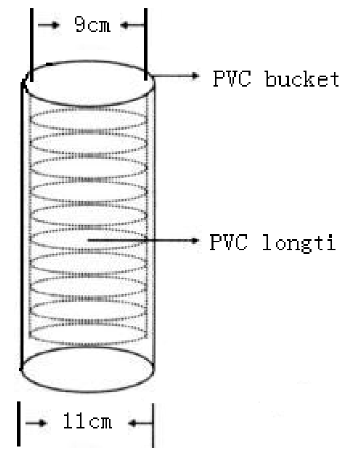

Fig. 2: Micro-lysimeter schematic diagram

contact time with the soil. Two groups of experiments under same scheme were conducted to avoid the failure of one group. The measured values were averaged when both of the groups succeeded. The soil temperature were concurrently conducted by a self-made instrument at depths of 0 cm, 2 cm, 5 cm, 10 cm, 15 cm, 20 cm, 0 cm, 40 cm, 50 cm, 75 cm and 80 cm, with a half hour time step. Using special ground thermometer measurement measured ground surface temperature every 2 h. The relative humidity, temperature, wind speed and atmospheric pressure were measured at a height of 50 cm from ground every 2 h. The experimental schemes were as follows:

Scheme 1: Measure the condensation water in fine and medium sand simultaneously to investigate the relationship between soil particle size and soil condensate formation; Compare the results with the laboratory results.

Scheme 2: Micro-lysimeters were buried in the experimental area partly with stones covered and no-stones covered on surface, compared and analyzed these two experiments to explore the influence of soil particle size change on soil condensation water.

Scheme 3: In the adjacent area which has the same underlying surface with experimental area, there were some parts covered with a layer of stones of 0.5-2 cm diameter (from experimentation area sand stones). The surface soil samples at depth of 0-4 cm from stone-covered area and adjacent areas covered with no stones were collected every 2 h concurrently. Thermostatic drying chamber was employed to dry gathering soil samples. After that calculating the soil moisture content to analysis the effect of surface coverage with stones to soil condensation water formation through comparing soil moisture content between stones covered region and bare area.

Table 1: The soil hygroscopic water formation with different soil particle size in different air relative humidity (unit g)

Depth	Loam hygroscopic water			Fine sand hygroscopic water			Medium sand hygroscopic water			Coarse sand hygroscopic water		
	50%	70%	90%	50%	70%	90%	50%	70%	90%	50%	70%	90%
0-5 cm	0.998	0.251	0.154	0.251	0.154	0.226	0.270	0.158	0.138	0.210	0.072	0.082
5-10 cm	0.245	0.068	0.110	0.068	0.110	0.120	0.074	0.087	0.091	0.143	0.059	0.047
10-15 cm	0.092	0.035	0.067	0.035	0.067	0.092	0.056	0.064	0.063	0.024	0.046	0.037
15-20 cm	0.134	0.057	0.067	0.057	0.067	0.085	0.047	0.062	0.054	0.027	0.036	0.029
0-20 cm	1.469	0.411	0.397	0.411	0.397	0.523	0.447	0.372	0.346	0.405	0.213	0.196

EXPERIMENTAL RESULTS

Soil condensation water includes two parts: hot condensate and hygroscopic water. Soil hot condensation water refers to liquid water condensate form atmospheric water vapor and soil pore water vapor in the ground and surface soil when ground temperature and surface temperature reach to dew point; Soil hygroscopic water refers to gaseous water absorbed by molecular attraction and electrostatic force around the dry soil particle surface from air or soil. Current experimental methods still can't distinguish these two parts, therefore, soil condensation water in this study means the sum of hot condensate and hygroscopic water.

Indoor experimental results: In indoor experiment process, there is only soil hygroscopic water due to the temperature did not reach to dew point. Indoor experimental observations results was showed in Table 1. It shows soil hygroscopic water volume of loam, fine sand, medium sand and coarse sand at different depth of soil, at the time the air relative humidity was set at 50%, 70% and 90% respectively.

According to indoor observation experiment of soil condensation water, under the same experiment conditions, soil particle size had obvious effect on the formation of soil hygroscopic water. Under the same air relative humidity conditions, the formed volume of soil hygroscopic water in loam was significantly greater than it is in coarse sand, medium sand and fine sand, hygroscopic water volume of fine and medium sand was slightly higher than coarse sand and there is little difference between hygroscopic water of fine and medium sand.

Figure 3-6 shows soil hygroscopic water change with depth at air relative humidity of 50%, 70% and 90% respectively, It can be seen that, the formation of soil hygroscopic water reduced gradually with the increased of soil depth, mainly occurred in the 0-10 cm depth. Meanwhile soil hygroscopic water formation volume at 0-5 cm depth was far greater than at 5-10 cm depth.

The soil hygroscopic water formation in coarse sand at 0-10 cm depth (x) and 0-20 cm depth (y)

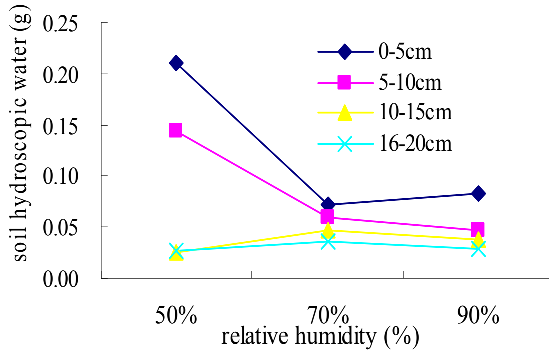

Fig. 3: Coarse sand hygroscopic water variation with depth diagram

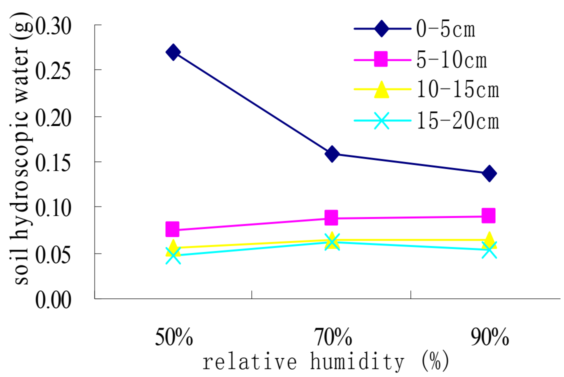

Fig. 4: Medium sand hygroscopic water variation with depth diagram

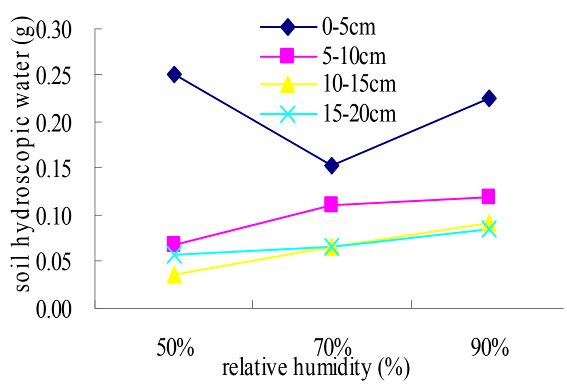

Fig. 5: Fine sand hygroscopic water variation with depth diagram

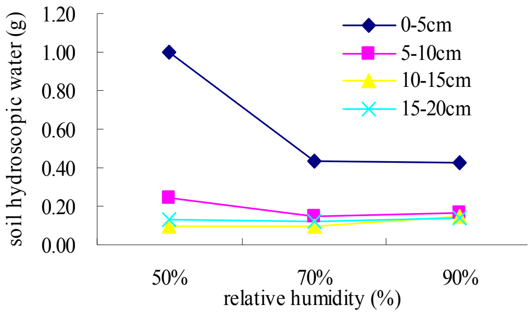

Fig. 6: Loam hygroscopic water variation with depth diagram

showed extremely significant linear relationship, relation equation was $y = 1.899x+0.088$, $R^2 = 0.999$; the soil hygroscopic water formation in medium sand at 0-10 cm depth (x) and 0-20 cm depth (y) showed extremely significant linear relationship, relation equation was $y = 1.835x+0.161$, R2 = 0.997; As well as it were in fine sand and loam, their relation equations separately were $y = 2.342x+0.029$, $R^2 = 0.856$ and $y = 1.963x+0.272$, $R^2 = 0.998$.

Field experimental results:

- **Medium sand, fine sand soil condensation water contrast experiment:** In field experiment process, the surface temperature may reach to dew point in some time period, therefore, the observed soil condensation water includes hot condensate and hygroscopic water concurrently. Figure 7, we can see that during the time of October 1 to 8, 2008, soil condensation water reduced with the decrease of soil particle size

Figure 8-9 reflected formation variation of soil condensation in medium sand and fine sand at different depths. Both in medium sand and fine sand, soil condensation water at 0-5 cm depth was far outweighed the other depths of the same thickness scope. The soil hygroscopic water formation in fine sand at 0-10 cm depth (x) and 0-20 cm depth (y) showed extremely significant linear relationship, relation equation was $y = 1.684x-0.011$, $R^2 = 0.82$; the soil hygroscopic water formation in medium sand at 0-10 cm depth (x) and 0-20 cm depth (y) showed extremely significant linear relationship, relation equation was $y = 2.131x-0.177$, $R^2 = 0.71$. The formed soil condensation water at depths of 5-10 cm, 10-15 cm and 15-20 cm differed little, the results showed that overall trend of soil condensation water formation reduced gradually with increasing of the soil depth, just consistent with indoor experiment results.

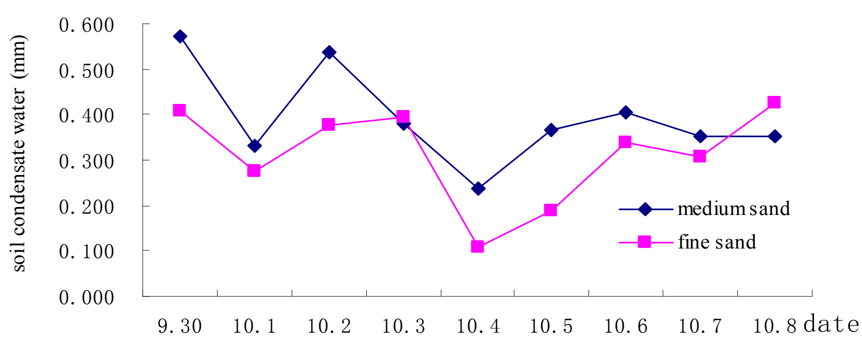

Fig. 7: Comparison diagram between medium sand and fine sand formation amount of soil condensation water

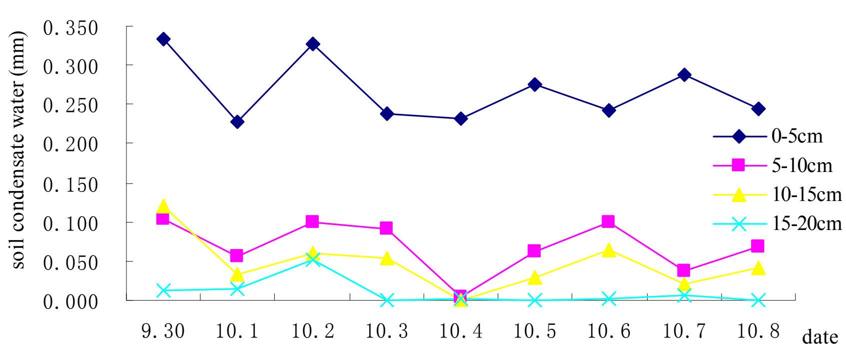

Fig. 8: Medium sand soil condensation water variation with depth diagram

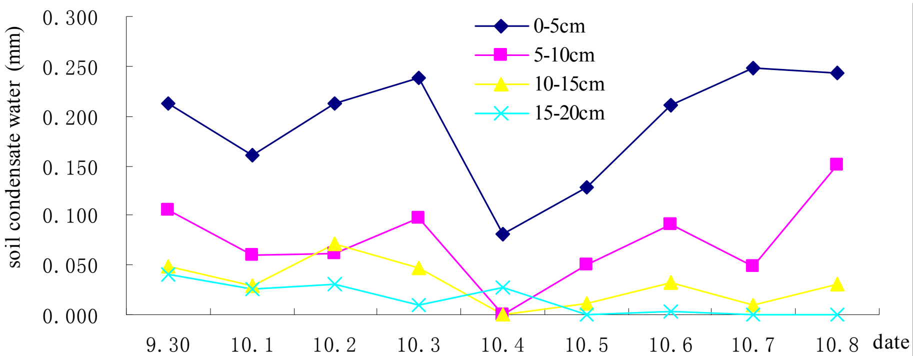

Fig. 9: Fine sand soil condensation water variation with depth diagram

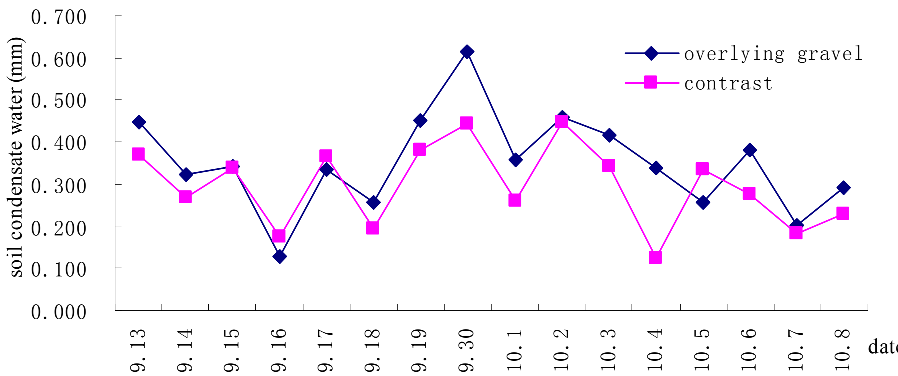

Fig. 10: Soil condensation water comparison diagram between stone-covered surface and the control soil sample

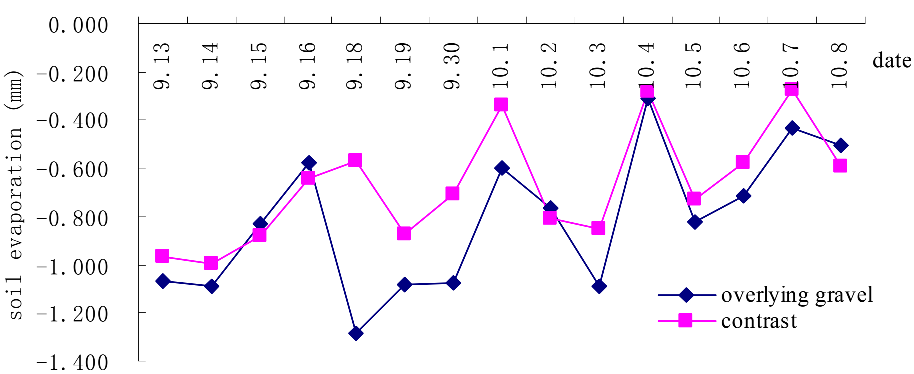

Fig. 11: Soil evaporation comparison diagram between stone-covered surface and the control soil sample

- **Contrast experiment of stone-covered soil condensation water:** Figure 10-11 showed during September 13 to October 8, 2008, the relationship diagram of soil condensation water volume, evaporation at 0-30 cm soil depth with control sample which surface covered with stones. Since September 20 to September 27, 2008, it rained intermittently which effected formation of soil condensation, so experimental observations stopped during this period. Daily average of soil condensation volume and evaporation respectively were 0.365 mm and 0.672 mm at 0-30 cm depth under the case of sandy soil surface covered with stone, daily average of soil condensation volume and evaporation were respectively 0.299 mm and 0.816 mm at 0-30 cm depth without stone covered. The results showed that soil evaporation of stone-covered soil surface was generally smaller than the control soil sample (Fig. 11). The formation volume of soil condensation water with stone-

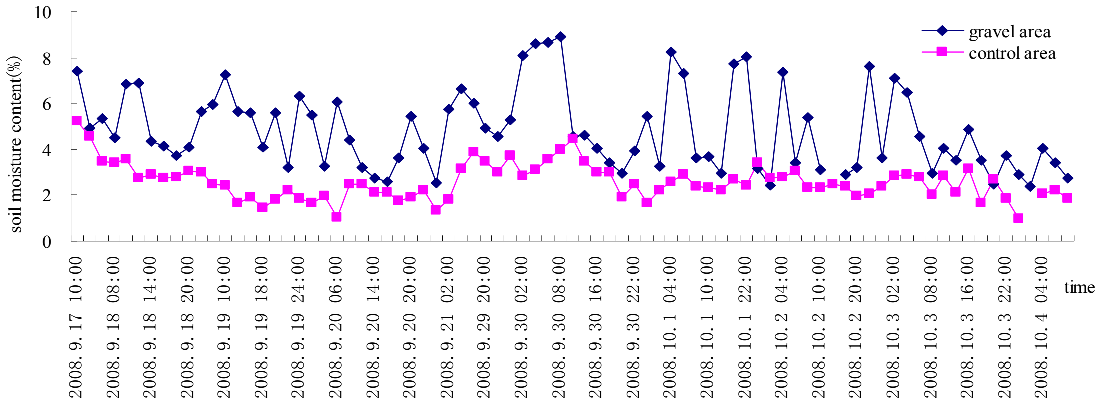

Fig. 12: Soil moisture content comparison diagram between stone-covered region and the control region

covered surface was larger than no stone-covered region, while soil evaporation was quit contrary.

- **Contrast experiment of stone-covered soil moisture content:** As showed in Fig. 12, during various periods a day, soil moisture content at 0-4 cm soil depth of stone-covered region was higher than region which no stones covered. As while, soil moisture content change range at 0-4 cm soil depth of stone-covered region was far larger than region which no stones covered

DISCUSSION

The relationship of soil particle size and soil hygroscopic water: Indoor experimental results showed that soil hygroscopic water volume at 0-20 cm depth in different sized particle soil were very different, the order of hygroscopic water volume was: loam>fine sand>medium sand>coarse sand. Formation volume of soil hygroscopic water reduced gradually with soil particle size increasing which was consistent with the conclusions of other scholars. In field experiment, results showed that condensation water volume in medium sand was greater than fine sand which contrary with indoor experimental conclusions and other scholars]. The reasons may be the hygroscopic water formation. Almost every night surface temperature reached to dew point caused by climate change which leaded to diurnal temperature increasing. The field experimental result was sum of hot condensation water and hygroscopic water. At present time, there still no ways to separate the two proportions. There was a larger proportion of hot condensate formation during observation period, leading to greater soil condensate formation in medium sand than in fine sand.

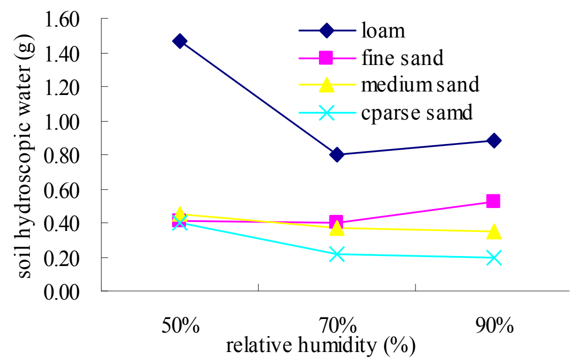

Fig. 13: Hygroscopic water variation with air relative humidity diagram

The influence of soil particle on formation of soil hot condensation water: As showed in Fig. 13 and 14, soil condensate formation in medium sand at 0-5 cm soil depth was greater than fine sand, but differed little at 5-20cn soil depth. Consequently, cause of medium sand surface cooled faster to reach dew point than fine sand, due to soil hot condensate formation in medium sand at 0-5 cm soil depth was greater than in fine sand. This result also proved that, in experimental time, soil hot condensation water mainly formed at the surface 0-5 cm depth of soil and hot condensate formation volume far outweighed soil hygroscopic water in this depth, leading to the soil condensate water formation medium sand is greater than in fine sand.

The influence of soil particle size and soil moisture content on hygroscopic water: Usually, formation volume of soil hygroscopic water increases along with the rise of air relative humidity, but the indoor experimental results only showed at 0-5 cm soil depth and formation volume of soil hygroscopic water of

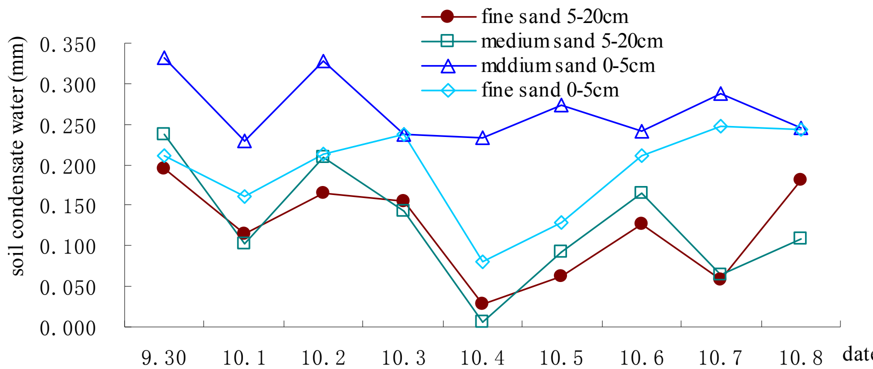

Fig. 14: Comparison diagram of medium sand and fine sand soil condensation water variation with depth

different particle size displayed a decreasing tendency with the rise of air relative humidity instead (Fig. 3-6) which consisted with Li (1996, 2010) research conclusion . The reason may be that, at beginning of the experiment, the soil was relatively dry lead to more soil hygroscopic water formed at soil surface, with the extension of experimental time, soil moisture content gradually increased conversed to hygroscopic water formation, At 5-10 cm depth of soil, hygroscopic water formation in coarse sand and medium sand increased along with the increasing of air relative humidity, however it presented the trend of decreasing in fine sand and loam, the reason was as same as above which related to moisture content of fine sand and loam.

Research significance: Moisture content of surface soil with stones-covered region was commonly higher than the region without stone-covered. Covering the soil surface with stones in experimental area can increase the volume of formed soil condensate water and reduce soil evaporation which consisted with observation conclusion of soil condensation with stone-covered. Under the same condition, the soil surface temperature was easier to achieve dew point to form hot condensation water surface with stone coverage. Therefore, we can change soil particle size, such as stones coverage, coarse gravel sand method to increase soil condensate water formation, thus to create more favorable conditions for vegetation growth and to protect ecological environment in arid and semi-arid region.

Limitation and direction of research: In field observation experiment, soil condensation water included hot condensation and hygroscopic water and current experimental methods still can't distinguish these two parts, accordingly, the relationship between hot condensate and hygroscopic water cannot be quantitative analyzed.

At present, the research significance of soil condensation water mainly concentrated in ecological field, rarely reported in specific application research field. In ecological significance research, it advocates multi-disciplinary conjunction of botany, thermodynamics, meteorology, geology and combination with production practice. It important to study the ecological function of soil condensation water and exploited it. Application research about soil condensation water should be strengthened, such as provision drinking water for extreme water shortage area (arid or poor water quality region), protection ancient architecture, art form damage caused by the presence of condensation water, etc.

CONCLUSION

The experiment results showed that in the indoor experiment the formed volume of soil hygroscopic water increased gradually with decreasing size of soil particles, the formed volume of soil hygroscopic water in loam was significantly greater than in coarse sand, medium sand and fine sand.

The formation volume of soil hygroscopic water gradually decreased with increasing soil depth and hygroscopic water at 0-5 cm soil depth was much greater than at soil depth of 5-10 cm, 10-15 cm and 15-20 cm.

In the field experimental period, the formation of soil condensation water included hot condensate and hygroscopic water. The formed soil condensation water at 0-5 cm soil depth mainly was hot condensation water, in the meantime, formation volume of hot condensation far outweighed soil hygroscopic water in this depth

Though the contrast experiment of stone-covered soil condensation water and determination of soil moisture content, it proved that soil surface covered with stones can improve soil condensation water formation volume and reduce evaporation just to maintain relatively high soil moisture content.

ACKNOWLEDGMENT

The study was supported by grants from the Institute of Hydrogeology and Environmental Geology (SK200720). Thank Jia Chong and Jia Min for helping experimental observation of soil condensation water, thank Song Shuhong for technical advices to this study.

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