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Root–soil contact of field-grown winter wheat[α]

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ABSTRACT

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Roots following existing macropores and voids normally have only partial root–soil contact. Roots penetrating the soil matrix (creating new macropores) initially have complete root–soil contact. Partial root–soil contact may decrease the roots effectivity in taking up water and nutrients. If all roots have complete root-soil contact, however, aeration may be problematic unless roots have a high air-filled porosity. For field-grown winter wheat, root-soil contact was quantified from horizontally oriented thin sections at three depths, 15, 25 and 45 cm, respectively. One day prior to sampling, surface-connected pores were stained by infiltrating a methylene blue solution. Roots were observed microscopically using polarized light, and their diameter, roundness (indicating orientation) and degree of soil contact were measured with a Quantimet 970 image analyzer.

No relation was found between root–soil contact and root diameter or roundness. At 45 cm depth root–soil contact was less. For two fields, differing in soil organic matter content and current crop management, a different frequency distribution of root–soil contact was found in the plough layer. The percentage of roots with 100% root–soil contact was 65 and 37, that with 0% root–soil contact 5 and 14, respectively. For roots with partial root–soil contact the average degree of contact was about 60% in both cases. Average root–soil contact for the plough layer of the two fields was 84 and 66%, respectively. Roots without direct contact with the soil were growing mostly in surface-connected (blue stained) macropores. There was no difference in blue staining of the macropores with roots with 1–49% root–soil contact and those of the whole sample. Roots with 50–99% root soil contact occurred mostly in relatively small, non-stained pores.

INTRODUCTION

Roots are interacting with soil structure in two ways: they may depend on pre-existing macropores and cracks (voids) to grow, and they may create new

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macropores by penetrating the soil matrix. After decay of the penetrating roots macroporosity can thus be increased. If roots penetrate the soil matrix they will initially have complete (100%) root–soil contact. If they follow pre-existing macropores or voids they will have no or partial contact with the soil, except when they completely fill a pre-existing macropore. Root–soil contact may change during the life of a root. Temporary root shrinkage during plant water stress or decay of epidermis and cortex leads to a decrease of root–soil contact. Secondary thickening of roots may increase root–soil contact.

The degree of root–soil contact is important for both aeration and uptake activities of the root. The chance that roots will obtain sufficient oxygen to survive periods of reduced soil aeration after heavy rainfall decreases with a higher degree of root–soil contact (De Willigen and Van Noordwijk, 1984, 1989). The ability to obtain water and nutrients from the soil matrix, however, increases with increasing root–soil contact (De Willigen and Van Noordwijk, 1987; Veen et al., 1992).

Root–soil contact may change with changing soil water status. Huck et al. (1970) described diurnal shrinkage–swelling cycles of roots under drought stress. Root shrinkage may lead to air gaps around the root and to increased resistance to water uptake (Faiz and Weatherley, 1982; Herkelrath et al., 1977). In these descriptions it is normally assumed that root–soil contact was complete in a wet soil and is reduced by root shrinkage. Actual measurements of the root–soil geometry are required to test these ideas. Thin-section preparation methods as described by Altemüller and Haag (1983) and Altemüller and Vorbach (1987) allow observation of root–soil geometry, including the role of root hairs. Samples are dehydrated by gradual acetone replacement, which is a time-consuming process.

Root–soil contact can also be quantified from thin-sections of the soil made by freeze-drying samples before impregnation of the soil with resin. Previous tests of this method on a pot experiment with maize at three soil porosities showed that roots do not shrink (at least not beyond the normal diurnal range) and that all root cross-sections are recognized (Van Noordwijk et al., 1992). In this pot experiment the average degree of root–soil contact was found to increase from 60 to 87% when soil porosity decreased from 60 to 44% (Kooistra et al., 1992). A study of root–soil contact for field-grown winter wheat was made as part of the Dutch Programme on Soil Ecology of Arable Farming Systems (Kooistra et al., 1989).

METHODS

Observations were made on June 7 1990 on two winter wheat fields at the Lovinkhoeve Experimental Farm in the Noordoostpolder (Marknesse, The Netherlands), with potato as the preceding crop. The soil is a calcareous silt loam with pH-KCL 7.5 and was reclaimed in 1942. At about 45 cm depth there is a sandy layer of several cm thickness, with many shells, which restricts root development. Below that zone root length density normally increases again. A series of samples of 80 mm × 150 mm × 20 mm was taken from a vertical profile wall and horizontally oriented samples were taken at 15, 25 and 45 cm depth (the latter in the middle of the sandy layer), from a single soil pit in two fields: (1) field 16A with a relatively high soil organic matter content (2.7% in the top 20 cm) due to previous management, and currently under "integrated" management, i.e. reduced N-fertilization, reduced pesticide use and shallower soil tillage (12–15 cm cultivator in stead of 20–25 cm ploughing), (2) field 12B with a relatively low soil organic matter content (2.1% in the top 20 cm) due to previous management, and currently under "conventional" management.

Further data on the fields and the experiment are given by Kooistra et al. (1989). One day before the samples were taken, a methylene blue dye solution was infiltrated in the soil to stain surface-connected macropores and voids.

Thin sections, of 25 μm thickness, were prepared after freeze- drying the samples as described by Van Noordwijk et al. (1992). Vertically oriented samples were used to measure macroporosity (>30 μm diameter). The horizontally oriented samples were scanned under a dissecting microscope, using crossed polarization filters below and above the sample to increase contrast between cell wall material and macropores. All roots were mapped on photographic enlargements (using the thin section as negative), and the root intensity (number of root intersections per cm^2) was measured. Quantitative analysis of roots and pore geometry was done with an image analyzer (Quantimet 970, Leica) at a magnification of ×213 (length of one pixel 1.36 μm), on 640 fields of view (0.94 mm^2 each) in the thin section. The primary root parameters measured were: number (N), area of cross-section (A), perimeter (P), largest (L) and smallest (S) Feret (caliper) diameter and percentage of root perimeter having direct root–soil contact. From the primary parameters a shape factor $[P^2/(4\pi A)]$ was derived indicating the "roundness" of the roots. For a transverse section of a cylindrical root roundness is close to 1.0; for an elliptical shape of a root intersecting the plane of observation at a smaller angle, higher values (at least up to 5.0) are found. In a population of circles and ellipses the roundness factor thus indicates the orientation of roots. Estimates of the angle of interception from $\arcsin(S/L)$ may, however, contain a serious bias (Van Noordwijk et al., 1992). Within the population of roots on a single thin-section, a regression analysis was performed to test whether or not root–soil contact is related to root diameter or roundness. Comparisons of proportions of roots in four root–soil contact classes (0, 1–49, 50–99, 100%) between thin sections were based on a chi-square test.

A series of auger samples (7 cm diameter; 12 per field) was taken on the same day as the soil samples for the thin sections. The auger samples were washed over a fine sieve (0.3 mm mesh), root length was determined with the line intersect method (Tennant, 1975) and diameter was measured on 20 randomly chosen roots per sample under a dissecting microscope.

RESULTS

Root length density and root diameter in the auger samples and root intensity on the thin sections are given in Table 1. The average root diameter on the thin sections was 0.178 mm; the average for the equivalent auger samples, weighted for root length per sample, was 0.203 mm. As the frequency distribution of root diameters on the thin section was skewed, a logarithmic transformation was used and the few roots of more than 2 mm diameter were discarded. Expressed this way, the average root diameter on the thin sections increased significantly with depth, from 0.161 to 0.208 and 0.242 mm for 15, 25 and 45 cm depth, respectively. No difference in root diameter between the two fields was found.

The average roundness of roots was 1.75. No effects of depth or field on roundness, a rough indication of root orientation, were found. Roundness and root diameter were not correlated either.

Figure 1 presents two of the thin sections showing the two main positions of roots in soil: growing in macropores along aggregate surfaces (A) and penetrating the soil matrix (B). The first group has a partial, the second a complete root–soil contact. Figure 2 shows details of root–soil contact, varying from 0 to 100%.

Figure 3 shows the frequency distribution of root–soil contact observed in

TABLE 1

Root diameter (Diam) and root length density (L_{rv}) observed in auger samples and root intensity (N) observed on horizontally oriented thin section samples for two fields, 12B and 16A

Depth, cm	Diam (mm)		L_{rv} (cm/cm^3)		N (cm^{-2})	
	12B	16A	12B	16A	12B	16A
0– 5	0.203	0.223	13.2	18.4		
5– 10	0.199	0.197	7.87	10.1		
10– 20	0.193	0.188	3.85	4.98	4.90	4.25
20– 30	0.206	0.227	2.94	3.22	2.85	1.86
30– 40	0.233	0.241	1.49	1.80		
40– 50	0.220	0.239	1.27	1.06	0.81	0.28
50– 60	0.213	0.221	1.44	1.37		
60– 70	0.191	0.217	1.20	1.74		
70– 80	0.187	0.219	0.84	1.47		
80– 90	0.196	0.227	0.28	0.95		
90–100	0.199	0.220	0.12	0.29		

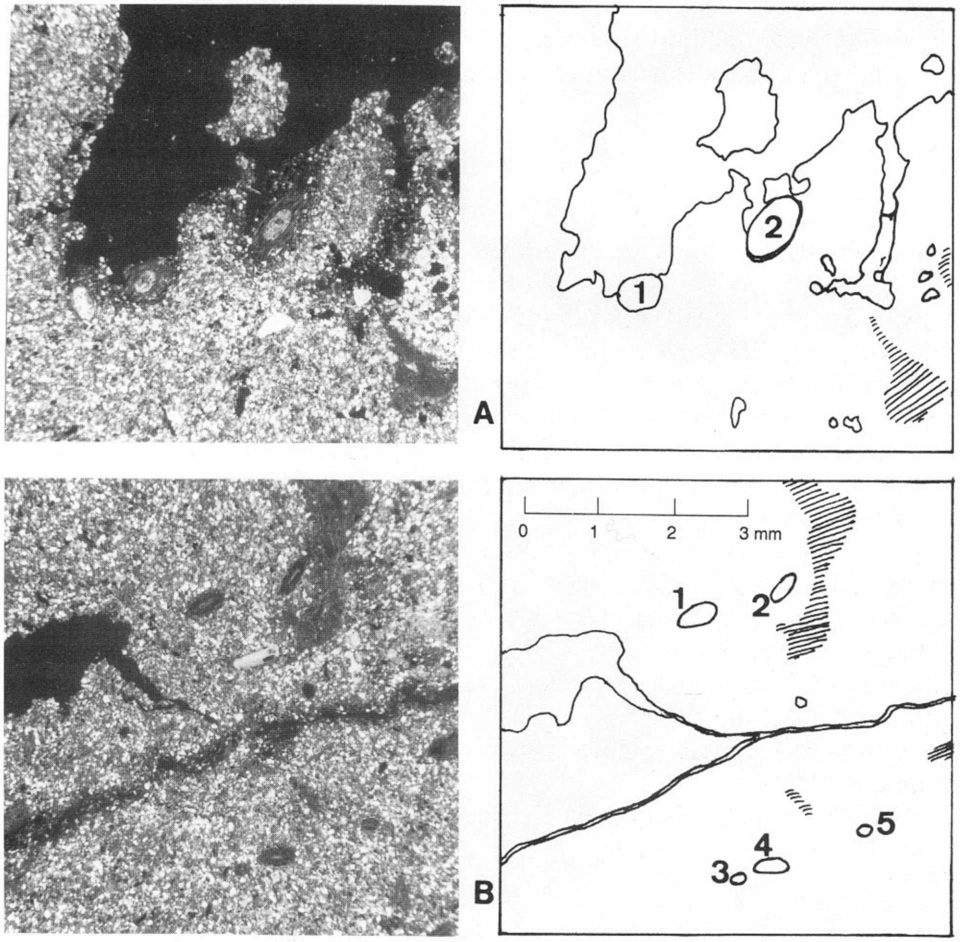

Fig. 1. Overview of two main positions of roots in soil. (A) Two roots growing in a void, along an aggregate wall, with partial root–soil contact. (B) Five roots penetrating the soil matrix, with 100% root–soil contact. Hatched areas on the sketches indicate organic matter accumulations; black areas on the photographs are voids (macropores and cracks).

six thin-section samples. Linear regression analysis showed that no relation existed between root–soil contact and root diameter (only 7% of variation accounted for) or roundness (no variation accounted for). A chi-square test of homogeneity of the frequency distributions indicated ($0.05<p<0.10$) a difference between the three depth layers, when results for the two fields were pooled. For a combination of the two samples in the plough layer, a chi-square test indicated a significant ($p<0.05$) difference between the two fields in frequency distribution of root–soil contact. In field 16A fewer roots with complete root–soil contact (forming their own channel) were found, and for the