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Minirhizotron Observation of Pigeonpea Root System after Waterlogging

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Abstract: The root growth of pigeonpea plants [*Cajanus cajan* (L) Millsp.] was studied with a micro-video camera inserted into a glass tube embedded in the soil, and the effects of soil waterlogging were quantified. Daily changes in root length density (RLD) and the differences in root growth between waterlogged and control plants were calculated by adopting curve-fitting into the time-course data of RLD. Roots which suffered from waterlogging exhibited higher daily changes in RLD during the recovery process than unstressed roots. After waterlogging, an increase in RLD was first observed in the upper soil layers, and then in progressively deeper layers. This study demonstrates that root growth can be successfully studied by frequent observations of the same soil-plant interface through glass tubes. Furthermore, the effects of waterlogging can be adequately studied using this technique.

Key words: *Cajanus cajan* (L.), Minirhizotron, Root system, Waterlogging.

湛水後のキマメ根系のミニリゾトロンによる観察：伊藤　治・松永亮一・飛田　哲**・T. P. RAO***・Gayatri DEVI***・K.K. LEE***（国際農林水産業研究センター，**国際農林水産業研究センター沖縄支所，***ICRISAT）

要　旨：キマメ［*Cajanus cajan* (L.) Millsp.］の根の生長を土壌中に設置したガラス管に微小ビデオカメラを挿入することにより観察し，湛水の影響を定量的にとらえることを試みた．根長密度の日変化，湛水処理区と対照区との根の生長の差異を根長密度の経時変化データを曲線回帰することにより計算した．湛水処理を受けた根は回復過程においては対照区より高い日変化を示した．湛水処理後根長密度は最初土壌表層部でより増加し，徐々により深い部分でも増加した．本研究により，根の生長はミニリゾトロンによりガラス管を通して土壌-植物の接点を頻度高く観察することにより追跡することができ，この方法は湛水処理の影響を調査する上にでも有効であることがわかった．

キーワード：キマメ，根系，湛水，ミニリゾトロン．

The observation of root systems through a transparent tube installed in the soil was first proposed by Bates[1] who used a mirror to monitor roots intersecting the tube. The mirror was later replaced with a fiber-optic cable[21] or a borescope-type of video camera and recording systems[19]. These changes have facilitated field studies where large numbers of measurements need to be made.

There has been much debate on the reliability of root length density (RLD) data obtained by minirhizotron systems. Minirhizotron data have been compared with those obtained by core sampling[6,1318] and with rhizotron observations made through flat-sided viewing panels[7]. The minirhizotron method frequently underestimated RLD in the surface layers compared to conventional methods[15]. Another problem with the minirhizotron technique is the method of installation of observation tubes in the soil. Tubes can be installed by: digging trenches; digging holes with an auger with a slightly larger diameter than the tube; and putting an inflatable rubber tube into a hole and taking it out whenever the observation is conducted[5]. Each method has its advantages and disadvantages; no installation method is universally recognized to date.

Root growth rate and root system morphology in response to physiological stresses can be better studied by the minirhizotron technique than by other methods[3], as the minirhizotron permits non-destructive field observations.

In the semi-arid tropics, low-lying fields with uneven topography are often waterlogged for short periods after heavy rainfall. This is particularly the case for heavy clay soils such

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as Vertisols. Waterlogged plants exhibit chlorosis followed by defoliation as well as subtle changes in growth rate[11]. Waterlogging can even result in a considerable reduction in yield[2]. The root system is a primary site of waterlogging damage. The death and regeneration of roots, during and after waterlogging, should be studied for a better understanding of the physiological impact of waterlogging. In the present study, the minirhizotron technique was used to observe the effects of temporary waterlogging on root system development in a short-duration pigeonpea crop growing on a Vertisol.

Materials and Methods

1. Crop Cultivation

Short-duration pigeonpea [*Cajanus cajan* (L.) Millsp., cv. ICPL 87] was planted on 17 June 1991 in a Vertisol field at Hyderabad in peninsular India. Ten days before sowing, single superphosphate and urea were broadcasted at 20 kg P and 25 kg N ha^{-1}, respectively, and incorporated into the top 20 cm soil using a disc plough. Seeds were sown 15 cm apart in two rows spaced 60 cm apart, on either side of ridges. Fourteen days after sowing (DAS), plants were thinned to one plant per hill, giving a population of 2.2×10^5 plants ha^{-1}. A temporary waterlogging treatment was imposed 56 DAS by bunding each plot to retain standing water. Water levels were maintained around 5 cm above the tops of ridges for three days. The plot size was 9×10 m and the experiment was carried out with three replications. Two days after the termination of waterlogging (DAW), urea was top-dressed at 50 kg N ha^{-1} to both control and waterlogged plots.

2. Minirhizotron Technique

Glass tubes (58 mm in diameter and 100 cm in length) used for the minirhizotron observations were marked with white paint at 10 cm intervals to facilitate accurate location in the video image. A trench was dug in each plot and glass tubes were placed 10 cm away from a plant, perpendicular to the row direction and fitted at a 45° angle to the horizon. Observations were made with a minirhizotron camera (CIRCON MV 9011 agriculture system with MV 9390 color CCD microvideo camera) 4, 7, 11 and 22 DAW. The images of roots from the video camera were recorded on video cassette tape. The intersections of roots with grids placed on a TV minitor were counted and RLD was calculated on an area basis. Root intersections were counted at 20 randomly chosen locations within 10 cm of the tube. Thus the RLD calculated for a particular layer was a mean of 60 determinations per treatment.

Results

1. Simulation of Rooting Profile

The data obtained by minirhizotron technique were fitted with the equation, $Y=A\,[B/\{(2\pi)^{0.5}X\}\ \exp\ \{-(\log BX)^2\}]^C$ (X : depth in m, Y : RLD in mm cm^{-2} and A, B, C : constants), used by Phene et al.[14] to describe the profile distribution of the sweet corn root system. An example of the fitted data is presented in Fig. 1. The constants were obtained with a least square method and are shown in Table 1. The coefficients of determi-

Table 1. Constants and coefficients of determination obtained by simulation.

Treatment	DAW†	A‡	B‡	C‡	R^2§
Control	4	11.1	0.60	2.10	0.97
	7	18.5	0.58	2.70	0.96
	11	12.8	0.65	2.10	0.98
	22	18.8	0.65	2.70	0.99
Waterlogging	4	41.6	0.55	4.20	0.97
	7	35.3	0.50	3.55	0.96
	11	43.0	0.60	3.50	0.96
	22	48.8	0.65	3.75	0.92

† Days after the termination of waterlogging.
‡ Constants obtained from simulation with an equation of $Y=A[B/\{(2\pi)^{0.5}X\}\exp\{-(\log BX)^2\}]^C$, where X and Y are depth in m and root length density in mm cm^{-2}.
§ Coefficient of determination

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nation (R^2) between simulated and obtained values were greater than 0.9 in all cases.

The depth-wise profile of RLD obtained by curve fitting is pressented in Fig. 2. Distinctive differences in the shape of curves were found between control and waterlogged plants.

2. Root growth

The daily increment in RLD was calculated from the difference between the simulated data from two consecutive sampling points

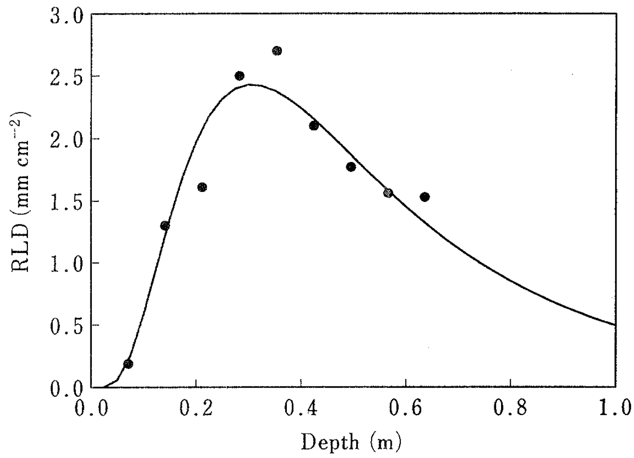

Fig. 1. Root length density (RLD) obtained by minirhizotron (closed circle) and by curve fitting (line) with an equation of $Y=A\ [B/\{2\pi\}^{0.5}X\}\ \exp\{-(\log BX)^2\}]^C$ where X and Y are depth (m) and root length density (mm cm^{-2}), and A, B and C are constants obtained by a least square method (see Table 1).

(Fig. 3). Both control and waterlogged plants gave a similar depth-wise profile of RLD. There was a considerable increase in RLD within the upper 40 cm from 4 to 7 DAW, but no significant increase below 40 cm depth. From 7 to 11 DAW, roots were lost from the upper 20 cm of soil, and new roots appeared in deeper layers. The development of the root system was negligible in both control and waterlogged plants from 11 to 21 DAW. The changes in the RLD profile were more pronounced in waterlogged plants than in the control.

3. Effect of waterlogging

The difference between treatments can be clearly seen when simulated values from waterlogged treatment are subtracted from those of control (Fig. 4). During the first week, the root mass in waterlogged plants decreased considerably below 20 cm compared with the control plants. Afterwards, greater root growth was observed in the upper 20 cm in waterlogged plants than in the control. As time progressed and plants recovered from waterlogging, root growth shifted to deeper layers. Finally, by 22 DAW there was no significant difference between waterlogged and control plants.

Discussion

The maximum RLD was obtained at 0.4 m

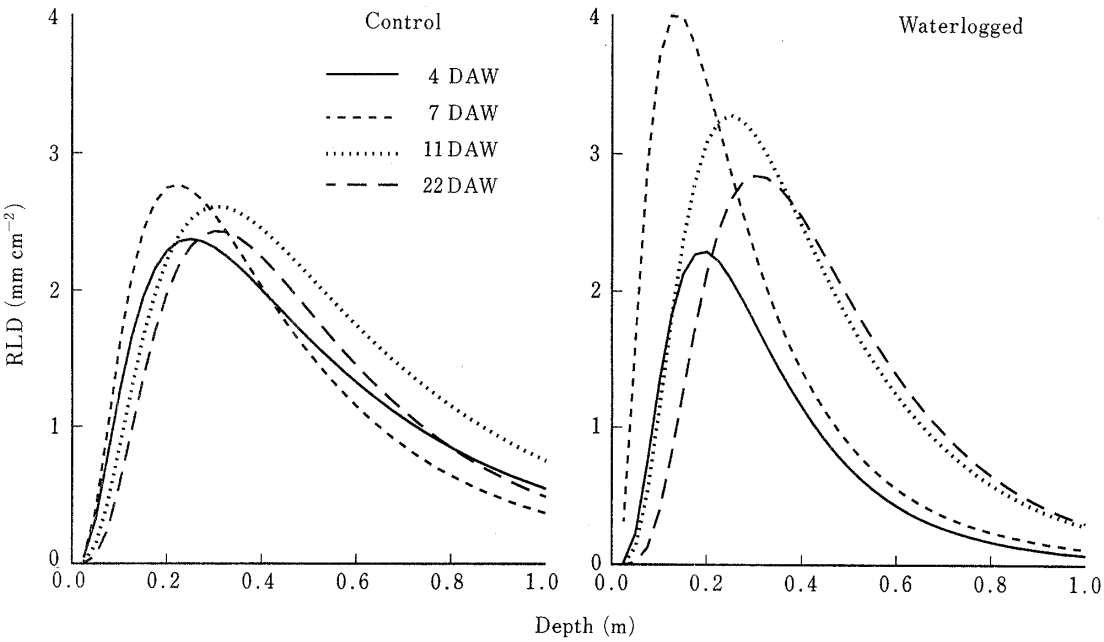

Fig. 2. Simulated root length density (RLD) of pigeonpea grown under control and waterlogged conditions at 4, 7, 11 and 21 days after the termination of waterlogging (DAW).

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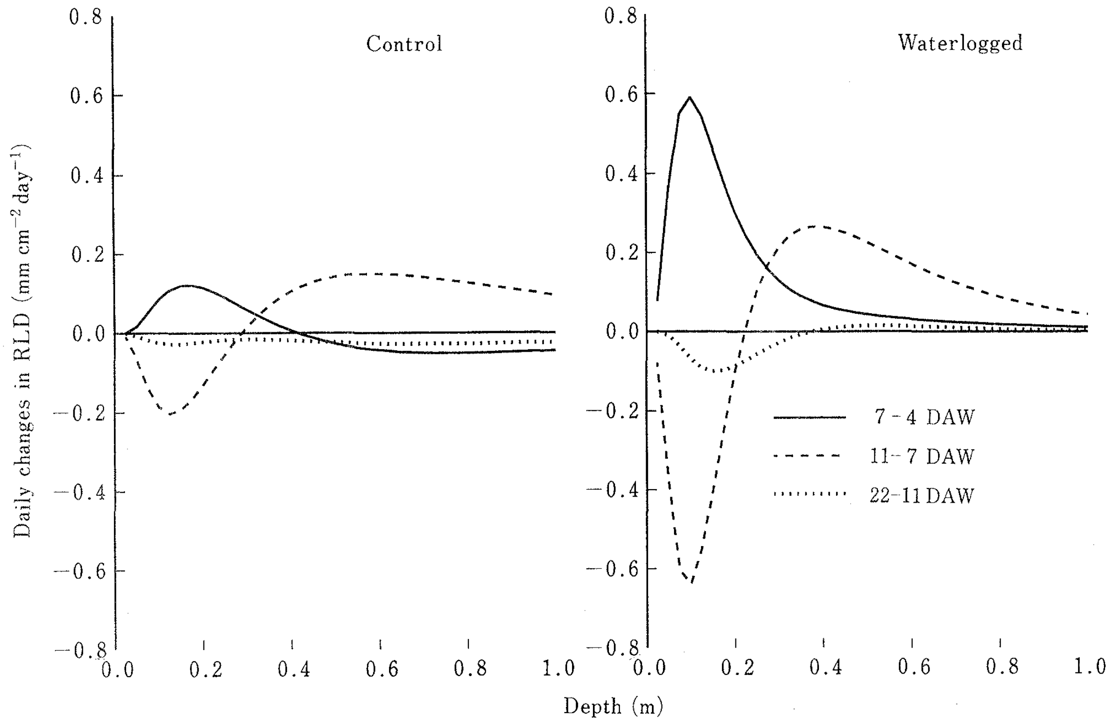

Fig. 3. Daily changes in root length density (RLD) for control and waterlogged plants calculated as the difference between simulated values at two consecutive sampling points.

depth (Fig. 1) as reported by Taylor et al.[15]. Similar changes in RLD with depth have also been reported by Upchurch and Ritchie[19], who used fifth degree polynomials to describe their data. In the present study, a RLD profile obtained by the minirhizotron method was successfully simulated using the equation of $Y=AB\ [\{B/(2\pi)^{0.5}X\}\ \exp\{-\log BX^2\}]^C$ (X: depth in m and Y: RLD in mm cm^{-2}). The R^2 between measured and simulated data was

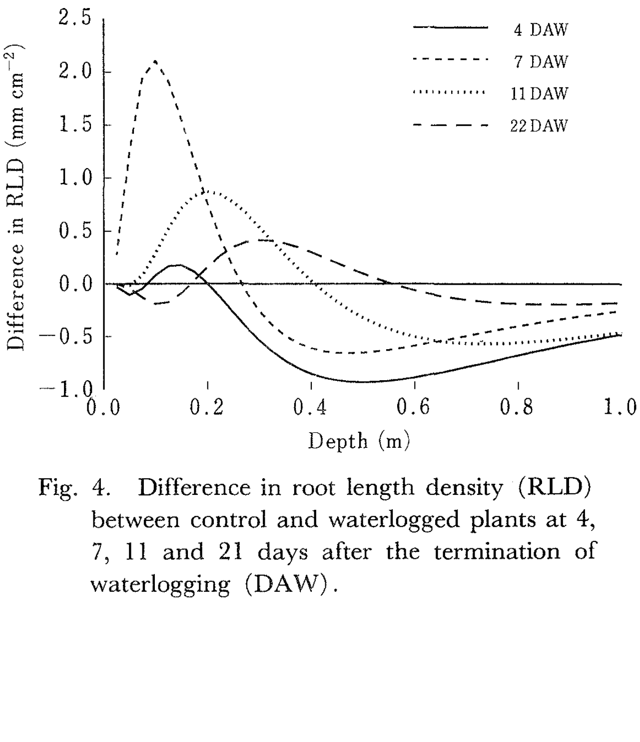

Fig. 4. Difference in root length density (RLD) between control and waterlogged plants at 4, 7, 11 and 21 days after the termination of waterlogging (DAW).

always higher than 0.90 (Table 1).

Root growth was greater in waterlogged plots (Figs. 2 & 3), suggesting that pigeonpea roots responded substantially to environmental changes in the rhizosphere as a result of waterlogging. Waterlogging reduced RLD in all soil layers with the exception of the upper 20 cm at 4 DAW (Fig. 4). Thereafter, plants damaged by waterlogging developed more roots in the upper 20 cm than observed in control plots. The recovery of roots at deeper layers occureed gradually. The increase in RLD in the shallow soil layer is attributable to the formation of new adventitious roots[8,9,10] due to either an adaptive response to excessive moisture conditions in many crop species[4,12,16,17] or an improved water regime after waterlogging.

The minirhizotron proved a useful tool for field studies on the effects of environmental stresses on root growth. These non-destructive observations reduce sampling variations caused by plant and soil factors, as the same plants and plots can be monitored throughout the growing season. Dynamic features of root development can only be quantified from data-sets with frequent observations and limited sampling errors. The minirhizotron pro-

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vides not only root length data but also information on root system morphology, such as root thickness and branching frequency. With those two types of data on the profile distribution of root length and morphological traits of roots, the effect of environmental stresses on root systems would be evaluated more properly, and the uptake of water and nutrients could be predicted more accurately.

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