

The effects of changed subsoil structure on yield and yield quality

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ABSTRACT

A new trial funded by GRDC was established in 1997 to examine ways of changing the soil structure of the subsoil with a view to increasing yield and yield quality. A special "tillage rotation" treatment was compared to no-till and conventional cultivation. The tillage rotation used deep tillage (up to 150 mm but varying from year to year) to shatter the compacted layer below the normal cultivation depth but allowed seed placement at normal depth in a one pass operation. In comparison with no-till and conventional cultivation, tillage rotation reduced penetration resistance, had more roots that penetrated more than 300 mm depth, recorded more water at 100-150 mm depth, took up more nutrients, and produced higher grain yield and dry matter. There was a significant rotational effect within TR with wheat-grain legume-canola-wheat and wheat-pasture-pasture-wheat produced higher dry matter compared with continuous wheat.

Key words

Tillage rotation, no-till, conventional cultivation, subsoil, water use efficiency, roots, nutrient uptake, yield.

INTRODUCTION

The structure of the cultivated soil layer in cropping systems undergoes frequent changes due to compaction during tillage and harvesting. The soil water content at the time of field operations and the characteristics of the machinery (load, tyre type) influence the extent of structural changes and their consequences for the crop. Soil compaction is defined as an increase in soil bulk density (BD) under the influence of external loads implying a loss of soil volume. The soil BD in itself is not sufficient to assess, for example, conditions for crop growth. However, changes in pore size distribution and soil strength due to soil compaction affect many properties and processes in the soil, including unsaturated hydraulic conductivity, air content and transport of gases, root growth and function, nutrient transport and uptake, conditions for soil organisms, mineralisation of nitrogen, soil workability and, ultimately, crop yield and the environment. (5, 6, 7). Different methods to alleviate the effects of compaction can be found in the contributions by many researchers reporting in *Advances in GeoEcology* 32, a Subsoil Compaction book. For example, Castrignano *et al.* (2) evaluated the effects of tillage depth, residue management and water content on soil penetration resistance. They found significantly higher penetration resistance at 250-520 mm depth when the soil was ploughed to 200-250 mm compared to ploughing to 400-450 mm. However, the authors question whether the deep ploughing was economically feasible. Australian soils are shallow and tillage is mainly in the 0-60mm soil layer. Therefore, the compacted layer will be shallower than in European soils where tillage is deeper. Hence, amelioration of compacted soil in Australia may be easier than in Europe.

Long-term tillage, applied yearly at the same depth, has resulted in the formation of a compacted layer in the subsoil (4). Studies comparing one-time measurements on the effect of tillage on soil properties may obtain contradictory results because the effects of tillage are time-dependent (8), and the response of different soils to a certain mechanical disturbance can be different. A 5 year field experiment was designed to study the effects of tillage regimes (one with fluctuation of depth of cut during seeding) and cropping rotation systems on soil structure in the mid-north of South Australia.

MATERIALS AND METHODS

Site and soil

The subsoil trial site is located at Halbury, South Australia at Latitude 34° 06'S and Longitude 138° 31'E, on a fine, mixed thermic red-brown earth (Calcic Haploxeralf). The long-term average annual winter dominant rainfall is 450 mm. The sand-silt-clay values in the 0-200 mm depth are given in Figure 1a. There is a compacted layer at 80-150 mm depth.

Trial design and treatments

Crop rotations are the main blocks with tillage as split plots and grazing as split-split-plots. There are three rotations (replicated 4 times): (i) continuous cereal (WWWW), (ii) continuous cropping with wheat, pulses and canola (WGICaW), and (iii) two years of pasture followed by a continuous cropping phase (WPPWGI). In 1997 all plots were sown to wheat, to initiate the trial. Each rotation has three tillage regimes: (i) Conventional cultivation, CC (full soil disturbance at least twice before sowing with 175 mm points and 50 mm depth of cut), (ii) No-till, NT (sowing into uncultivated soil with 15 mm points and 70 mm depth of cut), and (iii) Tillage rotation, TR. So far TR plots have been sown with "super seeder" points (Primary Sales, Australia) – 8 mm leading edge, 50 mm wing width and 40 mm wing depth and depth of cut 120 mm, 150 mm, 120 mm and 150 mm in 1997, 1998, 1999 and 2000 respectively. To penetrate to 150 mm depth in 1998, the plots were cultivated once with wide shares to 50 mm to reduce draft force. In 2000, the 150 mm depth of cut was possible without prior cultivation as the soil strength had been reduced. All treatments received 80 kg/ha of N and 12 kg/ha of P each year.

Procedures and measurements

Bulk density (BD), penetration resistance, infiltration rate and root numbers were determined by the methods described by Malinda *et al.* (5). Porosity was calculated using the equation $\varepsilon = (\rho_s - \rho_b)/\rho_s$ where ρ_b is the measured BD and ρ_s is the density of soil particles taken as 2.6 Mg m^{-3} . Water content was measured using a CS615 Water Content Reflectometer (Campbell Scientific Inc.). Performance of the crops was monitored by measuring plant establishment, tiller density, dry matter production, nutrient uptake at the end of tillering, water uptake, grain yield and grain protein.

RESULTS

Soil profile physical differences

After ten years of continuous cropping with conventional cultivation by the farmer, the soil penetration resistance, even at a water content in the mid non limiting water range (NLWR), increased with depth to more than 5MPa (Figure 1b). After two years of tillage treatment, TR decreased BD in the original compacted layer (5), and increased porosity (Figure 2a). Penetration measurements done in the fourth year of experimentation (Figure 2b) show that, at a moisture content of 18%, penetration resistance at about 80 mm for NT and CC increased to unacceptable levels of >2.5MPa, but for TR it remained lower than the limit that restricts root growth down to 150 mm.

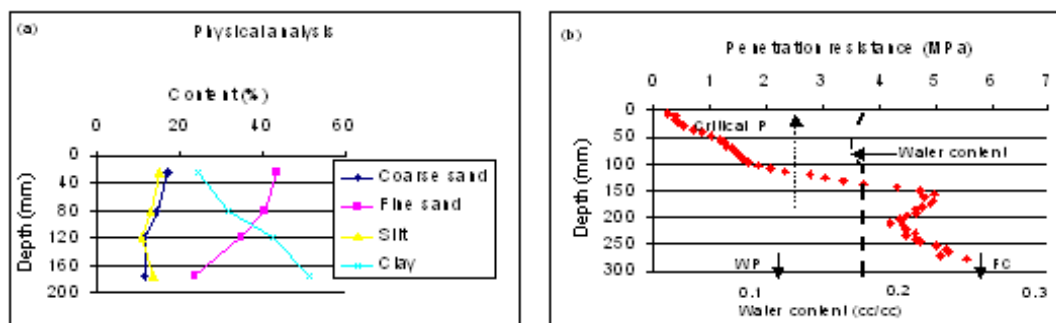


Figure 1. Soil physical composition at the Halbury subsoil trial site (a) and the effect of the previous farming system on penetration resistance (b). Critical P is the penetration resistance above which root penetration is restricted.

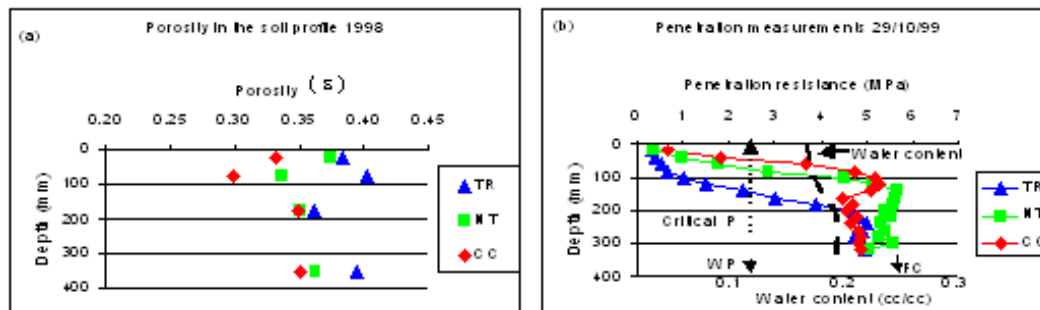


Figure 2. The effect of tillage regime on soil porosity in the second year of experimentation (a) and penetration resistance in the fourth year of experimentation (b).

Measurement of soil water showed that there was more water at 100 mm soon after every rainfall event (Figure 3a). This water was depleted quicker with TR compared with NT and CC (Figure 3b).

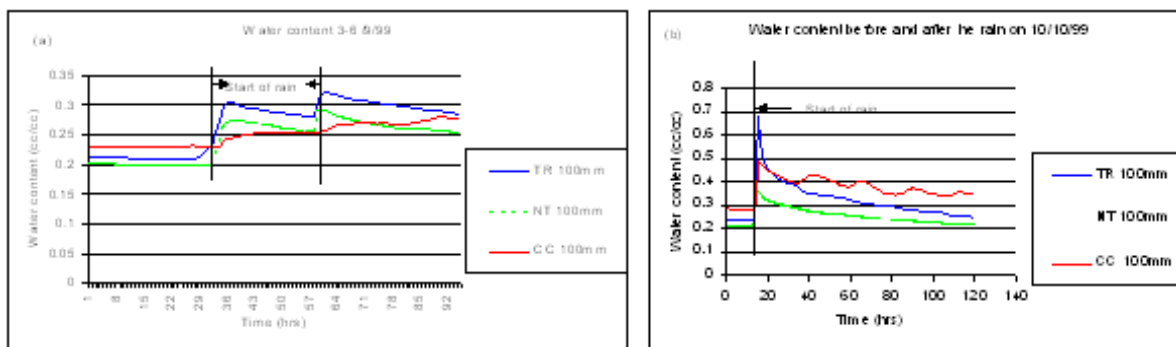


Figure 3. The effect of tillage regime on soil water content (a), and soil water depletion (b).

Measured agronomic differences

TR had significantly higher grain yield and grain protein in 1997 and 1999 (Figure 4a, b). In 2000, when all rotations were in wheat, TR again produced higher dry matter compared with NT and CC (Figure 4c). There was a significant rotational effect within TR, in that WGICaW and WPPW produced higher dry matter compared with WWWW. Also TR produced higher pasture dry matter (Figure 4d).

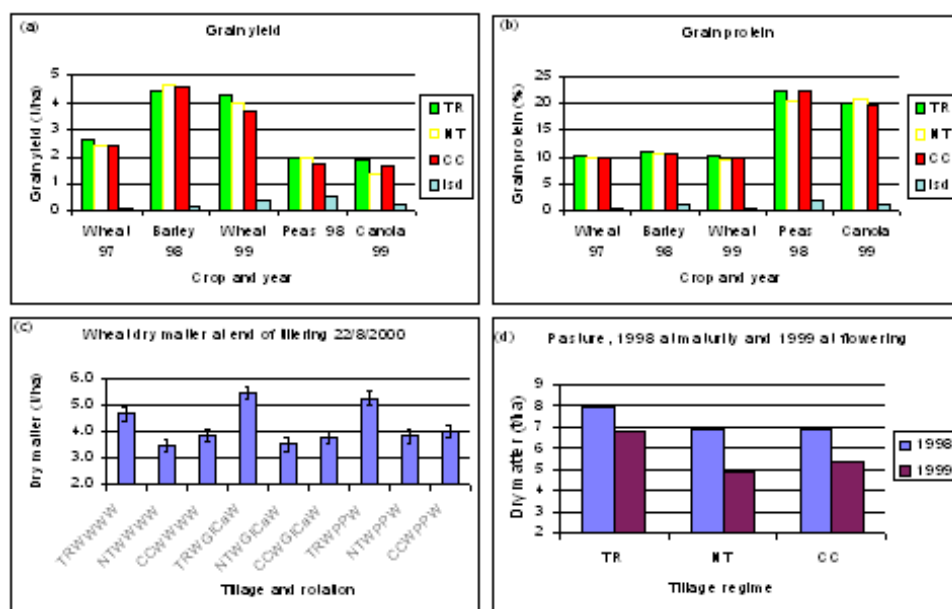


Figure 4. Effect of tillage regime on grain yield (a), grain protein (b), tillage and crop rotation on wheat dry matter (c) and pasture dry matter (d).

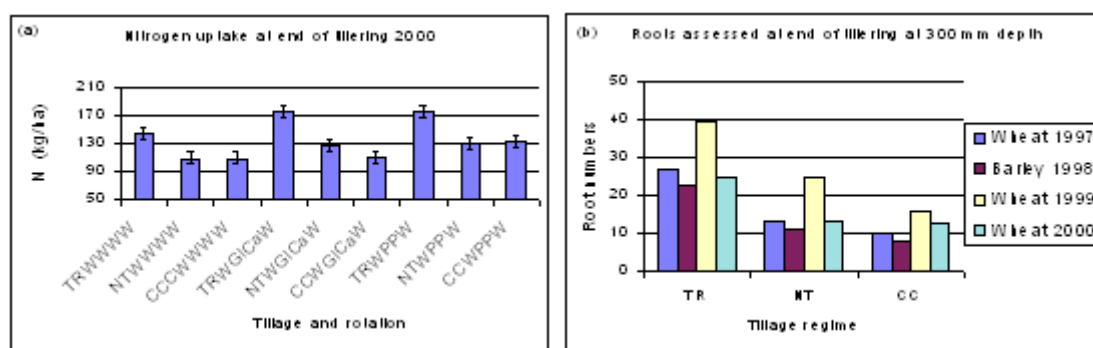


Figure 5. The effect of tillage regime and crop rotation on the uptake of N (a) and on root numbers (b).

Shoot N was higher in TR than NT and CC. In the first 3 years, N content for TR in continuous cereal was nearly twice the 80 kg/ha N applied at seeding and for CC was less than that applied at seeding. In 2000, shoot N content in TR in the continuous cereal rotation was similar to the previous years and in the other two rotations it was even higher at 175 kg/ha (Figure 5a). The increased uptake with TR indicates that the bigger rooting system (Figure 5b) was effective in taking up more N from deeper depths. Other macro and micro nutrients followed similar trends.

DISCUSSION

At the Halbury subsoil research site, compaction was found at 80-150 mm depth. This depth contains the right particle size distribution to result in maximum BD when the soil is under stress. It is most likely that the compaction was caused by machinery working annually at a constant depth of 50-60 mm and at wetter than optimum moisture content. The potential to improve soil structure by the action of earthworms has been reported by many scientists (3). However, biological amelioration of degraded soil takes a long time. In an experiment run for 18 years, Malinda *et al.* (4) found that, although many parameters were

improved by a conservation farming system, penetration resistance changed little and remained higher than that which limits root growth. In the current work, we were able to improve the soil structure (BD, penetration resistance and porosity) within 3 years by varying the depth of cut during direct seeding at the optimum moisture content. The improvement is most likely to make further biological improvement of physical and chemical properties more efficient and speedier. One observed disadvantage with TR cultivation was an increase in rut depth as a result of recompacting the loosened soil when spraying was done at high soil moisture content. But as we repeat this cultivation every year, changing the depth of cut, the recompacted soil is loosened again. The results of this study also stress the importance of proper management after soil loosening.

The decrease in penetration resistance and BD and the increase in porosity within the formerly compacted layer increased roots at greater depths. The greater root numbers in TR were responsible for extracting more water and nutrients from deeper depths than in NT and CC. This resulted in production of higher grain yield, dry matter, and protein. Voorhees (7) and Alakukku (1) report long-term effects of compaction on yield, confirming previous reports that subsoil compaction is very persistent. Alakukku also demonstrated that compaction caused a big reduction in nitrogen uptake and in crop yield. Our results confirm this finding and suggest that the effect is related to the depth and proliferation of the root system. These findings demonstrate the fact that subsoil compaction makes cropping less efficient.

A preliminary economic appraisal indicates that the TR system is more profitable for farmers than CC.

ACKNOWLEDGMENT

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REFERENCES

1. Alakukku, L. (2000). Response of annual crops to subsoil compaction in a field experiment on clay soil lasting 17 years. *Advances in GeoEcology*, **32**, 205-8.
2. Castrignano, A., Maiorana, M., and Fornaro, F. (2000). Evaluation of mechanical impedance of a silt clay soil in two soil tillage systems in Southern Italy. *Advances in GeoEcology*, **32** 242-50.
3. Larink, O. and St Schrader (2000). Rehabilitation of compacted soil by earthworms. *Advances in GeoEcology*, **32** 284-94.
4. Malinda, D.K., Schultz, J.E., and Darling, R. (1998). Soil physical requirements for crop production in a mediterranean climate in South Australia. *Proceedings International Symposium on Arid Region Soils, Izmir, Turkey, September 21-24; 200-07*.
5. Malinda, D.K., Schultz, J.E. and Darling, R. (2000). Advances to overcome root zone constraints to crop productivity. CD Proceedings 4th International Conference on Soil Dynamics (ICSD-IV), March 26-30, Adelaide, South Australia.
6. Soane, B. D., and Van Ouwerkerk, C. (Eds.) (1994). Soil compaction in crop production. Elsevier, Amsterdam, Netherlands, 662 pp.
7. Voorhees, W.B. (2000). Longterm effect of subsoil compaction on yield of maize. *Advances in GeoEcology*, **32**, 331-8.
8. Zhai, R., Kachanoski, R.G., and Voroney, R.P. (1990). Tillage effects on the spatial and temporal variation of soil water. *Soil Sci. Soc. Am. J.*, Vol.**54**, 186-92.