Spatial variation in the growth of lupin roots in the sandy surface of a duplex soil

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Summary. There is pronounced spatial variation in crop growth on duplex soils in Western Australia. In this study of early lupin root growth in areas of 'good' and 'poor' crop growth we showed there was severe restriction to root growth through the sandy surface 30 cm in 'poor' areas. There was no evidence to implicate waterlogging, disease or chemical factors. Rather, the restriction appears to be caused by mechanical impedance: although there was no hard pan, both soil bulk density and penetrometer resistance were high and root growth was markedly improved by even mild soil loosening. However, root growth was not restricted by high soil strength *per se* since the better root growth in the 'good' area was associated with similar apparent high soil strength. Soil in the 'good' area contained 10% clay but in the 'poor' area it contained only 3% clay and the low clay content in the 'poor' area may have led to high frictional resistance to movement of soil particles. With the high soil density this may have exacerbated mechanical impedance of root growth.

Introduction

Duplex soils with a sandy top soil overlying a clayey subsoil are widespread in Western Australia's cropping areas. Crop growth on the soils varies spatially at a scale of tens of metres and yields are lower than the potential estimated from growing season rainfall. To understand the reasons for this poor performance, crop growth was studied on a duplex soil site about 160 km east of Perth. In 1988 wheat growth on the site was surveyed and areas of distinctly poor or good growth identified as early as six weeks after sowing. The areas of 'poor' growth were usually also associated with inferior root growth. Here we report investigations into the cause(s) of the inferior root growth in following lupin crops using selected 'poor' and 'good' growth areas. Studies were made during the six weeks after sowing in both 1989 and 1990 using different areas each year. Results were similar in both years, so for brevity only data collected in 1990 are presented here.

Methods

The site is located 25 km east of Beverley and the soil is duplex (Dy) with sand (typically 210% clay, 4-7% silt and 85-95% sand) overlying sandy clay loam at a mean depth of 30 cm. Lupins *(Lupinus angustifolius* L. cv. Gungurru) were sown at 4 cm on 25 May 1990 after cultivating to 6 cm. Separate pairs of 'good' and 'poor' areas were studied in 1989 and 1990 and each pair and each member of the pair was separated by over 100 m. The site was split, having a 1:1 wheat:lupin rotation on either side but out of phase; thus lupins could be studied in consecutive years in areas where wheat had grown in the previous year. There was little evidence of root diseases and no detectable nematodes.

On each sampling occasion 10 to 30 root systems were randomly sampled from within the `poor' or 'good' areas by washing away the surrounding sand. Root depth was measured in situ and root length was measured either directly or, after branching started, using the line intersect method (4). Roots were bulked and dried before weighing. Error terms for root lengths are +/- 1 standard error.

Bulk density, and soil moisture were determined from three horizontal cores of 41.6 cm' at depth increments of 5 cm. Soil strength was determined across the range of water contents by regular use of a penetrometer (Rimik) with a cone having an included angle of 30 degrees and diameter of 12.83 mm. The perched water table was monitored using dip wells inserted to 50 cm in each corner of the sampling areas. Electrical conductivity and pH were measured using 1:5 soil:water extracts. Exchangeable Al was measured in 1:5 soil:5 mol/m^3KC1(2) and values are expressed +/- 1 standard error.

Results

Roots grew at about 8 mm/day down to 15 cm; thereafter there was little additional root extension in the 'poor' area while in the 'good' area extension continued, although the rate decreased to about 5 mm/day at the time roots reached the clay at about 30 cm (Fig. 1). Despite these pronounced differences in root penetration, at 38 days after sowing (DAS) there were negligible differences in length or dry weight of the roots; these were 184 +1-11 mm and 178 mg respectively in the 'poor' area and 210 +/-12 mm and 151 mg respectively in the 'good' area.

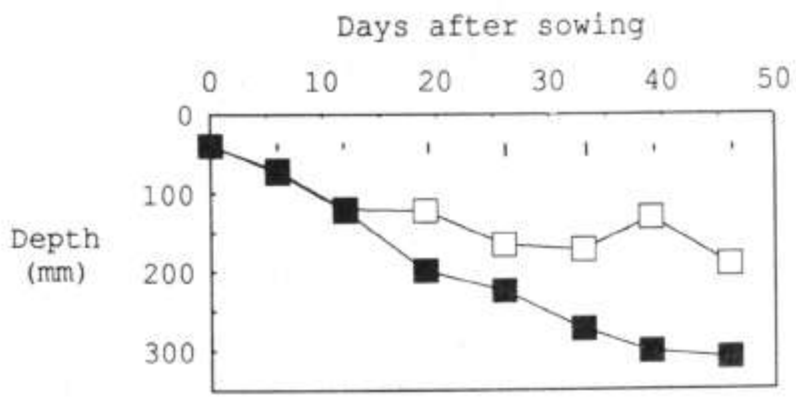

Figure 1. Depth of tap roots in the 'poor' (open symbols) and 'good' areas. Data are mean maximum depth of 10 to 20 tap roots and bars indicate one standard error of the difference between means.

When roots in the 'poor' area were about 15 cm deep their apical regions became swollen with an uneven surface and irregular bending (Fig. 2) and death of the terminal apices often followed; no such changes occurred in roots from the 'good' area (Fig. 2) until they neared the sand/clay interface. At 38 DAS lateral roots were emerging far closer to the apex in the 'poor' area (15 +/-2 mm) than in the 'good' area (117 +/-12 mm).

In 1989 plants were also grown in cores (15 cm diameter) in situ which had been pushed in as far as the clay on the day of sowing. In contrast to the above results, roots in cores in the 'poor' area grew at similar rates to the roots either inside or outside cores in the 'good' area. Comparison of penetrometer resistances showed that the soil profile had been loosened within the cores when pushing them in.

Electrical conductivity at 15-20 cm was only 3 mS/m, precluding salt toxicity as a problem. Also at this depth, the soil contained 3% clay in the 'poor' area but 10% clay in the 'good' area, pH was 6.1 in both areas, and Al concentrations were 7.2 +/-1.3 mmol/m^3 in the 'poor' area and 3.1 +/-0.1 mmol/ m^3 in the 'good' area.

Penetrometer resistance progressively increased with depth (Fig. 3) and at 15 cm there was little difference between the two areas. Likewise, bulk density increased to between 1.8 and 1.9 Mg/ m^3 at 13 cm and remained at these values down to the clay layer. The perched water table remained at least 30 cm below the surface during the study.

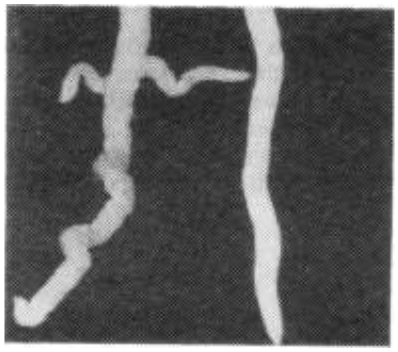

Figure 2. Root tips from the 'poor' (left) and 'good' (right) areas 23 days after sowing. Scale divisions represent 1 mm.

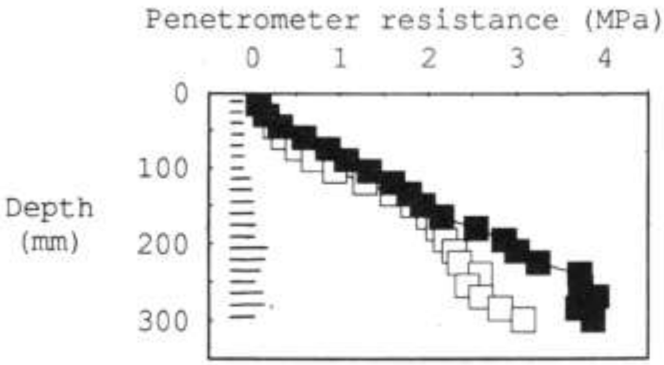

Figure 3. Penetrometer resistance in the 'poor' (open symbols) and 'good' (closed symbols) areas 26 days after sowing, when soil water was close to field capacity. Data are the mean of 10 measurements and bars indicate one standard error of the difference between means.

Discussion

Root extension through the top 30 cm of sand was much slower in the 'poor' area than in the `good' area. In the 'poor' area extension beyond 15 cm was negligible during the period of this study and was associated with marked swelling and contortion of the root tip, while extension only slowed slightly below 15 cm in the 'good' area. There are several possible explanations for this root behaviour:

- Poor soil aeration. Waterlogging can reduce root growth and thus crop growth on duplex soils (1). However, this does not explain variable root growth in this study since the perched water table remained below the sand/clay interface at 30 cm and in sandy soil the capillary fringe is not likely to be much greater than a few cm (3).
- Adverse chemical conditions. Concentrations of N, P, K, Na, Ca, Mg, S, CI, Cu, Fe, Mn, Mo, Zn, and B in plant tops from the two areas gave no indications of any nutritional differences which might have affected growth. However, adverse chemical conditions at 15 cm would not necessarily show up in nutrient concentrations in whole tops. As already discussed, nutrient disorders associated with oxygen deficiency and therefore low redox potentials are unlikely. Nutrient disorders associated with pH are also unlikely and it is difficult to evaluate the toxicity of Al which was higher in the 'poor' area than in the 'good' area; its activity and the concentrations necessary to reduce lupin root growth are not known.
- High mechanical resistance. At 15 cm both penetrometer resistance and bulk density were very high. However, the values were similar in both areas suggesting soil strength per se is unlikely to account for the differences in root growth. Nevertheless, mechanical impedance is the most plausible explanation for the poor root growth since the morphological symptoms in the roots are

typical of physical restriction and even mild loosening of the soil when pushing in cores markedly improved root growth in the 'poor' but not in the 'good' area.

The differences in root growth could be related to the resistance to soil particle movement caused by differences in the clay content. With the very high soil density it is possible that the soil matrix in the 'poor' area is very rigid because of interlocking of soil particles. However, the higher clay content in the 'good' area may sufficiently reduce the frictional resistance to particle movement that the soil matrix can be deformed by pressure from roots. Alternatively there could be differences in the pore size distribution, particularly involving macropores sufficiently large to accommodate the wide lupin tap root (1-2 mm diameter); the high soil density may make it imperative that roots be able to penetrate with little particle displacement. Differences in chemical bonding between particles is a further possibility, although in a preliminary study using thin sections of soil from the two areas there was no visible evidence to support this.

Acknowledgments

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