

**COTTON RESEARCH AND DEVELOPMENT CORPORATION**

# **FINAL REPORT**

**"Attendance by Mr D.C. McKenzie at 9th International Working  
Meeting on Soil Micromorphology"**

**DAN 74C**

**March 1993**

**Mr D.C. McKenzie, Rydalmere**



**NSW Agriculture**

**FINAL REPORT TO**  
**COTTON RESEARCH AND DEVELOPMENT**  
**CORPORATION**

**Project Number:** DAN 74C

**Title:** ATTENDANCE BY MR D.C. McKENZIE AT 9TH  
INTERNATIONAL WORKING MEETING ON SOIL  
MICROMORPHOLOGY

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## 1. INTRODUCTION

In July 1992 the 9th International Working Meeting on Soil Micromorphology was held in Townsville, Queensland. It was sponsored by Sub-Commission B of the International Society of Soil Science. One hundred and ten participants from 23 countries met to discuss recent developments in the field of soil micromorphology. David McKenzie presented a paper about his structure assessment work on cotton soils, and assisted with a post-conference tour.

This report provides details about these activities and summarises information from the meeting that is of relevance to research and advisory staff within the Australian Cotton Industry.

## 2. PRESENTATION OF PAPER

David McKenzie orally presented a paper entitled : "A pragmatic role for image analysis when assessing compaction in Vertisols", co-authored by A.J. Koppi, C.J. Moran and A.B. McBratney. A copy is attached. It has been accepted for publication in a book entitled : "Proceedings of 9th IWMSM, Eds. A.J. Ringrose-Voase and G.S. Humphreys, Developments in Soil Science, Elsevier, Amsterdam".

## 3. POST-CONFERENCE TOUR

Sixteen of the delegates participated in a post-conference tour that examined a wide range of representative soils between Canberra and Broken Hill. David McKenzie, David Hall and Philippa Commins from NSW Agriculture, and Jim Beale of Auscott Ltd. Warren, hosted the visitors for half-a-day at Trangie and Warren. Topics discussed included the genesis of grey clays and red-brown earths in the Macquarie Valley, and the impact of management systems such as irrigated cotton production on key soil properties.

## 4. NEW ANALYTICAL PROCEDURES AND CONCEPTS FOR COTTON SOIL RESEARCH AND MANAGEMENT

- Elles and Rabenhorst (USA) – the degree of waterlogging in soil can be assessed micromorphologically by examining the nature of iron and manganese segregations.
- Dabbakula *et al.* (Thailand/USA) – the microvariability of Vertisols, particularly with respect to calcium carbonate, has been characterised using electron microscopy, X-ray diffraction, differential thermal analysis, thin sectioning and C<sup>14</sup> dating.
- Mohamed and Bruand (France) – calcium carbonate in soil can be characterised morphologically, using optical and electron microscopy, to determine the conditions of its formation.

- Foster (Australia) – the relationship between soil microbiota and bonding within aggregates can be observed directly using recently-developed wet electron microscope techniques; ultraradiological studies of labelled organisms also are becoming more sophisticated.
- Chotte *et al.* (France) the morphology of microorganism habitats has been described in a tropical Vertisol.
- Krebs *et al.* (Germany/France) – spatial dependencies between the root systems of four temperate plant species and soil channels, cracks and other voids were determined quantitatively.
- Smettem *et al.* (Australia/France) – pore space created by earthworms is very dynamic and not always useful for plant growth, so the timing of image analysis sampling is very important.
- Chadouf *et al.* (France/Australia) – a positive correlation was obtained between the location of shrinkage cracks and earthworm channels in a Vertisol.
- Nortcliff *et al.* (UK/USA) – a procedure is being developed to identify soils susceptible to rapid leaching of applied materials (e.g. nitrates, pesticides) through image analysis of their macropore characteristics.
- Hallaire and Curmi (France) – the importance of separating active from disconnected macropores in image analysis was highlighted; a combination of methylene blue tracer and fluorescent resin impregnation is recommended.
- Sullivan (Australia) – the coating of the surfaces of subsoil cracks and biopores by materials such as clay and manganese oxide can strongly influence the movement of gases, liquids and solids within the soil.
- Hallaire (France) – a method for describing and classifying cracks according to their surface area and orientation is proposed.
- Fedoroff and Weber (France/Poland) – heavy metal distribution following sewage application has been described using an ion microprobe on large thin sections.
- Rhoton and Lindbo (USA) – the benefits of micromorphological investigation were demonstrated in a comparison of contrasting tillage treatments on a broad range of loam soils.
- Shahid and Jenkins (Pakistan/UK) – the composition of salt crusts can be determined using a combination of X-ray diffraction and electron microscopy.

## 5. RECOMMENDATIONS

Soil scientists associated with the Australian cotton industry have the expertise and facilities to apply most of the recently developed procedures outlined above to their studies. However, funds will be required for attendance at similar meetings in the future to ensure that they remain up-to-date with new developments in other parts of the world.

## 6. ITINERARY

| Date       | Activity, Location   |
|------------|--|
| July 12    | Travel Sydney - Townsville                                       |
| July 13-17 | Attend 9th International Working Meeting on Soil Micromorphology |
| July 18    | Travel Townsville - Sydney                                       |
| July 19-23 | Assist with Post-Conference Tour at Trangie and Warren           |

## 7. SOURCES OF FUNDING

*Salary:* NSW Agriculture

*Airfares and expenses:* Cotton Research and Development Corporation (\$1,210.00)

## A pragmatic role for image analysis when assessing compaction in Vertisols

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### ABSTRACT

Compaction and smearing of the subsoil of Vertisols is a major management problem which restricts root growth and causes cotton lint yield losses as great as 30%. Assessment procedures, for use by both research and advisory staff, to ascertain the severity of the problem are not well defined. An experiment was carried out in a Vertisol used for irrigated cotton production to compare a broad range of procedures for the measurement of soil structural form. Methods were considered in terms of the value of the information that they provided and their expense. We propose that a successful assessment scheme will have to describe both intra-aggregate aeration and strength, particularly within the larger units, and the nature of any continuous vertical macropores that allow roots to bypass inaccessible zones. The soil was studied under a wheeled furrow and below a well-structured ridge, on which the cotton plants are grown, to provide contrasting physical conditions. Examination of vertical and horizontal blocks of soil impregnated with resin containing a fluorescent dye provided evidence of features that are not shown clearly by the other methods, *i.e.* high variability of aggregate size to a depth of 250 mm under the ridge and the presence of fine cracks that may connect the strongly compacted furrow with relatively loose soil under the ridge. The SOILpak score, a semi-subjective morphology-based measure of soil physical condition used routinely in the field as part of a soil management "expert system", correlated well with the measures of soil strength and aeration over 4 depths, but is prone to bias. Mesomorphological parameters - particularly macroporosity - that were obtained from image analysis of the impregnated blocks followed the same trends as the more conventional measures of soil structure.

## INTRODUCTION

Most Australian cotton is grown on Vertisols. Subsoil compaction and remoulding are a major management problem on this soil type, causing lint yield losses as great as 30 %. Damage is due mainly to the adverse effects of traffic and tillage under wet conditions. However, compaction can also occur due to the natural collapse and excessive swelling of aggregates that contain large amounts of exchangeable sodium. Compaction and remoulding usually decrease cotton root growth and profitability due to:

- (1) Poor aeration when the soil is wet.
- (2) High soil strength at low water contents, applicable particularly to lateral roots and root hairs which have to extract water and nutrients from within soil aggregates.
- (3) Disruption of continuous vertical channels (macropores) that allow roots - especially taproots - to bypass problem zones.

Assessment procedures - for use by both research and advisory staff - to ascertain the severity of the problem are not well defined. Methods are available to measure aeration, strength and macroporosity directly, although many of the procedures require complex equipment and are time consuming. When measuring soil aeration, oxygen flux density (Hodgson and MacLeod, 1989) is the most sensitive procedure. It is relevant to the biological processes taking place, but it is time consuming and requires expensive equipment. Air-filled porosity is a crude, but useful, first approximation. Hodgson and MacLeod (1989) found that significant oxygen diffusion only occurred when air-filled porosity exceeded 14% in cracking clays used for cotton near Narrabri, northern New South Wales. The most commonly used measuring devices for soil strength are penetrometers and shear vanes; they are easy to operate but soil water content needs to be measured at the same time in clay soil to standardise the results if between-site comparisons of the degree of compaction are required. Taylor and Ratliff (1969) have defined critical values of soil strength for cotton root growth. Soil macropore structure can be measured using the SOLICON image analysis system described by Moran et al.(1990), and modified recently by Koppi and McBratney (1991) to allow large, continuous soil monoliths to be impregnated with resin containing a fluorescent dye prior to video scanning. Vertical and horizontal sections of soil can be examined. Pore space with a diameter as small as 0.2 mm can be detected routinely. Indirect measures of soil structure,

such as clod shrinkage indices (McGarry and Daniells, 1987), are also available but are not discussed here.

Unlike research staff, cotton advisors currently do not use such expensive procedures. They rate soil condition visually according to the fineness and hardness of aggregates and the frequency of shiny aggregate faces, using the SOILpak score (Daniells and Larsen, 1991). The larger the estimated values are on a scale ranging from 0 to 2, the better the soil structure with respect to cotton growth. Advisory staff use the information, via a soil management "expert system", to determine the most profitable land preparation procedures for the following cotton crop in individual fields. Methods available include deep ripping, gypsum application and minimum tillage. Advisory staff regard the SOILpak score as a useful first approximation, but there appears to be much scope for making their assessment more objective. In addition the score needs to be related to aeration, strength and macroporosity.

We propose that a successful compaction assessment scheme, both for advisory and research staff, will have to describe both intra-aggregate aeration and strength, particularly within the larger units, and the nature of any continuous vertical macropores that allow roots to bypass inhospitable zones.

This paper describes part of an experiment that was carried out under moist conditions in a Vertisol used for irrigated cotton production. A broad range of procedures for the measurement of soil structural form (defined by Kay, 1990) were compared, in terms of the value of the information that they provide and their expense, in an attempt to produce field-structure assessment packages. The role of image analysis in relation to other methods is emphasized.

## MATERIALS AND METHODS

The site is on a grey clay (Stace et al., 1968) (Entic Chromustert) near Warren (Auscott Ltd., Field 26), NSW, Australia (31°44'S, 147°53'E). Site elevation is 195 m and the mean annual rainfall is about 450 mm. The soil is a

medium clay (clay content approximately 50%), and is near-neutral, non-sodic and non-saline, to a depth of 400 mm.

The field was first developed for furrow-irrigated cotton in 1967 after natural rainfed pasture. Numerous operations have since been carried out on the soil but the recent relevant ones are as follows. Following a wheat crop in 1989, before which the soil was in poor physical condition because of two consecutive wet harvests, the dry soil was chisel ploughed in February 1990 with the chisel point set at 350 mm. Shattering occurred between this depth and about 200 mm. In March 1990, 200 mm high ridges spaced 1 m apart were formed with a listing rig pulled by a 'Caterpillar® D8' crawler tractor. They are used to improve drainage in the upper part of the root zone, and to direct the flow of irrigation water. Cotton was planted into these ridges in October 1990 under moist conditions which persisted during 2-3 mechanical weeding operations in the following months. In July 1991, after a dry harvest, a light lister was used to reform the ridges in preparation for another cotton crop. The depth of the lister point penetration in the furrows was approximately 120 mm. It should be noted that, before 1989, ridges and furrows were not always kept in the same place, ridges often being inadvertently positioned over old furrows after disc ploughing and re-listing.

When sampled in August 1991 the soil was near 'field capacity' ( $\theta_g = 0.307 \text{ kg kg}^{-1} \pm 0.012$ ; Number of samples(N) = 14), except for the surface 80 mm which was close to permanent wilting point ( $\theta_g = 0.208 \text{ kg kg}^{-1} \pm 0.055$ ; N = 2). The soil was studied in duplicate under a furrow, taken as depth zero at the surface, and at the same level below a well-structured ridge where the cotton plants were to be grown. The contrasting sites were within 3 m of each other. The soil was sampled from the sides of 1.5 m deep pits.

Blocks of soil, one vertical and one horizontal, were impregnated with epoxy resin containing a fluorescent dye at each of the 4 locations (Koppi and McBratney, 1991). Vertically oriented blocks were 400 mm high x 150 mm wide and horizontal ones 250 mm x 250 mm at a depth of 150 mm. The tops of the vertical blocks were positioned at the level of the furrow. The method used is the same as Method I described by Koppi and McBratney (1991), except that the profile was not sprayed with resin before attaching the backing boards.

The face of each block was ground flat using a disc grinder and scanned under UV light to produce a digital image. The pixel size was  $195\ \mu\text{m} \times 195\ \mu\text{m}$  for the vertical sections and  $390\ \mu\text{m} \times 390\ \mu\text{m}$  for the horizontal sections. Image segmentation and pore attribute data were obtained for the vertical images using the SOLICON system (Moran et al., 1990). Mean values of macroporosity, macropore surface area, macropore star length and macrosolid star length were calculated using data from 5 mm wide  $\times$  100 mm long strips across each vertical block centred at depths of 50, 150, 250 and 350 mm. The strips contained 25 scan lines, each representing a depth increment of 0.2 mm.

Bulk density, air-filled porosity and gravimetric water content were measured at 50, 150, 250 and 350 mm depth below the furrow level using single 50 mm long, 50 mm diameter thin walled rings. These cores were inserted vertically at each of the 16 sampling points using a large hammer. Soil strength (apparent cohesion) was assessed nearby in duplicate using a 'Geonor' hand-held shear vane. For the lower three depths the vane was inserted horizontally, but at 50 mm depth it was used vertically to avoid the separation and lifting of weakly bonded platy clods. The SOILpak score, described earlier, was also estimated. At each of the 16 sampling points these measurements, and the collection of vertical monoliths, were carried out within about 200 mm of each other.

Linear correlation was used to determine the degree of relationship between the image analysis parameters, air-filled porosity, shear strength and the SOILpak score.

## RESULTS AND DISCUSSION

The upper half of Fig. 1 shows a pair of binary images from 2 of the 4 vertical monoliths. Under the furrow the greatest zone of compaction (smallest pore space, shown as black) extends from about 70 to 220 mm below the surface. Beneath this, the amount of pore space increases but there are still relatively large areas without pore space. This suggests that the compaction due to machinery traffic extended below the sample depth. The loose soil above about 70 mm has resulted both from self-mulching of the surface and from slumping of the adjacent ridges.

(Insert Figure 1 near here)

Under the ridge, above about 200 mm, the soil appears to have large surface area and short aggregate length between relatively large aggregate fragments that appear to have been dislodged by chisel ploughing. The regions of greatest surface area may offer root growth pathways which allow plants to avoid the potential detrimental effects of the massive areas. The more compacted zone below about 200 mm probably remains from the damage caused by the 2 consecutive wet harvests prior to 1990.

A horizontal section (200 x 200 mm) from the centre of the most compacted zone (150 mm depth) under the furrow (Fig. 1) indicates that there are infrequent, vertical cracks within relatively dense soil. These may facilitate water and root movement through a material that otherwise appears to be impermeable. The horizontal section from under the ridge at an equivalent depth (Fig. 1), like the vertical image, shows a large relatively massive lump and several smaller ones, that have persisted since chisel ploughing.

It should be noted that the images do not prove that the observed pore spaces are continuous and connect with the surface. Supplementary procedures, such as those described by Hulme et al. (1991) and Moran and McBratney (1992a,b), are required where dye solutions or resins are applied to the soil surface in the field prior to resin impregnation in the laboratory.

The regression analysis (Table 1) showed that the 4 structural attributes from the binary image parameters, macroporosity, macropore surface area, macropore star length, and macrosolid star length (shown in Table 2), related fairly well to the direct measures of aeration and strength, as did the SOILpak score. These conventional measures of soil compaction, also presented in Table 2, confirm that soil under the furrow was less well aerated and harder, when considered at a similar water content, than soil under the ridge.

(Insert Tables 1 and 2 near here)

## CONCLUSIONS

The vertical and horizontal images provide a clear record of the soil structure in the field. The zones of large porosity could probably be used by roots to bypass damaged areas. The images indicate which depths are most crucial for further evaluation, and provide a good impression of the degree of variability. However, the good correlation between the binary image attributes and direct measures of aeration and strength suggest that this further testing may not be required because image measurements are sufficient. A greater range of field sites should be studied to test this conclusion more thoroughly. The SOILpak score, which is cheaper than the other procedures under consideration, also related well to these factors. This confirms its value as a first approximation for use by advisory staff, but the subjectivity of the scoring procedure means that some observers may introduce bias unless regular calibration takes place using more objective procedures, such as image analysis.

## ACKNOWLEDGEMENTS

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## LIST OF FIGURES

Figure 1. Representative vertical (360 x 100 mm; pixel resolution = 195  $\mu\text{m}$ ) and horizontal (200 x 200 mm; pixel resolution = 390  $\mu\text{m}$ ) SOLICON images of a compacted furrow and an undamaged cotton ridge.

## LIST OF TABLES

Table 1. The degree of correlation between the 4 SOLICON binary image parameters, air-filled porosity, shear strength and the SOILpak score. The numbers shown are Pearson product-moment correlation coefficients ( $\times 100$ ).

| VARIABLE<br>(N=14)           | Binary image parameters |                              |                             |                              |                            |                   |                  |
|------------------------------|-------------------------|------------------------------|-----------------------------|------------------------------|----------------------------|-------------------|------------------|
|                              | Macro-<br>porosity      | Macropore<br>surface<br>area | Macropore<br>star<br>length | Macrosolid<br>star<br>length | Air-<br>filled<br>porosity | Shear<br>strength | SOILpak<br>score |
| Macro-<br>porosity           | 100                     |                              |                             |                              |                            |                   |                  |
| Macropore<br>surface<br>area | 98                      | 100                          |                             |                              |                            |                   |                  |
| Macropore<br>star length     | 64                      | 51                           | 100                         |                              |                            |                   |                  |
| Macrosolid<br>star length    | -76                     | -80                          | -54                         | 100                          |                            |                   |                  |
| Air-filled<br>porosity       | 64                      | 63                           | 28                          | -51                          | 100                        |                   |                  |
| Shear<br>strength            | -55                     | -51                          | -48                         | 33                           | -70                        | 100               |                  |
| SOILpak<br>score             | 75                      | 72                           | 60                          | -60                          | 74                         | -77               | 100              |

NOTE. Data for the uppermost sampling points under the furrows (total of 2 points) have been excluded from the analysis because of their dryness.

Table 2. Mean soil macroporosity ( $V_{vp}$ ), macropore surface area ( $S_v$ ), macropore star length ( $l_p^*$ ), macrosolid star length ( $l_s^*$ ), bulk density (BD), gravimetric water content ( $\theta_g$ ), air-filled porosity (AFP), shear strength (SV) and SOILpak score (Spak) as a function of depth under the ridge and furrow. (Units:  $V_{vp}$ ,  $\text{mm}^3 \text{mm}^{-3}$ ;  $S_v$ ,  $\text{mm}^2 \text{mm}^{-3}$ ;  $l_p^*$ , mm;  $l_s^*$ , mm; BD,  $\text{Mg m}^{-3}$ ;  $\theta_g$ ,  $\text{kg kg}^{-1}$ ; AFP,  $\text{mm}^3 \text{mm}^{-3}$ ; SV, kPa).

| Site   | Depth<br>mm | $V_{vp}$ | $S_v$ | $l_p^*$ | $l_s^*$ | BD   | $\theta_g$ | AFP  | SV  | Spak |
|--------|-------------|----------|-------|---------|---------|------|------------|------|-----|------|
| Ridge  | 50          | 0.17     | 1.05  | 0.97    | 8.74    | 1.23 | 0.30       | 0.18 | 3.5 | 1.7  |
| Ridge  | 150         | 0.15     | 0.80  | 1.27    | 10.72   | 1.25 | 0.31       | 0.16 | 3.7 | 1.7  |
| Ridge  | 250         | 0.07     | 0.49  | 0.93    | 17.87   | 1.24 | 0.32       | 0.15 | 3.7 | 1.4  |
| Ridge  | 350         | 0.15     | 0.83  | 1.34    | 11.78   | 1.33 | 0.32       | 0.09 | 5.5 | 1.5  |
| Furrow | 50          | 0.42     | 1.34  | 3.06    | 3.06    | 1.14 | 0.21       | 0.33 | 9.9 | 0.2  |
| Furrow | 150         | 0.03     | 0.21  | 0.76    | 37.71   | 1.43 | 0.30       | 0.05 | 7.9 | 0.5  |
| Furrow | 250         | 0.06     | 0.49  | 0.75    | 15.72   | 1.39 | 0.30       | 0.07 | 6.8 | 1.1  |
| Furrow | 350         | 0.06     | 0.48  | 0.78    | 29.32   | 1.34 | 0.30       | 0.10 | 6.3 | 1.4  |

