The Monitoring Forecasting Assessing Decision-Making Service
System of Soil Moisture Stress of Winter Wheat
and Its Application in North China Region

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ABSTRACT

During the growing season of winter wheat , the precipitation amount in the North China Region , where the water resource is seriously insufficient , amounts to only 100-250 mm and can not meet the demand of winter wheat .

This paper demonstrated the geographic distribution of the difference between the water demand and supply of winter wheat in different climatic years (guaranteed probability of precipitation during growth period of winter wheat at 75% , 50% and 25% respectively) . The water differences were calculated with a field water balance equation .

To determine proper irrigation time and amount , and to ensure stable and high production of winter wheat with limited water resource , Monitoring Forecasting Assessing Decision-Making Service System (MFADSS) of soil moisture stress of winter wheat was constructed on the basis of experimental research on the relationship between soil moisture and winter wheat . The techniques and functions of each subsystem are also demonstrated .

The system was applied to more than 3 million ha. of winter wheat in 90 counties of the North China Region . Accuracy of the decision of the irrigation reached about 95 per cent . The water-saving and high yield function of the system was shown clearly . Obvious social , economical and ecological benefits were obtained during 1990-1995 under the support of the government.

Key words : winter wheat , soil moisture stress , system , MFADSS

1. Introduction

The North China Region is the main region for wheat production , is responsible for 48% of national total wheat production , and its planting areas compose 40% of the national total planting areas . In the region , the winter wheat growth period matches the season of low rainfall , when precipitation ranges from 100 to 250 mm , which is lower than the water demand of wheat in the range of 150 to 300 mm . Under such circumstance , irrigation is essential for stable and high production of winter wheat . However , the water resource is seriously lacking (cultivated land possesses a water resource amount of 3645 m³ per ha. on average) and can not meet the water demand of agriculture in the region .

China has a large population and to meet the demand for food , present planting areas as well as high production must be ensured . This makes scientific irrigation a key problem for improving water use efficiency and for maximizing the economic benefits of limited water resource . MFADSS of soil moisture stress of winter wheat in the North China Region was developed under such circumstance . It mainly focuses on service for scientific irrigation of the winter wheat in the region .

2. Difference between water supply and demand of winter wheat in different climatic years .

The difference between water supply and demand of wheat varies with climatic conditions of each area . According to the field water balance equation :

$$\Delta W = P + F_1 + I - ET - R - F_2 \quad (1)$$

where Δw is the changing amount of soil moisture content , P is the effective precipitation amount , F_1 is the supply amount of underground water , I is the irrigation amount , ET is the actual evapotranspiration amount , R is the runoff amount , and F_2 is the water amount seeped into soil under the root zone . All the above quantities are measured in mm.

During the growth period of winter wheat , the precipitation amount is inadequate and precipitation intensity is not enough in the region , so R and F_2 can be ignored . Hence Eq.(1) is simplified to

$$\Delta W = W_2 - W_1 = P + F_1 + I - ET \quad (2)$$

where W_1 and W_2 are the soil moisture at the beginning and end of a given period (mm) , respectively . Eq.(2) can be rewritten as

$$I = ET - [(W_1 - W_2) + P + F_1] \quad (3)$$

According to the principles of an optimal irrigation scheme for winter wheat , ET is the optimal water consumption which ranges from 340 to 370 mm and increases from south to north . W_1 is the non-stress soil moisture content at seeding time which remains at 100 mm in average years , 70 mm in drought years , 140 mm in wet years , W_2 is the non-stress soil moisture content during the harvest period which could be considered as 0 , because after optimal irrigation , soil moisture content is low in the harvest period but this does not influence wheat yield . Inter-planting maize is in the seedling stage and does not need much water . Because the scale of the area where underground water is within 3 m is quite limited , F_1 can also be ignored . Hence Eq.(3) is further

simplified to

$$I = ET - P - W_1 \quad (4)$$

Using Eq.(4) , we worked out the water deficit during the whole growth period of winter wheat in the region in different climatic years (guaranteed precipitation probability at $P=75\%$, 50% and $P=25\%$) . results are shown in Fig.(1) . In average precipitation years , in the areas of Zhumadian and Nanyang , southern Henan province , there is abundant water and irrigation is not needed . From this area to the north , the water deficit increases , so irrigation should be applied . In most areas 1-2 irrigation treatments are needed at 75 mm per time . In drought years ($P=75\%$) , most areas , except south of Nanyang , need 2-3 irrigation treatments while particular areas (such as Dezhou) need 4 treatments . In wet years ($P=25\%$) in areas to the south to Zhengzhou , Kaifeng , Shangqiu , Luoyang there is abundant water where irrigation is not needed while the northern areas need only one treatment .

3. Composition of the system

The system is composed of five subsystems as shown in fig.2. The system was established on the basis of the experimental study of the relationship between winter wheat and soil moisture . The system utilized monitoring sites in winter wheat fields , meteorological stations , techniques for monitoring soil moisture by NOAA's satellite , a soil moisture simulation model , computer and telecommunication systems , etc. for collecting , processing and transferring information on soil , wheat and atmosphere.

(1)Monitoring subsystem

The monitoring subsystem mainly focuses on monitoring conditions of soil , wheat and atmosphere , and provides basic data for irrigation decision . 250 monitoring sites in winter wheat fields were set up according to climate and soil type . In each site , feild capacity and soil apparent specific gravity were first measured .Then soil moisture (100 cm depth) , growing stages , plant density , leaf area and depth of underground water level were observed systematically . Relative meteorological information (temperature , wind velocity , sunshine hours , air humidity , precipitation , etc.) can be obtained from meteorological stations nearby the monitoring sites of the winter wheat fields . In addition , an estimation model of soil moisture by meteorological satellite was used .

$$W=a+bp \quad (5)$$

$$P=B(1-A)/\Delta T \quad (6)$$

where W is soil moisture , P is soil thermal inertia , a , b are coefficients . $B(1-A)$ is the radiation absorbed by the soil and ΔT is the soil surface temperature difference between daytime and nighttime.

Table 1. Values of a and b in Eq.(5)

soil depth (cm)	10	20	30	40	50
a	33.3	43.3	45.5	36.6	43.2
b	6.525	6.033	5.997	8.796	8.212

(2) Forecasting subsystem

This subsystem forecasts future soil moisture with a soil moisture forecasting model which is expressed as

$$W_t = W_{(t-1)} + P_{(t-1)} + G_{(t-1)} - 10K_{(t-1)}ET_{0(t-1)} \quad (7)$$

where W_t and $W_{(t-1)}$ are the soil moisture in the root zone 10 days from the present day , and the present day respectively , $P_{(t-1)}$ is the effective precipitation in the 10 day period (mm) , and $G_{(t-1)}$ is the underground water supply during the same 10 days . $ET_{0(t-1)}$ is the average potential evapotranspiration in the 10 day period . $K_{(t-1)}$ is the average relative evapotranspiration in the 10 day period .

The underground water supply (G) depends mainly on the depth of the underground water level and the soil character . After jointing , wheat has established roots deeply into the soil , and underground water supply should be considered . In the region , G is expressed as

$$G = (A - B \log H) \frac{t}{\tau} \quad (8)$$

where H is the depth of underground water (m) , τ is the number of days from jointing to maturing . t is the number of days from jointing to the forecast day . A and B are coefficients relating to soil character .

Table 2. Values of A and B in Eq.(8)

type of soil	light soil	sandy soil	light clay soil	medium clay soil	heavy clay soil	clay
A	80	100	120	150	200	
B	210	210	199	249	332	

Potential evapotranspiration (ET_0) is calculated with the Penman equation modified by FAO (1979).

$$ET_0 = \frac{(P_0 / P)(\Delta / \gamma)R_n + E_a}{(P_0 / P)(\Delta / \gamma) + 1.00} \quad (9)$$

where ET_0 is the average potential evapotranspiration (mm/d) . P_0 is the average sea-level pressure (hPa) . P is the average station pressure (hPa) . Δ is the slope of the saturated vapor pressure vs. temperature curve at the mean air temperature . γ is the psychrometer constant . R_n is the net radiation (mm/d) . E_α is the aerodynamic term (mm/d) .

The average relative evapotranspiration (K) is a function of soil moisture and leaf area index , and is expressed as

$$K=a+b\ln(W)+c\ln(LAI+1) \quad (10)$$

where W is the soil moisture content . a , b , c are coefficients . LAI is the leaf area index , and is a function of accumulated temperature and soil moisture expressed as Eq.(11).

$$LAI=LAI_{\max}f(\sum T)f(W) \quad (11)$$

$$f(\sum T)=\exp[-b_0+b_1(\sum T)+b_2(\sum T)^2+b_3(\sum T)^3] \quad (12)$$

$$f(W)=a+b\ln W+c\ln^2 W \quad (13)$$

Where $LAI_{\max}$ is the maximum leaf area index under the conditions of proper moisture . $\sum T$ is the accumulated temperature from seeding to the forecast day . W is the soil moisture during the forecast period , and is expressed as a percentage of the weight of dry soil . The forecast depth of the soil zone is determined according to the depth of the root zone at each growth stage . Based on the results of observation , the forecast depth of the soil zone is 50cm before jointing and 100cm during the jointing-maturing stage .

(3) Assessing subsystem

On the basis of monitored soil moisture and forecast soil moisture , this subsystem assesses the soil moisture stress level with a soil moisture stress index and adequate moisture index of winter wheat .

Table 3. Soil moisture stress index and adequate soil moisture index of winter wheat (W , mass soil water content , %)

soil moisture stress rank	extreme stress		severe stress		mild stress		adequate moisture	
	W	%	W	%	W	%	W	%
indices	<7.5	<34.0	7.6-9.0	34.1-40.0	9.1-12.6	40.1-55.0	12.7-17.5	55.1-80.0

(4) Decision-making subsystem

The subsystem decides whether to irrigate as well as when and how much to irrigate . The decisions are made mainly on the basis of the soil moisture stress level , the condition of the water resources and the potential economic benefits of irrigation , etc. .

In regions where the water resource is sufficient , irrigation should be applied when soil moisture reaches the soil moisture stress index . In regions where water resource is limited , more importance should be attached to the economic benefits of irrigation . Soil moisture stress at different growth stages of winter wheat affects production differently . In other words , water sensitivity varies in different growth stages of winter wheat . According to the results of the experiment in Zhengzhou , the water sensitivity is 0.433 in the three leaf-overwinter stage , 0.306 in the overwinter-jointing stage , 0.585 in the jointing-heading stage , and 0.825 in the heading-maturing stage . It is clear that in the jointing-maturing stage , soil moisture stress has the most serious effect on production , and water supply should be ensured in this period . The irrigation amount is decided according to the target function as

$$\begin{aligned} B_{ij} &= C_1 \Delta Y_{ij} - C_2 I_{ij} - C_3 S_i \\ S_i &: I_{ij} \leq (F_c - W_t) \end{aligned} \quad (14)$$

where B_{ij} is the economic benefit resulting from the j th irrigation amount in the i th growing stage (RMB Yuan/ha.) . I_{ij} is the j th irrigation amount in the i th growing stage (mm/ha.) . ΔY_{ij} is the change of production resulting from the j th irrigation amount in the i th growing stage (kg/ha.) . S_i is an irrigation switch factor ($S_i=0$:off , $S_i=1$:on) , C_1 is the price of wheat (RMBYuan/kg) . C_2 is the price of water (RMBYuan/mm.ha.) . C_3 is the irrigation cost (such as labour , machine ,etc) per time (RMBYuan/time) . F_c is the field capacity (mm) . W_t is the soil moisture content (mm) . Irrigation should not be applied when $B_{ij} < 0$, when $B_{ij} > 0$ irrigation should be applied with the amount to maximize B_{ij} .

$$B_{ij} = \max \{ B_{ij} , j=1,2,3,\dots \} \quad (15)$$

In addition , in regions north of 38°N , where winter wheat often suffers from serious freeze injury , overwinter irrigation should be applied to decrease the injury effect . In the east coastal areas of the North China Region where irrigation uses slightly saline water (2-9g/l) , irrigation should be conducted after jointing stage , not before the stage .

(5) Service subsystem

The irrigation decision is sent immediately to leaders of villages via high-frequency telephone , alarm and paper material , and to the farmers via news media such as television and radio broadcast .

4. Application of the system

The system was applied to more than 3 million ha. in 90 counties of the North China Region (Hebei , Shandong , Henan , Inner Mongolia) . Accuracy of the irrigation decision reached about 95 per cent . Before the introduction of the

system , 4-5 irrigation treatments were applied during whole growing period of winter wheat . Now only 1-3 irrigation treatments are conducted and water use efficiency is greatly improved . The application of the system resulted in a sturdy plant , proper structure of plant communities , diminished plant diseases and insect pests and lodging , extended irrigation areas , stable and high production , lower input and higher income , and saved 270 RMBYuan per ha. . Application of the system has been welcomed by governments and farmers , and has become an important agricultural measure for sustained development of irrigation agriculture in the North China Region .

5 . Conclusion

(1) The system was constructed on the basis of experimental research and is able to monitor and forecast soil moisture stress in time and make rational irrigation decision for winter wheat .

(2) Application of the system has achieved good results in saving water and energy , and has ensured stable and higher production .

(3) Because the relationship between wheat and water involves soil , plant and atmosphere, and is quite complex , more research is needed for further improvement of the system .

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Fig. 1 Distribution of difference between water supply and demand of winter wheat in different climatic years in North China Region

Fig. 2 Monitoring Forecasting Assessing Decision-making Service System of soil moisture stress of winter wheat