

## Using New Techniques for Detecting the Degradation of Soil Structure Under Cotton

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### Introduction

One of the major problems faced by cotton farmers is the degradation of their soil by compaction. Large yield losses have been reported due to this soil problem. The most common soil type that is used for irrigated cotton production in Australia is the cracking clay (or Vertisol). The problem with this soil type is that it is very weak when wet and because of this, damage can be done by simply driving heavy equipment on it. The nature of cotton farming inevitably makes this damage almost unavoidable. Even with attempts to reduce compaction from knowledge already gained many problems still remain and compaction is still a threat to cotton yields.

Farmers need a soil assessment test that can be done quickly and accurately to measure the state of compaction in the soil. Some traditional methods, such as bulk density and air filled porosity do not fully characterise the structure of the soil (1). Improved methods such as air permeability, oxygen diffusion and clod shrinkage don't relate well to plant performance partly due to biased sampling that tends to exclude important macropores such as cracks and root channels (2). Visual assessments such as those used in SOILpak are inadequate and very subjective and results can vary greatly between observers. A recent attempt to develop a method using a soil structural index based on moisture content, soil strength and root characteristics was found not to relate well to the soil structure as described by the clod shrinkage technique (3).

Image analysis techniques have been used recently, with success, to quantify the state of the soil structure (4 & 5). Here "image analysis" includes the field sampling and image capture as well as the processing and analysis of images. This series of procedures is known as the SOLICON analysis system. There is still much work to be done on refining these procedures. The major developments to be made are concerned with making the system practical, quick, and affordable so that it can be used routinely and used for making management decisions. Presently the system involves procedures that are often very labour intensive and time consuming as well as expensive, they also usually require expert knowledge and equipment to conduct.

The aim of the project outlined here is to try and develop the SOLICON techniques that are already being used by soil researchers in order to find a practical technique available to cotton consultants or agronomists (SOLICON 2) that gives an accurate analysis of soil compaction. Here a new, cheaper field technique for acquiring images of soil structure using paint is compared to the existing resin method. The existing method of impregnation (6 & 7) is labour intensive; it takes at least two days of field work followed by at least 2 hrs per sample of laboratory work (reimpregnation, grinding and photography) before the images can be analysed.

### **Materials and methods**

All experiments were conducted at Auscott, Pty. Ltd., Warren, NSW. The new technique proposed here (based on earlier work (8)) involves the use of acrylic paint for discriminating between macropores and solid soil. The paint is diluted 3:7 paint:water. The two techniques were compared under both artificially compacted and well structured (uncompacted) soil on which cotton plants were grown, this was in order to provide contrasting physical conditions. Five replications of the new paint method were compared to the standard resin method on both the compacted and uncompacted soil types. The two specimen preparation methods were compared for both horizontal and vertical sections.

#### Resin technique

The existing method for investigating the soil compaction involves the use of an expensive epoxy resin which is poured onto the soil and left to harden. The hardened soil block is later dug out and ground back so that a smooth surface remains. The resin contains a fluorescent dye, enabling the smoothed blocks to be photographed in a dark room using ultra violet lights which highlight the pore structure. In this way an image of the structure of the pores in the soil block is acquired. The image is analysed using a Macintosh Quadra computer and SOLICON 2 image analysis software.

#### *Vertical Sections*

To get vertical images of the soil, foam rubber (25 mm thick) backed with particle board (600 × 150 mm), is stuck onto the vertical face of a smoothed soil pit wall with a quick setting araldite. The soil profile must be fairly moist (close to field capacity). When the araldite has set these boards are dug out with a layer of soil about 100 mm thick attached. The samples are then placed horizontally and the soil surface is picked so it is unsmearred (allowing easy infiltration). The samples are then saturated with the epoxy resin containing fluorescent dye. The resin takes approximately 24 hours to harden. The hardened blocks are then wrapped for transportation to prevent drying and taken to the laboratory for grinding.

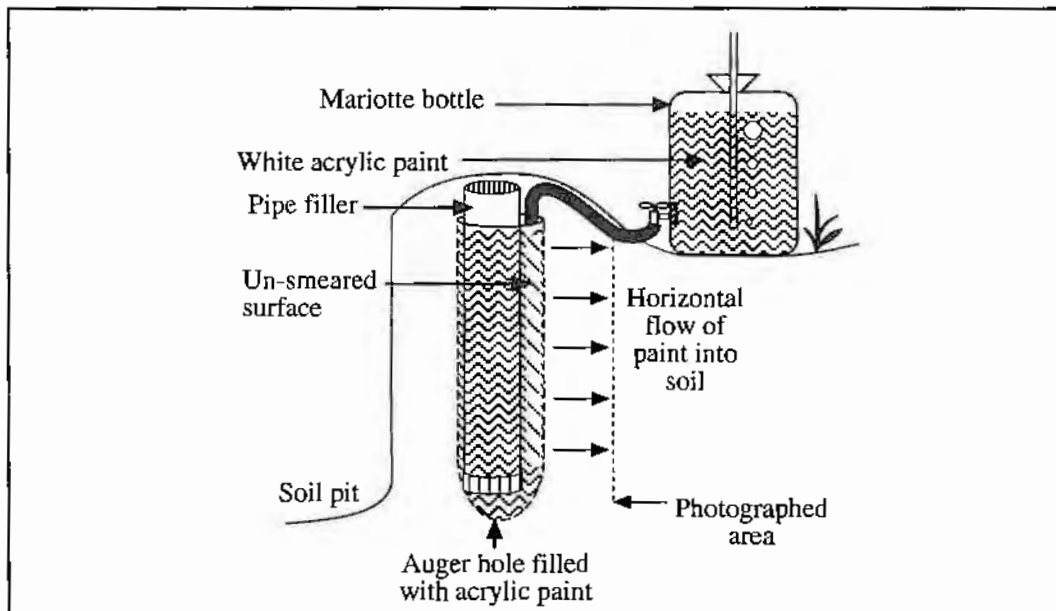
### *Horizontal Sections*

To obtain horizontal samples, clear an area of soil leaving a level surface about 150mm below the natural surface of the soil ridge (this can be varied depending on the depth of interest). This area is unsmeared with an araldite peel (8) and a square wire frame (250 × 250 mm) is placed on the surface to define the area of interest. The mixed fluorescent resin is poured onto the surface within the frame. The samples are then left overnight to harden, dug out and wrapped to be taken back to the laboratory. In the laboratory the samples are resaturated with resin on the reverse side for extra strength and then ground and photographed under UV lights.

### Paint technique

#### *Vertical Sections*

The new paint method requires that 150 mm auger holes be dug to about 700 mm deep. This hole must be about 200 mm from the vertical edge of a soil pit. The inside edge of the auger hole facing away from the soil pit is picked so it is unsmeared. This enables the paint to flow horizontally from this side of the hole. The auger hole is filled with a pipe filler (to avoid using too much paint). The diluted white acrylic paint is then poured into the area around the pipe enabling the paint to saturate the soil, this is kept topped up using a mariotte bottle (Figure 1). The set up was left over night for thorough paint infiltration, the next day the hole was excavated carefully and the vertical face where the paint had penetrated was carefully picked back so the dark soil aggregates could be seen outlined by the white paint. Photos were taken of this vertical face, the photos becoming the data source for the image analysis.



**Figure 1.** Field layout for Vertical Paint method showing set up of equipment and position of photographed area.

### *Horizontal Sections*

The horizontal version of the paint technique requires that an area be cleared free of plants and loose soil. A fairly even horizontal area should be dug to the depth required (in this case ~150 mm). A square plastic frame (~250×250 mm and about 150 mm tall) is pushed gently into the soil and sealed with excess soil. The diluted white paint is then poured into these frames and left to infiltrate overnight. The saturated layer at the surface is gently removed and the surface is cleared of any loose particles. A layer of quick setting araldite is poured on and, once hard (~5 mins), is peeled off revealing the paint stained pores and the unstained aggregate structure. Photographs of this stained structure are used for the image analysis.

### Image Capture

In the methods used above a 35mm camera was used to take photos of the soil structure. Using an Ektachrome ASA 100 film developed into slides, a slide scanner is used to digitise the images. Normal photos can also be used and scanned onto computer using a flat bed scanner however the resolution is not as high as the slide scanner. In the future it is assumed that a digital camera would be most practical. The resolution of the digital cameras is presently not high enough to be practical and they are very expensive. The slide scanner gives an image 2592 × 3888 pixels which is 5.1 times larger than images from the original CCD video camera.

### Segmenting digital images

The images that are scanned into the computer are 32 bit colour. A newly developed segmentation procedure means that instead of the image being segmented purely on the basis of the brightness of the features in the image, the colours in the image are used to distinguish between pores and solids. This is an important development that means that more realistic binary images can be used for the measurement of structural attributes. The "top hat" procedure that was used for grey level segmentations is no longer required. The binary images from this new technique are far better representations of the original image than the grey level segmentation procedure.

### Analysis of binary images

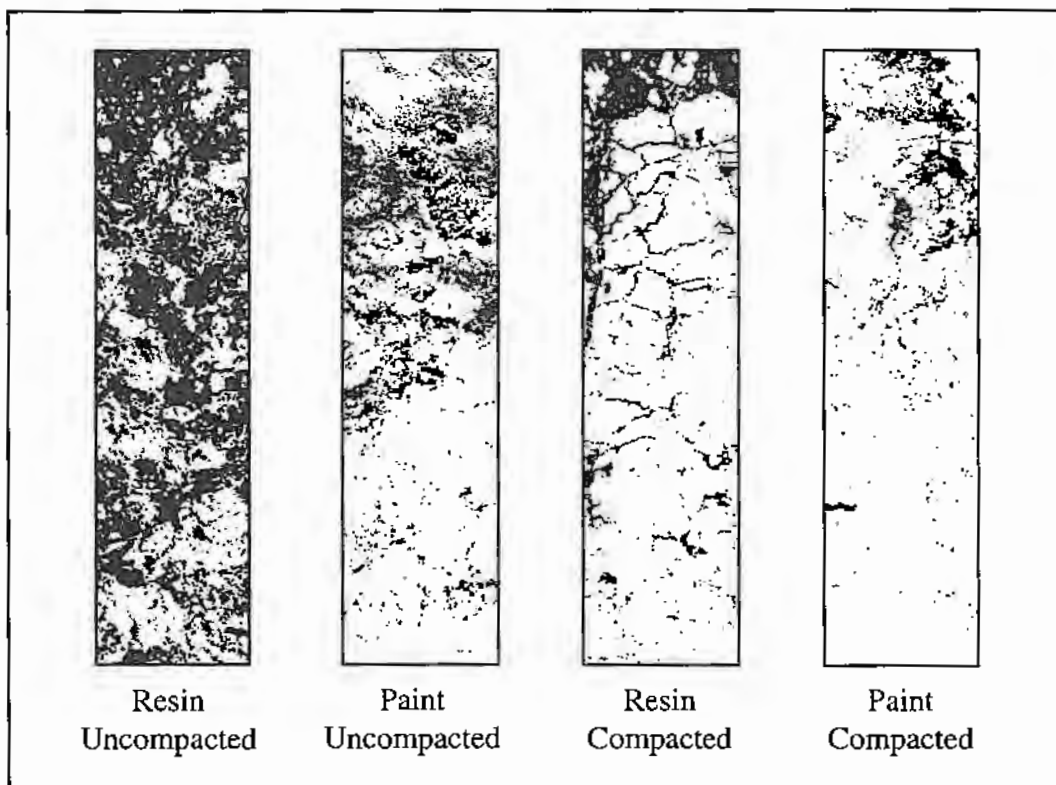
Binary images representing pore space (black) and solid aggregates (white) are used for all measurements of soil structure which is why it is so important that these are of high resolution and accurate representations of the structure in the field. These images give the quantitative data relating to soil macroporosity, surface area, solid and pore sizes.

For vertical analysis, the raw data is taken from the image at 0.237 mm intervals (every pixel row) along horizontal lines for the length of the image. The estimation of structural attributes is made using a stereological model, that is, the structure is isotropic in any plane normal to the vertical. In this way the structural attributes are analysed as functions of depth.

Macroporosity ( $\text{mm}^3 \text{mm}^{-3}$ ) was estimated as the proportion of pore pixels along each line. The surface area ( $\text{mm}^2 \text{mm}^{-3}$ ) is an estimate of interfacial area between pore and solid pixels in a given volume of soil. Surface area is estimated from the number of intercept or changes from pore to solid along each line. Pore and solid star lengths (mm) are attributes concerned with the size of each phase of the structure. The former is the expected continuous length of pore in the horizontal plane that would be encountered in any direction from a point at random at some fixed depth in the soil. No assumption of shape is made and therefore pore star length should not be thought of as a pore radius. The solid star length conducts the same task as pore star length on the solid phase. Detailed information on these soil measurements are given elsewhere (9).

The horizontal analysis involves the measurement of the same four soil attributes, however because the sample is taken at one depth, the horizontal estimate is given as one number for each structure attribute. That is, the average of each attribute over the entire image represents one level of the soil depth.

## Results



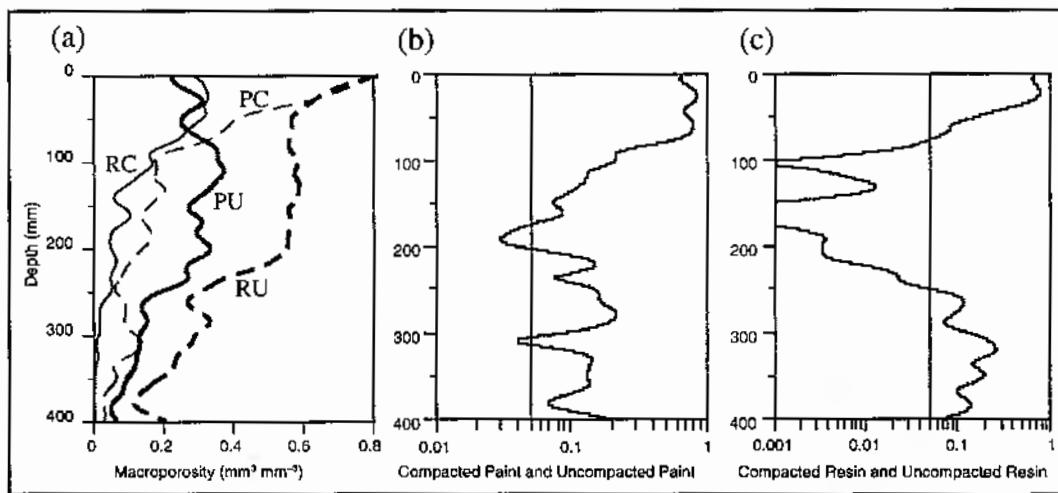
**Figure 2.** Sample of vertical binary images from each treatment ( $400 \times 100\text{mm}$ ), black = pore, grey = solid

### Vertical Results

The images shown in Figure 2 are representative binary images produced from the vertical methods in the compacted and uncompacted sites. The images represent  $400 \times 100$  mm in each case. The uncompacted images are quite easily distinguished using both

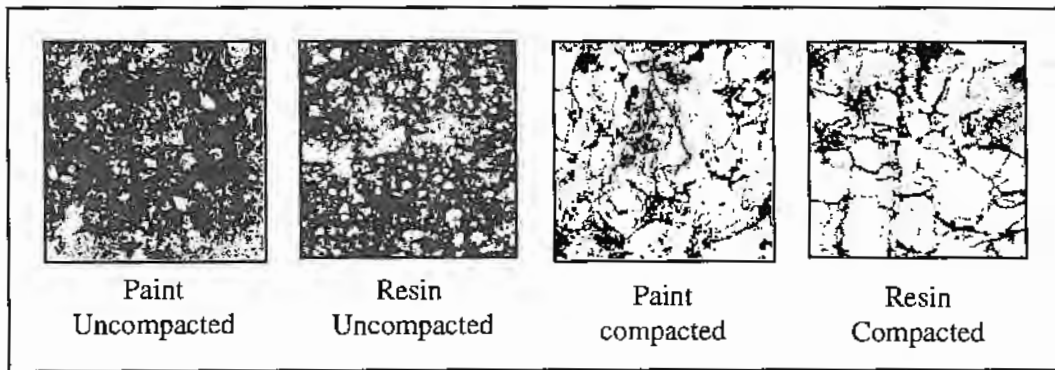
methods, however the resin method tends to illustrate this far better than the paint method. In some of the images large black areas representing pore space can be seen, the macropores are not really so large, they are actually made up of many small pores that cannot be individually resolved at this scale.

The vertical analysis was conducted on the five images representing each of the four treatments. The average results for macroporosity, surface area and solid state lengths generally showed significant differences between compacted and uncompact treatments but not for the differences between paint and resin thereby suggesting that either method can be used to distinguish between the soil structures. The only exception was with the pore state lengths where no differences were found between samples, indicating that the pores are of a similar size.



**Figure 3.** Analysis of vertical macroporosity (a) Means of two field techniques on compacted and uncompact treatments; --- Compacted paint (PC) method; — Uncompact paint (PU) method; — Compacted resin (RC) technique; - - Uncompact resin (RU) technique (a) & (c) Probability graphs of paired treatments being the same.

Figure 3 (a) shows a graph of the average macroporosity results from the five replications of the vertical analysis using both the paint and resin methods. The resin technique seems to overestimate the porosity, some values as large as 80% can be seen near the surface. The probability graphs (b) and (c) illustrate the significant differences between the compacted and uncompact treatments (they show the probability of treatments being the same, where 1 = same, and the vertical line shows the 95% confidence interval). Here the paint technique does not tend to detect the difference between compacted and uncompact as well as the resin as only small areas show significant differences. The resin technique finds that the major differences are between 80 and 250 mm depth. Resin is better at distinguishing the treatment difference. The limited significant differences in the paint results seems to be due to one of the compacted samples having a lot of resin throughout. By removing this one sample from the analysis, more significant results were obtained.



**Figure 4.** Sample of horizontal binary images from each treatment (20 cm x 20 cm), black = pore, white = solid.

### Horizontal Results

Figure 4 shows a sample of the binary images from the horizontal analysis. The quantitative analysis of the images shows that the uncompacted and compacted samples are significantly different using both techniques. Additionally, the uncompacted paint and resin as well as the compacted paint and resin are not significantly different. This suggests that the paint method would be successful in obtaining images that differentiate the soil pores from the aggregates in horizontal sections. One can also see that the paint images show the structural aggregates well.

The resin method can still be used to distinguish the fine pores and aggregates better than the paint method. This is because the resin is solid which means the pores and aggregates can be physically cut in half not just broken along lines of weakness as with the paint. The paint is simply a dying technique that stains the pores. The resin is far better as a precise research tool whereas the paint saturation method could be used as a quick routine management assessment technique as it measures aspects of the pore space important for crop growth. It is particularly good at quickly revealing compaction problems.

### **Conclusion**

Both paint and resin methods aim to recognise and measure aspects of pore space important for crop growth, especially for the prediction of problems. It appears that both techniques can be used to pick up differences between compacted and uncompacted soil. The vertical resin technique is superior to the proposed vertical paint technique in image quality and the time saved with no laboratory work (paint) is made up for by the easier field technique (resin). With the horizontal comparisons of samples close to the ground surface, the paint method offers a quick technique that provides good structural images that can be quickly analysed.

For the management of cracking clays under cotton, subjective visual assessment of soil structure by an experienced person has been the routine diagnostic method. An image analysis approach to quantify soil pore structure tends to give the user a more practical and reliable tool that also gives more detail than is possible by visual field observations.

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