乾燥ストレスおよび塩ストレスに応答する動的根群成長モデルによる根群分布の予測
Prediction of Root Distribution with a Dynamic Root Growth Model Responding to Drought and Salinity Stresses

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要旨(Abstract)
土壌中の水分や塩分の移動および作物の吸水の正確な数値予測の精度向上のため、水分の低いあるいは塩分濃度の高い領域を避け、吸水しやすい低い領域に根を伸ばそうとする植物の特性を組み入れた簡易な動的根群成長モデルを考案し、その特徴と精度をインド北部における点滴灌漑による小麦栽培における測定値との比較により検討した。

キーワード:蒸散、吸水、塩ストレス
Key words: transpiration, root water uptake, salinity stress

1. Introduction

Prediction of the distribution of root activity is important to accurately predict water flow and solute movement in soils. It has been widely known that roots tend to avoid dry and saline zone and extend to zone where water uptake is easy. Nonetheless, root development sub-models employed in widely used simulation model such as HYDRUS or SWAP are static: they do not respond to dry and salinity in soils. To improve accuracy in predicting root distribution, we have developed a simple two-dimensional dynamic root growth model and evaluate its performance for data obtained in an irrigation experiment.

2. Dynamic root growth model

In the macroscopic root water uptake model, the water uptake rate, S (cm s^{-1}) is given as the product of reduction coefficient, α, and potential root water uptake rate, S_p, which is given as the product of potential transpiration rate, T_p(cm s^{-1}), and root activity, β(cm^{-2}).

$$S=S_p\alpha=T_p\beta\alpha \quad (1)$$

The root activity, β, is a value obtained by normalizing root length density such that integration of the across the root zone gives unity:

$$\int_0^{drt}\int_{-grt}^{grt}\beta\,dxdz=1 \quad (2)$$

where x is horizontal coordinate (cm), z is depth (cm), d_{rt} is lower boundary of the root zone (cm) and g_{rt} is rightward limit of the root zone. In a numerical model WASH_2D which we use, d_{rt} is given as a function of cumulative transpiration, τ:

$$d_{rt}=a_{drt}\left[1-\exp\left(b_{drt}\tau\right)\right]+c_{drt} \quad (3)$$

where a_{drt}, b_{drt}, and c_{drt} are empirical parameters. Various functions for expressing β have been presented and following one is used in WASH_2D.

$$\beta_p=0.75\left(b+1\right)d_{rt}^{\left(-b-1\right)}\left(d_{rt}-z+z_{r0}\right)^b g_{rt}\left(1-x^2g_{rt}^{\left(-2\right)}\right) \quad (4)$$

where β_p is potential β without any stresses or if the plant is completely insensitive to stress, b is empirical shape factor and and z_{r0} is the depth below which roots exist. Then β is given by multiplying average α from germination to the time, $\overline{\alpha}$, to β_p, and normalized as:

$$\beta=\frac{\beta_p\overline{\alpha}^\gamma}{\int\int\beta_p\overline{\alpha}^\gamma dxdz} \quad (5)$$

where γ is adaptivity. If γ = 1, roots escape difficult zone and preferably extend to easy zone. If γ = 0, roots grow as described with eq.(4) regardless of dry or saline zone. This model requires to store cumulative potential and actual water uptake rate for each element as:

$$\bar{\alpha} = \frac{\int_0^t S\,dt}{\int_0^t S_p\,dt} \quad (5)$$

This submodel has been incorporated to the latest version of WASH_2D. The new version of WASH_2D model also allows second plant (row) in calculated region.

3. Field experiment

The experiment was carried out in Central Soil Salinity Institute in Carnal, India. Wheat was grown with drip irrigation in which three lines, 11 cm from drip tubes and center between the tubes whose interval was 75 cm. Salinity of the irrigation water was 4 dSm^{-1}. Root distribution was measured on 29 April, at harvest, by taking soil blocks at an interval of 9.4 cm and 10 cm in horizontal and vertical direction, respectively. Root lengths were measured with image analysis after sieving in water.

4. Results and Discussion

Measured root distribution somewhat skewed to the side of drip tube as shown in Fig.1. Potential root distribution using parameter values of (b, g_{rt}, a_{drt}, b_{drt}, c_{drt}) = (1, 20cm, 20cm, -0.5cm^{-1}, 9cm) also skewed to the wetter side as shown in Fig.2 because row distance was denser in the tube side (22 cm) than in the other side (26 cm). Distribution predicted with the dynamic model (γ=1) clearly over-skewed. Adaptivity of wheat may be small.

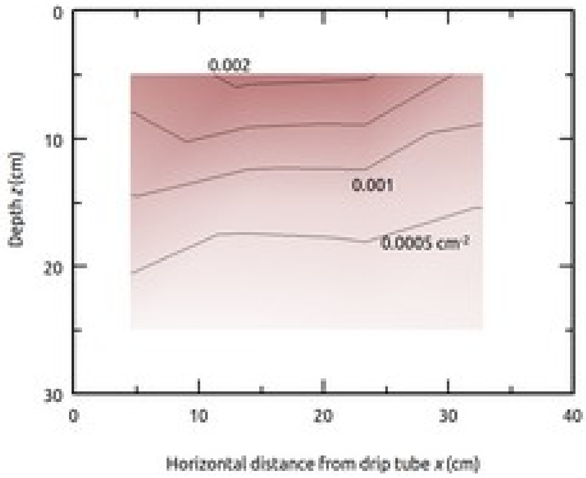

Fig.1 Measured and root length distribution at the end of drip-irrigated wheat

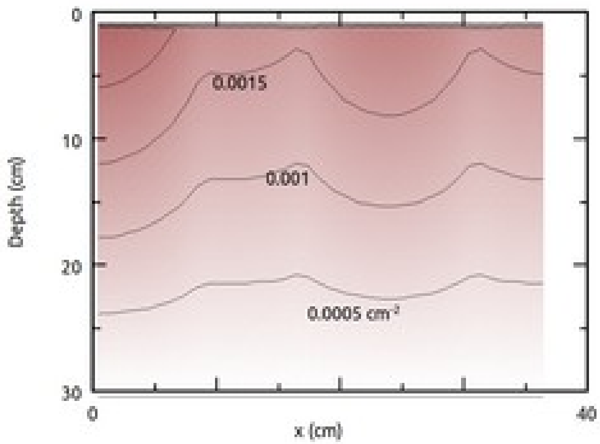

Fig.2 Simulated potential root activity under drip irrigated wheat

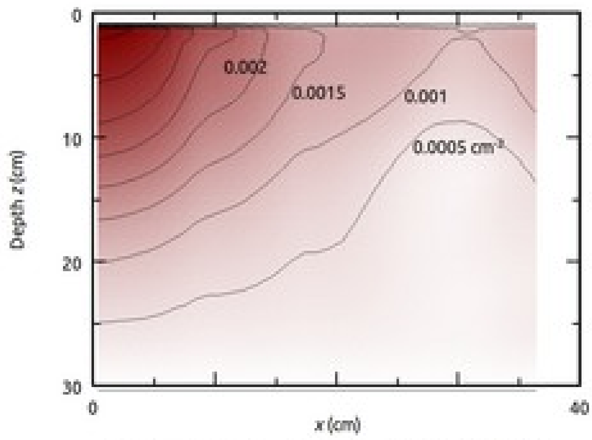

Fig.3 Simulated root activity under drip irrigated wheat

5. Conclusions

The presented dynamic root growth model demonstrated the ability to preferentially extend into zone where roots can uptake water near potential rate. Nevertheless, in case of the drip-irrigated wheat did not show strong preference, flexibility or escapability. Further experiments using various plants under various conditions are required for further validation of the model.