DECISION SUPPORT SYSTEM OF VARIABLE RATE IRRIGATION BASED ON MATHEMATICAL MODEL AND GIS

Jianjun Zhou [1], Gang Liu [1*], Su Li [2], Xiu Wang [3], Man Zhang [1]

[1] *Key Laboratory of Modern Precision Agriculture System Integration Research, China Agricultural University, Beijing, 100083;*

[2] *Computer College, Beijing Technology and Business University, Beijing 100037;*

[3] *National Engineering Research Center for Information Technology in Agriculture, Beijing, 100089, China.*

[*] *Corresponding author, Address: P O. Box 125, China Agricultural University, 17 Tsinghua East Road, Beijing, 100083 P. R.. China, Tel:+86-10-62736741, Fax:+86-10-82377326, Email:pac@cau.edu.cn, zhoujianjun@cau.edu.cn*

Abstract: Owing to the difference of soil water in the farm, a system of variable rate irrigation was developed with Visual C++ and MapObjects that can save water as well as can improve economy benefit. Soil water content can be forecasted by using the forecast model of soil water, according to the real soil water content of different sampling sites in this system. Irrigation or not can be decided by comparing the current soil content with the light drought and serious drought index of the crop. The water amount of irrigation can be decided by the analysis of economy benefit according to the model of water consumption-yield, thus the irrigation prescription map can be created. This system can also query the information of fields, manage and analysis the data of soil. The test was performed in national precision agriculture demo farm.

Key words: variable rate irrigation; geographic information system; model; prescription

1. INTRODUCTION

China is one of the countries that are short of water resource. Farmland irrigation consumes most of water resource, so how to use water reasonably is an insistent demand in agriculture production. (Wang haijiang, et al., 2001)

Spray irrigation is a kind of advanced irrigation technology for saving water and has been used in many places. Generally spray irrigation can save between 30% and 50% of water. Parallel moving machine of spray irrigation can move in the fields independently, and it can save water and work force (King B A, et al., 1999). Currently Geographic information System (GIS), Global Positioning System (GPS), Expert System (ES) have been quickly developed, which make variable rate irrigation possible. Spray irrigation machine can irrigate automatically according to prescription map. The decision support system was developed for variable rate irrigation, which can irrigate according to real water content in every manipulation cell and the forecast model of soil water. Irrigation or not can be decided by comparing with the index of water requirements. The amount of irrigation can be determined by the analysis of economy benefit. Thus water can be saved as well as better benefit can be obtained with less water consuming. This system can provide the prescription map for irrigation.

The first aim is to build a model for variable rate irrigation. The second is making a map of irrigation prescription. The third is to develop a decision support system for variable rate irrigation of winter wheat and implement of variable rate irrigation.

2. SYSTEM DESIGN

2.1 Software environment

Visual C++, MapObjects and MS SQL Sever2000 were adopted in this system. Visual C++ has many characters as follows. Firstly, the character of object oriented programming make the system can support the modularized design, according to the inner character and function. Secondly, VC++ has high speed of implementing and uses less memory. MapObjects OCX is the earliest component offered by ESRI Company, which is the biggest software supplier of GIS. It provides the common function of GIS by the least interface, even the dynamic characteristic of GPS. MapObjects has the reasonable construction and can be understood easily (Zhu yan, et al., 2003).

2.2 Function analysis

The decision support system of variable rate irrigation is a geographic information system based on the module, which can import a few data formats such as text, table, etc. In this system, the property data can be queried the spatial data with each other. It also can offer many GIS function involving zooming in the map, moving the map or eagle eye etc. Irrigation prescription can be created according to the soil water data and the climate parameter. This system can be directly applied in the region of Beijing. For the expandability of the system, the module for expansion is designed. After the consumer imports the relative data of other region, this system can be immediately applied in that region.

3. SYSTEM REALIZATION

3.1 Interpolation of the sampling sites

The Kriging interpolation and the inverse distance weighted interpolation are accomplished. Through the interpolation, the distributing map of water content in a field can be immediately gained.

3.2 Database design

Three greatest databases such as the spatial database, the property database and basal database are designed. The spatial database includes the background map of national precision agriculture demo farm and the sampling sites' distributing map. The property database includes the soil water content in the sampling sites, which is acquired for the decision. The foundation database uses MS SQL Server2000 to establish relational database, among which there are four tables. They are the climate parameter table, farm crop parameter table, the price of water and wheat price table and the table of water index needed by wheat. There are seven fields in climate parameter table such as region, date, the sun radiation (Ra), the biggest possible sunshine hour (N), experience constant a, experience constant b and wind velocity correction coefficient (C). These seven fields are required for calculation the potential evapotranspiration (EToi). There are four fields in farm crop parameter table such as region, the period of crop growth, farm crop coefficient and yield reflection coefficient, which can be used to compute the amount of practical evapotranspiration. There are four fields in the price of water and wheat price table such as region, the price of wheat, the price of water and machine depreciation expenses, which can be used for the analysis of economy benefit. In the table of the index of water needed by wheat, there are five fields such as the region, the type of soil, the growth stage of the crop, the light drought index and the serious drought index, which can be used to decide to irrigate or not. The data in the later three tables can be extended by users, thus the extensibility of the system is increased. SQL Server is safe and data can not be changed without permission, which increases the security of the system.

4. GENERATION OF PRESCRIPTION MAP

The main function of the system is to generate the prescription map of variable rate irrigation. The prescription is made according to the soil water forecast model, the model of water consumption-yield, the optimal decision model and basal data.

4.1 Foundation data acquirement

The soil water content in 40 cm depth, field moisture capacity of the plot (Fc) has been measured. GPS was used to give the longitude and latitude of every sampling site, which can be transferred into layers of GIS. Through the interpolation, the surface data can be obtained. The experiment data can be got from national precision agriculture demo farm, where have taken 100 sampling sites in the winter wheat plot. Soil water content is recorded once every 15 days.

4.2 Forecast module of soil water content

4.2.1 Potential evapotranspiration model of farmland

The potential evapotranspiration amount of farmland is computed using Penman formula recommended by FAO1979. (Hu jichao, 2002)

$$ET_{0i} = \left\{ \frac{5.08\times10^{7}\times10^{(8.5(T-273)/T)}}{P\times T^{2}} \left[0.75 Ra\left(a+b\frac{n}{N}\right) - 2*10^{-9} \right.\right.$$

$$\left.\times T^{4}\left(0.56-0.079\times\sqrt{6.1\times10^{(8.5(T-273)/T)}\times r}\right)\left(0.10+0.90\frac{n}{N}\right)\right] + 0.26$$

$$\left.\times 6.1\times10^{(8.5(T-273)/T)}(1-r)(1.0+C\cdot U)\right\} / \left(\frac{5.08\times10^{7}\times10^{(8.5(T-273)/T)}}{P\times T^{2}}+1.00\right) \quad (1)$$

where: ETоi is the potential evapotranspiration amount, P is the air pressure in the field plot (hPa), T is the average temperature of a day (absolute zero), Ra is the sun radiation, n is an actual sunshine hours , N is the hour of biggest and possible sunshine, a and b are experience constant, r is the relative humidity of the atmosphere, C is the revised coefficient of wind velocity and U is the wind velocity above the ground 2 meters (m/s). In these parameters, except the T, P, U, r, n need user to input, others can be obtained from database.

4.2.2 Practical evapotranspiration model of soil

The practical evapotranspiration amount (ETai) can be computed using formula (2) (Gong yuanshi, et al., 1998) . Crop coefficient (k_c) can be got from database.

$$ETai = EToi * k_c \quad (2)$$

4.2.3 Water equilibrium model in farmland

The basis of soil water forecasting is an equilibrium equation of water in soil:

$$W_{T+1} = W_T + Pj + G - ETai \quad (3)$$

Where, WT+1 is soil water content end period (mm), WT is the soil water content start period, Pj is the effective rainfall inside the time (mm) and G is the quantities of the groundwater replenishment inside the time (mm). The amounts of groundwater replenishment can be zero in Beijing region. Formula (3) can reckon soil water content when decision-making from the soil water content that were measured.

4.3 The irrigation amount model

The soil water content in every cell of spray irrigation by decision-making can be obtained from above, and formula (4) or formula (5) can compute the irrigation amount in every irrigation cell.

$$H1 = Hg * (Fc - \theta) \qquad \text{(mm) sufficient irrigation} \quad (4)$$

$$H2 = Hg * (k * Fc - \theta) \qquad \text{(mm) insufficient irrigation} \quad (5)$$

where, Fc is field moisture capacity (volumetric soil water content), θ is the volumetric soil water content when the crop is short of water (coming from the model), k is the lower limit of irrigation under the condition of insufficient irrigation (the percent to the field moisture capacity, commonly it use 80%), Hg is the depth of irrigation management (mm), usually 600mm (Annandale J G, et al. 1999).

4.4 Water consumption-yield model of winter wheat

The practical irrigation amount can be determined by the economy benefit brought by the different irrigation amount. The yield increment aroused by different irrigation amounts can be got from formula (6).

$$\Delta Y = Ki*(-0.00008H^3 + 0.0095H^2 + 0.6355H - 1.5217)*(-3.5714W + 2.5357) \quad (6)$$

Where: Δ Y is the increment of yield (kg/666.7 m2), H is the quantities of irrigation (mm), W is the relative humidity of the soil (%), Ki is the response coefficient of yield (kg/mm·666.7m2). The value of Ki can be got from the farm crop parameter table.

4.5 The optimal decision model

Owing to the amount of the spraying water is coincident in the perpendicular direction of the spray machine moving, whereas the irrigation amount computed may be different in each grid in this direction, so the analysis of economy benefit is needed to decide a uniform amount in this direction. The function for the economy benefit is inducted.

$$B_{ij} = C_1 * \Delta Y - C_2 * H_{ij} - C_3 * S_i \quad (7)$$

Its restrictive condition is $H_{ij} \leq (1000*Fc-W_{T+1})$. The depth of the layer of the soil is 400 mm in this research. H_{ij} is the amount of irrigation (mm/666.7 m2). Bij is the economy benefit received after irrigation (yuan/666.7m2), Δ Y is the potential increase of yield from the irrigation (kg/666.7m2), Si is a variable that show whether or not irrigation. Irrigation occur when Si is equal to 1, and not occur when Si is equal to 0. C1 is the price of the wheat (yuan/kg), C2 is the price of water (yuan/mm·666.7m2), C3 is the expenditure of labor and machine depreciation after proceeding irrigation once in the unit area (yuan/666.7m2). The restriction condition controls the irrigation amount, is used for fear occurring leakage. When decision-making, firstly Si is supposed equal to 1, namely proceeding irrigating. The economy benefit (Bij) of each grid in vertical direction can be computed from the amount of irrigation in each grid. When Bij is less than or equal to 0, irrigation isn't done. When Bij is more than 0, take the biggest value of Bij under different irrigation amount circumstance, then the opposite Hij is the irrigation amounts of all the grids in the upright direction against the machine moving.

4.6 Flow of prescription map generation

In the framework, Wp is the light drought index, and Wd is the serious drought index. They can be got by experiment. The flow chart of generating prescription map is Fig. 1.

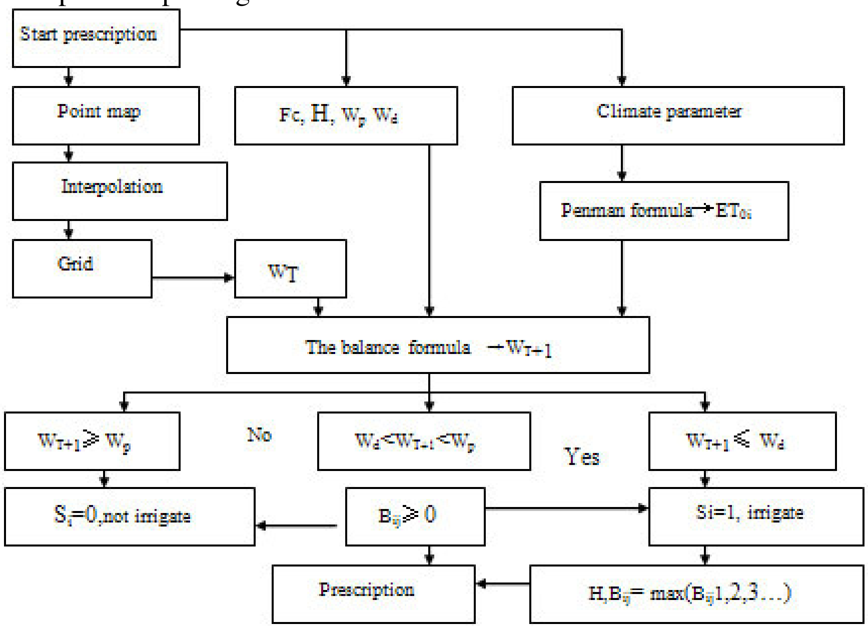

Fig. 1 Flow chart of making prescription map

4.7 Extension of Module

After the user inputs the right password, the modules of this system can be extended and the domain of system can be spread. Users can input the parameters such as the crop coefficient of other regions, the yield reflecting coefficient and the field moisture capacity etc., thus this system can be applied in other regions to generate prescription of irrigation.

5. APPLICATION

An Embedded computer was equipped in the irrigation machine. The variable rate irrigation system run in the computer and the map of irrigation prescription can be import into the system. The GPS fixed in the top of machine was connected with the computer through the COM1 port. The system can receive the GPS signal, thus the location of the machine can be obtained in real time. The location of the machine matched with the prescription map. Then the system knew the count of the irrigation in real time and control flow capacity of valve to realize variable rate irrigation (XU Di; LI Yi-nong, 2007).

This decision support system has been put into use in national precision agriculture demo farm, where the soil type is clay loam. On April 17, the soil water contents of the sampling sites are measured.

Irrigation prescription has been made using the soil water content in 40cm depth in the farm on April 30. In table 1 the part key data is listed and the map of irrigation prescription is Fig.2.

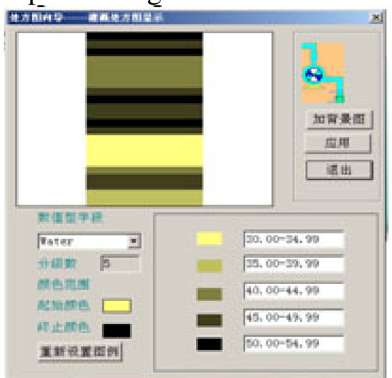

Fig.2. The map of prescription

Table1 The experiment parameter of the plot

parameter	value
ET_{0i}	5.1
Kc	0.8
ET_{ai}	4.08
The effective rainfall (mm)	2.2
The days of interval	13
Wp(mm)	287
Wd(mm)	192.7
Fc(%)	41%
Total evaporation	53.04

6. CONCLUSION

Soil, atmosphere and crop are sufficiently taken into account in the irrigation model. The decision support system for variable irrigation can forecast soil water content by using the forecast mathematical model of soil water content which is measured according to the different (sampling) sites using GIS. Whether or not irrigation can be decided by comparing the current soil water content with the light drought and serious drought indexes of the crops. The amount of irrigation can be determined by water equilibrium model in farmland and water consumption-yield model of winter wheat.

The irrigation prescription map obtained can be used for parallel moving spray irrigation. This decision support system of variable rate irrigation was developed which have GIS plain function. Further more two kinds of interpolation method were achieved, through which soil water distributing map can be created.

Variable rate irrigation can save water in a distant degree, which is important to the development of china's agriculture. Variable rate irrigation machine is diversiform, so irrigation prescription map for other type of irrigation machine can be researched later.

REFERENCES:

Annandale J G, Jovanovich N Z, BenadèN, et al. 1999. Modeling the long-term effect of irrigation with gypsiferous water on soil and water resources. Agriculture, Ecosystems and Environment, (76):109-119.

Gong yuanshi, Li zizhong, Li chunyou. 1998. Measurement of crop water requirements and crop coefficients using time domain reflectometry. Journal of China Agricultural University,3 (5) : 61-67.

Hu jichao, 2002. The research on the moisture connection of crop and moisture manage system. Nanjing Agriculture University Transaction,9.

King B A, McCann I R, Eberlein C V, 1999. Computer control system for spatially varied water and chemical application studies with continuous-move irrigation systems. Computers and Electronics in Agriculture, 24:177-194.

Wang haijiang, Wang bo, 2001. Reasonable crop irrigation system based on GIS.Bulletin of science and technology,17 (2): 36-33.

XU Di; LI Yi-nong, 2007. Review on advancements of study on precision surface irrigation system. Journal of Hydraulic Engineering, 38(5)529-534.

Zhu yan, Cao weixing, Wang shaohua etc. 2003. Application of soft component technology to design of intelligent decision-making system for crop management, Transaction of the CSAE, 19(1):132-137.