ROOT DISTRIBUTIONS AND THEIR INTERACTIONS WITH THE SOIL

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ABSTRACT

We discuss recent studies on root systems and correct some common misconceptions about roots and root growth by examining some effects of soil physical characteristics on rooting patterns. Annual and long-term perennial crops share similar characteristics of root-length density distribution, and are discussed as one group.

Preferential root growth through pores, channels and cracks between soil peds or blocks is one reason why many crops have low occupancy ratios in subsoils. This can make definition, and measurement of a unitary rooting depth very difficult.

A positive correlation between mean root-length density and mean soil bulk density in the range 0.66 to 1.22 T.m-3, and a negative correlation with soil macroporosity, was obtained from a survey of kiwifruit root distribution in several locations. This probably reflects the greater concentrations of nutrients in the finer textured soils.

We emphasize the importance of studying the soil plant system as one entity. A lack of appropriate descriptions of soil properties taken together with root distribution studies makes it impossible to describe concise relationships between soil properties and root growth. Overall the study of root systems in relation to soils present some challenging research problems.

Additional Keywords: Root-length density, occupancy ratios, rooting depth, soil bulk density, macroporosity, maize, kiwifruit, drainage

INTRODUCTION

Crop roots are difficult to study (Russell, 1981). This is partly because data are often highly variable (Atkinson, 1980). This in turn makes it difficult to devise realistic models and methods of describing root distributions. Procedures of studying roots range from excavation, which directly shows the root system morphology in the field; to soil coring which provides sufficient data for root mass or root length calculations. This data can be presented in graphical or mathematical ways limited only by the imagination and skill of the experimenter.

The basis of this paper is a survey of nine kiwifruit orchards by Hughes et al. (1986), with subsequent descriptions of root-length per unit volume of soil by Gandar & Hughes (1988). This together with unpublished data on maize roots, provides for firstly a discussion on how roots occupy soils; and secondly, how to make observations about the influences of some soil properties on rooting patterns.

Describing root systems

The study of roots in the field is labour intensive and difficult primarily because of soil and root variability. In orchard or row crops, the three-dimensional distribution of roots originating from either an individual plant or from a row adds another facet. A parameter often recorded is rooting depth, which provides an estimate of the maximum potential soil volume from which water and nutrients can be removed.

Secondly, root-length density is often obtained. This is the total length of roots per unit volume of soil and provides an estimate of the degree to which roots have penetrated a particular soil horizon or horizons. Average root-length density is often used, albeit with little success, to calculate water uptake rates by plants (Reid 1985). Both rooting depths and root-length densities vary with species (Evans, 1976).

An additional parameter, the 'occupancy ratio', can be defined. This is the proportion of a potential rooting volume occupied by roots. Gandar & Hughes (1988) calculated occupancy ratio by dividing the number of randomly positioned soil samples containing roots by the total number of samples collected from a given soil volume. However, a problem arises here in that an 'occupancy ratio' is not an absolute value but depends on the volume of the samples on which it is based i.e., the likelihood of a randomly positioned core sample containing a root increases with sample size.

These methods of assessing the extent to which roots occupy soil give different, but often complementary information, and we illustrate this with soil coring data taken in 1988 from a long term field trial on a Tokomaru silt loam, where maize had been grown under three cultivation treatments for 10 years. Details of the trial have been given by Hughes (1985) and Ross & Hughes (1985). The maximum depth at which roots were found in samples was found to be about 1 m in all three treatments. However not all samples contained roots. A plot of the occupancy ratios for each cultivation treatment is shown in Fig. 1. Fig. 2 shows the same data plotted as mean root-length densities at various sampling depths. Although each treatment has an approximately similar rooting depth (defined as the depth at which mean root-length density reaches zero), maize roots in the tilled treatment apparently occupied

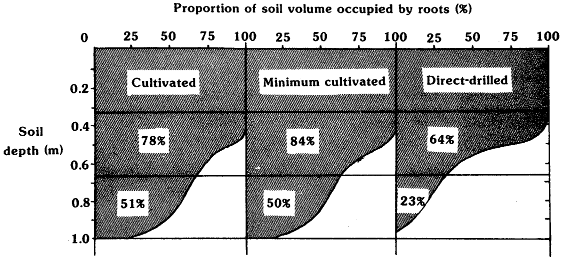

Figure 1: Proportions of soil volume in the top 1 m occupied by maize roots at silking, under three tillage treatments.

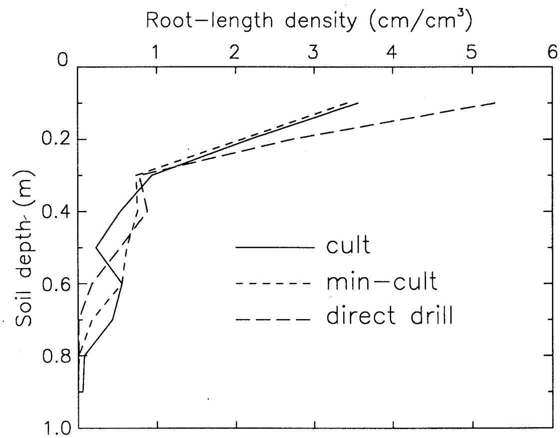

Figure 2: Mean root-length density of maize roots at silking under three tillage treatments.

about twice the volume of soil below 0.6 m than the roots of the direct-drilled treatment (Fig. 1). Actual rooting volumes for all three treatments are smaller than those indicated by measuring maximum rooting depth alone.

Several questions arise from these observations. Firstly, how do we now define a singular rooting depth, since much of the soil below 0.5 m is unoccupied? Secondly, how do we measure rooting depth since it will vary with sampling position? Thirdly, what has caused the large treatment differences in occupancy ratios below 0.5m, when bulk soil properties in that region are apparently unaffected by tillage (Ross & Hughes, 1985), and roots fully occupy the soil above 0.4 m?

The maize data, and those from kiwifruit discussed by Gandar & Hughes (1988), suggest that roots are usually not evenly-spaced throughout an explored soil volume, but are clumped, or concentrated into regions of high root-length density. This is partly because of the natural growth and exploration habit of roots. Superimposed on this are the effects of soil texture, layering, fertility, competition with other plants, management practices, climate and disease. These present some challenging opportunities for biologists to exercise their descriptive skills.

Soil properties influencing root growth

The ability of roots to penetrate a soil is limited by the size and rigidity of the smallest pores (Wiersum, 1957). Consequently soil bulk density, which provides an average measure of the pore volume relative to the total soil volume is often proposed as an index of ability of roots to penetrate a soil (Cornish *et al.*, 1984; Reid *et al.*, 1987; Thompson *et. al.*, 1987). We suggest that for many soils bulk density does not indicate how readily roots will penetrate a soil because of the large variability in the spatial distribution of voids within different soils. In many soils, voids are not evenly-distributed throughout the soil matrix. Furthermore, the size distribution of pores within soils of similar bulk density vary. A soil horizon with many small pores can have the same bulk density as one with few large pores.

Mean soil bulk density of a profile is sometimes used as a parameter to predict rooting characteristics. For example, maximum observed rooting depths in Canterbury pea crops have been shown to be negatively correlated with mean soil bulk density in the top 0.3-0.4 m (Reid *et al.*, 1987). In a short-lived annual crop such as peas, compaction in the top 0.4 m or so appeared to restrict depth of root penetration. However, in studies on reconstituted mine soils, Thompson et al., (1987) found it difficult to predict maize rooting depth or root-length density from soil properties in the top 0.5 m or so. The explanation given was that roots followed structural cracks rather than growing through the soil matrix. Thus rooting was somewhat unrelated to the bulk soil properties. A good relationship between both penetrometer resistance or soil bulk density, and rooting characteristics was obtained at greater depths where cracks were absent.

Other studies in New Zealand using indirect measurements have also observed the effects of soil voids on apparent root distribution. Scotter *et al.*, (1979) reported the difficulty they had in defining a clear rooting depth when using neutron probe moisture profiles to estimate available water-holding capacity in the Tokomaru silt loam (a loessial soil). They suggested that non-uniform water extraction by pasture grasses was caused by roots growing between large structural units. Soil within the interiors of units was considered to be unexplored. We have observed maize roots concentrated in similar inter-structural cracks below about 0.2 m depth. This partly explains the relatively low occupancy ratios below 0.5 m given in Fig. 1. Dye studies in alluvial and loessial soils of the Manawatu (Land and Soil Science Division, D.S.I.R. unpub. data) have shown that ponded surface-free water preferentially moves through the continuous structural cracks, worm holes and old root channels. Roots may also seek out these regions in which to grow, and aerial parts of plants may channel rain water into these macropores.

Root-length density

An opportunity to compare the mean root-length densities of kiwifruit with soil properties is provided by the survey of Hughes *et al.* (1986). Additional data have been obtained since then. We use kiwifruit here, in the absence of survey data from other field crops, as an example to test rooting characteristics in several soils. Root density

TABLE 1: Brief descriptions of soils, with mean profile macroporosity and bulk density to 1 m depth (more details available from authors).

Location*	Description	Macroporosity (%)	Bulk density ($t.m^{-3}$)
Northland	Strongly structured; friable clay loam over tightly packed friable silty clay containing scoria (from basaltic scoria and ash)	10.9	0.92
Wanganui	Strongly structured; friably silt loam over friable clay loam on firm clay (from loess)	7.6	1.21
Wanganui	Strongly structured; friable silt loam over friable clay loam on firm clay (from loess)	7.6	1.14
Horowhenua (3)	Moderately structured; friable silt loam over weakly structured firm silt loam (from loess)	10.3	1.20
Taranaki	Weakly structured; very friable silt loam on sandy loam on firm strutureless silt loam (from volcanic ash)	14.0	0.67
Te Puke (2)	Weakly structured; friable sandy loam on friable silt loan on friable structureless sandy loam (from volcanic ash)	13.8	0.93

*More than one orchard sampled on the soil indicated

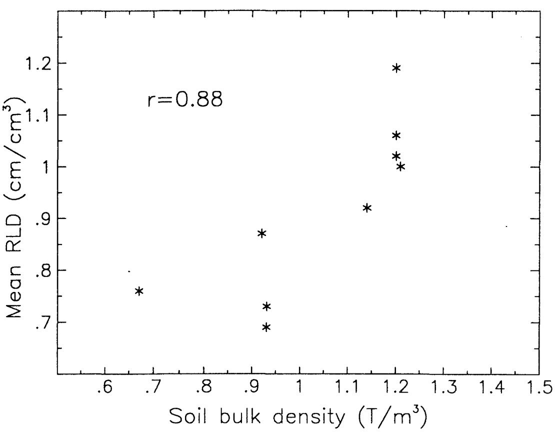

Figure 3: Mean kiwifruit root-length density in the top 1 m of soil as a function of soil bulk density.

distributions were measured for the soils listed in Table 1. We use data only from orchards older than 10 years to eliminate those in which roots had not yet evenly explored the area between vines. A plot (Fig. 3) of the mean root-length density versus the means of soil bulk density in the top 1 m shows a strong positive correlation (r = 0.88), and a strong negative correlation (r = −0.73) when plotted with percentage macroporosity (Fig. 4). There seems to be more roots in the clay and loessial soils which have the higher bulk densities and fewer macropores, and fewer roots in the less compact recent volcanic soils with lower bulk densities and higher macroporosities. These differences between the volcanic and loessial soils raise questions of parent material and texture effects on root growth.

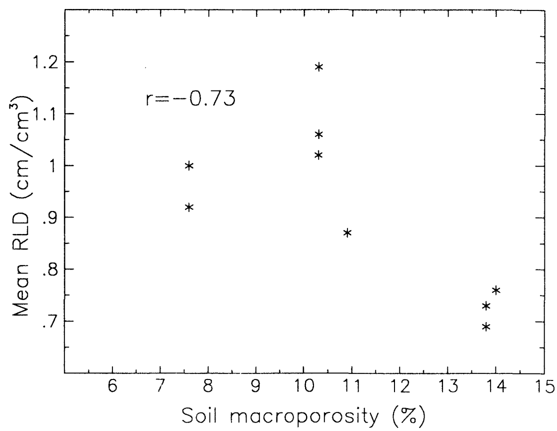

Figure 4: Mean kiwifruit root-length density in the top 1 m of soil as a function of soil macroporosity.

We suggest that higher root-length densities may have resulted from increased branching due to low soil macroporosities (e.g. 8% macroporosity for loessial soils near Wanganui) and lower root-length densities from reduced branching in soils with high macroporosities (e.g. 14% macroporosity for volcanic soils at Te Puke). Silty or clayey horizons appear to promote root branching as rootlets seek out smaller voids and cracks. In contrast, within sandy or coarse loamy horizons, nutrient levels are lower, roots may push directly through the soil matrix without branching. The result is a lesser net root-length density in the coarser soils, distributed throughout a larger rooting volume.

CONCLUSION

We have presented a brief review of how root-length density is distributed in the soil using maize and kiwifruit as examples. From this we outline reasons why important parameters such as a singular rooting depth are often very difficult to define and measure, despite there being practical uses for such a parameter.

In light textured volcanic soils of Te Puke and New Plymouth, plant roots are distributed over a larger volume of soil compared with heavier textured Wanganui and Horowhenua loessial soils. Our data show that, as a result, kiwifruit grown on the former have a lower root-length density compared to the latter, provided there are no drainage impediments. However, the complex relationships between soils and plant roots, and the logistical difficulties of root studies make it a challenging task to relate more precisely bulk soil properties to rooting characteristics.

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REFERENCES

Atkinson, D. 1980. The distribution and effectiveness of the roots of tree crops. *Horticultural Reviews 2:* 424-490.

Cornish, P.S., So, H.B., McWilliam, J.R. 1984. Effects of soil bulk density and water regimen on root growth and water uptake of ryegrass. *Australian Journal of Agricultural Research 35:* 631-644.

Evans, P.S. 1976. Root distribution and water-withdrawal patterns of some crop and pasture species. *Proceedings of plant water symposium 25-27 May 1976. Palmerston North, New Zealand:* p. 186-190.

Gandar, P.W., Hughes, K.A. 1988. Kiwifruit root systems I. Root-length densities. *New Zealand Journal Experimental Agriculture 16:* 35-46.

Hughes, K.A. 1985. Maize/oats forage rotation under 3 cultivation systems, 1978-83 1. Agronomy and yield. *N.Z. Journal of Agricultural Research 28:* 201-207.

Hughes, K.A., Gandar, P.W., Menalda, P.H., Snow, V.O. 1986. A survey of kiwifruit root systems. *Technical report No. 22, Plant Physiology Division, D.S.I.R., Palmerston North.*

Reid, J.B. 1985. Soil physical properties and water take by crop root systems. *New Zealand Agricultural Science 19:* 170-174.

Reid, J.B., Kraft, J.M. Scott, R.E. 1987. Subsoil conditions and maximum rooting depths of commercial pea crops grown in Canterbury, New Zealand. *New Zealand Journal of Agricultural Science 30:* 27-33.

Ross, C.W., Hughes, K.A. 1985,. Maize/oats forage rotation under 3 cultivation systems, 1978-83 2. Soil properties. *N.Z. Journal of Agricultural Research 28:* 209-219.

Russell, E.W. 1961. The development of plant roots in soil.In: *Soil Conditions and Plant Growth. Pub. Longman, Green & Co. Ltd, London. Chapter 24:* 447-449.

Scotter, D.R., Clothier, B.E., Corker, R.B. 1979. Soil water in a fragiaqualf. *Australian Journal of Soil Research 17:* 443-453.

Thompson P.J., Jansen, I.J.., Hooks, C.L. 1987. Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. *Soil Science Society of America Journal 51:* 1288-1293.

Wiersum, L.K. 1857. The relationship of the size and structural rigidity of pores to their penetration by roots. *Plant and Soil 9:* 75-85.