Jpn. J. Crop Sci. 61(2) : 304—309 (1992)

# Root Spatial Distribution of Field-grown Maize and Millets

Tomomi NAKAMOTO, Akio MATSUZAKI and Kazuo SHIMODA
(*Experimental Farm, Faculty of Agriculture, the University of Tokyo, Midori-cho 1-1-1, Tanashi-shi, Tokyo 188, Japan*)
Received October 22, 1991

**Abstract** : The development of two-dimensional root distribution was studied with the generally-used profile wall method for field-grown cereal plants. Root length density was determined in each 5×5 cm area of a 1×1 m profile wall transverse to plant rows. Foxtail millet had a type of root system in which the root length density decreased exponentially with distance from row both vertically and horizontally. Barnyard millet had a shallow and broad rooting zone in which the root length density was high and considerably uniform. The other species fell in between these extremes. The order of foxtail millet, maize, common millet, pearl millet, adlay, barnyard millet, based on root distribution patterns, was in accordance with the decreasing order of sensitivity to waterlogging. The possible relationship of root spatial distribution to ecological habits was indicated.
**Key words** : Maize, Millet, Profile wall method, Root distribution, Root length density, Waterlogging.

**雑穀類における根系の空間分布の種間差** : 中元朋実・松崎昭夫・下田和雄（東京大学農学部附属農場）
**要　旨** : Profile wall method によって，圃場に栽培した 6 種（7 品種）の雑穀類の根系分布を経時的に調査した．うねに直角方向に設けた土壌断面（深さ 1 m, 幅 1 m）において 5 cm 平方のます目ごとに根長密度を測定し，根系の 2 次元分布を推定した．アワの根系では，鉛直方向にも水平方向にもうねから離れるにしたがい根長密度が指数関数的に減少した．これに対しヒエの根系には，浅い土壌層に根長密度が高くかつ一定した領域がみとめられた．その他の種の根系はこれらの中間的な形態を示し，根系の分布様式に着目して，アワ，トウモロコシ，キビ，トウジンビエ，ハトムギ，ヒエをこの順に並べることができた．この順序はこれら雑穀類の湛水に対する感受性の強弱とよく一致しており，根系分布と種の生態特性との関連が示唆された．
**キーワード** : 根系分布，根長密度，雑穀，湛水感受性，トウモロコシ．

Root spatial distribution is important because it influences on the uptake of water and nutrients[5]. Although the vertical distribution of roots is of great concern in agricultural practices and has been well studied[9], two- or three-dimensional distribution should be investigated to understand root ecology[10].

Tillage, irrigation and N fertilization can affect root distribution[1,3,13]. Root distribution is determined not only by these environmental factors but also by genetic factors. Some maize and foxtail millet cultivars differ in the depth and width of root system[11].

In Japan's Kanto plain, cereal crops are sometimes injured by a long rain in early summer. It has been generally known and partly supported by experiments[7] that cereal species differ in sensitivity to waterlogging. Sensitivity decreased in the order of foxtail millet, common millet, barnyard millet, which belong to the Tribe Paniceae. Pearl millet, also Paniceae, is considered to be as sensitive to waterlogging as common millet. In the Tribe Maydeae, adlay is less sensitive than maize. There is a possibility that the sensitivity (or tolerance) to waterlogging is related to the pattern of root distribution, which has hardly been studied.

The objectives of this investigation are to determine the specific development of root spatial distribution in cereal crops and to discuss its possible relationship to ecological habits.

## Materials and Methods

This experiment was conducted at the Experimental Farm of the University of Tokyo, Tokyo, in 1991. The soil used was volcanic ash of the Kanto loam type (Humic Andosol). Soil strengths measured by a penetrometer (25° 20′ cone, strength of spring 8 kg/40 mm) at depths of 10, 20, 30, 40, 60, 80 and 100 cm were 0.26, 0.34, 0.59, 0.58, 0.58, 0.71 and 0.90 MPa, respectively. Gravimetric water contents were 30-40% in topsoil (0-30 cm in depth) and 40-45% in subsoil (30-100 cm) and were confined within these ranges during the experiment. Chemical fertilizer (8 g N, 12 g $P_2O_5$,

NII-Electronic Library Service

10 g $K_2O$ per $m^2$) was applied on the soil surface before sowing. Precipitation, average temperatures at 10 cm and 50 cm in depth were 60 mm, 18.8°C, 15.9°C (May 1-May 31), 190 mm, 22.8°C, 19.3°C (June 1-June 30) and 94 mm, 24.5°C, 21.7°C (July 1-July 23).

On April 30 the seeds of foxtail millet (*Setaria italica* BEAUV. cv. Rikuu 8), common millet (*Panicum miliaceum* L. cv. Shinano 1), barnyard millet (*Echinochloa frumentacea* LINK cv. Touya), pearl millet (*Pennisetum typhoideum* RICH. strain MIH-1N), adlay (*Coix lacryma-jobi* L. var. *frumentacea* MAKINO cv. Okayama-zairai) and two maize cultivars (*Zea mays* L. cv. Nagano 1 and cv. DK 789) were planted in rows 1.8 m wide. After emergence, plants were hand-thinned to 8.3 plants $m^{-1}$ row (0.12 m interhill space). Weeds were completely removed.

The widely-used profile wall method[2,8] was employed to determine the two-dimensional distribution of roots. Six and 9 weeks after planting and at heading (11 weeks after planting for barnyard millet, pearl millet and maize, 12 weeks after planting for the other three species), two pits per cultivar were dug. Each profile wall was transverse to a row and right in the middle of two plants in the row (Fig. 1). The profile wall was smoothed with a trowel and scissors and a soil layer 5 mm thick (marked with pins) was removed from the working profile wall with the use of a water sprayer. There was no need for a scraper, which has often been used for hard soil layers[2], since the soil was soft and homogeneous. After the roots were exposed, a $1 \times 1$ m frame with 400 $5 \times 5$ cm grids was placed on the profile wall so that its top was positioned at the soil surface and its center below the row. The length of roots which were fresh and light in color was estimated by counting the number of 5 mm length units in each grid area. Since there was no reason to discriminate between the right and left halves of the $1 \times 1$ m working area, each 1 m (deep) $\times 0.5$ m (from below row towards interrow) area was treated as a replicate and four replicates were thereby obtained. Data were given as root length densities ($cm \cdot cm^{-3}$) and the two-dimensional distribution of roots was examined by drawing contour lines (Fig. 2) and complementarily, by calculating mean root length density in each 5 cm thick horizontal (Fig. 3) or vertical (Fig. 4) soil layer.

## Results

By 6 weeks after planting the species had differed in the shape of their root systems. While the root system of foxtail millet extended mainly in a vertical direction, that of pearl millet and of barnyard millet extended horizontally (Fig. 2). Two maize cultivars rapidly developed a deeper and wider root system than the others (Fig. 3, 4). The region of root length density $>0.1$ cm • $cm^{-3}$ reached at a depth of 30 cm extending the whole width studied (Fig. 2).

Between 9 weeks and 11/12 weeks after planting, specific features became increasingly clear. In foxtail millet the contour lines of root length density 10, 3, 1, 0.3 and 0.1 cm • $cm^{-3}$ formed concentric circles round a plant row and the contour lines were positioned at regular intervals (Fig. 2), namely root length density decreased exponentially with distance from row. Mean root length density decreased gradually both with depth (Fig. 3) and distance from row (Fig. 4).

The root distribution of maize was very similar to that of foxtail millet (Fig. 3, 4), except that the root system of maize developed well in a horizontal direction as shown by some horizontally orientated contour lines (Fig. 2).

Barnyard millet, on the other hand, had a large area of root length density $>3$ cm • $cm^{-3}$ although the root length density closest to the row base was not very high and did not exceed 10 cm • $cm^{-3}$ even at heading (Fig. 2). The horizontal contour lines of 1, 0.3 and 0.1 cm • $cm^{-3}$ were densely stacked. Eleven weeks after planting its roots were uniformly distributed in the 0-30 cm soil layer (Fig. 3, 4). In brief, barnyard millet showed superficial

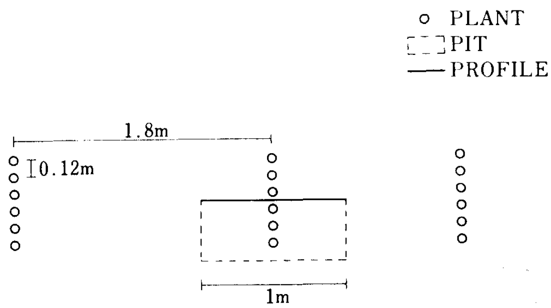


Fig. 1. Sampling scheme for the profile wall method.

NII-Electronic Library Service

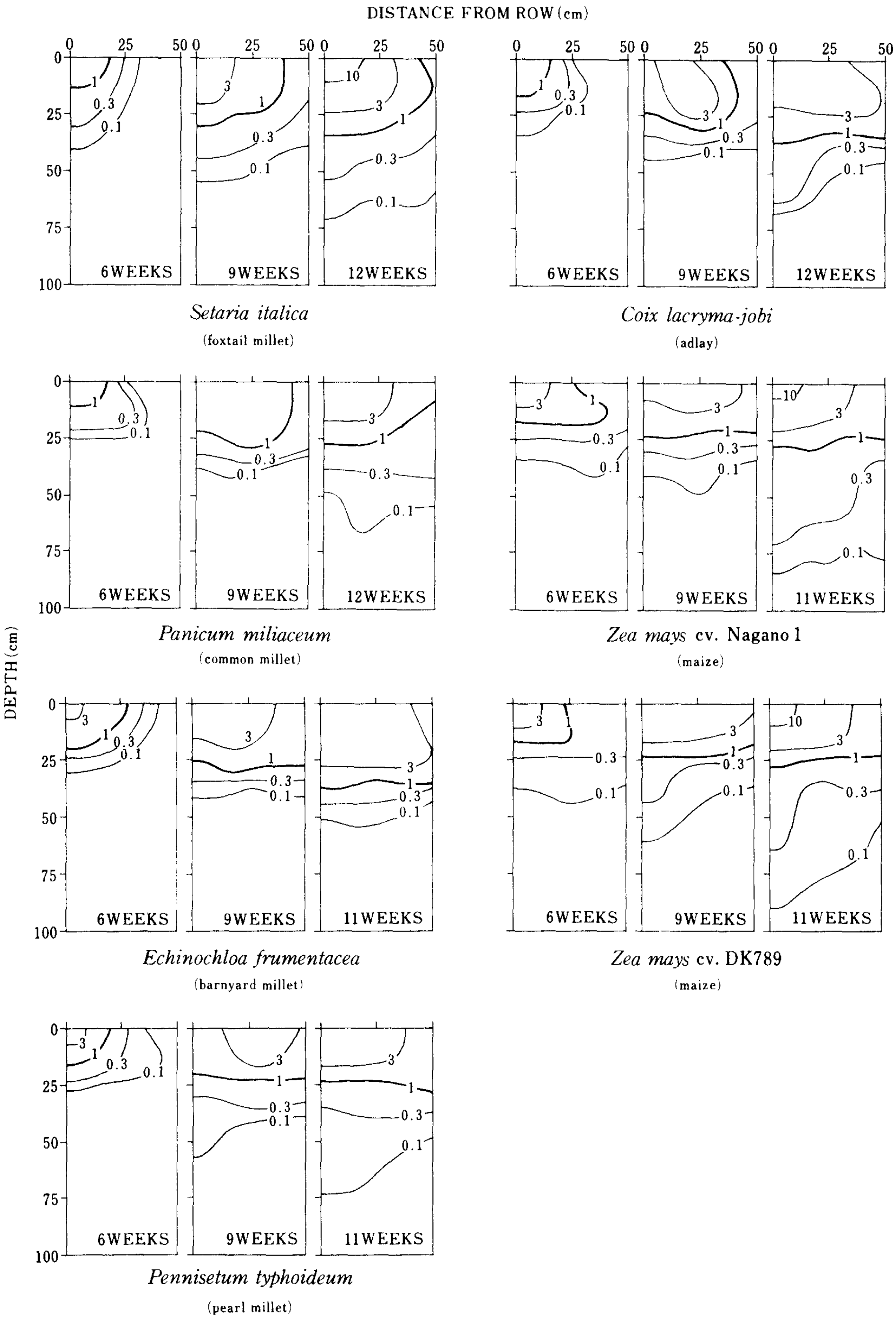


Fig. 2. Development of two-dimensional root distribution. Contour lines of root length densities of 10, 3, 1, 0.3 and 0.1 cm • cm$^{-3}$ are obtained by the profile wall method.

rooting.

The other three species were in between foxtail millet and barnyard millet (Fig. 2). Judging from both the vertical and horizontal distribution of roots in 11/12 weeks (Fig. 3, 4), adlay was more similar to barnyard millet and common millet to foxtail millet.

## Discussion

This field experiment was conducted under favorable soil conditions using conventional methods (except for planting density). Soil hardness, soil water and nutrient contents, although not uniform in a vertical direction,

NII-Electronic Library Service

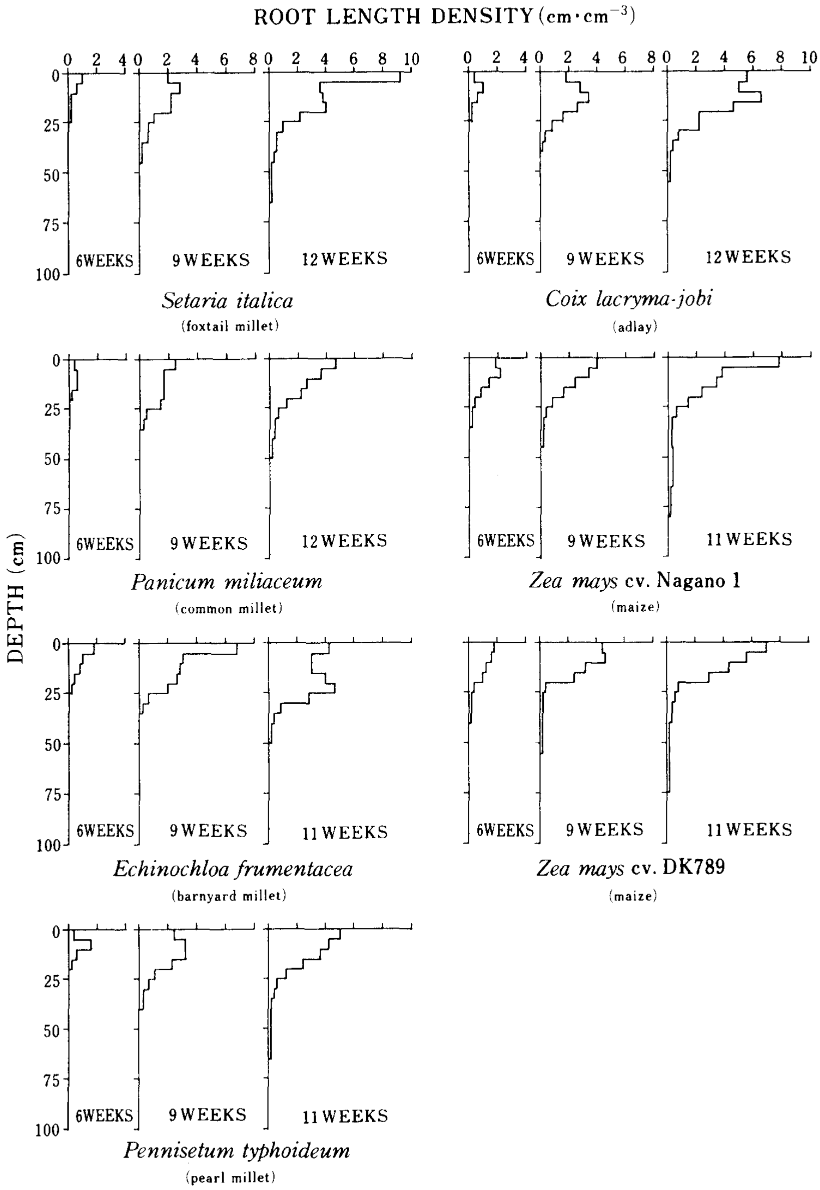


Fig. 3. Vertical distribution of roots. Mean root length density is calculated in each 5 cm thick soil layer.

were supposed to impose little restrictions on root growth. Root distribution observed in this study can thus be specific and genotypic.

Being based on a root distribution pattern, six species can be arranged into a series; foxtail millet, maize, common millet, pearl millet, adlay and barnyard millet. In the root systems of foxtail millet and maize, root length density gradually decreases with distance from row, both vertically and horizontally. Barnyard millet has a shallow and wide rooting zone, where root length density is considerably uniform. Foxtail millet and maize have higher root length densities than barnyard millet in deep soil layers (>50 cm in depth). The other species are ranked between these extremes. The series of species is in accordance with the decreasing sensitivity to waterlogging[7]. It is quite probable that the species, such as barnyard millet and adlay, are advantageous because their roots, distributed broadly beneath the soil surface, will have a fair chance to escape submergence or stresses caused by a lot of rain. Barnyard millet and adlay are known to have large air spaces in the cortex of nodal roots. Although having such nodal roots rich in aerenchyma may be morphologically more effective in tolerating waterlogging, barnyard millet's type of root distribution is more or less beneficial for plants grow-

NII-Electronic Library Service

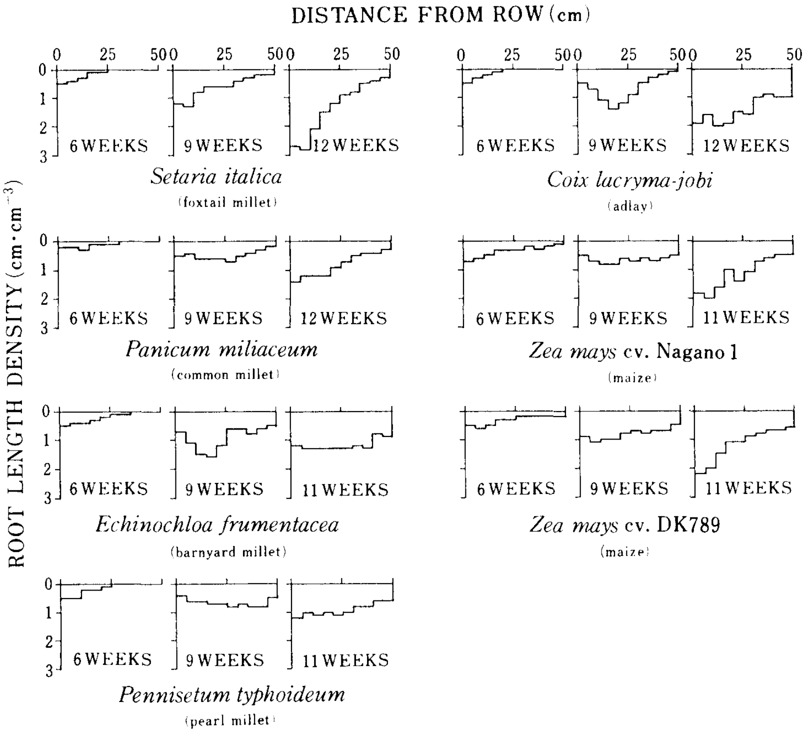


Fig. 4. Horizontal distribution of roots. Mean root length density is calculated in each 5 cm thick vertical soil layer to a depth of 100 cm.

ing in moist habitats. Rice, which develops many but short nodal roots[6], is supposed to have a similar root distribution. Meanwhile there is only partial knowledge about the sensitivity of the cereal species to drought in Japan. Foxtail millet and maize, which are more tolerant to drought than the other Paniceae and adlay, respectively, have a less partially distributed root system. This fact agrees with the general view that deep rooting is advantageous under dry soil conditions. The relationship between the interspecific difference of root distribution and of drought tolerance is a subject awaiting more study in cereal plants.

Specific root spatial distribution of cereal plants is determined by the morphological characteristics of nodal and seminal roots, such as length, elongation direction and branching intensity. We still know little about the specific root distribution and related parameters although great progress has recently been made by studies on the simulation model of three-dimensional root distribution[12] and on the trajectory of nodal roots[14]. These parameters are difficult and laborious to estimate under field conditions because (1) the nodal roots of cereal plants are heterogeneous. That is, the morphology of nodal roots varies according to the position of internodes from which they originated.[18] (2) The elongation direction[11,16] and branching intensity[17,18] change much along a nodal root axis even under little environmental constraints.

A disadvantage of the profile wall method is that obtained root length densities are often lower than those with monolith washing methods[15]. The factor that indicates the difference between the two methods is 2.06 in oat[8] and variable with time in sugar beet[4]. The main reason for the difference seems to be that some roots on the profile wall adhere to each other and are not distinguished. We have noticed, however, the profile wall method has its own advantage. Many roots of cereal plants, above all of foxtail millet, are measurable only *in situ* since they are too thin and easily broken to be separated from soil without any loss. Careful consideration must be taken if we intend to examine the interspecific difference of total root length because it is sometimes doubtful whether the root lengths of different species can be measured on the same base, no matter what the sampling method might be. The study in which the distribution pattern of roots is a main issue is saved from

NII-Electronic Library Service

this skepticism. It is rewarding to elaborate the profile wall method and to apply it extensively to root study.

## References


1. Anderson, E.L. 1988. Tillage and N fertilization effects on maize root growth and root : shoot ratio. Plant Soil 108 : 245—251.
2. Böhm, W. 1976. *In situ* estimation of root length at natural soil profiles. J. Agric. Sci. Camb. 87 : 365—368.
3. Chaudhary, M.R., R. Khera and C.J. Singh 1991. Tillage and irrigation effects on root growth, soil water depletion and yield of wheat following rice. J. Agric. Sci. Camb. 116 : 9—16.
4. Gäth, S. and H. Meuser 1989. Vergleich von Methoden zur Bestimmung der Wurzellängendichte bei Kulturpflanzen. J. Agron. Crop Sci. 163 : 124—128.
5. Jackson, L.E. and A.J. Bloom 1990. Root distribution in relation to soil nitrogen availability in field-grown tomatoes. Plant Soil 128 : 115—126.
6. Kawashima, C. 1986. Elongation of crown roots in rice plant in relation to the growth stage of the top. Jpn. J. Crop Sci. 55 : 408—419*.
7. Kono, Y., A. Yamauchi, N. Kawamura, J. Tatsumi, T. Nonoyama and N. Inagaki 1987. Interspecific differences of the capacities of waterlogging and drought tolerances among summer cereals. Jpn. J. Crop Sci. 56 : 115—129.
8. Köpke, U. 1983. Die Profilwandmethode-Eine universelle Feldmethode zur Bestimmung des Wurzelwachstum. Root ecology and its practical application. Int. Symp. Gumpenstein, 1982, Bundesanstalt Gumpenstein. 75—80.
9. Mengel, D.B. and S.A. Barber 1974. Development and distribution of the corn root system under field conditions. Agron. J. 66 : 341—344.
10. Nakamoto, T. 1989. Development of rooting zone in corn plant. Jpn. J. Crop Sci. 58 : 648—652.
11. ————, K. Shimoda and A. Matuzaki 1991. Elongation angle of nodal roots and its possible relation to spatial root distribution in maize and foxtail millet. Jpn. J. Crop Sci. 60 : 543—549.
12. Pagès, L., M.O. Jordan and D. Picard 1989. A simulation model of the three-dimensional architecture of the maize root system. Plant Soil 119 : 147—154.
13. Shaviv, A. and J. Hagin 1991. Interaction of root distribution of corn with fertilizer placement and frequency of irrigation in lysimeters. Fertili, Res. 28 : 49—54.
14. Tardieu, F. and S. Pellerin 1990. Trajectory of the nodal roots of maize in fields with low mechanical constraints. Plant Soil 124 : 39—45.
15. Vepraskas, M.J. and G.D. Hoyt 1988. Comparison of the trech-profile and core methods for evaluating root distributions in tillage studies. Agron. J. 80 : 166—172.
16. Yamazaki, K. and N. Kaeriyama 1982. The morphological characters and the growing directions of primary roots of corn plants. Jpn. J. Crop Sci. 51 : 584—590*.
17. ———— and ———— 1983. The diameter of primary roots and the lateral root formation in corn plants. Jpn. J. Crop Sci. 52 : 59—64*.
18. ———— and T. Nakamoto 1983. Primary root formation in growing shoots of several cereal crops. Jpn. J. Crop Sci. 52 : 342—348*.


* In Japanese with English summary.

NII-Electronic Library Service