Model experiments on the behaviour of roots at the interface between a tilled seed-bed and a compacted sub-soil

I. Effects of seed-bed aggregate size and sub-soil strength on wheat roots

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Summary When elongating seminal roots of developing plants reach the base of a tilled seed-bed, they often encounter a layer of dense, strong untillled soil. At this interface, they may be deflected horizontally and instead of penetrating the sub-soil, they may form a horizontal mat of roots at the base of the seed-bed. If this occurs, the plants are unable to absorb the reserves of water in the sub-soil, and are very sensitive to short periods of drought.

Model experiments were done with artificial sub-soil layers having a range of strengths and with artificial seed-beds having sieved soil aggregates in the 4–7.7, 2–4 and 1–2 mm size ranges. Roots of wheat were grown through the aggregate beds and the proportions of roots which penetrated into the sub-soil were investigated as functions of sub-soil strength and diameter of the aggregates in the seed-bed. The proportion penetrating was found to decrease exponentially with sub-soil strength. The rate of decrease was similar for the 2–4 and 1–2 mm aggregates but was greater for the 4–6.7 mm aggregates. It is concluded that, provided that the roots of different plant species behave similarly, the base of the seed-bed should be composed of fine aggregates and that the penetrometer strength of the underlying untillled sub-soil should not exceed 0.4 MPa for plants with a single seminal axis or 3 MPa for plants such as wheat with 4 seminal axes.

Introduction

In many parts of the world, compaction by vehicles and by tillage implements has produced hard, dense layers or pans in the soil. In other parts, hardened or indurated layers have occurred naturally. These pans may prevent deep rooting of crops. This, in turn, can prevent crops from drawing upon reserves of water in the sub-soil, and this can result in yield reductions in some circumstances. In Australia, these pans are often not broken-up periodically by tillage for one or more of the following reasons: the shallowness of the top-soil, the presence of rocks or tree stumps just below the depth of tillage, the cost, or because the farmer does not know that a problem exists.

This paper, which is the first of a series of three, examines aspects
of the behaviour of roots which have grown down through a tilled seed bed and which encounter a compacted, stronger layer of untilled soil beneath. At the base of the tilled layer there is often a sharp discontinuity of soil structure and strength. This type of discontinuity is illustrated in Fig. 1 which shows penetrometer strength as a function of depth in the Urrbrae loam at the Waite Institute on 17 June 1981 when the soil water content was near to field capacity. The plot had been rotary cultivated to a depth of 10 cm 9 days earlier. When the roots of seedlings grow downwards through the tilled layer and meet the strength discontinuity, they may be unable to penetrate the stronger soil beneath. They are then deflected sideways and tend to grow horizontally along the top of the discontinuity. Mats of roots growing horizontally at the base of the tilled layer have been observed at several sites in Australia.

The greater the strength of the soil beneath the seed-bed, the less likely it is that roots can penetrate the sub-soil. Soil strength can arise in a number of ways: natural pedogenic processes; compaction by agricultural vehicles and implements; hard-setting on drying; and age-hardening or curing after mechanical disturbance.

There have been several studies of the behaviour of roots at structural interfaces or strength discontinuities in soil. Taylor and Gardner developed a technique of simulating the strong layer by waxes having well-defined and reproducible strength properties. They found that the proportions of roots penetrating decreased with increasing wax strength and with decreasing rigidity of the soil layer overlying the wax. The method was then used to demonstrate differences in the abilities of roots of 7 plant species to penetrate the strong wax layers. Experiments on the abilities of cotton roots to penetrate wax layers examined effects of the properties of the overlying soil. The proportion of roots penetrating the wax increased to a maximum as soil water matric water potential was decreased from −5 kPa to −52 kPa, and then decreased steadily to zero as the soil water matric potential was further decreased to −1.08 MPa. Decreased aeration also reduced penetration, but variations in bulk density of the overlying soil between 1000 and 1400 kg m−3 had no effect.

Greacen et al. examined the combined effects of the strength of the underlying compact layer and the angle of incidence of the root with the compact layer on the proportion of pea roots which penetrated the compact layer. It was found that the proportions of roots penetrating decreased with increasing strength of the compact layer and that there was a strong decrease in the proportions penetrating as the