MINIMUM TILLAGE EFFECTS ON SOIL STRUCTURE MEASURED USING IMAGE ANALYSIS

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Abstract

The long-term effects of minimum tillage operations on soil macropore structure were investigated on a furrow-irrigated Vertisol in northern New South Wales. Data are presented from an experiment established in 1985 to study the effects of minimum and intensive tillage systems sown to either continuous cotton or a wheat-cotton rotation. Soil physical properties in the surface 150 mm were measured 9 years after the experiment began. Soil samples were impregnated with epoxy resin and the horizontal macropore structure was described quantitatively using image analysis. Vane shear strength and air permeametry were also measured from the same sites. Both the imaging and physical assessment results indicate that there were no significant differences between the management and tillage treatments at this depth. Image analysis, however, detected significant differences in soil aggregate size between the two ends of the irrigated field. This effect may be due to the soil moisture gradient that results from furrow irrigation although no structure differences were detected by the other measurements. This structure gradient could have important implications on the management of these irrigated fields. Image analysis appears to be a useful technique for quantifying structure effects in swelling soils that are not detected using other physical measurements. The image data are valuable supplements to other methods of quantifying soil structure although the technique is time consuming and not well suited to routine diagnosis of structural degradation.

Key words: Soil structure, minimum tillage, rotations, cotton, image analysis, vane shear strength, air permeametry, Vertisol, furrow irrigation.

Irrigated cotton (*Gossypium hirsutum* L.) based farming systems occur largely on deep cracking clays or Vertisols. The large water-holding capacity and low wet-soil strength make these soils prone to structural degradation especially under the intensive land preparation and tillage operations used for growing cotton. Cotton yield declines due to structural degradation have been well documented. Minimum tillage practices and rotations with other crops such as wheat (*Triticum aestivum* L.) are claimed to reduce this degradation (1, 7) and have therefore become increasingly important practices intended to sustain these soils. Most previous studies have addressed the short-term (<3 years) effects of these practices, (2, 4) however it is important that the long term effects of these practices be quantified to evaluate their ability to restore the soil structure over long periods.

Image analysis provides a useful tool for assessing soil morphological structure (9). The advantage of image analysis is that soil images can be quantified and compared, not only across different sites, but they can also be permanently stored and used to compare the changes in structure over time. Attributes measured from the images are well correlated to important properties that affect plant growth and indicate structural degradation (3). Physical soil attributes, such as soil strength and permeability, need to be measured in addit-ion to the soil morphology.

The objective of this study was to determine the value of image analysis data, along with other soil physical measurements of shear strength and air permeability, to quantify the long-term effects of minimum tillage and a cotton-wheat rotation sequence on the soil structure of an irrigated Vertisol.

Materials and methods

The trial was located at the Australian Cotton Research Institute, Myall Vale, NSW (150?E, 30?S). The field experiment was conducted on a deep uniform grey clay or Vertisol. The experimental treatments, imposed from 1985 to 1993, were minimum tillage with a winter wheat and cotton rotation (Min W/C), minimum tillage and continuous cotton (Min CC) and maximum tillage and continuous cotton (Max CC).

The minimum-tillage treatments involved planting on ridges retained intact from previous years with soil disturbance being limited to deepening of the furrows with disc-hillers. Cotton was sown with minimum-tillage in October and wheat with no-tillage in May. Continuous treatments were planted to cotton in October each year. Maximum tillage involved disc-ploughing to 0.2 m depth, chisel ploughing to 0.3 m depth followed by ridging each year.? Following harvest, the crops were slashed and all residues retained *in situ*. The plots were irrigated by furrow irrigation only when rainfall and profile water storage were insufficient to meet evaporative demand.

The experiment used 4 replicated blocks in which the tillage and cropping sequence treatments were completely randomised within each block. Individual plots consisted of 12 rows (ridges), 174 m long, spaced at 1 m intervals. When sampling for this study samples were taken from near the supply channel and near the tail drain of the plots to avoid bias.

The structural assessment was conducted on the plots in January 1994. At each sampling site an area on top of the soil ridge was gently cleared of loose top soil and vegetation to a depth where the surface was firm (~150 mm). Three techniques were used to assess the structural state of the soil at this depth. A resin saturated soil block was collected for the computer assessment of pore stained images, an air permeameter reading was made to determine the continuity of the pore space and five vane shear measurements were made to assess the soil strength. Along with these, air temperature and soil moisture content was determined to help interpret the structural measurements.

For image analysis the undisturbed soil was impregnated with the fluorescent resin mixture described by Moran *et al.* (10). The resin solution was applied to the horizontal surface (~250 mm square) until saturated (~750 ml per sample). After 24 hours the soil block was excavated and later re-saturated for extra strength and stability. The original surface of the sample was then ground smooth to expose the resin-impregnated soil macropore space. These horizontal surfaces were photographed under ultra-violet lights.

The colour images were scanned into a Macintosh computer to obtain digital images of 2000 x 2000 pixels representing 200 x 200 mm of soil. These were segmented using a classification procedure that involves manually identifying pixel areas that represent the pore and non-pore phases of the image. The image was then automatically divided into two distinct classes which are represented as a black and white pixels in a binary image.

The binary images were quantified using *SOLICON-2* software. The horizontal analysis used a similar model to that proposed by McBratney and Moran (8) for assessing vertical soil profiles except the model was altered and attributes specifically applied to the horizontal plane. The image attributes calculated included: macroporosity (V_{vp}), a measure of the area density of pore pixels which is equivalent to the volume proportion of pores; surface area (S_v), an estimate of the interfacial area between pore and solid in a given volume of soil and pore and solid star lengths (l_p^* and l_s^*), which measure the expected continuous length of pore or solid that would be encountered if measured randomly from any point within that depth of the soil. All measurements are scale dependant; however, for the purpose of comparison this is not a problem as they are all the same resolution.

The air permeameter used was that described by Fish and Koppi (5), one reading was taken at each sampling site at the same depth as the image sample. A hand held vane shear was used to take soil shear strength measure-ments, five repetitions at each site. The soil moisture potential and content were measured gravimetrically using the filter paper method from the same locations.

Results and discussion

The mean image attributes and soil physical measurements from each treatment are given in Table 1. The results show that there were no significant differences between treatments implying that each management approach gave rise to a similar soil structure at this depth. Further analysis was conducted to see if there were any differences between the overall minimum and maximum tillage operations and between the wheat rotation and continuous cotton options. The effects of the treatment blocks and field ends were also investigated. The ANOVA statistics from these investigations are presented in Table 2. Again, results indicated no statistical difference between any of the management approaches. The blocks had no effect except in one case where the shear strength was significantly higher than the others, however, this did not relate to any of the other findings. The field ends on the other hand appeared to have a considerable effect.

Table 1: Soil structure image and physical measurements, treatment means for minimum tillage cotton and wheat rotation (Min C/W), minimum tillage continuous cotton (Min CC) and maximum tillage continuous cotton (Max CC) with basic ANOVA statistical results.

Attributes	Units	Min C/W means	Min CC means	Max CC means	Standard error	Prob > F[a]
Macroporosity - V_{vp}	mm/mm	0.073	0.046	0.039	0.0185	0.4178(n)
Surface area - S_v	mm^2/mm^2	0.367	0.225	0.228	0.0892	0.5158(n)
Pore-star length - l^*_p	mm	1.52	1.19	1.24	0.182	0.3921(n)
Solid-star length - l^*_s	mm	51.1	69.0	62.8	14.5	0.6792(n)
Vane shear strength - τ	kPa	11.3	12.1	11.4	1.33	0.8939(n)
Air permeability - k_a	m^2	154	93.7	254	55.0	0.1388(n)
Matric potential - ψ	kPa	-213	-161	-145	37.4	0.4062(n)
Gravimetric water content - θ_g	g/g	0.27	0.28	0.30	0.012	0.2690(n)

Min is minimum tillage; Max is maximum tillage; C/W is cotton-wheat rotation, CC is continuous cotton

[a] Symbols in parenthesis indicate level of significance at which means differ: n = not significant (P>0.05).

Table 2: ANOVA probabilities of > F ratio for tillage type, crop rotation, block and field-end.

Attributes	Max/Min[a]	CC/CW[a]	Blocks[a]	Field end[a]
Macroporosity - V_{vp}	0.3824n	0.1903n	0.9245(n)	0.2330(n)
Surface area - S_v	0.4536n	0.2525n	0.6433(n)	0.0558(n)
Pore-star length - l^*_p	0.6108n	0.1704n	0.6665(n)	0.2223(n)
Solid-star length - l^*_s	0.8788n	0.4036n	0.3575(n)	0.0035(**)
Vane shear strength - τ	0.8281n	0.7944n	0.0046(**)	0.1675(n)
Air Permeability - k_a	0.7136n	0.4264n	0.8149(n)	0.1944(n)
Matric Potential - ψ	0.3806n	0.1877n	0.3314(n)	0.0187(*)
Gravimetric water content - θ_g	0.1038n	0.3646n	0.5525(n)	0.0244(*)

Min is minimum tillage; Max is maximum tillage; C/W is cotton-wheat rotation, CC is continuous cotton

[a] Symbols in parenthesis indicate level of significance at which means differ: n = not significant (P>0.05), * = significant (P<0.05) and ** = very significant, (P<0.01).

The soil aggregate size, measured from the horizontal structure images, is affected by the distance to the irrigation supply channel. Near the channel the aggregates are significantly larger (l^*_s = 83.2 mm) than those near the tail drain (l^*_s = 38.7 mm). This indicates degradation of the soil structure near the channel. The measurements of matric potential and gravimetric moisture content indicate that the soil was also significantly wetter at the channel end (–127 kPa and 0.30 g/g versus –218 kPa and 0.27 g/g). This moisture gradient is probably due to the nature of flow in furrow irrigation where the supply channel end gets more water during irrigation and is also wetter for longer periods. This end of the field is therefore frequently more prone to compaction from traffic and machinery than the drier end near the tail drain which would explain the larger aggregates. The macroporosity (V_{vp}), surface area (S_v) and pore sizes measured (l^*_p) were not significantly affected by the field end. This may be due to the image pixel resolution (100 mm) not being small enough to detect the pore sizes that were affected. The moisture differences did not particularly affect the average vane shear (t) and air permeability (k_a) values although they were lower (10.6 kPa and 120.6 m^2 versus 12.7 kPa and 213.5 $m^{2)}$ near the irrigation channel than the tail drain. The difference in aggregate structure along the irrigated field could have important management implications for irrigated crop production.

Other authors (6) working on this site have found that the minimum tillage system provides more porous ridges with better structure than the maximum tillage treatments. However, after nine years at this location, no significant differences between tillage and rotation practices were detected here. This may be due to the depth chosen and techniques used, but more likely, due to a poor sampling strategy and inadequate replication. As the sampling was limited to near the tail drain and head ditches of the field this may have influenced the results. That structural differences were found between the ends of the field indicate that this is probably true. This has implications for sampling these irrigated fields. Other workers have found these observations very relevant to many cotton fields and now avoid sampling from these ends, leaving a buffer zone of 50 to 100 m (depending on the field size) and sampling from the central part of the field (middle 60 to 70 m) only which has enabled treatment differences to be observed (N. Hulugalle? *pers. comm*.).

The image analysis technique described here was useful in detecting differences in soil structure that were not discovered using other physical soil measurements.? It appears that this technique would be a valuable supplement to existing methods for assessing soil structure.? Unfortunately the technique is time consuming and expensive which may make it prohibitive for routine diagnosis.

The moisture content at the site would possible effect the image results as these high clay soils shrink on drying and this can result in increased pore sizes measured in drier soils.

The sampling depth not being representative, however 150 mm was chosen as it lies with in the rooting zone and is close enough to the surface to be affected by tillage implements. Instead, these results probably reflect

Conclusion

The results of the structural assessment at 150 mm depth found no detectable difference between the three management and tillage treatments. Large differences in aggregate size (solid star length), measured from soil images, were found between the ends of the irrigated field. This could be due to the moisture gradient with distance from the irrigation supply channel, however, these differences were not always reflected in the other morphological or physical measurements. Overall, the results suggest that over the experimental field structural results ranged widely from extremely poor to reasonably good. The results also testify that the differences occurring within a single treatment are far more variable than those that exist between them. This work provides a reminder that experimental sampling design should be considered carefully when sampling from such fields.? Sampling from the centre of these fields may give better representation of treatment effects. The image analysis procedure can provide information not detected using other physical soil measurements. If the procedure was cheaper and faster it would provide a valuable supplement to existing techniques for routine diagnosis.

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