ANALYSIS OF WATER CHARACTERISTICS OF BLACK SOIL OVER LONG-TERM EXPERIMENTAL RESEARCHES IN NORTHEAST CHINA

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Summary. Long-term investigations of soil moisture at different precipitation patterns in the black soil in Hailun county, Northeast China were made. This area is an important base for marketable grains production due to a short cultivation history, high soil organic matter content, and high yield potential. In this region, precipitation is the principal water source during the cropping season, hence soil water storage is very important for agricultural production. Estimation of the soil water retention characteristics of the black soil is necessary to assess the risk of drought, soil water potential to meet crop water requirements, and irrigation scheduling.

The soil water conditions are influenced by meteorology, soil physical properties, vegetation and other related factors. Ten years of field research were the basis for our definition of soil water characteristics of the black soils at Hailun Agri-ecology Experimental Station, Songnen plain, Northeast China. This paper identifies three different kinds of precipitation which affect soil water movement and soil water characteristics in different seasons. Investigations were performed during the normal rainfall year of 1995, the above normal rainfall year of 1997 and the drought year of 2001. The basic characteristics of soil water in farmland of the black soil region and also the vertical motion of soil water were discussed. Based on the results of soil water measurement and analysis, the movement of black soil water was divided into four periods - a thawing stage in spring, a dry stage in summer, a wet stage in autumn and a frozen stage in winter. Four soil water zones were identified within the depth range 0-270 cm - a highly varying zone (0- 40 cm), a weakly

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varying zone (40-110 cm), a slightly varying zone (110-260 cm) and a non varying zone (270 cm and more).

Keywords: black soil, soil water characteristic, water moving regularity

Abbreviations: HL = Hailun Agricultural Ecological Experimental Station

INTRODUCTION

Black soil farmland is a rain-fed agricultural area, located in the northern part of Northeast China. This area has a temperate and semiarid climate being an important grain producing region, partly due to the short cultivation history and the high soil organic matter content. The water table in this area reaches more than 30 meters below the surface. Thus, it has no direct impact on soil water movement. Rainfall is the main source of soil water and it directly influences the storage and the movement of soil water (Wang, et al.,1996; Qiao, 1963; Shen, 1980). Therefore, research concerning relationship between precipitation and soil water content, changes in soil water movement and crop water needs is of high priority. Meanwhile, the information on soil water availability and the relationship between crop production and crop water use during the growing season is needed to assess the risk rate of drought, as well as the crop water requirements, and irrigation scheduling. This knowledge can help improving water use efficiencies and increase returns to the producer (Wallace et al., 1997; Gaze et al., 1997; Siddique et al., 1990; Payne et al., 1997). It can also be useful for farmers and the government as a planning tool for the development of investment strategies in the area. Beginning in 1993, long- term soil moisture observations were continually done in the same field of the black soil region. Three different types of precipitation years were chosen to observe the soil water content difference to a depth of 270 cm. The objectives of this research were: (1) to determine the soil water movement patterns and the influence of different factors on soil water dynamics within the different seasons; (2) to determine the soil water retention curve in different horizons of a black soil arable field.

MATERIALS AND METHODS

The experimental site with long-term climate, cropping and soil water records was established in 1978. The site, named the Hailun Agricultural Ecological Experimental Station (HL), was located in Hailun city, on the Songnen plain, in northeast China (47°26′ N and 126° 38′ E, at an altitude of 240 m). The average annual temperature is 1.5 °C, with the highest temperature in summer (32 °C), and the lowest temperature in winter (-37 °C). The area belongs to the northern temperate zone and continental monsoon area, which is cold and arid in winter, and hot and rainy in summer. The biggest rainfall and temperatures appear from July to September. The soil type is middle thick black soil, which was formed in the end of tertiary from original material loess. This soil has high clay content and low infiltration rates with slow capillary movement. The soil characteristics at HL can principally stand for the black soil properties in China. (Meng, 1993)

Table 1. Physical characteristics of the black soil

Dep#	OMC	BD	TP	FC		SC		WC		IR		ST
cm	g kg^{-1}	g cm^{-3}	%	%	mm	%	mm	%	mm	t	k_{10}m/d	
0-29	50.64	1.08	53.65	38.64	121.02	56.29	176.61	12.72	39.84	0.08	0.07	Heavy clay
29-60	14.66	1.24	49.18	30.65	117.55	46.74	179.67	11.82	45.44	0.06	0.055	Light clay
60-100	4.07	1.29	49.21	28.98	85.98	43.31	128.50	11.15	33.08	0.06	0.055	Light clay

#Dep: depth, OMC: organic mater content, BD: bulk density, TP: total porosity, FC: field water capacity,
SC: saturation water capacity, WC: wilting water content, IR: infiltration rate, ST: soil texture.

Farmland water holding capacity in the first meter below surface was 387.26 mm, equal to 73 % of the annual precipitation. At saturation, the soil contains 575.9 mm, equal to 108 % of the annual precipitation. Available water storage is 242.7 mm, equal to 46 % of the annual precipitation (Meng, 1996). The black soil arable land has high water holding capacity and with its loose topsoil and compressed subsoil is a huge reserve for water storage.

At high clay content, the wilting percentage of the black soil is high which results in lower water availability. It impacts available soil water, too. The black soil contains more than 60% clay, solid state >50 %, dilatancy >25 % and its compact nature reduces infiltration. These negative properties often result in waterlogged farmland.

This test was performed as a long-term soil moisture observation. Beginning in 1993, water content was measured with a neutron probe and TDR spectrometer every 10 days from April to November (during the whole growing season). Measurements were centered at layers of 10, 20, 30, 40, 50, 70, 90, 110, 130, 150, 170, 190, 210,230,250 and 270 cm. Other crop growth parameters as rainfall, crop growth season, etc. were also measured.

The soil profile was divided in three layers according to the diagnostic layers and the characteristics (Gong, 1999). Simultaneously with the water content, water potential in different layers of the soil profile was measured using tensiometer. The water retention curve was determined by the soil water contents and their respective water potentials.

RESULTS AND DISCUSSION

Black soil water retention curve

The water retention curves were similar in the three different layers A, B and C. When water content decreased, further water suction increased (see Fig.1). However, when the soil water content decreased to a certain level, the water retention curves of A and B layers crossed. The curves of A, B and C intersected each other when water potential was near -1.0 Bar. The variation range of water suction was greater in black soil compared to other soils in China. In layer A it was mainly affected by soil organic matter and clay content. It changed smoothly depending on soil water content and suction at the different layers. When soil water had values from 25% to 52%, soil suction values varied from 0 to -0.9 Bar. The values coincided at the high suction stage when soil water contents and water suctions were different in all layers of the soil profile. At field capacity, the water suction of layer A was -0.2 Bar, B was -0.26 Bar, C was almost the same as in the B layer. At saturation capacity these values were 0 Bar, -0.1 and -0.2 Bar, respectively.

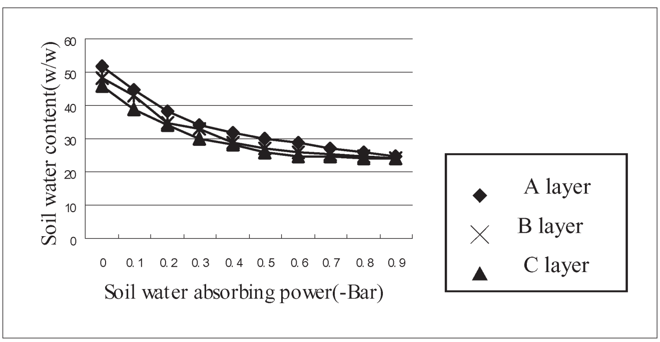

Fig.1. Soil water retention curves for layers A, B and C of soil profile

Water content patterns during different precipitation years

In the soil-crop-atmosphere continuum, soil absorbs precipitation, stores water and releases it to plants, therefore, soil water retention and movement is very important for supplying crop water needs.

The normal rainfall year 1995 (583.2 mm), the above normal rainfall year 1997 (784.5 mm) and drought year 2001 (234.6 mm) were studied in order to analyze the soil water dynamics during different precipitation years (fig. 2, 3 and 4). Fig. 2, 3 and 4 show the moving regularity of soil water in different layers – a decrease during April to July and an increase during August to December. Soil water movements under 110 cm were slow, and their fluctuation tended to reduce.

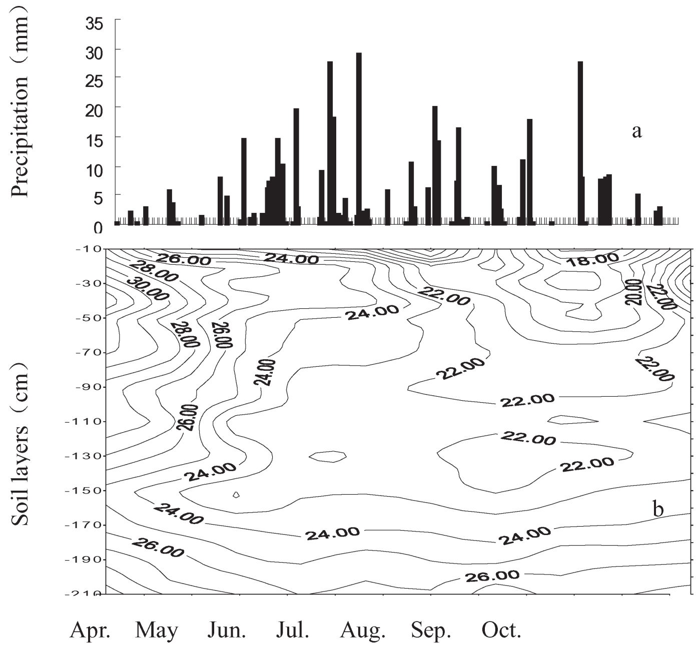

Fig.2. Black soil water characteristics in normal rainfall year (Apr.-Oct. 1995) a. Precipitation. b. Isoline of soil water content dynamics

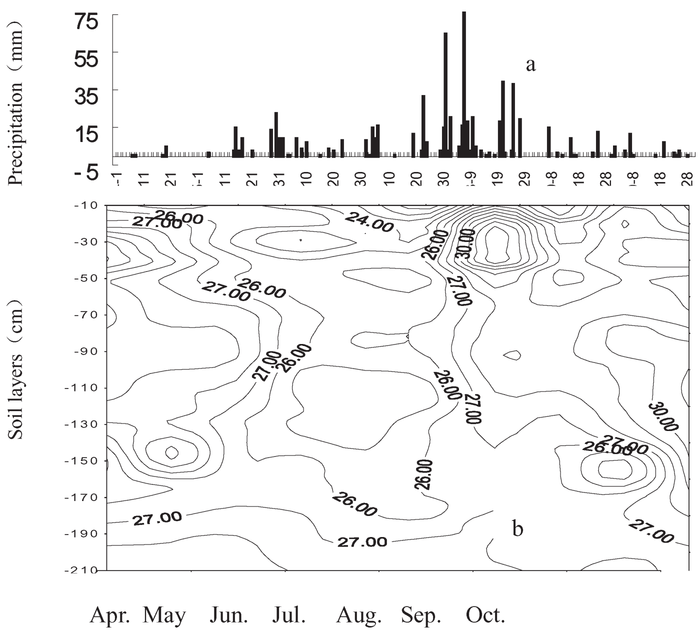

Fig.3. Black soil water characteristics in above normal rainfall year (Apr.-Oct. 1997) a. Precipitation, b. Isoline of soil water content dynamics

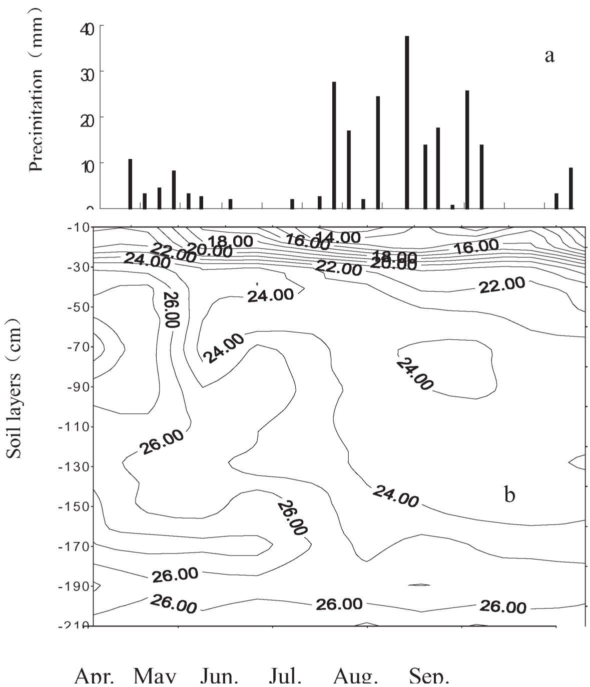

Fig.4. Black soil water characteristics in drought year (Apr.-Oct. 2001) a. Precipitation, b. Isoline of soil water content dynamics

Soil water movement regularities in different seasons

Movements of the black soil water were divided into four periods according to the results from the measurements and the analysis as follows : thawing stage in spring, dry stage in summer, wet stage in autumn and freezing stage in winter.

1.Thawing stage in spring

There are about 70 days from late March to early June during which soil is in the process of thawing. There is little rainfall during this period, approximately 10 -15 % of the annual rainfall, and light showers are the main form of rainfall. Dry and strong wind and high evaporation rate result in "meteorological drought". However, many years of collecting data indicated that soil water content was higher during this period and even was so wet that the crop planting was affected during some of the years. For example, soil moisture in the layers of 0 to 50 cm were 18-24 % (gravimetric measurements), 22-28 % and 26-32 % during drought year, normal year and above normal precipitation year, respectively. The average soil moisture varied from 18 – 32 %, close to or exceeding field capacity. Therefore, soil moisture content was not only affected by the weather of the same year, but also by the amount of soil water stored from the pervious year. The soil kept higher water content during this stage mainly due to the water released from the seasonal thawing process. For many years, soil water content values at that stage varied close to the field capacity (Meng, 1996). The soil water was held by the deeper frozen soil layer which formed the temporary gravitational water or the so called unfrozen water. Nevertheless, it had the property to flow out of the soil layer. Water was stored in the upper unfrozen soil layer. It was moved downwards by the soil melting process and upwards by unfreezing-capillary soil processes. Therefore, formation, storage and movement of soil unfrozen water is the principal characteristic of black soil. At early stage, the unfrozen water in the upper layers of the black soil resulted in temporary wet soil. The unfreezing of farmland black soil in spring is one of its most important features. It reduces the effect of drought on crops in spring, and helps the study on the difference between temporary soil water content and the amount of rainfall.

2. Dry stage in summer

This stage includes June to early August. Plants grow rapidly during this stage. Rainfall is approximately 20-30% of the annual rainfall, thus benefiting to crop growth. Due to the crops fast growth at this stage, soil evaporation and plant transpiration are high. The frozen layer of the soil disappears and the soil water content decreases. In most of the years observed, soil water content at this stage was lowest. The soil layer ranging from the surface of soil to the depth of 30 cm formed a "calabash- shaped" zone of low soil moisture which was close to crop wilting point water content. In the topsoil, dry and wet conditions circulated frequently due to the rainfall. However, at the early stage, frozen soil layer and capillary water existed together in the deeper soil layers. When the upper frozen layer disappeared, water in the deeper layer of the soil moved upward by capillary and was utilized by crops. During this stage, previously stored in the soil water was used at the same time as the water from the rainfall. Soil water content at this stage was determined by the rainfall.

3. Wet stage in autumn

Wet soil stage ranged from early August to late October before the soil becomes frozen. During this period 50-60% of the annual rainfall was concentrated, so it was the main stage for soil water recovery and storage. As the temperature fell, evaporation and transpiration reduced gradually. The results from many years of observation showed that soil water content was recovered and restored and thus early stage dry soil was supplied with an excess of water. At this wet stage the water content in topsoil was higher than the field water capacity. Due to the heavy clay layer in the subsoil, the infiltration was very slow and loss soil water moved down to the deep layers. Large amount of water was kept in the upper layers of the soil for a long period of time, thus resulting in a wet soil in the autumn. The water stored in the black soil went into the freezing stage in the form of wet soil and next spring affected the soil water content in the unfrozen stage.

4. Freezing stage in winter

This stage includes five months from November to March. Temperatures fall rapidly resulting in a cold dry air. Soil water freezes. Gradually the exchange of water between air and soil slows down, when soil is covered with snow, the water movement between air and soil almost stops. Large amount of water is stored in the frozen layer of soil until next year spring.

Seasonal factors influencing water soil dynamics

The whole year is divided into two stages, the first one is the growing period which includes the summer and autumn, and the second one is the non-growing period which includes the winter and spring. Both determine the soil water balance that forms the drought and wet conditions during the growing season. Plant growing season is from May to October. Crop growing season includes the whole summer and autumn and is the main stage of soil water uptake. The water absorption of soil during the growing season depends mainly on the amount of rainfall, the number of days with rainfall, the topographic characteristics and water absorption by soil. The waste of soil water depends on the intensity of plants transpiration, water evaporation from soil surface and filtration in the soil. On flat arable land, the amount and distribution of rainfall and the seasonal change of evapotransporation are the principal factors affecting soil water.

During non-cropping winter and spring, frozen and unfrozen stages depend on the development and the activity of the frozen soil layer. During these stages, there is little rainfall, which is only about 15% of the annual rainfall. Because of the frozen land during this period, little water can be absorbed. Therefore, the amount of rainfall during this period is not the dominant factor which affects the soil water.

Vertical variability of soil water content in the arable field

According to the observation and analysis from Fig.2, 3 and 4, soil water content vertically distributed as a circular cone or a funnel downwards from surface depending on the continuance and the amount of rainfall. This variability was divided into four main types: (1) significantly varying zone, from the depth of 0 to 40 cm (variation rate is 14-32 % gravimetric unit), maximum change range - 18%; (2) weakly varying zone, from the depth of 40 to110 cm (amplitude change was 24%-32 %, maximum change - 8%) (3) slightly varying zone from the depth of 110-260 cm (amplitude change - 28-32 %, maximum change range - 4 %) and (4) not varying zone, under the depth of 270 cm. The characteristics of soil water vertical changes were: I. The vertical influence of biological meteorology on soil water gradually reduces from the surface. II. The vertical exchange takes place in depth about 0-20cm under the surface of soil in the season of growth (from March to May), and is the main water supplying resource of crops from emergency to shooting. The maximum water supply (in the depth 0-260 cm) is in June, the circular cone dismisses at the depth of 260 cm. At the end of June, soil water content presents circular cone or funnel, with vertex down. III. The zero interface of the black soil is at 270 cm that means soil water from the depth of 0 to 270 cm takes part in the movements of soil-crop-atmosphere continuum. IV. Holding, infiltration and plant rhizosphere distribution capacities of soil water are factors of the soil water vertical movements, as well. Tolerance of soil to drought and waterlogging depends on the capacity of soil water. If the holding capacity of soil water is higher, no flood or drought occurs due to the higher precipitation and out of the drought range. The low infiltration rate is a principal factor that limits the water movement from topsoil to subsoil.

CONCLUSION

Observing black soil located in the northern temperate zone and continental monsoon area, allowed to divide its movements into four stages: 1. Unfreezing stage in spring 2. Dry stage in summer, 3. Wet stage in autumn and 4. Freezing stage in winter. In accordance with the annual variability of soil water, in the layers between 0 and 270cm four soil water zones can be divided: 1. significantly varying zone (within 0 -40 cm); 2. moderately varying zone (from 40 to110 cm); 3. slightly varying zone, (from 110-260 cm); 4. not varying zone (270 cm and below). Different soil water conservation practices should be used in the different stages and in the different precipitation types of year.

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REFERENCES

Gaze, S.R., Simmonds, L.P., Brouwer, J., and Bouma. J., 1997. Measurement of surface redistribution of rainfall and modelling its effect on water balance calculations for a millet field on sandy soil in Niger. J. Hydrol, 188-189: 267-284.

Gong, Z.T., 1995. Sols isohumiques.In: China soil system classification. Agricultural Science & Technology Publisher, Beijing. pp.442-480 (Ch).

Meng, K., 1993.The characteristics of ecological system in farmland blacksoil.The research of ecological agriculture, 1(3): 63-68(Ch).

Meng, K., 1996.Research on the features and effectiveness of soil moisture in the north black soil area. In: Liu C.M.(editor). Research on water problems in China. Beijing,China Meteorological Press. pp. 198-202(Ch).

Payne, W.A., 1997. Managing yield and water use of pearl millet in the Sahel. Agron. J,89: 481-490.

Qiao, J., 1963.The characteristics of black soil water and the process of soil formation. In: part I, Study on black soil water in the north part of northeast, China. Acta pedologica sinica. 11(2): 186-195(Ch).

Shen, S.M and et al., 1980.The assure of black soil water and prediction of spring drought. Study on black soil water in the north part of northeast, China. Acta pedologica sinica. 17(3): 203-216(Ch).

Siddique, K.H.M., D. Tennant, M.W. Perry, and R.K. Belford., 1990.Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. Aust. J. Agric. Res,41:431-447

Wang J.G and et al., 1996. Study of agricultural ecological system in Songnen plain. Heilongjiang Science & Technology Publisher, Harbin. 103 -130 (Ch).

Wallace, J.S., and C.H. Batchelor., 1997. Managing water resources for crop production. Philos. Trans. R. Soc, London Ser. B 352:937-947.