

Soil strength/soil wetness relationships on Red Ferrosols with visually assessed soil structure differences in north-west Tasmania.

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Abstract

The relationship of soil wetness to soil strength in Red Ferrosols was compared between paddocks of good to poor soil structure. Soil structure was assessed using a visual rating. Soil resistance measurements were taken over a range of soil wetness, using a recording penetrometer. Readings were taken as the soil dried by evapotranspiration after both irrigation and rainfall events.

The influence of soil wetness on penetration resistance was greater on poorly structured paddocks than on well-structured paddocks. In paddocks with degraded structure, the wetter the soil, the smaller were the penetration resistance readings. Paddock soil structure was negatively correlated to the slope of the line relating soil wetness and penetration resistance at both 0-150 mm and 150-300 mm depths. Degraded paddocks that were assessed at or below 4 with the structure scorecard, had a highly significant relationship between penetration resistance and soil wetness at 150-300 mm depth. In well-structured paddocks, variations in soil wetness had less effect on penetration resistance.

These results indicate that visual assessment can be used with confidence to assess Ferrosol structure. The implications for soil management are that paddocks with degraded soil structure have greater resistance to root growth at drier moisture contents than well-structured paddocks. Consequently, farmers need to keep degraded soils wetter with more frequent irrigation than well-structured soils, to ensure optimum plant growth.

Key Words

Resistance, structure score, wetness, root growth

Introduction

Soil degradation is an important issue in soil conservation management in the north-west region of Tasmania (Cotching *et al.* 2002). Cultivation when soils are wetter than the plastic limit, or loading the soil with heavy traffic, can result in compaction and clod formation. Intensive cultivation can cause excessive breakdown of soil aggregates resulting in an overly fine and loose tilth. This can cause a seed drill to go too deep with the consequence being poor seedling emergence and growth.

Visual attributes of Red Ferrosols in north-west Tasmania with good and poor structure have been described by Cotching (1997). Good structure is characterised by many rounded, irregularly shaped aggregates of 2 – 10 mm diameter, with larger aggregates having many holes for good aeration. Poor structure is characterised by large firm clods of 20–100 mm diameter, that are angular with smooth faces and no pores. The clods and overworked soil break into loose, fine powdery soil.

Soils with degraded structure are difficult to manage due to a restricted range of soil wetness for tillage operations and can result in low yields (Cotching *et al.* 2004). If a soil has poor structure this can lead to problems with drainage due to the blocking of soil pores resulting in a decrease in the rate at which water can enter soil (infiltration rate) and the rate at which water can drain through the soil (hydraulic conductivity). Compaction can lead to reduced aeration when wet, particularly on heavier textured soils, resulting in restricted volumes of soil available for root growth (Letey 1985). The ability of plants to penetrate the soil is also reduced when structure is poor, which affects access to both soil nutrients and moisture, and so crop yields. Poorly structured soils are more likely to form a surface crust after heavy rainfall and are more easily eroded by wind or water.

Soil compaction, leading to large soil strength, can limit plant growth by restricting root elongation, as well as limiting the range of tillage options for soil preparation. Soils need to be kept at an appropriate wetness so as not to limit plant growth. Penetration resistance is a measure of soil strength that the roots

of plants encounter when growing. Penetration resistance is strongly dependent on soil wetness (Cass 1999). Use of a 'Rimik' penetrometer to measure penetration resistance was found to distinguish compacted from well-structured Vertosols (McKenzie 2001a).

It is important to have an understanding of the relationship between structural degradation and soil wetness because farming practices can influence both attributes. Structural degradation can be caused or avoided by management practices including tillage, trafficking and irrigation, which are normally used to optimise crop and dairy pasture production in north-west Tasmania during summer.

The objective of this study was to determine the difference in the relationship between soil strength, as measured by penetration resistance, and soil wetness on poorly and well-structured paddocks of Red Ferrosols.

Materials and methods

Five paddocks were selected on Red Ferrosols in north-west Tasmania. They were selected based on the paddock's topsoil structure score and the crop that had been sown; four were cropped to potatoes and one to buckwheat. The paddocks were chosen so as to give a range of structure scores, from well-structured (score of 9) to poorly structured (score of 2). The structure status of the paddocks was assessed visually using a pictorial scorecard (see appendix) which follows that of Peerlkamp (1967) and Batey (2000), with the concept also having been developed for use on Vertosols in Australia by McKenzie (2001b). A structure score of 6 or less was considered degraded (Cotching *et al.* 2004). The sampling and structure score assessments were conducted in January 2003. In the experience of the junior author, the combination of pictures and descriptive text on the scorecard allows for repeatable visual assessment of soil structure condition over a range of soil wetness. Each paddock was sampled 6 times so that soil penetration resistance measurements were taken at a range of soil moisture contents after both irrigation and rainfall events. Successive readings were taken as the soil dried by evapotranspiration. At each sampling in each paddock, ten penetrometer (Rimik Agricultural Electronics CP20 Cone Penetrometer) readings were taken to a depth of 600 mm at random locations along a defined transect in each paddock.

Soil samples were taken from the area immediately surrounding where each penetrometer measurement had been taken. Two soil samples were taken using a 50 mm diameter tube at 0-150 mm and 150-300 mm depth. The soil samples were weighed at field moisture content and then oven-dried (105° C) for 24 hours to determine soil wetness (g/g). Both the average and the maximum data from the penetrometer resistance values for 0-150 mm and 150-300 mm depths (10 values over each depth) were plotted against soil wetness. The slopes of the relationships between penetration resistance and soil wetness were plotted against the structure scores for all paddocks.

Results and discussion

The relationship between average penetration resistance and soil wetness in a paddock with a low structure score (2) and a paddock with high structure score (9) are shown in Figures 1 and 2 respectively. The influence of soil wetness on penetration resistance was greater (i.e. steeper slope) on poorly structured paddocks than on well-structured paddocks. In paddocks with degraded structure, the wetter the soil, the smaller were the penetration resistance readings.

The average penetration resistance values were greater in the poorly structured paddock (500-3000 kPa) than in the well-structured paddock. (300-2000 kPa).

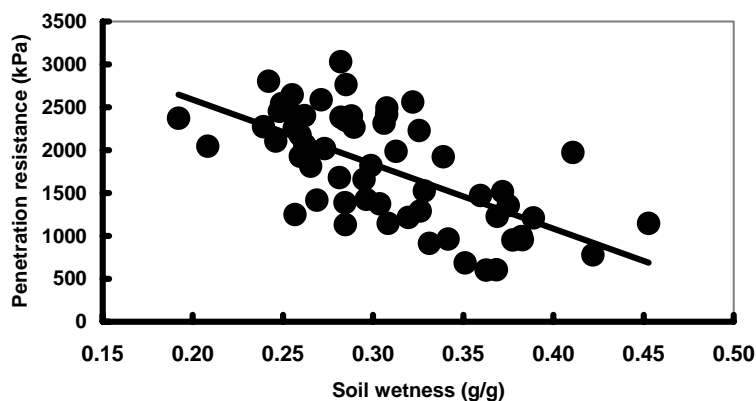


Figure 1. Average penetration resistance (150-300 mm depth) and soil wetness in a paddock with structure score 2 ($r^2 = 0.41$; $P < 0.001$).

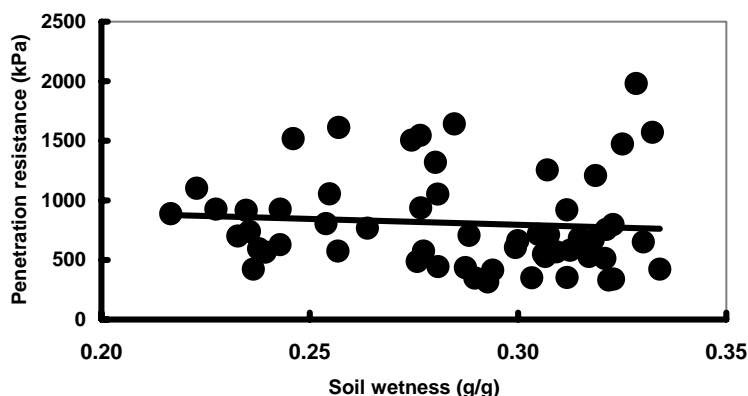


Figure 2. Average penetration resistance (150-300 mm depth) and soil wetness in paddock with structure score 9 ($r^2 = 0.01$; $P = 0.54$).

The amount of spread within the data points for the 150-300 mm depth, decreases from the best structured paddock to the worst structured paddock (Table 1). At particular moisture contents the resistance readings vary more in well-structured paddocks than in those with poor structure (structure score < 4).

Table 1. Probability values (P value) and r^2 for the relationship between average and maximum penetration resistance and soil wetness for the five paddocks.

Structure score	2		4		6		8		9	
0-150 mm	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
r^2 Value	0.09	0.14	0.12	0.14	0.04	0.02	0.003	<0.001	0.01	0.02
P Value	0.02	0.003	0.007	0.003	0.11	0.24	0.66	0.88	0.54	0.35
150-300 mm										
r^2 Value	0.41	0.46	0.38	0.35	0.21	0.23	0.10	0.07	0.01	0.01
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.03	0.54	0.55

Absolute penetration resistance values

The number of average penetration resistance values greater than 2000 kPa was much greater in poorly structured paddocks (5-42%) than in well-structured paddocks (0%). This effect was exaggerated for maximum penetration resistance values with poorly structured paddocks having 31-77% of values exceeding 2000 kPa, and well-structured paddocks having 6-23% (Table 2). In the three paddocks with structure scores of 6 or less, the maximum resistance measurements were greater than 3900 kPa. These differences are probably due to the presence of a greater number of clods with harder consistence in structurally degraded paddocks than in well-structured paddocks. The paddock with the lowest structure

score of 2, had maximum penetration resistance measurements greater than 2000 kPa at field capacity of 0.40 Mg/Mg wetness (data not shown).

Published critical values of resistance that retard root growth and seedling emergence are 720-3000 kPa, with values varying between crops (Taylor and Ratliff 1969, Cass 1999). At penetration resistances between 1000–2000 kPa seedling emergence may fail without the presence of surface cracks and root growth may be restricted. This is due to the likelihood of greater resistance values being reached as the soil moisture is used by crops. Penetration resistances of 2000–3000 kPa at field capacity stop root growth except through and around the soil clods and cracks. The available moisture in soil with greater resistance is also limited.

Table 2. Soil penetration resistance measurements for the five paddocks

Structure score	Maximum Resistance		Minimum resistance		Average resistance	
	0-150	150-300	0-150	150-300	0-150	150-300
Depth (mm)						
2	4325	5083	35	240	189-1983	601-3029
4	1566	3908	35	172	86-922	296-2578
6	1392	4348	35	141	63-547	253-2153
8	2726	2779	35	65	59-1054	156-1585
9	1597	3439	35	141	85-653	316-1981

Structure score plotted against resistance/soil wetness slope

The slopes of the relationship between penetration resistance and soil wetness (e.g. Figures 1 and 2) were plotted against structure score for 150–300 mm depth (Figure 3). Data was plotted only from significant relationships ($P < 0.05$ from Table 1). No plot could be made for data from 0–150 mm depth as only 2 of the 5 relationships were significant. This may have been because the unconfined soil and tillage effects made the results too variable.

As the structure score increased at 150–300 mm depth, the slope of the average resistance / soil wetness relationship decreased. There was a strong relationship between soil wetness and penetration resistance in paddocks with degraded structure (score of 6 or less) but in better structured paddocks, this was not the case. Drying increased resistance much more in the poorly structured soils. The relationship established indicates that moisture content has a much greater control on penetration resistance in poorly structured paddocks than in well-structured paddocks. The relationship could be used to predict the likelihood of resistance problems, depending on the paddock’s structural condition score.

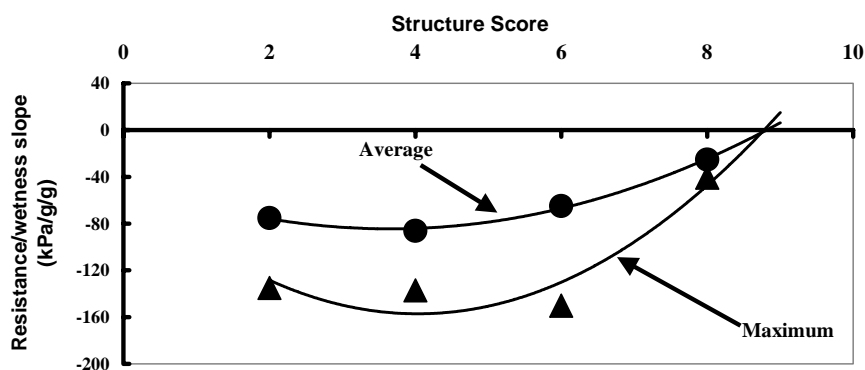


Figure 3. Structure score and slope of the penetration resistance / soil wetness relationship for the five paddocks at the 150-300 mm depth (Average resistance $r^2 = 0.996$; Maximum resistance $r^2 = 0.88$).

Moisture contents

The soil moisture contents at both 0–150 mm and 150–300 mm depths (Table 3) indicate that the paddocks sampled were often drier than the recommended refill point of 0.32 g/g (Cotching, unpublished data), which suggests that farmers are not keeping their paddocks wet enough for optimum crop growth. A few observations were above field capacity of 0.40 g/g (Cotching *et al.* 2002), but the number was minimal

with the bulk of the measurements being below a wetness of 0.32 g/g. Red Ferrosols in north-west Tasmania have been found to have topsoil total porosities of 0.60 m³/m³ (Cotching et al 2002), consequently, the likelihood of reduced root growth due to poor aeration, even at the greatest moisture contents recorded, is considered to be low. The majority (85%) of penetrometer measurements were taken at moisture contents at or less than the plastic limit of 0.34 g/g (Cotching et al 2002) which is likely to produce the most valuable experimental data (McKenzie and McBratney 2001).

Table 3. Soil wetness (g/g) at sampling.

Structure score	Maximum wetness		Minimum wetness		Average wetness		Observations less than
	refill point (%)						
Depth (mm)	0-150	150-300	0-150	150-300	0-150	150-300	150-300
2	0.44	0.45	0.14	0.19	0.26	0.31	93
4	0.36	0.39	0.21	0.25	0.31	0.33	58
6	0.45	0.36	0.17	0.22	0.26	0.26	95
8	0.38	0.43	0.27	0.27	0.34	0.35	20
9	0.33	0.33	0.17	0.22	0.27	0.29	78

The penetration resistance vs soil wetness plots were examined to determine what soil wetness each paddock needed to be at in order to maintain an average soil penetration resistance of less than 2000 kPa at 150-300 mm depth (Table 4). 2000 kPa was chosen as the critical penetration resistance, as it is above 2000 kPa at field capacity that root growth is impeded except through cracks, channels and points of weakness in the soil. It is also likely that moisture uptake by the plant will be restricted (Cass 1999). The collected data indicated that the refill point in degraded paddocks with a structure score of 4 or less should be adjusted to an average of 0.345 g/g in order to keep average penetration resistance below 2000 kPa.

Table 4. Soil wetness (g/g) of samples that correspond to average penetration resistance of 2000 kPa (150-300 mm).

Structure score	Soil wetness
2	0.33
4	0.36
6	0.25
8	N/A (All penetration resistance
9	N/A values less than 2000 kPa)

Cass (1999) states that if resistance is 2000-3000 kPa at field capacity then the soil physical fertility is poor. From this project it has been shown that the soil structure in degraded paddocks also has effects at the dry end of the moisture scale. An outcome from this project is that when advice is given on irrigation refill points, these should be assessed on the structural condition of the paddock. In the degraded paddocks investigated within this project, the refill point would be increased from the current industry recommendation of 0.32 to 0.345 g/g. This increase of 0.025 g/g amounts to 7.5 mm of readily available water storage in the surface 300 mm of these Red Ferrosols (Cotching *et al.* 2002), or approximately 2 days of summer evapotranspiration. Irrigation on structurally degraded paddocks would need to be undertaken more frequently (every 8 days rather than every 10 days) than on well-structured paddocks and may amount to an extra 3 irrigations over the potato growing season.

Conclusions

Soil wetness has a greater effect on penetration resistance in poorly structured than in well-structured Red Ferrosols. Well-structured Red Ferrosols can be drier than poorly structured Red Ferrosols without affecting root growth because of their corresponding low resistance. Therefore plant roots are able to access a greater soil volume and more of the moisture and nutrients that are present in well-structured soils.

The greater number of maximum penetration resistance values that exceeded 2000 kPa in poorly structured paddocks than in well structured paddocks, may be attributed to the greater presence of clods with massive structure in degraded paddocks. Clod presence in soils with degraded structure is an on-going issue requiring management on Red Ferrosols used for cropping in north-west Tasmania.

Results from this project indicate that in paddocks with poor structure, soils must be kept wet enough to prevent penetration resistance exceeding 2000 kPa. The structure scorecard could be used to identify such paddocks before irrigation begins.

The use of the structure scorecard on Red Ferrosols by field officers and farmers will enable improved soil and water management practices and crop yields to be achieved.

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Appendix - Soil structure scorecard

For Red Ferrosol topsoils in Tasmania

Score 1 – 2

Large compact clods (50 – 100 mm) with few fine aggregates. Clods are angular or plate-like with smooth sides and no pores.



Score 3 – 4

Mainly firm large clods (20 – 50 mm) that are angular with smooth faces and no pores. Clods and overworked soil break into loose powdery soil.



Score 5 – 6

Few medium and large firm, rounded aggregates (5 – 30 mm) with mostly finer aggregates (< 2 mm) and some powdery unaggregated soil.

