Preliminary Study on Soil Moisture Forecast of Winter Wheat

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Xiumei Zhang[1,2], Yuchun Pan[2],Bingbo Gao[2],Chunshan Su,Jihua Wang[2*]
[1]School of Geography and Remote Sensing Science,Beijing Normal University, 100875,Beijing ,P. R. China
Xiumei_zhang@163.com
[2] Beijing Research Center for Information Technology in Agriculture. 100097, Beijing, P. R. China
wangjh@nercita.org.cn
3 Beijing MAG Agricultural Science & Technology Development Co, LTD. 100089，Beijing, P.R. China
Mofais1987@163.com

Abstract: Using four groups of survey data of soil moisture of winter wheat from returning green stage to harvest stage in Daxing region, the variation laws of soil moisture exponential depletion relations in 0-60cm depths during different growth stage are analyzed ,and based on soil moisture exponential depletion relations the forecast model of soil moisture depletion is built. The results indicate that the soil moisture exponential depletion relations in the same depth layer increase at first and then decrease. Moreover, for different depth layers they decrease with the increase of depth, and the dispersion degree also changes with the depth. Using the exponential depletion relations method, the soil water storage at the 20, 40 and 60cm depth layers are forecasted, and the minimum forecast error is 0.09%, the forecast accuracy in the layer of 60cm is highest, and the absolute error is between 0-1.5%. This method does not need much data, and its results are reliable and precise. So it is a practical method for soil moisture forecast in winter wheat field of Beijing and others whose soil condition is same as Beijing.

Keywords： Winter wheat, Exponential depletion relations, Soil moisture, Forecast method

1 Introduction

Winter wheat is a main grain in China which is planted in Northern part of China where is lack of water. The soil moisture forecast which is the main contents of the field moisture forecast is the best method to understand the dynamic variation rule and to adjusting ways of the soil moisture of the farmland soil [1]. Also it is meaningful for the reasonable distribution of the irrigation system and improving the utilization rate of water resources. Besides the soil type, there are lots of factors which

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First author: Xiumei Zhang, E-mail:xiumei_zhang@163.com
* **Corresponding author:** Jihua Wang, E-mail: wangjh@nercita.org.cn

affect the soil moisture, such as precipitation, temperature, air moisture, wind velocity, plant type, different growing periods and so on. By now many research methods for soil moisture forecast have been put forward, such as Soil-Moisture-Balance Model [2,3], soil hydrodynamics model[4], remote sensing monitor method[5,6], nerural network model[7,8], empirical formula method[9,10], and exponential depletion model[11]. Soil-Moisture-Balance Model, soil moisture dynamics model which is simple are based on soil moisture analysis equation and the principle of soil moisture dynamics to forecast future soil moisture variation. They are simple and are often used to calculate the change of the soil moisture when the needed factors and boundary conditions are satisfied they can give out satisfactory result. However, the fact that they need lots of factors and boundary conditions which are hard to get prevents the popularization of these models. Remote sensing monitor method is to build statistical model between statistics of soil moisture and factor (Thermal inertia、normalized difference vegetation index) affecting the soil moisture and soil moisture using remote sensing images to forecast the soil moisture. It can give out the change of the soil moisture in time, but the stability of model need to be researched further. The parameters of soil and planting in neural network model always have no physical significance and can't reflect the physical relationship between input parameters and soil moisture. Exponential depletion model can analyze the soil moisture depletion law by directly using the observed soil moisture data. It is simple and need less factors, but can produce exact forecast result. To give out an easy, reliable, exact and feasible method for winter wheat soil moisture forecast, this paper studied the soil moisture variation rule along with time of different depth layers based on exponential depletion model, tested the results with observed data, and discussed the applicability of exponential depletion model. The monitoring data from monitoring site of winter wheat soil moisture and meteorological site of Daxing in Beijing in 2009 was used in the study.

2 the monitor and frequency for soil moisture

2.1 the method of soil moisture monitor

The volumetric water content of soil is measured using ECH2O which is a ruler like soil moisture probe produced in America. ECH2O sends voltage signal and feedback voltage signal from soil to calculate the dielectric permittivity from which the soil moisture is calculated. It has the features of lower power consumption, higher resolution, less effected by temperature and salinity, simpler installation and use, solider design, longer buried.

2.2 soil moisture, the content and frequency of meteorological

The monitoring data from monitoring site of winter wheat soil moisture and meteorological site of Daxing in Beijing in 2009 include soil moisture 0~20cm、20~40cm、40~60cm、80~100cm and meteorological data such as daily precipitation, evaporation, temperature and so on.

3 Method and model for Soil moisture forecast

Soil moisture is decided by lots of factors like Climate, soil feature, plant suction and so on. During wheat growing periods in winter, it rarely rains and it hard to form runoffs. Soil water balance can be describe as below:

$$W_E = W_S + P + I - ET - Q \tag{1}$$

W_E and W_S in the equation represent water storage in one soil layer at the very ending and very beginning respectively; P represents the effective amount of precipitation during this period，mm；I represents the amount of irrigation, mm; ET represents the amount of plant evaporate and transpiration, mm; Q represents the water flux of lower boundary.

W_E , W_S can be calculated from observed soil moisture; P and I can be gotten from meteorological site；Q is much less than ET . Under soil water stress, ET and W has linear relationship, so in period there is no precipitation and irrigation, the relationship between ET and W can be described as:

$$ET = dW / dt = -kW \tag{2}$$

Where K is soil moisture exponential depletion coefficient, it is affected by meteorological，underlying surface, and growth phase of crop.

The soil moisture exponential depletion during no precipitation and irrigation period can be gotten by integrating the formula above within $t_E - t_S$.

$$W_E = W_S \mathrm{e}^{-k(t_E - t_S)} \tag{3}$$

If there is precipitation and irrigation during (tS ~tE), soil moisture exponential depletion can be separate to two stages.

$$W_E = (W_S \mathrm{e}^{-k\Delta t'} + \mathrm{P} + \mathrm{I})\mathrm{e}^{-k(t_E - t_S - \Delta t)} \tag{4}$$

Where $\Delta t'$ represents soil moisture exponential depletion time before raining or irrigating. The key to use depletion index forecasting soil moisture is to identify the value of depletion index. For some special area the soil feature is constant, and the change of meteorological elements have annual periods, depletion index is mainly is mainly affected by the species and growth season of plant. If there is no precipitation and irrigation, depletion index is:

$$k = (\ln W_S - \ln W_E) / (t_E - t_S) \tag{5}$$

4 Experimentation design and results analysis

4.1 Experimentation design

Experimentation site which belongs to Weishan village of Daxing region locates at E116° 25, N39° 37′ . It is part of alluvial plain formed by ancient canal. Its altitude is between 20m and 40m and its annual precipitation is approximately 489.9mm.The annual average temperature is 11.4° C. Its prevailing wind directions are south and north. The underlying surface is comparatively flat and the depth of its groundwater is 3.3m. The soil texture is siltloam and the soil dry bulk density is 1.4g/cm3. This paper use the soil moisture data of the Experimentation site from winter wheat turning green to winter wheat harvesting (March 5th to June 6th, counting 93 days).

The experimental area was separated into six small areas and was planted with winter wheat. They are numbered as 1A, 2A, 1C, 1B, 2B and 2C from east to west (shown in tab.1). 1A, 2A,1B and 2B are used to calculate the water storage of 20,40 and 60cm which are used to build models. 1C and 2C are used to test of the accuracy of the model.

Table 1. Small area charts of the experimentation site

1A	2A	1C	1B	2B	2C
For prediction models		For test	For prediction models		For test

4.2 Result of analysis

4.2.1 The law of exponential depletion according to depth

According to the observation data and the formula of exponential depletion, we can get exponential depletion on 20cm, 40cm, 60cm and 100cm depths. The law is below :

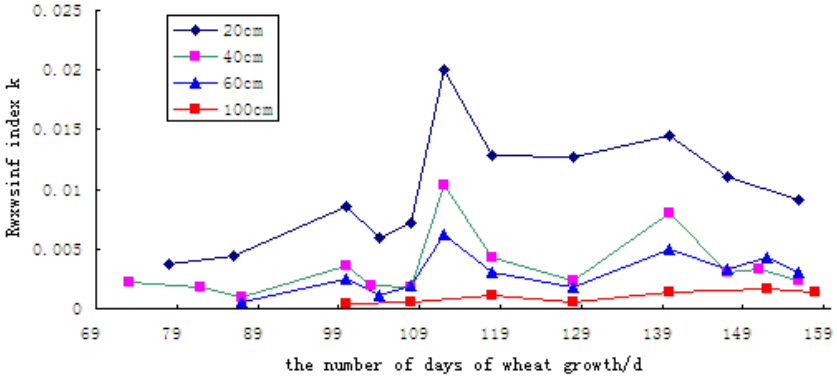

Figure.1. The law of exponential depletion according to depth

(1) The results indicate that the soil moisture exponential depletion relations in the same depth layer show the trend of increasing at first and then decreasing. That is because when the winter wheat turn green from winter to spring, it needs least water, so soil moisture depletion is slow, and the exponential depletion gets small. When it goes into jointing stage, exponential depletion begins to get bigger. Exponential depletion gets biggest when it goes into heading stage in late April . When it goes into filling stage in middle May, the exponential depletion gets biggest again, and the soil moisture

depletion gets fast. After that the consumption of water decreases, the exponential depletion gets small until the winter wheat gets ripe.

(2) With depth increasing, the exponential depletion gets small gradually. The water moisture is easy to be lost from surface layer to the layer of 20cm depth. It is also affected relatively large by evaporation, irrigation and rainfall. So the exponential depletion fluctuation is large. With the depth increasing, the influence of external conditions gets small gradually, so 40cm and 60cm change smoothly and there is nearly no measurable change in 100cm. That's because the crop evaporation and water absorption has little influence in deep soil layer.

4.2.2 The analysis of result for soil moisture.

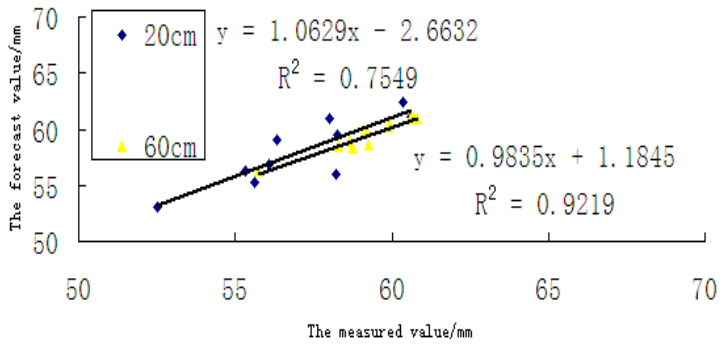

Figure.2. The linear regression result of measured value and forecasting value in different soil layers for winter wheat

The roots of winter wheat are mostly located in 0-60cm soil layers, so we research 20cm, 40cm and 60cm soil depth layers. The initial soil moisture value was the average value when the winter wheat turnes green on March 5th for 1C and 2C. Having deleted outliers caused by rainfall and irrigation. or measuring errors .We forecasted the soil moisture of 20cm,40cm and 60cm soil layers using formula 3 for data without rainfall and irrigation ,otherwise using formula 4. And then used the measured data and forecasted data to do linear regression for the measured soil moisture and the forecasting value of the exponential depletion for 20, 40 and 60cm layers. The result is shown in Figure 2. The correlation index of the forecast model of exponential depletion in 20cm layer is 0.7549 , the maximum forecast error on this layer is 5.02%, and the minimum error is 0.9%. By counting the relative error, the proportion of forecast exponential depletion whose relative error is less than 20% is higher than 80% on 20cm .The forecasting value in 40cm is slightly bigger than that of 20cm and 60cm, maybe it is caused by the soil circumstance and the law root system pattern. The biggest forecasting error on this layer is 3.91%, and the smallest is 0.09%, the proportion of forecast exponential depletion whose relative error is less than 20% is higher than 90% in 40cm layer, The correlation index on 60cm layer is 0.9219, The biggest forecasting error on this layer is 1.14%, and the smallest is 0.31%, by counting relative error, the proportion of forecast exponential depletion whose relative error which is less than 20% is higher than 90% on 60cm. With the depth gets deeper, the effect of temperature and humidity gets smaller, so the forecasting error gets smaller, causing the forecasting result became exact. Several studies show that the result of the exponential depletion forecasting model is more accurate than empirical formula method whose error is between 15%-30% [12,13]. The mainly reason is the exponential depletion method of this paper not only taking the meteorological factors into account but

also taking into account the difference of the exponential depletion caused by the difference of different growth period of plant, calculating several exponential depletion k of different growth periods of plant, using K in different period to forecast. However empirical models mainly consider those effects caused by rainfall, temperature and other meteorological factors for soil moisture to generate a multiple linear equations to forecast. So exponential depletion method is more suitable for soil moisture forecast of different periods and the forecast is more accurate. The exponential depletion can reflect water receding process of winter wheat field. Using exponential depletion to forecast soil moisture, the needed the factors only include time, rainfall and irrigation data, and the result is stable, reliable and accurate.

5 Conclusion and epilogue

This article build the soil moisture forecasting exponential depletion model using the measured data in Daxing monitor site, through this article, we can get several conclusion:

(1) The changing trade of the soil moisture exponential depletion relations of winter wheat in each depth layer is same, that's increasing first then decreasing during the period, returning green stage to harvest stage. They get maximum when the winter wheat gets into ear emergence and filling stage, and after that they become smaller and smaller until the winter wheat is ripe. For different depth layers they decrease with the increment of the depth. They fluctuates frequently in 20cm depth layer, mainly caused by external factors. As the depth increasing, the influence of external factors gets less, and the exponential depletion fluctuates more gently.

(2) As the depth of soil increasing, the water storage gets more stable, the influence of external meteorological factor get smaller, and the forecast became more exact. The absolute error of exponential depletion of 60cm depth layer is between 0-1.5%, and the forecast accuracy is much higher. The forecast accuracy of other depth layers can also meet the practical requirements. It shows that the model is suit to the forecast of soil moisture of winter wheat.

(3) Due to different soil feature, meteorological factors, and plant water absorption in different area, the variation laws and area features of exponential depletion relations in other planting area and different planting conditions should be studied further.

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