Variations regularity of soil moisture in Hebei Piedmont plain based on SWAP model

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Abstract. Field experiment was conducted at Ranzhuang water resources experiment station in Hebei Piedmont Plain. The parameters of soil bulk density, saturated hydraulic conductivity, soil water characteristic curve etc. were tested, which were used to calibrate the parameters of SWAP model. On this basis, the dynamic variation of soil moisture was simulated in thick vadose in 2004–2012 years by the application of SWAP, and the simulation results show that soil moisture varies periodically in 8 winter wheat and summer maize rotation periods. Soil moisture is lower in March every year and the two peak zones of soil moisture occur during the summer maize growth period. The first peak zone has no significant change each year, and the second peak zone changes markedly with the variation of precipitation and its distribution and initial soil moisture. The maximum infiltration depth of soil moisture is 5.7 m and the soil moisture tends to be stable below 600 cm soil profile. The fluctuation of groundwater level varies with precipitation variation and it shows a "W" shape curve. It is to provide scientific basis for improving the utilization efficiency of irrigation water and protecting the ecological environment of groundwater.

Key words. Hebei piedmont plain, thick vadose zone, soil moisture, transport regularity, SWAP model.

1. Introduction

It is an important significance to obtain the transport regularity of soil moisture for scientific establishment of irrigation scheme, effective control of soil moisture, conservation of water resources and improvement of crop yield [1]. Because of the restriction of sampling and observation means, the past research on the dynamics variation of soil moisture was focused more on the crop root layer, and it was less to study on soil moisture transport below the root layer [2–6]. With the development and utilization of groundwater, the groundwater level is declining year by year and groundwater depth is increasing year by year. Then the recharge, runoff and dis-

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charge conditions of groundwater have changed and the regularity of soil moisture transport has also undergone a corresponding change [7]. Recently, soil moisture transport was researched in thick vadose zone by field experiment method [8, 9]. Based on field experiments, dynamic changes of soil moisture which is under conventional irrigation and fertilization conditions were simulated in Hebei piedmont plain by using SWAP model in paper. The dynamic variation regularity of soil moisture was obtained by analyzing simulated data. It is to provide scientific basis for improving the utilization efficiency of irrigation water and protecting the ecological environment of groundwater.

2. Experimental fields

The field experiment was carried out at Ranzhuang water resources experiment station, which is located in Taihang Mountain piedmont plains. It belongs to Semi-humid continental monsoon climate. Annual average rainfall is 500 mm, which concentrates in summer (from June to September). Annual average evaporation is 974.8 mm (E-601). Quaternary loose rock is thicker and sandy loam is dominant in vadose zone, of which contains more clay particle in 40–100 cm. Winter wheat and summer maize are the chief crops. The burial depth of groundwater is about 24 m. The winter wheat and summer maize crop rotation area worked as the experiment area, and non-planting area as the check group. Soil bulk density was tested by cutting ring method: sandy loam was $1.35\,\mathrm{g/cm^3}$ and clay loam was $1.48\,\mathrm{g/cm^3}$; saturated hydraulic conductivity was tested by Guelph parameter: sandy loam was 46.5–$110.2\,\mathrm{cm/d}$ and clay loam was $13.4\,\mathrm{cm/d}$. Soil water characteristic curve was tested by pressure chamber. All of the results work for SWAP model simulation [10].

3. Materials and methods

3.1. SWAP model

SWAP simulates one-dimensional vertical transport process of soil water in unsaturated soil zone and the equation of soil water transport is as follows:

$$\frac{\partial \theta}{\partial t} = C\left(h\right)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K\left(h\right)\left(\frac{\partial h}{\partial z} + 1\right)\right] - S\left(h\right), \tag{1}$$

where θ denotes soil moisture and t denotes time and C denotes the water capacity and h denotes soil water pressure head and K denotes the hydraulic conductivity (or conductivity) and z denotes the vertical coordinate and S denotes soil water extraction rate by plant roots.

3.2. Data sources and model inputs

Data including crop parameters, soil moisture, soil saturated hydraulic conductivity, soil water characteristic curve etc. were obtained by field experiment at

Ranzhuang Water Resources Experiment Station from 2011 to 2012 year. Meteorological data are routine monitoring data of the Ranzhuang Water Resources Experiment Station.

The upper boundary of SWAP is above the plant canopy and the lower boundary is located in the unsaturated zone. The groundwater depth is larger in well irrigation area; the lower boundary is zero flux boundaries. The initial soil moisture was the automatic calculation value according to the soil water characteristic curve by using the SWAP model.

3.3. The model parameters calibration

The model parameters were calibrated by using measured value of soil moisture during the winter wheat growth period, which is on November 19, 2011 and March 29, 2012. The simulated soil moisture close to the measured values by adjusting the parameters of VG, the mean square deviation is a good agreement between the simulation and experiment and it is as follows:

$$RMSE = \sqrt{\frac{\sum\limits_{i=1}^{n}(M_i - S_i)^2}{N}}, \tag{2}$$

where M is the measured soil moisture; S is simulated soil moisture; N is the number of observations.

The hydraulic parameters of soil after model calibration are shown in Table 1.

Table 1. Soil hydraulic characteristic parameter after the model calibration

Soil depth (cm)	soil texture	saturated conductivity k_s (cm d^{-1})	saturated water content θ_s (cm^3 cm^{-3})	residual water content θ_r (cm^3 cm^{-3})	α (cm^{-1})	λ	n
0–40	Sandy loam	108.5	0.43	0.09	0.008	−0.8	1.16
40–100	Clay loam	12.5	0.48	0.12	0.03	−3.0	1.13
below 100	Sandy loam	45.8	0.42	0.07	0.008	−2.5	1.16

The effectiveness and accuracy of the model have been tested by using measured soil moisture during summer maize. The results were shown in figure 1.

4. Simulation results and discussion

The dynamic variation of soil moisture was simulated by SWAP model from October 1st 2004 to September 30th 2012 which is 8 winter wheat and summer maize rotation periods.

X axis is the time, from October 1st to September 30th the next year, the day is as a unit of time; Y axis is the soil depth and positive from the ground surface to

(a) July 7, 2012　　　(b) August 10, 2012　　　(c) September 13, 2012
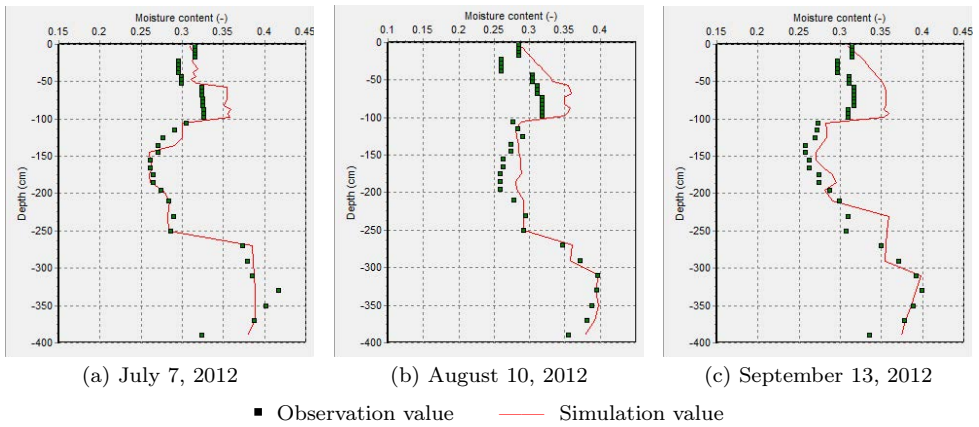
■ Observation value　　　—— Simulation value

Fig. 1. Comparison of simulated and measured values of soil moisture

down; Z axis is soil moisture content.

4.1. The variation regularity of soil moisture

(1) Planting area

(a) The variation of soil moisture from 2004 to 2007　　　(b) The variation of soil moisture from 2008 to 2011
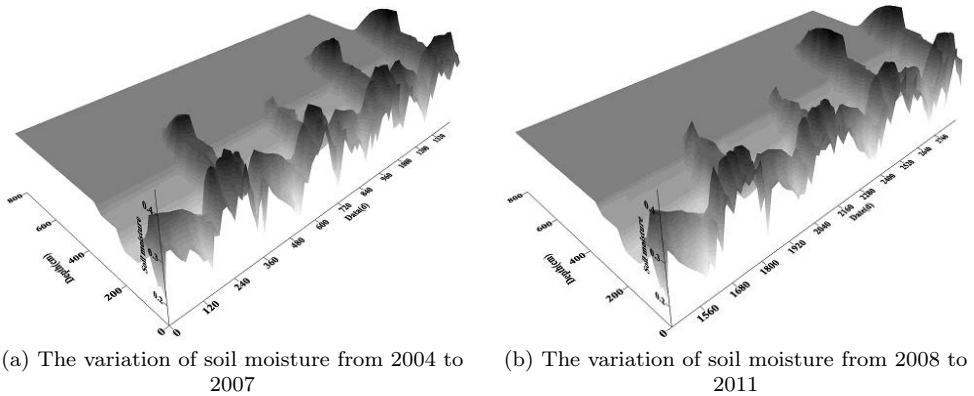
Fig. 2. The dynamic variation of soil moisture in planting area

Figure 2 shows that soil moisture is an evident periodic variation in the winter wheat and summer maize rotation period. In terms of time, the soil moisture is lower in March every year, which is mainly affected by the climatic conditions of the region. The winter is cold and dry, rain and snow is rare in winter; Temperature changes rapidly and it is arid and windy in spring. It is a less precipitation period in a year from the annual October to March next year. In order to meet the water quantity needed by normal growth of winter wheat, irrigation is very necessary; the soil moisture is the two peak zones during the summer maize growth period. The first peak zone has no significant change each year. However, the second peak zone is different each year; the more annual precipitation, the more the second peak zone.

The precipitation is 850.1 mm from October 1st 2007 to September 30th 2008; the second peak zone is broader during summer maize growth period. The precipitation is 216.2 mm from October 1st 2005 to September 30th 2006; the second peak zone doesn't emerge during summer maize growth period. In addition, the second peak zone is related to the precipitation distribution. For instance, the total amount of precipitation is moderate and it is 416.5 mm and 498.0 mm respectively from October 1st 2006 to September 30th 2007 and from October 1st 2010 to September 30th 2011. However, precipitation is relatively concentrated, and it is 329.9 mm and 433.6 mm respectively from June to September. The second peak zone is relatively larger.

(2) Non-planting area

(a) The variation of soil moisture from 2004 to 2007

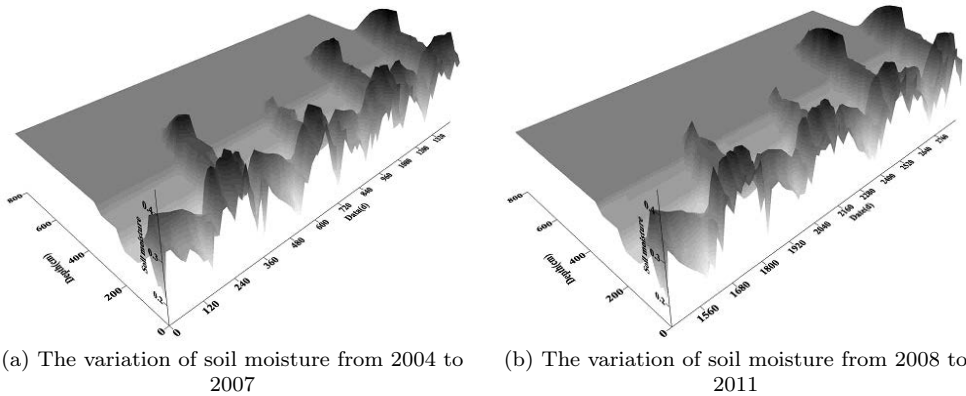(b) The variation of soil moisture from 2008 to 2011

Fig. 3. The dynamic variation of soil moisture in non-planting area

It can be concluded from Figure 3 that the periodic variations of soil moisture are evident in non-planting areas. In terms of time, soil moisture is relatively stable from October to April of the next year because of scarce precipitation. After May, with the increase of the rainfall, the range of soil moisture increases and the maximum depth is approximately 500 cm.The amount of precipitation and its distribution, evaporation and the initial soil moisture are the main influence factors related to soil moisture. The amount of precipitation was the least from October 1st 2005 to September 30th 2006, only 216.2 mm. The variation range of soil moisture was the least. The amount of precipitation was larger and 850.1 mm, however, the initial soil moisture is lower. Then, the variation range of soil moisture was not bigger. The amount of precipitation was not larger, and it is 433.6 mm from October 1st 2010 to September 30th 2011. But, the precipitation is concentrated and the initial of soil moisture is higher, the variation depth of soil moisture is broader and about 500 cm. The soil moisture tends to be stable below 500 cm soil profile.

4.2. The analysis of soil water infiltration depth

The infiltration depth of soil moisture was obtained by analyzing the simulated data of soil moisture in planting area and non-planting area during the winter wheat and summer maize growth period. The results were shown in figure 4.
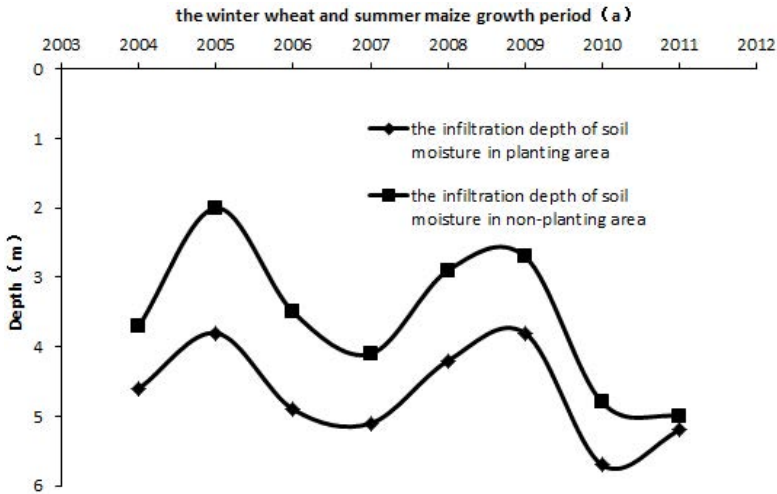
Fig. 4. The infiltration depth of soil moisture during the winter wheat and summer maize growth period

Figure 4 shows that the infiltration depth of soil moisture changes strongly each year. The infiltration depth of soil moisture is larger during the winter wheat and summer maize rotation period which is 2007–2008, 2010–2011, 2011–2012 years. The infiltration depths were 5.1, 5.7 and 5.2 m respectively in planting area and were 4.1, 4.8 and 5 m in non-planting area. High precipitation and its distribution are the main reasons. It is 850.1 mm, 663.7 mm in 2007–2008 years and 2011–2012 years respectively. Precipitation is concentrated in 2010–2011 years. Precipitation is lower, only 278.8 mm, and the infiltration depth of soil moisture is smaller, 3.8 m and 2.0 m in planting area and non-planting area respectively. In short, the infiltration depth is higher in planting area than that in non-planting area. The soil moisture tends to be stable blew 600 cm soil profile.

4.3. The response regularity of groundwater

The variation of precipitation, evapotranspiration and groundwater level fluctuation are shown in figure 5 from October 1st 2004 to September 30th 2012 which is 8 the winter wheat and summer maize rotation periods.

It can be drawn a conclusion that precipitation varies greatly each year. The amount of precipitation emerges a "W" shape from October 1st 2004 to September 30th 2012 which is 8 the winter wheat and summer maize rotation periods. The maximum precipitation is 850.1 mm, the minimum precipitation is 278.8 mm, and the maximum value is 3 times than the minimum value. The fluctuation of groundwater level varies with precipitation variation and it shows a "W" shape curve. The maximum fluctuation of groundwater is 0.55 m; the minimum fluctuation of groundwater is −0.76 m. There is a clear correlation between the fluctuation of groundwater level and precipitation.
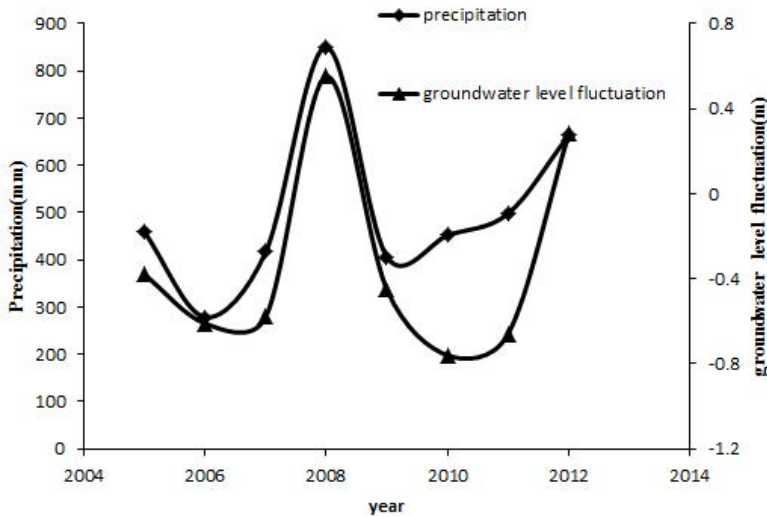
Fig. 5. the variation curve of precipitation and groundwater level fluctuation

5. Conclusion

Field experiment was carried out at Ranzhuang water resources experiment station from 2011 to 2012. The model parameters of SWAP were calibrated by using the experimental data. Based on this, the dynamic variation of soil moisture in a thick vadose in Hebei Piedmont Plain was simulated. The detailed conclusions were as follows:

(1) Soil moisture varies periodically in 8 winter wheat and summer maize rotation periods. Soil moisture is lower in March every year and two peak zones of soil moisture occur during the summer maize growth period. The first peak zone has no significant change each year and the second peak zone changes markedly with the variation of precipitation and its distribution and initial soil moisture. With the amount of precipitation and its concentration and initial soil moisture is higher; the second peak zone of soil moisture is greater. Soil moisture varies periodically and precipitation is the main influence factor in non-planting area.

(2) With the variation of precipitation, the infiltration depth of soil moisture varies accordingly. The higher precipitation falls, the bigger infiltration depth of soil moisture varies. In addition, the distribution of precipitation is an important influence factor. The infiltration depth of soil moisture is deeper in planting area than that in non-planting area. The maximum infiltration depth of soil moisture is 5.7 m in planting area and the soil moisture tends to be stable below 600 cm soil profile.

(3) The amount of precipitation emerges a "W" shape curve from October 1st 2004 to September 30th 2012 which is 8 the winter wheat and summer maize rotation periods. The fluctuation of groundwater level varies with precipitation variation and it also shows a "W" shape curve. There is a clear correlation between the fluctuation of groundwater level and precipitation.

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