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メタデータ	言語: eng 出版者: 公開日: 2009-08-25 キーワード (Ja): キーワード (En): 作成者: TANIGAWA, Torahiko, MURASHIMA, Kazuo, YABE, Katsuhiko, OGINO, Yoshihiko メールアドレス: 所属:
URL	https://doi.org/10.24729/00009218

Bull. Univ. Osaka Pref., Ser. B, Vol. 46,
大阪府立大学紀要，農学・生命科学，1994

Optimization of Soil Moisture Environment by Applying Simulation on Sub-irrigation Method (II) —Reappearance Trial by Using Conformal Mapping Method in the Distribution of Soil Moisture Tension—

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(Received October 31, 1993)

Abstract

This study was conducted to clarify the distributions of soil moisture tension in root zone under different conditions in case of applying the continuous sub-irrigation method by using negative pressure. That is, the different conditions were divided into six groups. The first is the rate of transpiration to evapotranspiration, the second the vertical direction of water source, the third the horizontal direction of water source, the forth the space of water source, the fifth the vertical direction of two water sources, and the sixth the horizontal direction of two water sources. Consequently, the differences of the distributions of soil moisture tension which were gained in this study were recognized larger than those in the previous paper.

Introduction

In the subsurface irrigation method by using negative pressure, water which are exuaded from porous pipe of source diffuses to the radial direction. Therefore, water movement is conducted at the unsaturated state. Usually, this water movement is dealt with moistue movement equation by using unsaturated permeability, the diffusion equation by using diffusive coefficient, and so on. On the other hand, the distributions of soil moisture tension around the water source reappeared here by using mapping method which is applied to the analysis method of drainage problem as the analysis method of steady flow. But there is few case which is applied to the analysis of the distributions of soil moistue tension. However, one problem which the constant unsaturated permeability must be given in the analysis region is existed in the mapping method though the unsaturated permeability fluctuate with the extent of soil moiture tension. This problem would be clarified and resolved at next chance. But to the some extent, the distributions of soil moisture tension can be reappeared in order to know the tendancies, the results obtained would be stated.

Analysis Method and Calculation Conditions

(1) *Analysis method*

Analysis method in case of one water source was stated at the previous paper. So, in this study, analysis method in case of much water sources would be discussed about the

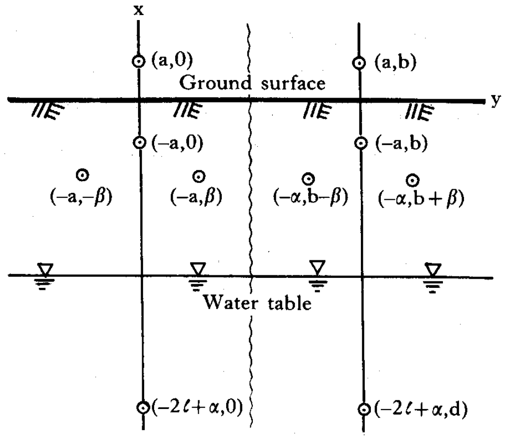

Fig. 1 A model mapping method in case of two sources and eight sinks under the application of subsurface irrigation method.

distributions of soil moisture tension around the sources.

Model for the analysis can be consisted of the positions of water sources (−a, 0) and (−a, b), those of transpiration sinks ($-\alpha$, $\pm\beta$) and ($-\alpha$, $\pm\beta+b$), those of evaporation sinks (−a, 0) and (a, b), and those of downward percolation sinks ($-2\iota+a$, 0) and ($-2\iota+a$, b) as shown in Fig. 1. Then, consider the rate of water source m_1, that of evaporation sink m_2, that of downward percolation m_3, and that of transpiration sink m_4, the rate of water sources can be expressed as follows.

$$m_1 = m_2 + m_3 + 2m_4 \tag{1}$$

On the other hand, the function of complex variable w can be added, so it can be formulated by using the principle of image by inversion as follows.

$$\begin{aligned} w = &-m_1\{\ln(z+a)+\ln(z+a-ib)\}+m_2\{\ln(z-a)+\ln(z-a-ib)\} \\ &+m_3\{\ln(z+2\iota-a)+\ln(z+2\iota-a-ib)\}+m_4\ [\ln\{(z+\alpha-i\beta)(z+\alpha+i\beta)\}+ \\ &\ln\{(z+\alpha)-i(\beta+b)\}\{(z+\alpha)+i(\beta-b)\}] \end{aligned} \tag{2}$$

Therefore, the function of velocity potential $\phi(x, y)$ can be expressed as follows.

$$\begin{aligned} \phi(x, y) = &-m_1/2\cdot\ln\{(x+a)^2+y^2\}-m_1/2\cdot\ln\{(x+a)^2+(y-b)^2\} \\ &+m_2/2\cdot\ln\{(x-a)^2+y^2\}+m_2/2\cdot\ln\{(x-a)^2+(y-b)^2\} \\ &+m_3/2\cdot\ln\{(x+2\iota-a)^2\}+m_3/2\cdot\ln\{(x+2\iota-a)^2+(y-b)^2\} \\ &+m_4/2\cdot\ln\ [\{(x+\alpha)^2+(y-\beta)^2\}\ \{(x+\alpha)^2+(y+\beta)^2\}] \\ &+m_4/2\cdot\ln\ [\{(x+\alpha)^2+(y-\beta-b)^2\}\ \{(x+\alpha)^2+(y+\beta-b)^2\}]+\phi_0 \end{aligned} \tag{3}$$

Here, ϕ_0 is constant and can be obtained as follows. Consider the total potential H in soil, the gravitational potential x, and the soil moisture potential h, the total potential and velocity potential can be expressed as follows.

$$H = h - x \tag{4}$$

$$\phi = -Ks\cdot H \tag{5}$$

where Ks is the coefficient of unsaturated permeability. Then, the boundary condition is expressed as follows.

$$\phi(-\iota, 0)=\mathrm{Ks}\cdot(-\iota) \quad (6)$$

Therefore, ϕ_0 can be written as follows.

$$\begin{aligned}\phi_0=&m_1/2\cdot\ln(-\iota-a)^2+m_1/2\cdot\ln\{(-\iota+a)^2+b^2\}\\ &-m_2/2\cdot\ln(-\iota+a)^2-m_2/2\cdot\ln\{(-\iota-a)^2+b^2\}\\ &-m_3/2\cdot\ln(-\iota+a)^2-m_3/2\cdot\ln\{(-\iota+a)^2+b^2\}\\ &-m_4/2\cdot\ln\{(-\iota+\alpha)^2+\beta^2\}^2\\ &-m_4/2\cdot\ln[\{(-\iota+\alpha)^2+(-\beta-b)^2\}\{(-\iota+\alpha)^2+(\beta-b)^2\}]-\mathrm{Ks}\cdot\iota \end{aligned} \quad (7)$$

On the other hand, soil moisture tension h (x, y) in any position (x, y) can be expressed as follows.

$$h(x, y)=\phi(x, y)/\mathrm{Ks}+x \quad (8)$$

And then, consider negative pressure Hp given in porous pipes under the subsurface irrigation method by using negative pressure and the diameter of pipes d, the following equation can be gained.

$$\phi(-a, d)=\mathrm{Ks}\cdot(-\mathrm{Hp}-a) \quad (9)$$

Furthermore, in case of one source as stated in a previous issue, the function of complex variable w can be written by excepting other source and sinks as follows.

$$\begin{aligned}w=&-m_1\cdot\ln(z+a)+m_2\cdot\ln(z+a)+m_3\cdot\ln(z+2\iota-a)\\ &+m_4\cdot\ln\{(z+\alpha-i\beta)(z+\alpha+i\beta)\}\end{aligned} \quad (10)$$

Therefore, the function of velocity potential $\phi(x, y)$ can be expressed as follows.

$$\begin{aligned}\phi(x, y)=&-m_1/2\cdot\ln\{(x+a)^2+y^2\}+m_1/2\cdot\ln\{(x-a)^2+y^2\}\\ &+m_3/2\cdot\ln\{(x+2\iota-a)^2+y^2\}\\ &+m_4/2\cdot\ln[\{(x+\alpha)^2+(y-\beta)^2\}\{(x+\alpha)^2+(y+\beta)^2\}]+\phi_0\end{aligned} \quad (11)$$

Then, constant ϕ_0 can be decided by using initial conditions and boundary conditions as the case of much water sources and sinks.

(2) Conditions of calculation

Arrange the conditions of calculation in order to simulate the distributions of soil moisture tension around porous pipe, they are shown in Table 1. Then, consider the water supply Q, the evapotranspiration ET, and transpiration T, the relationships between the inflow or outflow and water supply can be written as follows.

Table 1 Main parametets of calculation.

Parameter	Value
Water supply Q (ml/s/cm)	0.0005
Negative pressure given to the porous pipe Hp (cmH_2O)	10.0
Buried depth of the porous pipe a (cm)	5.0
Inside radius of the porous pipe r_1 (cm)	2.0
Qutside radius of the porous pipe r_2 (cm)	2.5
Radio of evapotranspiration and water supply ET/Q	0.9
Water table ι(cm)	500.0

$$m_1 = Q/2\pi$$
$$m_2 = (ET-T)/2\pi m_3 = (Q-ET)/2\pi$$
$$m_4 = T/4\pi$$
$$m_1 = m_2 + m_3 + 2m_4 \quad (12)$$

Results and Consideration

1. Influences to Distributions of Soil Moisture Tension in Case of One Source

(1) *Distributions of soil moisture tension in the different ratioes of transpiration to evapotranspiration*

The different ratioes of transpiration to evapotranspiration, that is, 50, 70, and 90% were selected in order to calculate the distributions of soil moisture tension. The results obtained from the simulations are shown in Fig. 2.

The more the ratio of transpiration increases, the more the line of equal moisture tension near the ground surface shows a tendency to spread out to the horizontal direction from water source, and soil is shown a tendency to dry. But their differences can not be judged so much. On the other hand, to the vertical direction from water source, the line

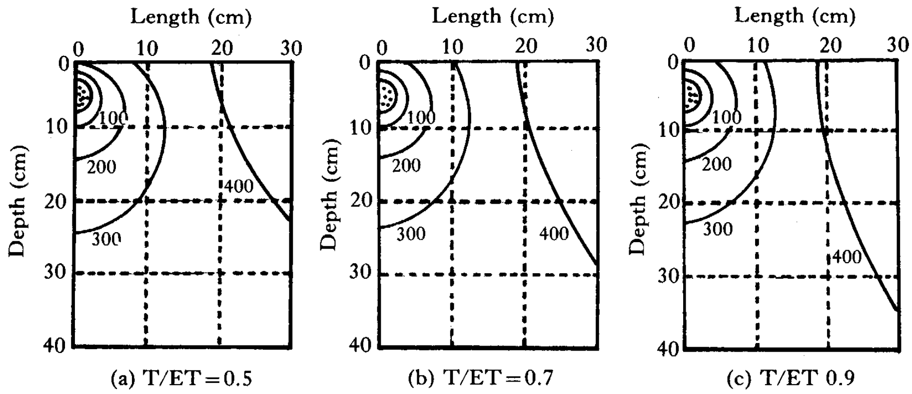

Fig. 2 Distributions of soil moisture tension (cm H_2O) around the porous pipe under the different ratios of transpiration T and evapotranspiration ET

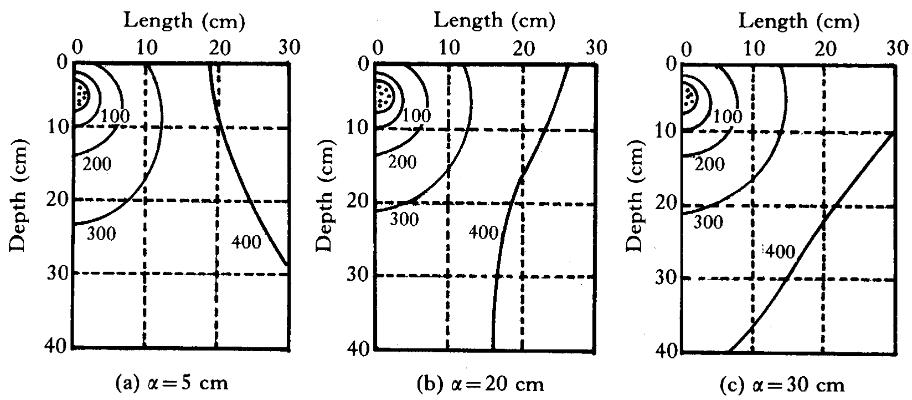

Fig. 3 Distributions of soil moisture tension (cmH_2O) around the porous pipe under the different depths of absorption roots (sinks).

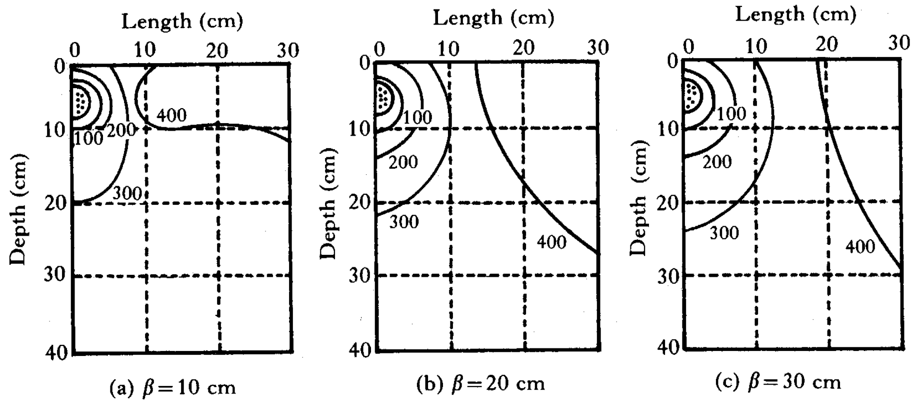

Fig. 4 Distributions of soil moisture tension (cmH_2O) around the porous pipe under the different horizontal lengths of absorption roots (sinks).

of equal moisture tension below 300cm H_2O can be recognized to be much different. Therefore, the different ratioes of transpiration to evapotranspiration are found to influence the distributions of soil moisture tension.

(2) *Distributions of soil moisture tension in the different vertical positions of transpiration sinks.*

The different vertical positions of transpiration sinks, that is, 5, 20, and 30cm were selected in order to calculate the distributions of soil moisture tension. The results obtained from the simulations are shown in Fig. 3.

The vertical positions of transpiration sinks become deeper, the line of equal moisture tension near the ground surface shows a tendency to spread out to the horizontal direction from water source, and soil is shown a tendency to dry. But their differences can not be judged so much. On the other hand, to the vertical direction from water source, the line of equal moisture tension below $300cmH_2O$ can not be almost different, but that of $400cmH_2O$ can be recognized to be much different. Therefore, the different vertical positions of transpiration sinks are found to influence the distributions of moisture tension.

(3) *Distributions of soil moisture tension in the different horizontal positions of transpiration sinks.*

The different horizontal positions of transpiration sinks, that is, 10, 20, and 30cm were selected in order to calculate the distributions of soil moisture tension. The results obtained from the simulations are shown in Fig. 4.

The horizontal positions of transpiration sinks become more distant, the more the line of equal moisture tension near the ground surface shows a tendency to spread out so much to the horizontal direction from water source, and soil shows a tendency to dry. And then, their differences are apparently judged larger. On the other hand, the line of equal moisture tension below $200cmH_2O$ can not be recognized to be different so much to the vertical direction from water source, but that above $300cmH_2O$ can be judged to be different so much.

Consequently, the different positions of transpiration sinks influence to the distributions of soil moisture tension so much, it is necessary enough to be careful in case of predicting and reappearing them.

2. Influences to Distributions of Soil Moisture Tension in Case of Much Sources

(1) *Distributions of soil moisture tension according to the different space of water source*

The different spaces of water source, that is, 50, 60, and 80cm were selected in order to calculate the distributions of soil moisture tension. The results obtained from the simulations are shown in Fig. 5.

The line of equal moisture tension near the ground surface can not be recognized to be almost different to the horizontal direction from water source. On the other hand, to the vertical direction from water source, the distributions of moiture tension below 200cmH_2O can not be recognized to be almost different, but that above 300cmH_2O can be recognized to be different. That is, the space of water source become more distant, soil under water source shows a tendency to dry a little.

(2) *Distributions of soil moisture tension according to the different vertical position of transpiration sinks*

The different vertical position of transpiration sinks, that is, 5 and 20cm were selected in order to calculate the distributions of moisture tension. The results obtained from the simulations are shown in Fig. 6.

The line of equal moisture tension below 200cmH_2O can be recognized not to be different so much to the horizontal and vertical direction according to the different vertical position of transpiration sinks. But the line of equal moisture tension 300cmH_2O shows

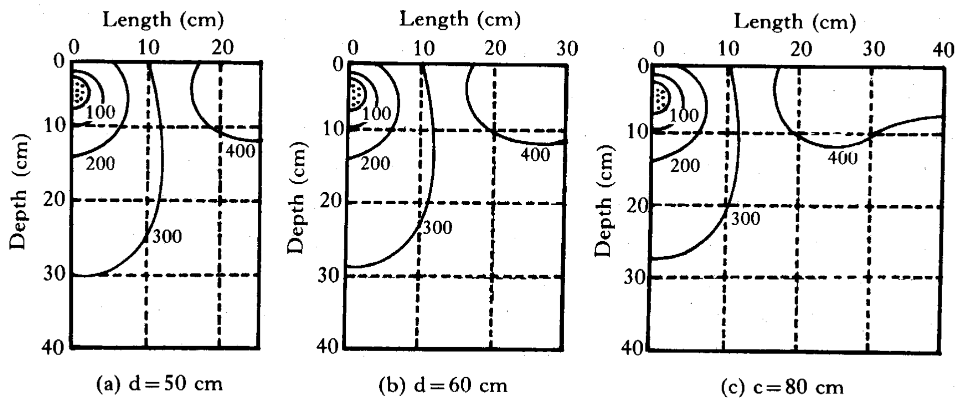

Fig. 5 Distributions of soil moisture tension (cmH_2O) around the porous pipe under the different space of the porous pipe buried in cace of two sources.

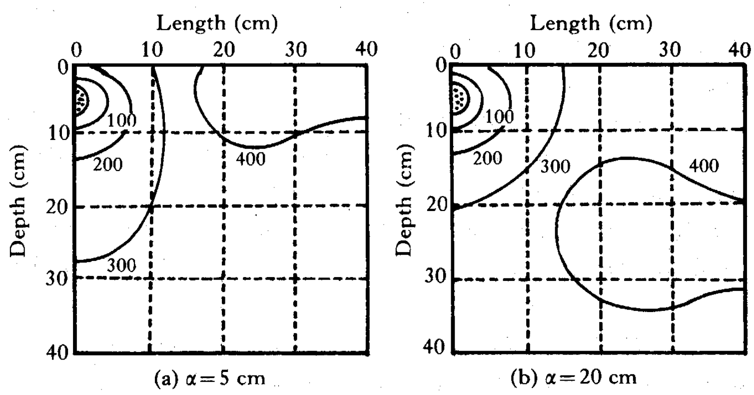

Fig. 6 Distributions of soil moisture tension (cmH_2O) around the porous pipe under the different depths of the different of the porous pipe buried in cace of two sources.

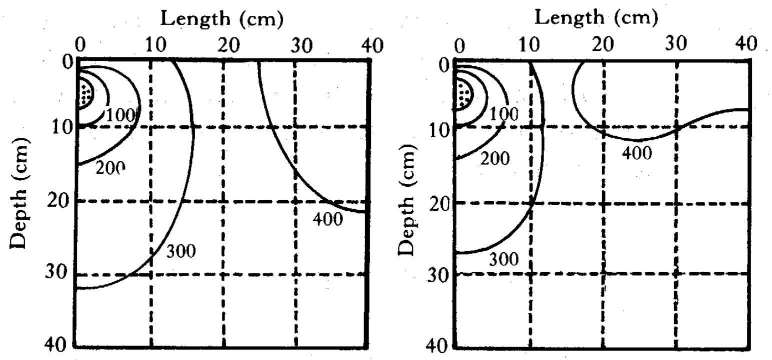

Fig. 7　Distributions of soil moisture tension (cmH_2O) around the porous pipe under the different horizontal lengths of the porous pipe buried in cace of two sources.

a tendency to spread out and that of equal moisture tension $400cmH_2O$ disappears near the ground surface as the vertical position of transpiration sinks become deeper. Especially, the vertical position of transpiration sinks becomes deeper, the line of equal moisture tension $300cmH_2O$ shows a tendency to near water source and that $400cmH_2O$ to distribute from the depth of 15 to 35cm from the ground surface. Consequently, it is found that the vertical position of transpiration sinks influences the distributions of moisture tension

(3) *Distributions of soil moisture tension according to the different horizontal position of transpiration sinks*

The different horizontal position of transpiration sinks, that is, 20 and 40cm were selected in order to calculate the distributions of moisture tension. The results obtained from the simulations are shown in Fig. 7.

The line of equal moisture tension below $200cmH_2O$ can be recognized to be almost same as the horizontal direction according to the different horizontal position of transpiration sinks. But that of equal moisture tension $300cmH_2O$ or $400cmH_2O$ shows a tendency to spread out. Especially, the line of equal soil moisture tension $400cmH_2O$ distributes near the ground surface. On the other hand, to the vertical direction, the line of equal moisture tension below $200cmH_2O$ can be recognized to be almost same. But the horizontal position of transpiration sinks becomes more distant from water source, the line of equal moisture tension, that is, $300cmH_2O$ or $400cmH_2O$ can be recognized to be deeper. Consequently, it is found that the horizontal position of transpiration sinks influences the distributions of soil moisture tension.

Conclusion

This study was conducted to clarify the distributions of soil moisture tension under the different conditions in case of applying the continuous sub-irrigation method by using negative pressure. That is, the different conditions, for example, the ratio of transpiration to evapotranspiration, the vertical position of water source, and the horizontal position of water source in case of one water source were investigated. And also, the space of two water sources, the horizontal position of water sources, and the vertical position of water source in case of two water sources were investigated. Consequently, the differences of the distributions of soil moisture tension were recognized so much. Especially, it is found that the influences which were caused to the distributions of soil moisture tension according to the different positions of water source and sinks were judged to be so much. On the other hand, in the analysis by applying conformal mapping method, the unsaturated permeability in the analysis region is given the average value as above-mentioned, so the problems would be left because the unsaturated permeability used in simulations is different from the actual phenomena.

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