根長密度モデルによる根系形態の解析(2)

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Analysis on Root System Morphology Using a Root Length Density Model

II. Examples of analysis on rice root systems*

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Abstract : The root system morphology of rice plants (cv.: Koshihikari) grown under control and shaded conditions was analyzed by the root length density model proposed in Part I. The root length densities were simulated under various combinations of the 'root length density constant' (k) and the 'rooting zone radius' (r_{max}) in the model, and the most suitable values of both parameters were selected so that the simulated root length densities should fit the actual densities. The values of k and r_{max} thus obtained and other observed data made it possible to calculate the indices relating to the root system morphology, i.e. 'model primary root length', 'coefficient of branching', 'hill primary root length', 'hill total root length', 'area primary root length', and 'area total root length', which are hardly accessible in field studies. The comparison of these parameters and indices between experimental plots suggested that the root system development was clearly poorer in the shaded plot as had been expected. The simulated root length densities were substantially closer to the actual densities. Although the model was based only on three simple assumptions, the results mentioned above well support its validity.
Key words : Model, Rice plant, Root length density, Root length density model, Root system, Simulation.

根長密度モデルによる根系形態の解析　第2報　水稲根系に関する一例：森田茂紀・菅　徹也・根本圭介（東京大学農学部）

要　旨：著者等が提案した根長密度モデルを用い，対照区と遮光区（幼穂形成期から出穂期に遮光処理）で生育させた水稲根系を解析し，モデルの有効性を検討した．根長密度モデルにおける条間距離，株間距離，"株半径" に，それぞれ対応する実測値を採用し，シミュレーションを行なった．その際，根長密度の実測値とモデル値とが最もよく一致するように，"根長密度定数"・"根域半径" を選定した．その結果，"根長密度定数"・"根域半径" の値は，いずれも対照区に比較して遮光区で小さかった．また，上記の "根長密度定数"・"根域半径" と，条間距離，株間距離，株の半径，1株当りの伸長1次根数の実測値から，根系形態に係わる種々の指標を算出した．算出した，"モデル1次根長"，"分枝係数"，"株1次根長"，"株全根長"，"面積1次根長"，"面積全根長" のいずれの値も，対照区に比較して遮光区で小さかった．以上の結果は，対照区に比較して遮光区で根系の発達が不良であることを示すものと考えられる．また，対照区および遮光区のいずれの場合も，根長密度の実測値とモデル値との適合度は悪くはなかった．ここで両者の値に「ズレ」が認められたのは，現実の根系を3つの単純な仮定（[1次根均等伸長]，[分枝均一]，[半球状根域]）によって近似しているためである．しかし，モデルを利用して選定したパラメーターや種々の根系形態の指標について対照区と遮光区の間に認められた差は，従来の推察を裏づけるものであった．これらのことはモデルの有効性を示すものと考えられる．
キーワード：根系，根長密度，根長密度モデル，シミュレーション，水稲，モデル

In our previous paper[7], we proposed a root length density model for analyzing fibrous root systems of gramineous crops, especially of rice. In order to ascertain the validity of the model and its assumptions, the root systems of rice plants grown under different conditions in paddy fields were analyzed using the model.

Materials and Methods

1. *Data for analysis*

Data for analysis were obtained from Mawaki et al[5] and Mawaki et al[6]. The origi-

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nal experiment was designed to analyze the root systems of rice cv. Koshihikari grown in paddy field. The plants were cultivated according to accepted practices (control plot) and were partially shaded 22% below normal radiation level using cheese cloth during the panicle initiation to heading stage (shaded plot).

2. *Simulation of the root length densities*

The root length densities of the control and the shaded plots were simulated by using the root length density model[7]. The necessary parameters for the simulation, such as distance between hills(a) and rows(b), 'hill radius' (r_0), total number of elongated primary roots per hill (N_r) and the root length densities were already given as actual values in Mawaki et al[5] and Mawaki et al[6]. Root length densities were simulated under various combinations of the 'root length density constant' (k) and the 'rooting zone radius' (r_{max}) in the model, and the most suitable values of both parameters were selected so that the simulated root length densities (ρ_{model}) should fit the actual densities (ρ_{actual}). Fitness of the root length densities between ρ_{model} and ρ_{actual} were evaluated by the methods of least squares[7].

3. *Determinations of the morphological indices of the root systems*

Based on the parameters given above, the following morphological indices defined in Part I [7] were calculated for both root systems. The indices were 'model primary root length' $[r_{max}-r_o]$, 'coefficient of branching' $[2\pi k/N_R]$, 'hill primary root length' $[N_R(r_{max}-r_o)]$, 'hill total root length' $[2\pi k(r_{max}-r_o)]$, 'area primary root length' $[N_R(r_{max}-r_o)/ab]$ and 'area total root length' $[2\pi k(r_{max}-r_o)/ab]$, respectively.

Results

1. *Determinations of parameters and morphological indices of the root systems*

Table 1 gives the root length density constant(k), the rooting zone radius (r_{max}) and all morphological indices of the root systems examined. All of them were smaller in the shaded plot than those in the control.

2. *The validity of the model*

The simulated root length densities (ρ_{model}) were compared with the actual ones (ρ_{actual}). In both of the control and shaded plots, no significant differences were found between ρ_{model} and ρ_{actual} (Fig. 1).

Discussion

1. *Assumptions of the root length density model*

In the previous paper[7], we proposed the root length density model for morphological studies on fibrous root systems of gramineous crops, especially of paddy rice plants. The model is based on the three simple assumptions: (1) uniform elongation of primary

Table 1. Parameters and indices in control and shaded plot.

Parameters and indices	Symbol	Unit	Control plot	Shaded plot
Distance between hills	a	cm	26.4*	26.4*
Distance between rows	b	cm	18.1*	18.1*
'Hill radius'	r_0	cm	1.80**	1.67**
Total number of elongated primary roots per hill	N_R		539**	498**
Actual root length density	ρ_{actual}	cm/cm^3	16.4*	12.7*
'Root length density constant'	k		1211	985
'Rooting zone radius'	r_{max}	cm	34	30
Model root length density	ρ_{model}	cm/cm^3	16.4	12.7
'Model primary root length'	$r_{max}-r_0$	cm	32	28
'Coefficient of branching'	$2\pi k/N_R$		14	12
'Hill primary root length'	$N_R(r_{max}-r_0)$	m/hill	170	140
'Hill total root length'	$2\pi k(r_{max}-r_0)$	m/hill	2400	1800
'Area primary root length'	$N_R(r_{max}-r_0)/ab$	km/10a	3600	3000
'Area total root length'	$2\pi k(r_{max}-r_0)/ab$	km/10a	1000	37000

* : Mawaki et al. (1987)[5], ** : Mawaki et al. (1987)[6].

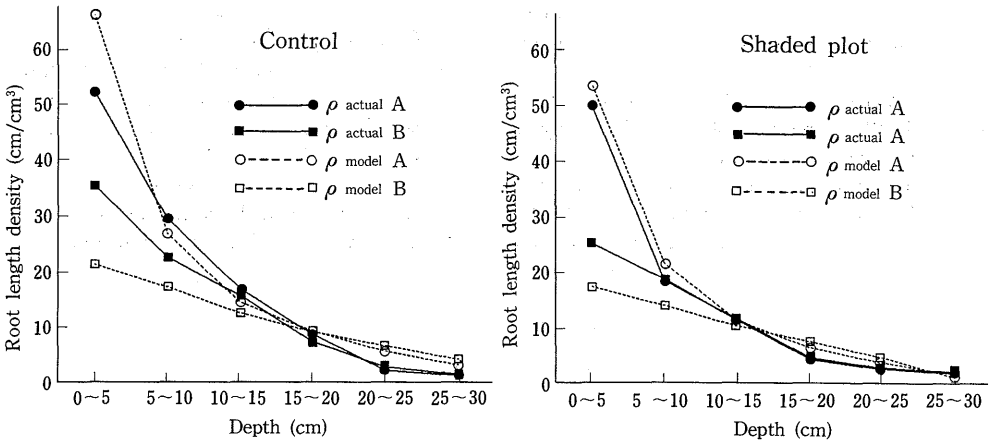

Fig. 1. Comparisons between ρ_{actual} and ρ_{model} in the control and shaded plots. $\rho_{actual}A$: Measured root length densities below hills, $\rho_{actual}B$: measured root length densities between hills and rows, $\rho_{model}A$: simulated root length densities below hills, $\rho_{model}B$: simulated root length densities between hills and rows.

roots, (2) homogeneous branching, and (3) hemispheric rooting zone.

Referring to the data obtained on actual situations[1,2,3,4] in rice plants, these assumptions seem to be plausible, though it is very difficult to verify their reality in detail from field and laboratory studies. However, as mentioned above, ρ_{model}s were substantially identified to ρ_{actual}s in both the control and the shaded plots. These results may to some extent support the validity of these assumptions.

2. *Indices of root system morphology*

From the parameters thus obtained, the following indices of root system morphology defined in Part I [7] were calculated: the 'model primary root length', 'coefficient of branching', 'hill primary root length', 'hill total root length', 'area primary root length' and the 'area total root length'. All these indices enabled us to visualize the 'extent' and 'concentration' of root system in the control and the shaded plots.

'Model primary root length' and 'coefficient of branching' (corresponding to root system extent and its concentration, respectively) were smaller in the shaded plots. This may indicate that average length of primary roots and root length densities were smaller in the shaded plot. The same trend was also found in all other indices. The total primary root length per hill or per unit area as well as the total root length (including length of all the branch roots) per hill or per unit area. In other words, the plants in shaded plot were supposed to have poorer root systems than those in the control. This consideration well agrees with the results and discussion derived from other methods of analysis by Mawaki et al.[5] and Mawaki et al.[6], on which the present study is based. Thus, the indices defined in Part I are very useful in evaluating the 'extent' and 'concentration' of root systems which are hardly accessible through direct measurements.

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