THE PHYSICAL PROPERTIES OF MIXTURES OF A AND B HORIZONS AND EVALUATION OF PROFILE MIXING FOR MANAGEMENT OF TRANGIE RED-BROWN EARTH.

By
Ian Douglas Hollingsworth

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF RURAL SCIENCE OF THE UNIVERSITY OF NEW ENGLAND

March 1989

DECLARATION

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree.

I certify that to the best of my knowledge any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

[redacted]..................

Abstract

Conventional methods of seedbed preparation have caused crop yields to decline on red–brown earths. This yield decline is attributed to reduced physical fertility brought about by the collapse of soil structure. Regeneration of favourable structure may be achieved by several means, one of which is mixing of subsoil with topsoil. Deep mouldboard tillage, which mixes A and B horizon soil, has increased cotton yield on some irrigated red–brown earths in the Lower Macquarie Valley of New South Wales. The beneficial effect of deep mouldboard ploughing may be enhanced by gypsum application. Deep mouldboard tillage loosens the topsoil to approximately 400 mm and changes the texture of the plough layer by mixing clay subsoil with loam topsoil. However, the physical basis for the yield response to deep mouldboard tillage has not been thoroughly investigated.

The morphology, particle size distribution and clay mineralogy of a red–brown earth on the Agricultural Research Centre, Trangie, N.S.W., indicates that it is prone to structural degradation when used for irrigated cultivation. The aim of this study is to quantify the compaction constraints to soil physical fertility of the Trangie red–brown earth and to determine the likely beneficial effects of deep mouldboard tillage. The results of an investigation of the penetration resistance, soil water and oxygen transmission properties affecting the physical fertility of Trangie red–brown earth soil as a function of compaction and soil horizon mixing is reported in this thesis. The effect of gypsum application on soil penetration resistance is also reported.

Drop cone penetrometer measurements of the plastic and liquid limits as a function of soil horizon mixing show that soil horizon mixing increases the liquid limit

and thereby increases the plasticity index. The plasticity index is related to the tillage energy required to produce a seedbed. The amount of soil horizon mixing attributable to deep mouldboard ploughing does not substantially increase the plasticity index of the soil and hence the energy required in tillage operations. The plasticity index is closely related to the geometric mean particle diameter of the soil horizon mixtures. The desirable amount of mixing, on the basis of energy required for seedbed preparation, appears to be that which does not substantially increase the plasticity index.

The purpose of Chapter 3 is to describe the effects of soil water content and soil horizon mixing on soil compaction behaviour under uniaxial compression. These and other effects, were investigated using cores reconstituted from disturbed soil by uniaxial compression. Particular levels of compaction were attained by varying soil water content and compaction force. Soil cores formed from mixtures of A and B horizon were prepared in a similar manner using ratios of 91:9, 75:25, 50:50 and 25:75 A:B horizon soil. The A and B horizon mixing increases soil resistance to compaction relative to A horizon alone while increasing soil water content reduces soil resistance to compaction. Soil compressive strength at the plastic limit is dependent upon the plasticity index. This relationship may be used to predict soil compaction at the maximum water content recommended for tillage. A multiple regression relationship between void ratio, uniaxial stress and soil water content is developed for use in the compaction management models in Chapter 7.

Soil penetration resistance directly affects root growth and, a quantitative model of penetration resistance is useful for predicting compaction conditions restrictive to root growth and in assessing the soil horizon mixing effect of deep mouldboard tillage. The material in Chapter 4 reports on an investigation of soil penetration resistance as a function of soil compactness, water content, soil horizon mixing and gypsum application. Penetration resistance is measured with a cone penetrometer on disturbed soil cores and the results are compared with cone penetrometer measurements in the field.

Field penetration measurements indicate that a level of compaction which restricts root penetration occurs beneath the tilled layer of Trangie red–brown earth.

The benefits of deep mouldboard tillage may result from a greater depth of loosened soil which does not mechanically impede root growth over the range of plant available soil water contents. The critical void ratio for root limiting penetration resistances in the plant available water range is 0.75 $m^3\ m^{-3}$ for the A horizon and 0.96 $m^3\ m^{-3}$ for the B horizon soil. Laboratory cone index measurements are not significantly different to cone index measured in the field. Consequently, the laboratory study of cone index as a function of void ratio, water content and soil horizon mixing may be used to describe penetration resistance in the field. Cone index is a logarithmic function of void ratio, water content and an interaction term. Soil horizon mixing increases soil penetration resistance. This effect will counteract any beneficial effect of an increase in resistance to compaction attributed to soil horizon mixing (Chapter 3).

Gypsum application (5 t ha^{-1}) does not affect the penetration resistance of the A horizon soil or a soil horizon mixture representative of deep mouldboard ploughing. Consequently the benefits derived from applying gypsum do not result from changes in the penetrability of the soil mass. It is possible that gypsum ameliorates a surface crusting problem on this soil.

The initial differences between moulboard ploughed and non-mouldboard ploughed soil may result from differences in compactness, and hence penetrability. However, both tillage treatments compact to similar void ratios in the field over two growing seasons. This indicates that processes other than traffic compaction are important. Soil settling during rapid wetting and on subsequent drying is another process which may compact the topsoil.

Chapter 5 reports the results of an investigation of the effect of soil horizon mixing and compaction on the plant available water and saturated hydraulic conductivity. Soil water storage and transmission are aspects of soil physical fertility which affect penetration resistance and soil aeration. Water storage and transmission are determined by pore size distribution, which is modified by compaction and soil texture. The aim of work reported in this chapter is to model the effect of soil horizon mixing and soil compaction on water retention and hydraulic conductivity. Water retention between matric potential values of -0.2 and -150 mH_2O and saturated hydraulic conductivity were measured in the laboratory for A and B horizon soil, and the range of soil horizon mixtures studied previously. Soil cores were compressed to different void ratios with a uniaxial compression testing instrument. The larger pores are removed by compaction, causing saturated and unsaturated hydraulic conductivity to decrease. Soil horizon mixing does not increase soil water storage. However, water transmission appears to be enhanced because of an increase in the tendency of soil to form aggregates during the wetting and sieving in soil preparation.

Critical water transmission and storage properties are determined for inclusion in the compaction management model (Chapter 7). A critical void ratio of 0.70 $m^3\ m^{-3}$ for rapid water intake is determined from saturated hydraulic conductivity data. Also, the upper and lower limits of plant available water are determined at matric potential values of -1 m and -150 mH_2O for each soil horizon and soil mixture.

Chapter 6 investigates soil aeration and the level of compaction critical for unrestricted oxygen supply to plant roots for the soil horizons and soil horizon mixtures. Plant root respiratory demand for oxygen is met by oxygen diffusing from the atmosphere, through the soil to the root surface. The supply of oxygen through the soil may be reduced by compaction.

Air–filled porosity, was measured on reconstutited soil cores at different void ratios. The cores were equilibrated at different matric potentials in pressure chambers. Transmission porosity is defined as the air–filled porosity at a matric potential of -1 m H_2O and represents the pore size fraction greater than 30 μm diameter. Void ratio is used as the index of soil compactness. The relative diffusion coefficient and oxygen flux density were calculated from oxygen concentration measured in a diffusion chamber using a polarographic electrode.

Compaction reduces transmission porosity, while creating a finer soil texture by soil horizon mixing tends to shift the relationship between transmission porosity and void ratio to higher void ratios. The relative diffusion coefficient is less sensitive than the oxygen flux density to changes in oxygen partial pressure gradient during the measurement period. Thus, the relative diffusion coefficient is used to model the oxygen transmission properties of the soil rather than the oxygen flux density. A two part linear function is used to relate the relative diffusion coefficient to transmission porosity.

Critical void ratios for adequate oxygen supply to respiring roots were determined from the relationships between relative diffusion coefficient and transmission porosity, and transmission porosity and void ratio. The critical void ratio for adequate oxygen supply is 0.68 ± 0.01 m^3 m^{-3} for the A horizon and 0.86 ± 0.02 m^3 m^{-3} for the B horizon soil. Soil horizon mixing tends to increase the critical void ratio. The critical void ratios for unrestricted aeration are calculated for inclusion in the nomograms of soil physical fertility in Chapter 7.

The aim of Chapter 7 is to model the effects of compaction and soil horizon mixing on the physical fertility of Trangie red–brown earth soil. The model is used to interpret the effect of deep mouldboard tillage on the soil physical fertility. The results of uniaxial compression testing (Chapter 3) are used to model soil compaction caused by vertical pressure attributed to traffic. Soil penetration resistance (Chapter 4), saturated hydraulic conductivity (Chapter 5) and oxygen diffusivity measurements (Chapter 6) are used to characterise soil physical fertility at different levels of compaction for the range of matric potentials from -150 to -1 m of water, representing the range of plant available water contents.

The model of soil fertility can be used to determine soil physical conditions limiting to crop production and to guide tillage management so as to minimise compaction degradation caused by traffic. It can be seen from the nomogram that soil compaction by a 200 kPa surface pressure at the plastic limit water content will mechanically impede root growth and restrict soil water availability. This is a reduction in the soils physical fertility. Greater surface pressures and or traffic at higher water contents are needed to create restriction to water intake or soil aeration. Consequently, soil penetration resistance is the primary limiting factor to soil physical fertility in this compacted soil.

The nomogram indicates that the mouldboard tilled soil following sowing was not sufficiently compacted to cause restriction to root growth while the disc–harrowed soil was. This combined with evidence that soil horizon mixing attainable by deep mouldboard tillage does not reduce soil resistance to compaction damage suggests that the beneficial effect of the deep mouldboard technique is temporary and related to soil loosening.

In conclusion, penetration resistance is the primary limitation to root growth in this soil and is not affected by gypsum application. Maintaining topsoil at void ratios greater than 0.75 m^3m^{-3} (bulk density less than 1500 kg m^{-3}) should prevent compaction restriction to root growth and crop yield. Compaction by wheel pressures greater than 100 kPa at the plastic limit water content may cause compaction damage. Wheel pressures should be kept below 100 kPa and wheel traffic should be confined to water contents less than the plastic limit. Also, there is evidence that the beneficial effect of deep mouldboard tillage is temporary and depends on thorough soil loosening, and not on an increase in the soils resistance to compaction damage brought about by soil horizon mixing. Any observed beneficial effects of deep mouldboard ploughing appear to be attributed to soil loosening, and aggregate formation, neither of which were investigated.

Acknowledgements

I would like to thank Dr. Alf Cass and Dr. Don McLeod for their supervision and assistance. Also thanks are due to Dr. Paul Blackwell and Dr. Mac Kirby for contributing ideas, Mr. David Hall and Mr. David McKenzie for the use of the tillage field trial at Trangie for my study, Dr. Ian Davies and Ms. Kerry Mengersen for statistical advice, Mr. Dan Alter and Mr. Allen Mitchell for laboratory assistance, Mr. Bob Hope for workshop assistance and Mr. Gary Woods for electronics work. This work was funded by a grant from the National Soil Conservation Programme.

Contents

List of Tables

List of Figures