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Abstract. Accurate soil water content simulation is the basis of disaster early-warning and evaluation about waterlogging and drought. In order to more accurately simulation the water movement in wheat field with temporary field ditches, a two-dimension soil water simulation model was developed in this study. The model included the water movement vertically(up and down) and horizontally(ribbing and ditch), and traditional runoff estimation was replaced by calculating the drainage water from ditches. The model could simulate the comprehensive effect of depth of plow layer, initial soil water content, precipitation intensity and infiltration rate of plow pan layer on runoff. The application of the model in Xinhua city, China showed good agreement between observation with simulation values.

Keywords: water; simulation model; wheat field; temporary field ditches

1 Introduction

Waterlogging is one of the major agrometeorological disasters in wheat production in middle and lower valley of Yangtze river due to consecutive rainfall and weak infiltration of the plow pan because of the prevailing rice-wheat rotation cropping system [1-2]. The simulation on soil water content could provide support for waterlogging forecast and yield loss evaluation. Now there are many models to simulate the soil water content. In some models, such as CERES-wheat, VSMB, without considering the weak infiltration of plow pan, all excessive water will infiltrate to the next layer. So they could not simulate the waterlogging condition [3-4]. Some models could simulate waterlogging, such as SWATRE [5], DRAINMOD [6], DHSVM [7], but they always were used to simulate the movement of soil solutions and water management at regional scales, so they ignored the diffusion of water. Lv (1998） simulated the dynamic change of soil water content at Zhejiang province with MARCOS model [8]. Recently, some models based on artificial neural networks have been developed to simulate the soil water content [9-10]. Such models could simulate the water content changes, but their explanations in soil water movement is poor and their applicability in easy waterlogging regions have no enough evidences. With the development of drip irrigation in arid regions, some models could simulated the water movement in vertical and horizontal directions[11-12].

Most of above studies think water movement only at vertical direction. But many temporary field ditches were digged for drainage in wheat production in middle and lower valley of Yangtze river [13]. So above models maybe cannot accurately express water movement character in easy waterlogging regions. It is necessary to develop a model to simulate the soil water movement which can realize the role of the temporary filed ditches on drainage.

The objective of this paper aims to develop a 2-Dimension model to simulate water movement which will suit to wheat field with temporary ditches at rainy regions. The study will provide the basis for the evaluation of waterlogging disaster and optimization of water management.

2 Model description

Rice-wheat rotation is a common cropping system in the middle and lower valley of the Yangtze river. Because of rice production, the infiltration rate of the plow pan layer is weak. When the rainfall is enough large in wheat production, the rainfall will be held up at the top of the plow pan and led to waterlogging damage to wheat plants, so in order to drain excess water, some temporary ditches were digged along the plant direction (Fig. 1).

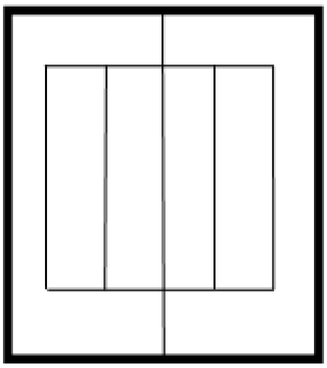

Fig. 1. Sketch map of temporary ditches in wheat field

2.1 Water movement character and Equation

Wheat field soil could be divided into three layers, plow layer, plow pan layer and underneath layer (Fig. 2). Rainfall will be absorbed by plow layer soil until its water content reach field capacity, the sparse and porous soil texture in plow layer led the excess rainfall can infiltrate easily to the bottom of the plow layer. But the tighten plow pan layer will led to weak infiltration, the rainfall will accumulate at the bottom of the plow layer, and water content at the bottom of plow layer will increase to saturation condition, thus waterlogging will happen. The saturation water will infiltrate though the plow pan layer or move to the temporary field ditches simultaneously.

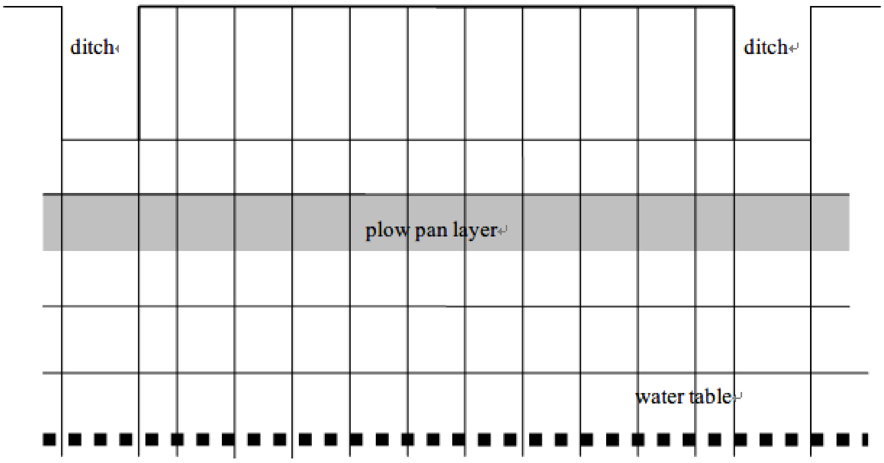

Fig. 2. Soil profile for the model

In order to better describe water movement, the soil profile was divided into six layers. The plow layer include two layers, which was determined as the depth of the ditch. Plow pan layer is look as one layer and the underneath layer include three layers. The depth of last layer is changed with the depth of water table.

The movement equation of soil water is listed as below:

$$
\begin{aligned}
&\text{Plow Layer 1:} \quad D_1 \frac{dW(i,1)}{dt} = P - DR(i,1) - E_a - D(i,1) - E_V \cdot RR_1 - RO \\
&\text{Plow Layer 2} \quad D_2 \frac{dW(i,2)}{dt} = DR(i,1) - DR(i,2) - D(i,2) - E_V \cdot RR_2 \\
&\text{Plow Pan Layer} \quad D_3 \frac{dW(i,3)}{dt} = DR(i,2) - DR(i,3) - D(i,3) \\
&\text{Underneath Layer1} \quad D_4 \frac{dW(i,4)}{dt} = DR(i,3) - DR(i,4) - D(i,4) \\
&\text{Underneath Layer2} \quad D_5 \frac{dW(i,5)}{dt} = DR(i,4) - DR(i,5) - D(i,5) \\
&\text{Underneath Layer3} \quad D_6 \frac{dW(i,6)}{dt} = DR(i,5) - DR(i,6) - D(i,6)
\end{aligned}
\tag{1}
$$

where Di is the depth of the ith layer, W(i,j) is the volumn water content at grid (i,j). P is rainfall, Ea is soil evaporation, Ev is crop transpiration. DR(i,j) is drainage amount at grid (i,j), RO is runoff and D (i,j) is the water diffusion at grid (i,j). j is the layer number, and i is the horizontal position for grids.

2.2 Precipitation infiltration

In plow layer, similar to other water balance models, we also assume that redundant water will all transfer to next layer when the water content is bigger than filed capacity until the top of the plow pan layer. When the excess precipitation led to soil saturation condition for soil at the bottom of the plow layer, water will move to temporary field ditches and infiltrate through to plow pan layer simultaneously. The infiltration amount (INF) is calculated using equation (2):

$$\mathrm{INF} = \begin{cases} DT_0 & \mathrm{DT} < \mathrm{DT}_0 \\ a \cdot (DT - DT_0) + DT_0 & DT \geq DT_0 \end{cases} \tag{2}$$

where DT is the depth of saturated layer at the bottom of the plow layer, DT_0 is maximum thickness of saturated layer for all infiltration in a day. a is coefficient, which relates to soil texture. The DTo in equation 2 was set to 2mm in this study.

2.3 Water diffusion

Water always moves from the positions with high hydraulic potential to those with low hydraulic potential. so when grid (i,j) has difference in water potential with nearby girds, including grids (i-1,j）,(i+1,j),(i,j-1) and (i,j-1), water diffusion will happen. The diffusion amount can be expressed as equ.(3):

$$\begin{aligned} D(i,j) = {} & K_h \cdot (\psi_{i-1,j} - \psi_{i,j}) / (Z_i - Z_{i-1}) + K_h \cdot (\psi_{i,j} - \psi_{i+1,j}) / (Z_i - Z_{i+1}) \\ & + K_V \cdot (\psi_{i,j-1} - \psi_{i,j}) / (D_i - D_{i-1}) + K_V \cdot (\psi_{i,j} - \psi_{i,j+1}) / (D_i - D_{i-1}) \end{aligned} \tag{3}$$

where Kv and Kh are the soil vertical and horizontal unsaturated hydraulic conductivity, respectively. Ψ is water potential and the subscribe expresses the position of grids. Di is depth of the ith layer and Zi was horizontal distance of grid i.

2.4 Runoff

Because the intensity of rainfall is small during the wheat growth season and the big roughness of wheat field, the surface runoff happens only when the plow layer was statured for the grids on the top of plow layer and the runoff values equal to the precipitation minus soil absorbable water. At the ditches, the water moved to ditches and precipitation minus infiltration amount and soil absorbable water will be leak out as runoff. The soil absorbable water equals to the saturation water content minus current soil water content.

2.5 Calculation of evapotranspiration

The potential reference evapotranspiration is calculated as Priestley—Taylor model [4]:

$$ET_P = K_S \cdot SR \cdot (0.00488 - 0.00437 \cdot ALBEDO) \cdot (\overline{T} + 29) \tag{4}$$

where, SR is daily solar radiation ($MJ/M^2/D$), ALBEDO was field reflection coefficient. T is mean air temperature,equals to 0.6TM+0.4TN. TM and TN are the maximal and minimal temperatures respectively. K_S is temperature coefficient, calculated as below equ (5)..

$$K_S = \begin{cases} 0.01\exp(0.18(\overline{T} + 20) & \overline{T} < 5 \\ 1.1 & 5 \le \overline{T} \le 24 \\ 0.05(\overline{T} - 24) + 1.1 & \overline{T} > 24 \end{cases} \tag{5}$$

ALBEDO is expressed as:

$$ALBEDO = \begin{cases} \gamma & sowing-emergenc \\ 0.23 - (0.23 - \gamma)\exp(-0.75L) & emergence-elonga \\ 0.23 + (L-4)^2/160 & elongation-maturi \end{cases} \tag{6}$$

where, γ is the reflection coefficient for bare soil, is set to 0.2.

The potential field evapotranspiration is calculated as equ (7) [14,15,16]:

$$ET_C = \begin{cases} ET_P & L \le 1.5 \\ \dfrac{(K_C - 1)L + (5 - 1.5K_C)}{3.5} ET_P & 1.5 < L < 5 \\ K_C \cdot ET_P & L \ge 5 \end{cases} \tag{7}$$

where, K_C is maximal crop coefficient.

The potential soil transpiration is calculated as $E_P = ET_P \cdot \exp(-\delta L)$, δ is extinction coefficient and set to 0.5 in this study. the crop evaporation is ET_C-E_P. The actual soil transpiration is:

$$E_a = \begin{cases} E_P & W > W_F \\ E_P \cdot \dfrac{W - W_P}{W_F - W_P} & W_P < W < W_F \\ 0 & W < W_P \end{cases} \tag{8}$$

where, W_P and W_F are soil water content for wilting point and field capacity.

2.6 Depth of water table

The depth changed as below equ.(9):

$$\Delta WT = DR(i,6) + 2K_V \cdot (W(i,6) - WSD) / Z(6) \qquad (9)$$

where ΔWT is change amount of water table, DR (i,6) is infiltration amount of grid (i,6), Kv is vertical diffuse coefficient, WSD is saturation soil water content for underneath layer. Z(6) is the depth of 6th layer.

Considering the movement of underneath water, the change of water table could use the mean value of ΔWT at each point.

3 Model Application

3.1 Soil parameter description

Xinhua City located at Jiangsu province is the easy waterlogging area because the elevation is the lowest in Lixiahe plain. According to filed investigation, the depth and its attribution for each layer is list as Table1

Table1 The

Layer	Thickness (cm)	Bulk density (g/cm^3)	field capacity (%)	water wilting point (%)
1	13	1.21	37.9	8.9
2	7	1.42	36.6	8.7
3 plow pan	10	1.44	30.9	10.3
4	10	1.38	33.5	9.8
5	10	1.35	35.3	9.5
6	variable	1.35	35.3	9.5

The thickness of layer 6 change with the water table and the initial value was set to 40cm, and parameters in layer 6 have no data, we assume their attributions equal to those in layer 5.

Water movement parameters are listed as belows

$$K_h = K_V = KS \cdot \left(\frac{\psi}{\psi_e}\right)^{-2+3/\beta}$$

$$\psi = \psi_e \cdot \left(\frac{W}{W_S}\right)^{\beta}$$

where, K_h and K_V are horizontal and vertical unsaturated hydraulic conductivity. KS is saturated hydraulic conductivity. Ψ and Ψe are hydraulic potential and saturated hydraulic potential.

3.2 Simulation

Using soil water content and water table observation data in 2012-2013 from Xinhua agrometeorology experiment station (32.95°N, 119.82°E), the model was validated. Because the wheat planted on Oct. 29, 2012, the model simulated from Oct. 20, 2012. The simulated water table change with observed values in good agreement. But the simulated soil water content was lower than observed values during before winter and after wheat heading. The possible reason for this phenomena maybe be the incorrect parameters input (Fig.3 and Fig.4).

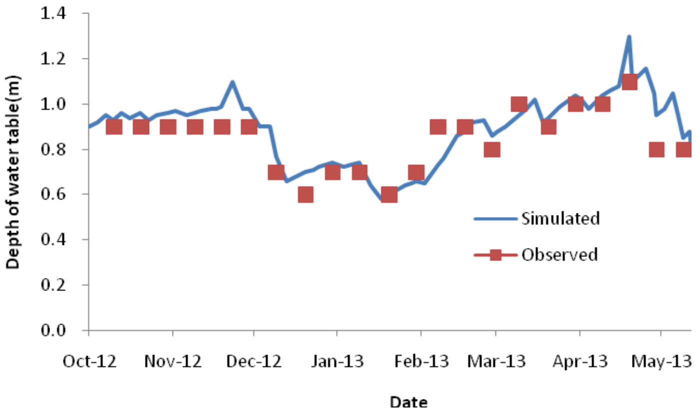

Fig. 3. The change of the depth of water table for 2012-2013 wheat production season

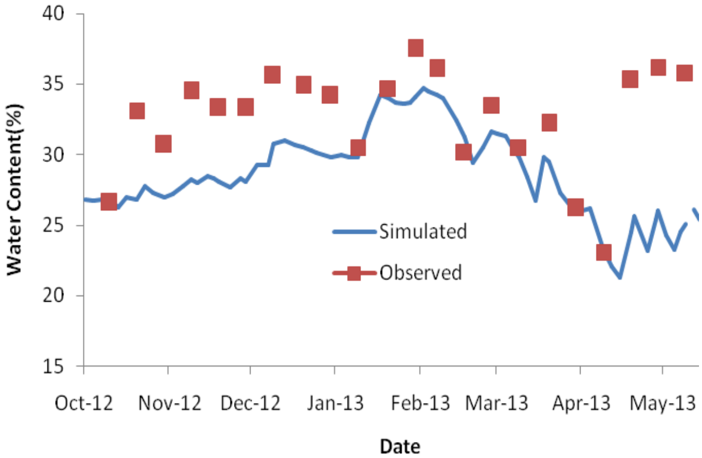

Fig. 4. The change of soil water content in layer 1 for 2012-2013 wheat production season

4 Discussion

In previous studies, the runoff always was estimated from the CN method proposed by department of agriculture, USA [4,7]. Such method considered the effect of soil texture, initial soil water content on the runoff. But it could not describe the impact of precipitation intensity and depth of plow layer. In this study, we consider the all above factors, so it is more reasonable.

The water movement always were considered only in vertical direction in previous models [3,4,7]. This paper expanded it to 2-D space which could be suited to most area in wheat field. But at the both sides of wheat field, several connected ditches with different depth makes the simulation of soil water more complex [8]. So further study should be needed to explore water movement wholly in wheat field.

Although there are some other simple models or analytical models to describe the water movement[17,18], they always could not suit to different ecological conditions.

Acknowledgment

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