Study on the thermodynamic function of farmland under drip irrigation

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Abstract: As drip irrigation is more and more beneficial to saving water resources, it has become a more popular way to irrigate farmland, so the research of drip irrigation farmland has been paid more attention to. Based on the dynamic simulation of farmland under drip irrigation and the analysis of control variables, the relationship among thermodynamic functions such as temperature, water content and soil water potential are studied by different methods in this paper and the corresponding conclusions are obtained. Under the condition of constant control temperature, the water conductivity of soil in farmland will decrease with the increase of soil water potential, that is, the conductivity of soil is inversely proportional to the water potential of soil. In the process of actual drip irrigation, it is impossible to control soil parameters such as temperature or water content and soil water potential separately. So the test in this paper is relatively ideal, but still has reference significance.

Keywords: drip irrigation of farmland; soil water potential; thermodynamic function; soil water conductivity

1. Introduction

Water shortage and soil salinization are important factors that hinder the sustainable development of agriculture in arid areas [1]. In Xinjiang, for example, more than 50% of rivers are used for agricultural irrigation, often leading to the drying up of downstream rivers and lakes and the expansion of deserts. Through drip irrigation, it can reduce soil water evaporation and deep water infiltration, thus effectively saving water and improving water use efficiency. As a large agricultural country, because of the complicated topography and uneven distribution of agricultural land [2]. For building resource-saving and environment-friendly agriculture, drip irrigation agriculture has been paid more and more attention to. Therefore, drip irrigation is one of the excellent development trends of agriculture in China.

Since modern times, China has paid more and more attention to soil science, and has begun to study soil from the perspective of energy. The research mainly regards the flow and transfer of soil water as the object of study. As a result, research in the field of farmland is even rarer. Soil research in different regions has been paid more attention.

The tensometer, the most widely used instrument for measuring the potential energy of water in farmland, is used here to test the thermodynamic functions (relative partial molar free energy ΔG, relative partial molar enthalpy ΔH, and relative partial molar entropy ΔS) of soil moisture at different water content and temperature for soil in different states (control variables). By comparing the experimental data, it is found that the thermodynamic function laws of farmland under drip irrigation and its adaptability to Gibbs Helmholtz equation [3].

2. Related Work

As early as 2000, Liu [4] of Northwest Agricultural University carried out research work on the thermodynamic analysis of all kinds of soils and made a preliminary study on the thermodynamic function relationship of unsaturated soil moisture in the Journal of Soil. Moreover, in the 2012 Journal of Agricultural Science [5], they made a study on the relationship between farmland soil moisture movement and thermodynamics function of straw returning in the long term which shows the results: with the increase of relative partial molar free energy and relative partial molar enthalpy, the unsaturated water conductivity of the soil increases when the soil moisture content is fixed. It can be seen that the current research object of soil thermodynamics is mainly to carry out verification analysis of the relation fitting curve of soil potential energy, the unsaturated water conductivity and so on through the study of soil moisture, the volume of soil water and the calculation of thermodynamic equation. Liu et al. [6] in the "Agricultural Research in Arid Areas" in 2011, through the discussion of three measuring methods of soil water potential, found that there were differences in these methods: the accuracy of pressure film is the highest, followed by centrifuge and finally the tensometer.

From the above research, one can see that the study of soil thermodynamics is difficult to some extent. There will be a lot of differences in thermodynamic properties restricted by geographical factors [7] and the choice of soil. In view of the above factors, the thermodynamic study of soil under drip irrigation [8] is based on the theoretical analysis of different water content and temperature. During drip irrigation, the water content of farmland varies with the season. Evaporation is different, so seasonal variations are simulated as temperature changes. The time of drip irrigation can be reflected by water content to simulate the test.

3. Experimental method

3.1 Relationship between soil moisture content θ and soil water absorption τ

Yang Ling of Shaanxi was selected as the locator, the soil for the experiment was bauxite, the area of the experimental plot was 30m2, and the experiment was repeated twice. The experiment began in October 2010 and continued until October 2018. The drip irrigation of different farmland was tested at the same time every year according to the season. Soil water absorption and water conductivity were measured. The physical and chemical properties of bauxite are shown in Table 1. The soil sample was air-dried bauxite treated with 2.0mm sieve. The organic matter was measured by potassium dichromate volumetric method, the specific surface wasadsorbed by ethylene glycol ether, and soil mechanical analysis adopted the straw method [9].

The soil water potential of soil adopted a widely used method-tensometer [10]. The instrument comes from the miniature tensometer (vacuum meter) made by Nanjing Institute of Soil Research, Chinese Academy of Sciences, with a precision of 2.5 grade. The range of calibration is 0 ~ 100kPa, and the range of measurement is 0 ~ 85 kPa. The tensometer was measured in a constant greenhouse with a temperature of 20 ±1 ℃. The soil sample was packed in a plexiglass plastic cylinder with a diameter of 10 cm, and a height of 10 cm, up to 8cm at a bulk weight of 1.38 g/cm3. The center of the tensometer clay head (= 10 mm) is 4 cm high, and the average water content is obtained by using a balance weighing of 0.01g according to the time prescribed in the instrument instruction. There are three duplicates in the experiment, and the soil water suction value under the same water content is also obtained by the average of three suction forces. Undoubtedly, all the experiments measured are the dehydration process of the soil. In Table 2, the relationship between soil moisture content θ and soil water absorbency τ is analyzed and measured, and the logarithm is taken to get the corresponding straight line fitting.

3.2 Effect of temperature on the soil moisture characteristic curve

The unsaturated water conductivity and saturated water conductivity of the experimental soil at different temperatures were measured by the constant head vertical soil column infiltration experiment [11]. Before the experiment, the soil was stratified with a preset bulk density (1.35 g/cm3) into a PMMA column with an internal diameter of 10 cm and a length of 40 cm. There were small holes in the column wall with a hole diameter of 1.5 cm and a hole spacing of 2 cm. The height of each layer is 5 cm, the quality of the layer is weighed according to the preset bulk density, the total height of the soil is 30 cm, and the water is supplied to the soil column with Markov bottle. Before the experiment, all the experimental devices were put into the temperature control room for certain time (≥ 3 h). For keeping the room temperature constant, the interference of the laboratory with the outside environment is minimized during the experiment.

The soil water diffusivity was measured by one-dimensional horizontal soil column absorption method. The experimental apparatus and the process were basically the same as the unsaturated water conductivity measurement process above.

All the experiments were carried out in the closed temperature control room except for the determination of soil moisture characteristic curve. The temperature of the laboratory test was set at 8 ℃, 18 ℃, 25 ℃, and 35 ℃ ($T \leq 0.5$ ℃), respectively, and the set temperature of the centrifuge was the same. All experiments were repeated.

3.3 Measurement of unsaturated water conductivity

In this experiment, a steady state flow method [12] was used to determine the unsaturated water conductivity of the soil. In a plastic cylinder with a diameter of 70 mm, and a length of 138 mm, the sample of bauxite was put into the soil column and the initial water content was 300g kg-1. Two small round holes in the plastic cylinder were inserted into the compound mercury tensometer (U tube type in the physics room of Nanjing Soil Research Institute). The two ends of the cylinder were sealed and placed in the thermostat box so that the upper part of the tensor was exposed outside the box. At the same time, a thermometer was put in the box and balanced under constant temperature. After balancing, the seal cover at one end of the differential tensometer was replaced by a hole cover to control the evaporation rate and make the evaporation rate relatively stable. The water in the soil column would flow to the evaporation surface as a result of evaporation. The variation of water content in the soil column was determined by weighing method. At the same temperature, the tensometer reading, the time required for each water content change stage and the soil moisture weight reduction were recorded when the water content changed from 300g·kg-1 to 280, 260, 240, 220, 200, 180, and 160 g·kg-1. The unsaturated water conductivity of the soil has been calculated in previous studies, so here [x] is quoted directly, and the formula is as follows:

$$K = \frac{\Delta g \cdot 24L}{\Delta t \cdot S \cdot 2\Delta h}$$

Here, k is water conductivity, (cm d-1); Δg is the weighing difference (g) between two weighing processes; L is the distance (cm) between the two clay heads of the tensiometer; Δt is the time interval (h) between two weighing processes; S is evaporation area (cm2); Δh is the difference of suction (Pa) between two ceramic heads.

In the same way, by means of the thermodynamic principle of soil [14], the thermodynamic function of soil moisture [15] can also be obtained as follows:

$$\Delta\overline{G} = -\overline{V \cdot \tau}\ , \quad \Delta\overline{S} = -\overline{V}\left(\frac{\partial \tau}{\partial T}\right), \quad \Delta\overline{H} = \Delta\overline{G} + T \cdot \Delta\overline{S}$$

V(m·3 mol-1) is the partial molar volume of pure water; τ(Pa) is soil water suction; T (K) is absolute temperature; ΔG (J·mol-1) is the relative partial molar free energy of soil water at atmospheric pressure; ΔS (J·mol-1·K-1) is the relative partial molar entropy of soil water at atmospheric pressure ; ΔH (J·mol-1) is the partial molar enthalpy of soil water at atmospheric pressure.

4. Results and discussions

4.1 Basic properties of the soils to be tested

Table 1 Basic properties of the tested bauxite

Soil	Depth (cm)	Organic mater (g/ kg)	Bulk density (g/ cm3)	Physical clay <0.01mm (g/ kg)	Clay <0.001mm (g/ kg)	Area (m2/ g)
	0~20	12.3	1.38	432.4	188.6	276.1

4.2 Fitting of the regression equation

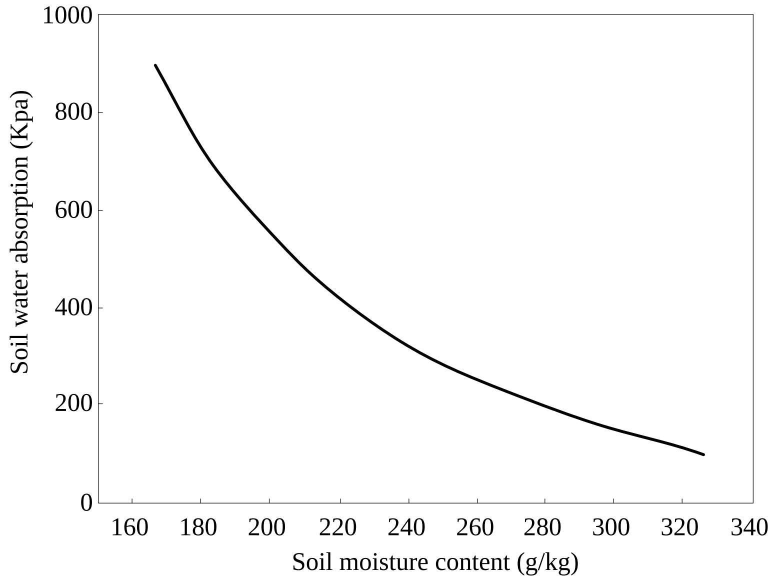
Table 2 Determination results of the tensiometer test method and the regression equation

(kPa) Soil suction of water	(g/ kg) Soil water content	Correlation coefficient
100	325.6	Logτ=3.9389-0.005θ
200	276.3	
300	244.5	
400	223.2	

500	207.0	
600	194.2	
700	183.0	
800	174.1	
900	167.5	

From this, one can draw a conclusion intuitively, that is to say, with the increase of soil water content, the water absorption rate of soil will gradually decrease; otherwise, the conclusion still holds. In the fitting curve, one can see that there is a basic linear relationship. In fact, in the process of drip irrigation, with the increase of soil moisture content, the water absorption capacity of soil will decrease, which is because the soil is in transition from an unsaturated state to a saturated state, and with the increase of water content, the soil water potential shows an increasing state.

Based on the simulation of the map and the increase of soil moisture content in the process of drip irrigation with the increase of drip irrigation time. Therefore, the drip irrigation condition in a region should first test the water absorption capacity of the soil. In the near saturation degree, the corresponding titration time is determined to save the water source and reduce unnecessary evaporation of water.



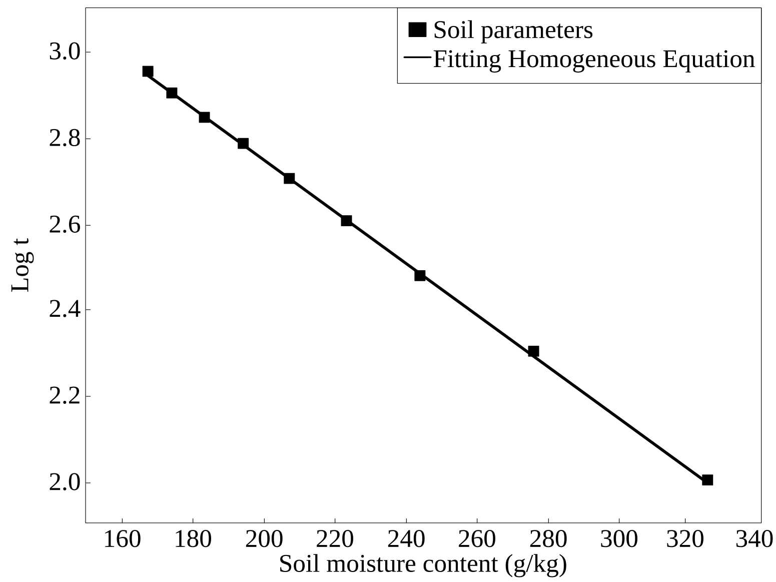


Figure.1 Relationship between soil water content and soil water absorption and the fitting curve

4.3 Analysis of the effect of temperature on the characteristic curve of soil moisture in farmland

Through the above experimental methods, this paper selected four temperature values for isothermal measurement to obtain the corresponding experimental data, as shown in figure 2. The average value of the obtained points has been calculated.

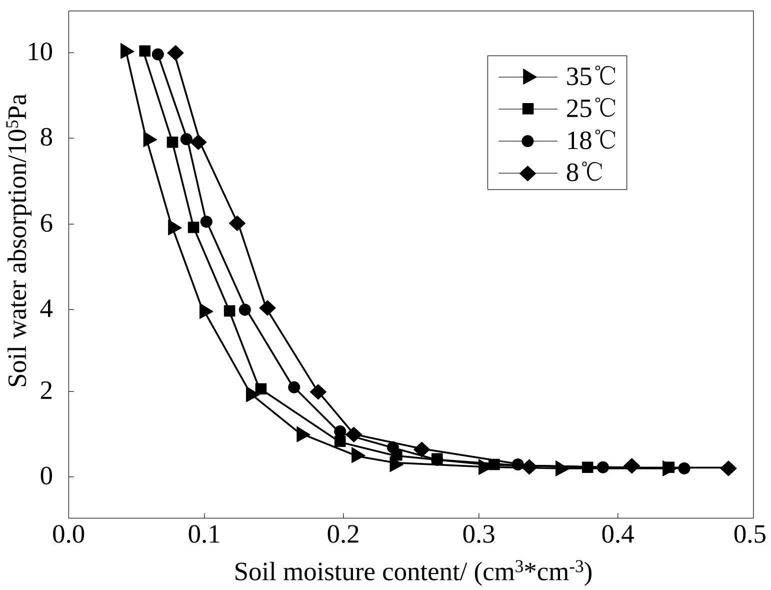


Fig.2 Water characteristic curve of farmland soil under different temperatures

In figure 2, one can more clearly compare the variation of temperature on soil water absorption compared to fig. 1 by the temperature difference. By selecting four different temperatures to control the variables, it is convenient to exclude the temperature and moisture content and act on the soil at the same time. Under the condition of constant temperature, the regression equation in this paper is confirmed. One can see that soil moisture content and soil water absorption are negatively correlated. If we map according to logarithmic coordinate, one can still get a regression linear equation of changing units. The results show that the change of temperature has an important effect on the soil moisture characteristic curve and that the increase of temperature will really lead to soil water loss.

During drip irrigation, temperature is also one of the problems that must be considered in actual production. However, for drip irrigation, there is a significant difference in soil moisture retention capacity between the regions with large temperature difference and those with little difference in temperature. The water holding capacity of farmland is more uniform than that of the areas with little temperature difference. It is necessary to analyze the duration and frequency of drip irrigation according to the soil water potential of soil thermodynamics during drip irrigation.

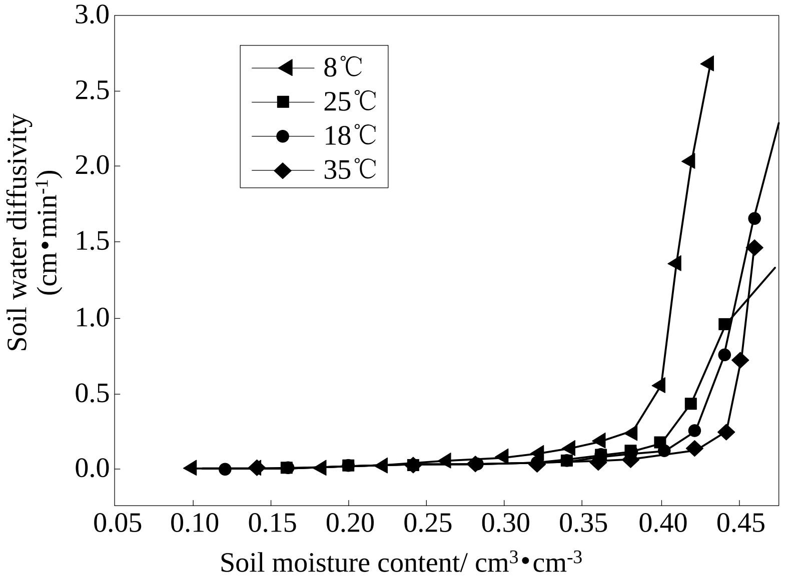


Fig.3 Soil water diffusivity of tested farmland soils at different temperatures

Using the horizontal soil column infiltration method to measure the soil moisture diffusivity under different temperature conditions, it can be seen that the soil diffusion rate and temperature are also closely related. Specifically, with the increase of temperature, the diffusion rate of water will increase obviously, and the movement of water molecules will increase. Under the condition of the same water content, it is relatively obvious in the diagram. Under the same diffusivity, the moisture content will gradually decrease with the increase of temperature. Under the condition of constant temperature, the soil moisture content and water diffusivity show a positive correlation trend, and the change is not very evident when the water content is low. Nevertheless, with the increase of water content in soil, the trend of change will be better reflected.

The diffusion of water in farmland under drip irrigation condition is also simulated by this method. During drip irrigation, with the increase of soil moisture content, farmland water control will gradually weaken and lead to water loss.

4.4 Study on unsaturated water conductivity and thermodynamic function of soil

Table 3 Water transmitting rate of unsaturated soil under different temperature and water potential (k)

Soil	Water content/ g·kg	Temperature/K							
		285K		290K		295K		300K	
		Ψ/kPa	k/10-3 cm·d-1	Ψ/kPa	k/10-3 cm·d-1	Ψ/kPa	k/10-3 cm·d-1	Ψ/kPa	k/10-3 cm·d-1
bauxite	180	-88.12	1.184	-81.68	3.325	-74.97	5.436	-68.8	7.541
	200	-74.26	1.978	-65.32	4.942	-58.91	7.527	-54.17	10.426
	220	-51.35	4.225	-41.7	8.629	-37.05	12.534	-32.15	16.234
	240	-37.45	11.236	-26.63	20.536	-21.33	25.742	-17.42	32.350
	260	-22.27	17.325	-19.94	25.214	-17.85	30.470	-14.96	36.725

The thermodynamic function has been described in the experiment and it has been known that the values of the three thermodynamic functions are all negative. With the increase of temperature, the absolute values of the three functions become smaller, and with the increase of free energy of water, it is not difficult to infer the relationship between the free energy and the water conductivity of farmland soil. Here, the calculated values and fitting curves of the tedious thermodynamic functions are not included in the table. The calculated thermodynamic function and the water conductivity relation are drawn to reflect the relationship between the two.

With the increase of temperature, the internal energy of water in farmland soil increases, the partial molar free energy ΔG, the relative partial molar free enthalpy, relative partial molar enthalpy ΔH and relative partial molar entropy ΔS in the system all show a rising trend. This can be seen intuitively in figure 4.

The purpose of this paper is to verify the water content and temperature as the main influencing factors based on the thermodynamics function of farmland under titration condition. It is difficult to control the temperature and water content simultaneously in the actual drip irrigation process. The soil selected in this experiment has only one-sided reference value, which is the deficiency of this paper. In the future research, it is hoped to be able to make up for the above deficiencies.

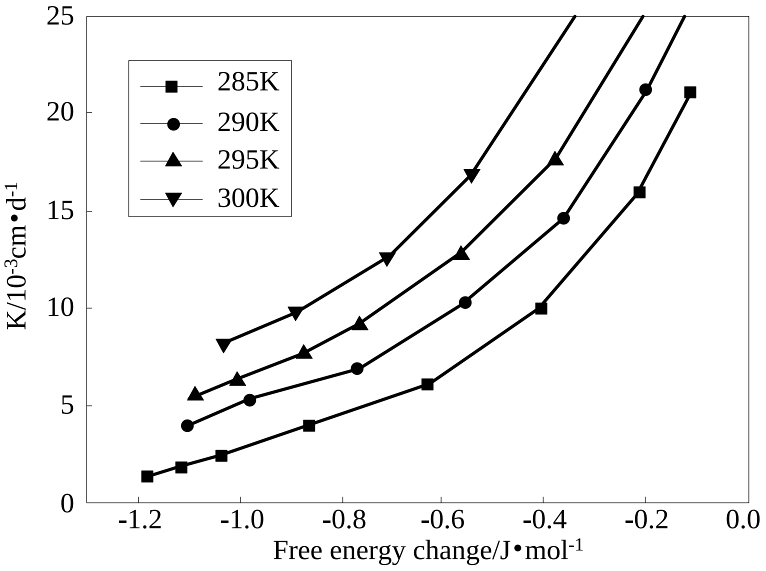


Figure4 Relationship between farmland soil [partial molar free energy (ΔG)] and hydraulic conductivity (k)

5. Conclusion

The research direction of this paper is to study the thermodynamics function of farmland under drip irrigation. Based on the fact that the farmland with direct drip irrigation has more complex influence factors, the simulation experiment of control parameters is carried out. Therefore, the control parameter method which is easy to carry out in the experiment is used to compare the main influencing factors and draw the following conclusions.

Through the linear fitting of soil water absorption and soil water content, one can draw a conclusion that with the increase of soil water content, the soil water absorption rate will gradually decrease. With the decrease of soil moisture content, the variation of soil water absorption rate will become smaller and smaller. With the increase of temperature and water content, the free energy, enthalpy and entropy of water in the soil will increase.

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