ACAPULCO, MEXICO
JULY 10-16, 1994

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15 th International Congress of Soil Science

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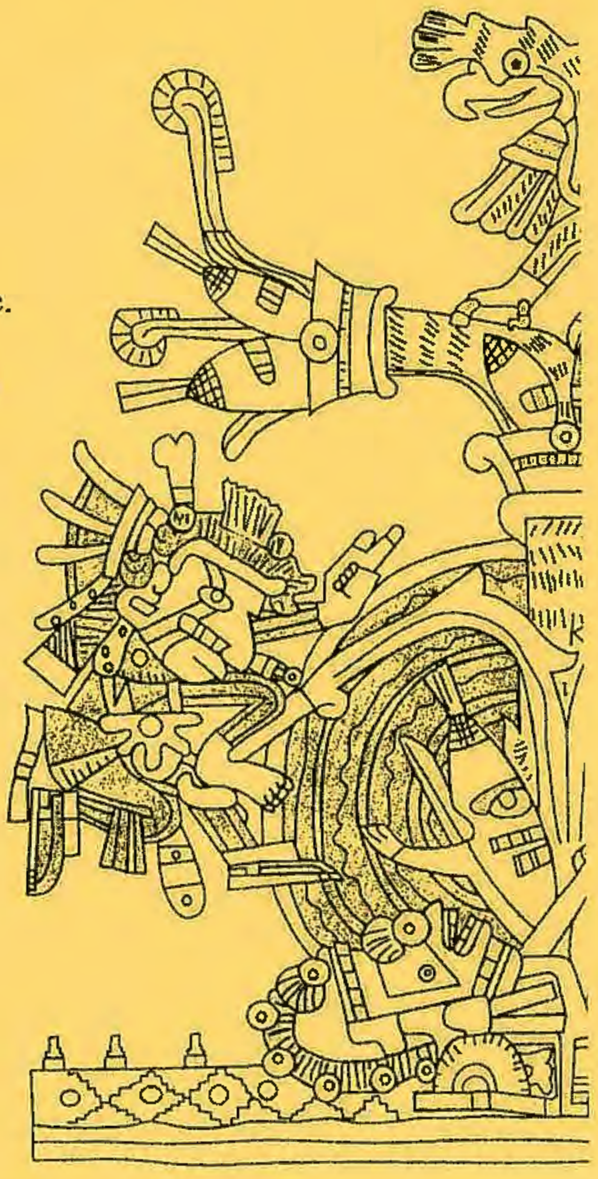

15th World Congress of Soil Science
15 Bodenkundlicher Weltkongress
15ème Congrès Mondial de la Science du Sol
15° Congreso Mundial de la Ciencia del Suelo

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David Anthony
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7th November, 1994

Dear Dave,

THE 15TH WORLD CONGRESS OF SOIL SCIENCE: 10-16 JULY

I'm sorry it has taken so long for this to get to you. I'd like to thank you and CRDC for approving the money for this trip as it was very rewarding for me. The conference was terrific with some excellent speakers and posters. I was particularly interested in the papers relating to measuring the physical soil properties and processes. However, there were many other issues raised that would be of interest to the cotton industry.

I found two papers from the poster session - "Soil physics and environmental protection" particularly relevant to my work. I spoke to the authors of both these papers (one from Portugal and another from Germany) and invited them to my talk which was on the following day. After my presentation (which went very well) we had a meeting to discuss the work that each of us are doing in more detail. This helped me personally to get a wider perspective on the work that I am conducting in my PhD. The report that follows gives an outline of these papers and other papers that were relevant to my project. I've also given the titles of some other symposia that might be of interest to other cotton researchers. If you wish for more information on any of these we have a copy of the proceedings and can send you any information that you require.

After the conference I visited the authors in Germany. The main author who was at the conference was away at the time however his colleagues were wonderful and showed me all around their facilities and discussed their work with me. They even gave me a copy of the computer program they are using for morphometric soil measurements. Their analyses looks at the hydrological aspects rather that structural aspects of soil voids however there are some important similarities. They used computer tomography as well as resin blocks to obtain their soil data. I found this technique to be very interesting as an alternative to the resin technique for soil research especially in terms of looking at the three dimensional soil structural. Whether we could do it as cost effectively here is a matter that would have to be looked into. Their work was very interesting and may even have a place in some of our research.

The conference was educational, interesting and stimulating and I'd like to extend my appreciation and thanks to the CRDC for funding my trip and conference attendance.

Yours sincerely,

L. Roesner

Libby Roesner
Postgraduate Research Student in Soil Science

In July 1994 the International Society of Soil Science held its 15th Congress in Acapulco, Mexico. Approximately 1800 ISSS members from almost 90 nations attended. The congress was held from Monday the 10th to Saturday 16th, the theme of this week was to discuss "Soil Utilisation in Harmony with Nature".

Libby Roesner from the University of Sydney's Agricultural Chemistry and Soil Science Department attended this conference with funding from the CRDC to present a paper on the new methods she is researching for using image analysis techniques to evaluate soil structure in vertisols.

Her paper was entitled: "Measuring the Impact of Intensively Irrigated Cotton Production in Australia - Using New Methods of Image Analysis to detect degradation of Soil Structure" and was co-authored by Tony Koppi and Alex McBratney. A copy of the extended summary of this paper is included at the end of this report.

Two papers in the symposia "Soil physics and environmental protection" were found to be particularly relevant to Libby's research. These papers both used computers to conduct quantitative analysis of soil structure, they looked at improving image analysis techniques to make them more practical to the end users.

This report will take the form of full summaries and discussion of these two papers and then brief summaries of other papers relevant to Libby's work. Also a list of the titles of some other symposia from the conference that may be relevant to other cotton researchers are included.

"Soil macroporosity continuity evaluated by a fast image analysis technique."

E. Sampaio, A. Azevedo, J. Sampaio. (Portugal)

This paper was concerned with using a fast, cheaper image analysis technique to evaluate the nature of soil macroporosity. Soil macropores (>50 mm) were classified using a shape factor to distinguish three void types; biopores, cracks and irregular pores. The soil surface was impregnated with a gypsum solution to contrast with the dark coloured soil. A colour video camera was used to capture these images. The continuity of pores was measured by the presence of pores at depth highlighted with the gypsum.

A vertisol was impregnated with the water and gypsum mixture within a square 500 mm frame. The soil was dug to each horizon and images were captured using the video camera. The images were processed digitally using a commercial imaging program (Mocha - from Jandel Scientific). Colour images were turned to grey level and a binary filter was used to segment the images. Parameter measurements were made on individual features in the images. One of these parameters was the shape factor, ($SF = 4 \times \pi \times \text{area} \times (\text{perimeter})^{-2}$), this enables round, biopores ($SF > 0.8$), elongated shapes such as cracks ($SF < 0.5$) and irregular shapes ($0.8 \geq SF \geq 0.5$) to be distinguished.

All the biopores in the image were divided into six classes:
1. **VLP** - Very large pores (diameter >5 mm)
2. **LP** - Large pores (5 mm ≥ diameter ≥ 1 mm)
3. **MP** - Medium pores (1 mm ≥ diameter ≥ 0.4 mm)
4. **SP** - Small pores -(0.4 mm ≥ diameter ≥ 0.15 mm)
5. **TP** - Thin pores -(0.15 mm ≥ diameter ≥ 0.03 mm)
6. **VTP** - Very thin pores (diameter < 0.03 mm)

Cracks were divided into eight classes:
1. **LLC** - Long/large crack (length >200 mm; width >5 mm)
2. **LMC** - Long/medium crack (length >200 mm; 5 mm ≥ width ≥ 1 mm)
3. **LTC** - Long/thin crack (length >200 mm; width < 1 mm)
4. **MLC** - Medium/large crack (5 mm ≤ length ≤ 200 mm; width >5 mm)
5. **MMC** - Medium/medium crack (5 mm ≤length ≤ 200 mm; 5 mm ≥ width ≥ 1 mm)
6. **MTC** - Medium/thin crack (5 mm ≥ length ≤ 200 mm; width < 1 mm)
7. **SMC** - Short/medium crack (length < 5 mm; 5 mm ≥ width ≥ 1 mm)
8. **STC** - Short/thin crack (length < 5 mm; width < 1 mm)

And irregular voids - **IV** were in a separate class.

The measurements that were made for each class of soil voids for each depth are;
1. Total area (mm^2)
2. Minimum area
3. Maximum area
4. Rate ($area/m^2$)
5. Number of voids.

This paper was concerned with the concentration and position of each pore type in the soil profile. The highest resolution that was achieved from the video images was a minimum pixel size of 0.442 mm^2. All the measurements made on the binary images relate to the individual pores, that is, they actually count the number of pores and make measurements on them individually. Some suggestions made at the end of the paper for improving the accuracy of the method include; 1) Capturing more images down the profile to get a better idea of what is happening in each horizon. 2) Using a photo camera with a "macro" lens to capture the images and importing them through a PhotoCD into the computer. The authors suggest this will improve the image resolution (<0.4 mm).

"A rapid and effective methodology for the quantification of soil structural parameters" *Ch. Porath, H. Diestel and H-J Wolf. (Germany)*

This paper was based on using image analysis techniques on quantifying soil structural parameters for showing relationships between the morphology of the larger pores and saturated flow through the soil. The paper outlines a set of quantitative indicators for the relationships between the morphology of the larger voids and saturated flow.

The basis for the methodology is an interrelated set of computer programs for personal computers with which digitised images are processed. The necessary numerical material can be produced in different ways, two are discussed in the paper.

Morphological information of soil structure can either be obtained from undisturbed soil through computer tomography (CT), which also permits repeated investigations on the same sample. More accurate information on soil structural morphology can be obtained by scanning polished sections of hardened and sectioned soil cores which have been impregnated with a resin to which a fluorescent dye has been added. Both methods yield valuable information.

In the investigations with CT based evaluation, the program allows you to choose the direction and the inclination of the image planes analysed, as well as their distance and the evaluated image segment. This is valid independent of the planes which were originally scanned by the tomograph. At present, a reliable resolution of details of the image can only be obtained down to 1 mm per pixel.

Evaluation of the polished soil sections proceeds by illuminating the soil sections with ultraviolet light by which the inter aggregate voids become visible. The surface of the sample is then photographed with a high resolution camera, the photographs are developed and then scanned into the computer.

The data elaborated in both procedures of soil structural analysis are converted in order to allow the visualization of the images and the calculation of morphometric parameters. In order to allow the processing of the CT data on any common personal computer the number of grey levels had to be reduced. However this disadvantage is offset by the flexibility given in the program which allows to specify the range of grey levels which is of special interest in the structural investigations. In addition, it is possible to select the sector of the image which is to be analysed. An additional program is the basis for the pixel by pixel calculation of relevant morphometric parameters, during which procedure the image which is being worked at appears on the screen of the personal computer.

A great variety of parameters could be quantified rapidly on personal computers with this procedure. In this study, the volume, the surface and the hydraulic radius of the inter-aggregate voids were calculated. In Distel (in print) it had been demonstrated that these parameters show in laboratory studies, relationships to hydro-mechanic parameters with which saturated non Darcy flow. Thus it is necessary to confirm these findings in the field, a task which can only be accomplished with data evaluation procedures as the one described here.

DISCUSSION:

The techniques used by E. Sampaio *et al.* in Portugal are surprisingly similar to those used by E. Roesner *et al.* in Australia. To compare the methods, a brief summary of the two techniques is given in Table 1. below.

Table 1. Comparison of two techniques of quantifying soil structure (Portuguese - E. Sampaio *et al.* & Australian - E. Roesner *et al.*)

Technique	Portuguese	Australian
Dye used:	Gypsum & water	White paint
Sample size:	50 cm^2	25 cm^2
Captured with:	Colour video camera (suggest photo camera with PhotoCD)	Normal camera with colour slide film
Pixel resolution:	0.442 mm^2	< 0.1 mm^2
Image used for analysis:	Greyscale	Colour
Type of segmentation:	One threshold on greyscale image	Threshold on colour image
Measurements made:	On individual pores, shape factor used to classify pore types	Over entire image
Measurements are:	Total area (mm^2) Minimum area Maximum area Rate (area/mm^2) Number of voids	Porosity (mm2/mm2) Pore star length Solid star length Surface area (other measurements are also made but not in this paper)

White dyes are being used by both as a contrast to the dark soil, the gypsum may have the advantage of not entering small pores, (i.e. those smaller than the size of the gypsum powder) and therefore be better at highlighting the macropores. The sample size used is larger in the Portuguese method which gives better representation however it means the resolution is not as good. The difference between using colour or grey scale images is in the quality of the segmentation. Colour segmentation should give higher quality binary images. Using a normal camera gives better resolution than the video camera where the image size is limited to 512×512 pixels. The reason discrete pores are not measured in the Australian images is because in the real three dimensional soil matrix, the pores are often interconnected and making the assumption that the pores in 2-D relate to the 3-D volume is not true unless the pores are all symmetrical channels. The image represents one two-dimensional slice of the soil and as the pore matrix is three dimensional, in one slice of the soil you may be looking at several branches on the same pore. In the Australian calculations, rather than looking at the individual pores and making measurements on them, the entire image is measured and the attributes are averaged, this also helps to compensate for the huge variability that exists in each image.

The German paper was particularly interesting because although it also used measurements on discrete pores, the measurements related the structural attributes to saturated (non-Darcy) flow (e.g. hydraulic radius of inter-aggregate voids). They used a technique very similar to the resin technique (E. Roesner *et al.*) for acquiring images as well as computer tomography. The resolution of the CT pixels is limited to 1 mm per pixel. The practicality of using this technique in soil structure research in Australia should be looked into further.

OTHER RELEVANT RESEARCH:

IMAGE ANALYSIS:

Soil macroporosity continuity evaluated by a fast image analysis technique from Portugal. E. Sampaio *et al.* (2a:90) *(Already reviewed)*

A rapid and effective methodology for the quantification of soil structural parameters. C. Porath *et al.* (Germany) (2b:122) *(Already reviewed)*

Porosity quantification of a basalt weathering profile using back-scattered Electron Scanning Images. A. Dekayir *et al.*(France) (2b:84) *Image analysis is used to study the process of mass balance and weathering by the evolution of the bulk porosity as well as the pore size and shape distribution. Thin sections were looked at under electron microscopes and grey level images of were used to identify pores, clays, plagioclases, Fe-Mg minerals and Fe-Ti minerals. The pores were characterised with a shape factor $SF=p^2/4ps$ and shape classes were used to determine the weathering stage. Pixel resolution 0.3 mm.*

Effect of root growth on groundmass porosity. A. Bruand *et al.* (France) (2b:86) *Image analysis is used to look at the cause of the decrease of porosity and to show that it results from a strong compaction of the ground mass fabric around the roots. Horizontal thin sections are used under electron microscope to look at root cross-sections. A "zone 2" was identified which was 40-60 mm from the pore wall of wheat and 150-300 mm from the pore wall of maize that was significantly higher than the groundmass fabric.*

Image analysis of the main horizons of an Oxisol/Utisol toposequence. V. Hallaire *et al.* (Brazil) (6b:94) *Quantitative analysis of macroporosity of main horizons are made in relation to their micromorphological characteristics using image analysis. Large thin sections (16 × 9 cm) embedded with fluorescent resin were taken in order to quantify macroporosity. Images were digitised in a hexagon grid of 512 × 512 obtaining a pixel resolution of 25 μm. Grey level images were segmented into three levels, according its histogram, (i) solid, dark (ii) interaggregate macropores resulting from the microgranular structure of the soil, dark grey, (iii) packing voids and vughs biological or dissolution voids, light grey. A shape index was used for this third class to allow elongated cracks and rounded vughs to be distinguished. The quantitative analysis was made on each soil type which emphasised the genetic transformation in the Oxisol/Utisol toposequence: (i) evolution of microstructure from B1 to Bt corresponds to a decrease in interaggregate porosity, (ii) structural and mineralogical transformation from Bt to A2 which results from surface water activity that induces hydromorphology and eluviation processes, correspond to an increase in vugh porosity and interaggregate porosity.*

DYING SOIL:

Dye-tracing study of preferential flow in Vertisols. H.S. Lin *et al.* (USA) (2b:171) *'Standard Blue' and 'Rhodomine Red' dyes were used to trace water flow in vertisols to see where the water has moved to and how the wetting front advances in structured soils. Disc permeameters were used to supply the dye solution to the soil. Immediately after infiltration stopped the soil was excavated to reveal dye flow patterns and soil morphological features. Photographing and accurate traces of the stained dye patterns were made of exposed vertical/horizontal sections on clear plastic sheets. Information on the plastic sheets was then digitised into a computer through a GIS for further analysis. For the purpose of comparison, a computer model was developed to simulate water flow in homogeneous* *and isotropic soil. Results showed that most dyes moved along slickenside fissures and root channels, while the soil bulk matrix was not dyed. Slickenside fissures and root channels were very common in this soil and they generally had a width/diameter ≤ 1 mm. This flow permitted rapid water movement to about 100 cm depth in ~20 hours, which is much deeper than was predicted by current flow equations. However not all slickenside fissures and root channels contribute to the bypass flow, conducting pores must have connection to the infiltration intake area. In the upper 20 cm of the pedon, the soil had strong very fine subangular blocky structure, therefore interpedal pores were effective in water movement while pores in the ped interiors were not conductive. Other connective pores included living roots and desiccation cracks. This highlights one limitation to extracting soil hydraulic properties from current water flow measurements as the simplified assumption that the soil is uniform and homogeneous. Macropores and mesopores are the preferential flow conduits.*

SOIL STRUCTURE:

A run off index for assessing soil structural degradation. G.W. Geeves *et al.* (Australia) (2b:126) *Here a soil structural index which uses a mechanistic soil water simulation model (SWIM; Ross, 1990) is proposed. The soil model was parameterised with measured soil moisture characteristic and near-saturated hydraulic conductivity data for at least two soil layers. Runoff was predicted during a single "design storm" rainfall event of 30 minute duration. The storms were designed using long term climatic records and had site specific rainfall intensity and temporal distribution. The runoff was found to be a sensitive process related indicator of the soil physical condition. A simple index, the volume fraction of channels or voids greater than 100 mm in equivalent diameter (macroporosity) was compared with the new runoff index. Where a number of sites had similar simple index results (macroporosity), the runoff values were found to be quite different. This is because the runoff index considers the interaction between structural condition and the characteristic of the storm event for each site whereas the simple indicator does not. Sites with poor soil structure, poor water entry and thus limited potential agricultural production were identified. Other soils showed a low runoff potential under woodland and well managed pasture, but much increased runoff after extended periods of intensive cropping.*

The least limiting water range and index of the structural quality of soils for crop growth. A.P. DA Silva *et al.* (Canada) (2b:129) *The least limiting water range (LLWR) is the range in water content in which limitations associated with water potential, lack of aeration and mechanical resistance are minimal. This study evaluated it as a potential index of structural quality. Undisturbed soil cores were taken from 0 - 20 cm and 20 - 40 cm depths and each sample was equilibrated to a specific water potential and measurements of water content at equilibrium, soil resistance, air filled porosity and bulk density were taken. The soil water release curve and the soil resistance water content curve were described by functions and multiple regression procedures used to relate the coefficients in the functions to bulk density, clay content and organic matter content. TDR probes measured moisture content on a daily basis at the same depths. The response of corn was assessed by measurements of leaf extension during growth and final yield. The water potential at which aeration and potential were limiting were defined as the water contents at 10 % air filled capacity and 1.5 MPa respectively. These data can then be used to predict the variation in least limiting water range with bulk density for this soil. Data on the spatial and temporal variation in soil water content was then used to determine the probability of the soil water content falling outside of the least limiting range and these probabilities related to crop response.*

Structure assessment to two agricultural soils from lower Austria. N. Rampazzo *et al.* (2a:131) *The aim of this study was to assess the structural status of two soils using structural parameters*

as described and grouped during the multilateral cooperation project "Assessment of soil structure in agricultural soils" between Austria, Czech-Republic, Hungary, Poland and Slovakia (1991-92). The bulk soils were air dried and sieved at 2 mm mesh size. For density, porosity and hydrological properties, 200 cm^3 undisturbed cores were taken. Chemical analyses: pH, Electrical conductivity, carbonate, exchangeable cations, CEC, total and organic carbon. Physical analyses: Particle size distribution, bulk density, total porosity, pore size distribution, saturated hydraulic conductivity. Mineralogical analyses. Semiquantitative analysis by X-ray diffraction of untextured soil powder patterns and of textured clay patterns using Cukα-radiation, determination of Na-dithionite-citrate-bicarbonate (DCB) - soluble, NH4 oxalate-soluble and Na-pyrophosphate-soluble contents of Fe, Al, and Mn. Micromorphological analyses: determination of microstructure on soil thin sections.
The alkaline pH, the low electrical conductivity and the high calcium saturation are favourable parameters for aggregation in both soils. Mechanical soil compaction under the ploughed layer is recognisable through the higher bulk density and lower total porosity. The tillage compaction destroys mainly the "secondary" structure-induced pore system.

SOIL COMPACTION:

Compaction of a volcanic ash soil after forest harvest. A.Gómez & K. Oleshko (Mexico) (2b:100) *Here the aims were to evaluate the compaction of a pine forest following logging and to examine and interpret variograms of the mechanical strength of the soil. A penetrometer was used to describe the soil compaction. Also soil was sampled for gravimetric water content at 10 cm depth. Five undisturbed samples of soil were taken using synthetic resin, the diameter of the pores was determined by using a Carl Zeiss microscope. Significant differences were found between harvested and unharvested sites. However, the penetration resistance that ranged between 65.7 and 111.6 kPa was low compared to the 3000 kPa that was found to be limiting for the root penetration of "Pinus radiata". Pore size was similar in both treatments and resistance to penetration was independent of water content in the range sampled. The variogram was used to find the optimum sample spacing which for penetration resistance would be 40 m.*

The effect of the use of microstructure and of the texture in compaction of Oxisols. K.L. Maltoni *et al.* (Brazil) (2b 102) *The aim of this paper was to try and forecast the susceptibility of the soil to compaction by means of granulometric and ideal curves. Soil analysis undertaken included, soil reaction, organic matter, amorphous iron, free iron and aluminium, total analysis, quantification of the minerals of the clay fraction, bulk density and micropores, texture, microaggregates and granulometric and ideal curves. The ideal curve described by the "Fuller equation" was found to be a good indicator of the potential compactability of the soil, when the granulometric curves of the soil were close to the ideal curve the larger the compaction potential.*

Sensitivity to compaction of central amazonian hasin soils. Role of mechanical and water stresses. J. Tavares Filho *et al.* *(Brazil/France)* (2b:98) *Looks at the compaction mechanism under mechanical comparison of clayey oxisols prepared at various water potentials and their subsequent behaviour as a function of their wetting-drying history. Undisturbed clayey oxisols were prepared at five moisture potentials between -1 kPa and -1000 kPa they were then compacted in an oedometric cell in the range of pressure from 3.2 to 1 MPa. Samples were then subjected to a complete wetting and drying cycle. Change in the total pore volume is measured in terms of the void ratio of the volume of voids to the volume of solids. Undried aggregates were also examined with the TEM in order to* *characterise the nature and arrangements of the constituents and the location of organic matter. They found that a relatively small pressure (20 kPa) seemed sufficient to collapse the soil macropores. This was because of low content of iron oxides cementing clay particles, which generally give a certain physical resistance.*

Factors affecting compaction behaviour of South African forestry soils. C. W. Smith & M. A. Johnstone (2a:96) *The aims of this paper were to investigate which easily measured soil properties are related to the compaction characteristics of forestry soil behaviour under conditions of varying applied stresses and moisture contents. For each soil type sampled, compressability, under short duration static load, water-pressure-density (WPD) and maximum bulk density (MBD) were measured. Compression indices (CI) were evaluated from the slope of the straight line portion of the curve when bulk density is plotted against the log of applied stress. Soils most sensitive to compaction were those having both high MBD and high CI values. Parent material was closely related to physical properties which are significantly correlated to with indices of compaction sensitivity, it was proposed that local geology is a useful guide to estimating the risk of compaction of forestry soils in the absence of detailed soil maps.*

Stress distribution in partly reloosened arable soils. R. Horn *et al.* (Germany) (2a:94) *Stress state transducers (SST) are used here to look at the effect of a "slot plough" procedure in reducing compaction. Although the plow can be used to partly ameliorate the compaction, with the advantage of a better conservation of the reloosened soil volume inside the slot, the data also underlines the increased sensitivity of this treated soil for recompaction under wetter soil conditions.*

Soil compaction: Effects on structure and porosity. E. Bricchi (Argentina) (2a:92) *The structure of a Typic Haplustoll (coarse loam with low organic matter) was studied using a callipers and a magnifying glass. The frontal face (x), lateral face (y), and height (z) of peds were measured. The equation; z/(x+y/2), was used in order to define the shape and size classes. The quantity and orientation of planer and tubular voids larger than 0.5 mm were measured and an estimate of the proportion relative to each ped was made. There was a gain in bigger soil blocks after compaction also, pore sizes larger than 0.6 mm are reduced. There is a scarce relative proportion of vertical tubular voids and also the presence of planar horizontal voids and a 80-90% reduction in the hydraulic conductivity in the top 18 cm.*

Porosity in clay and organic soil as affected by heavy traffic. Short -term effects. L. Alakukku (Finland) (2a:88) *Effects of heavy axle loads on soil are studied at field capacity after three years. Porosity was measured by taking 200 cm^3 soil cores and using the drying water retention curve to discover the soil pore distribution. In the topsoil (0.1 m - 0.2 m) of the clay, traffic tended to decrease the volume of pores larger than 0.03 mm. In the subsoil the porosity was similar every year, both soils were compacted to a depth of 0.5 m. In the clay soil the traffic only decreased the pores larger than 0.3 mm. The structure of the clay was good before the compaction. There was a lot of biopores in the soil and they seemed to be able to stand the heavy traffic. The heavy traffic was not found to change the porosity greatly in the organic soil. The traffic destroyed pores larger than 0.3 mm. The extent of organic decomposition would have an effect on the amount of compaction that occurred in the organic soil.*

Factors of Transformation and Geographical Peculiarities on Compaction Manifestation in Vertisols (Russia) (2b:104) *Looks at the difference between potential compaction (PC) and actual compaction (AC). PC is the state of physical properties in the C horizon whereas AC is characterised in the A horizon. Actual compaction only reflects the swell-shrink processes and depends on the realisation of potential compaction in a concrete regime of wetting and drying, that is, from climate, relief, vegetation cover, ground water depth and microrelief. Morphological analysis and a range of*

analytical parameters were measured to determine the degree of AC and PC. The PC appeared to be dependant on the intensity of marine smectite clays transformation during the soil formation. The degree of PC is decreased both in soils with a more mature profile and in young alluvial soils.

SYMPOSIA IN WHICH OTHER COTTON RESEARCHERS MAY BE INTERESTED:

Ia - Impact of intensive irrigation practices on degradation of soil quality.

Ib - Soil Physics and environmental protection.

IIb - Soil chemistry and the environment.

IIIa - Rhizophere microbiology and plant growth and health.

IIIb - Role of biota in sustainable agriculture.

IVb - Integrated nitrogen management in relation to leaching and ground water quality.

Vb - Modelling soil genetic processes.

VIa - Soil technology for sustainable agriculture.

VIb - Agrotechnology productivity, energetical efficiency and environmental issues and sustainable agriculture.

A - Impacts and hazards of salinization on ecological, environmental issues and sustainable agriculture.

B - Micromorphological indicators of anthropogenical effects on soils.

C - Assessment of long term soil degradation and rehabilitation. Field methodology and modelling.

ID-1 - Soil testing and plant analysis: Methodology and interpretation.

ID-2 - Stressed ecosystems and soil resilience.

ID-5 - Research for maximum yield in harmony with nature.

ID-6 - Options to slash and burn agriculture.

ID-9 - The role of soil science in the design and implementation of landuse and soil conservation policies

ID-10 - The use of nuclear and related techniques in soil -plant studies for sustainable agriculture and environmental preservation.

ID-15 - Soil data needs for expressing land qualities at different scales.

ID-19 - Fertilizer technology and its efficient use for crop production.

ID 20 - Interactions of soil components, agricultural ecosystems and health issues.

ID-21 - Representing soil spatial variability in GIS for resource assessment and environmental modelling.

Measuring the Impact of Intensive Irrigated Cotton Production in Australia - Using New Methods of Image Analysis to Detect the Degradation of Soil Structure

E.A. Roesner, A.J. Koppi & A. B. McBratney *Department of Agricultural Chemistry and Soil Science, The University of Sydney, NSW, 2006, Australia*

Introduction

One major limiting factor in any intensively irrigated agricultural crop is the degradation of soil by compaction. During cotton production in northern NSW, Australia, intensively irrigated soil can become compacted from heavy traffic passes. This compaction can cause declines in yield due to the restriction of root growth. The most common soil type in which furrow irrigated cotton is grown in Australia is the cracking clay (Vertisol); this soil is weak when wet and is prone to damage by machinery.

It is considered worthwhile in Australia to investigate techniques for detecting the extent of this degradation so that prevention or remedial action can take place. There is a need for a scientific, versatile and dependable routine analysis method to measure soil structure so that consistent, reliable measurements can be made.

There are various methods in use to measure the extent of compaction in a cracking clay. Traditional techniques such as bulk density and air filled porosity measurements have been used but they do not fully characterise the structure of the soil (1). Improved laboratory methods such as air permeability, oxygen diffusion and clod shrinkage have been applied but they don't relate well to plant performance partly because of biased sampling that tends to exclude the important macropores such as cracks and root channels (2).

Image analysis techniques have been used recently with success to quantify the state of the soil structure (3 & 4). Here "image analysis" includes the field sampling and image capture as well as the processing and analysis of the image. This is because so much of the final analysis depends on how each step of the process is carried out.

Image processing, measurement, suitable laboratory and field methods, as well as sensible models of soil geometry provide powerful new techniques for visualising and measuring soil structure. The techniques used are suitable for investigating the effects of tillage systems, crop rotations, increased traffic and irrigation practices on soil structure. The digital images allow for the direct measurement of total macroporosity, surface area, pore and aggregate size and distribution.

The general technique used for creating images for structural analysis involves: 1) saturating soil samples with a fluorescent resin to highlight the pore space; 2) leaving the samples to harden; 3) grinding smooth and 4) photographing under UV lights. The images are digitised by using a scanner and then segmented into binary images representing pores and aggregates. The binary images are analysed to quantify the soil attributes and relate them to the visual assessment. The established method of impregnation (5 & 6) is labour intensive; it takes at least two days of field work followed by approximately 2 hrs per sample of laboratory work (reimpregnation, grinding and photography) before images can be analysed.

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A new quicker and easier method proposed here (based on earlier work,(7)) involves the use of acrylic paint for discriminating between macropores and solid soil. Once the paint has permeated the soil (overnight), the saturated layer is removed and a photograph taken of the exposed, highlighted soil structure. The ability to acquire good quick images of the soil structure means that management decisions can be made promptly. The advantage of this method is that no laboratory work on the soil needs to be done after field work, the film is simply developed, digitised and analysed.

Materials and Methods

Experiments were conducted at Auscott, Pty. Ltd. in Warren, NSW, Australia (148°50′ East; 32°40′ South). To provide contrasting physical conditions, the techniques were compared under artificially compacted and well-structured (uncompacted) soil on which cotton plants were grown. 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 – Vertical

For the vertical resin samples, foam rubber (~25 mm thick) backed with particle board (600×150 mm), was stuck onto the vertical face of a soil profile close to field capacity water content with quick-setting araldite resin. When the araldite had set, these boards were cut out with approximately 100 mm of the soil-pit face still attached. The samples were then placed horizontally, unsmeared and impregnated with a resin containing UV sensitive dye. The epoxy resin takes about 24 hours to completely cure but samples were wrapped and transported after approximately 12 hours. The hardened samples were ground back so that only dye that is obviously in pores is present and then photographed under UV lights in the laboratory. This method is fully outlined, including the formulation of the resin used, elsewhere (3 & 5).

Resin technique – Horizontal

For horizontal samples, loose soil and cotton plants were cleared leaving a level surface approximately 150 mm below the natural surface of the ridge. The new surface was unsmeared using an araldite peel (8). A square wire frame (250 × 250 mm) was placed over a cleared area of soil on top of the ridge to define the area of interest. The same resin as for the vertical section was made up and poured slowly inside the wire frame. The resin was allowed to infiltrate and then was topped up until the surface was saturated. The samples were left overnight and carefully dug out and wrapped for transportation. In the laboratory the samples were turned upside down and resaturated with resin for extra strength. These samples were finally ground horizontally and photographed as for the vertical method.

Paint Method – Vertical

To stain pores with paint in a vertical section, 150 mm auger holes were dug ~700 mm deep, about 200 mm from the vertical edge of a soil pit. The surface of the auger hole facing away from the pit was unsmeared to encourage lateral movement of paint in this direction. The smeared surface retards flow in other directions. A plastic pipe closed at the bottom was filled with soil for weight and placed down the auger hole to save on the amount of paint used. The rest of the hole was filled with diluted white acrylic paint (3:7 paint:water) from a Mariotte bottle which kept the hole filled with paint until the bottle was empty (Fig. 1). The paint was left to infiltrate overnight prior to excavation from the pit to the infiltrated surface. This surface was carefully picked back to expose the areas where paint had infiltrated. Colour photographs were taken of this vertical face in the shade using 35 mm slide film.

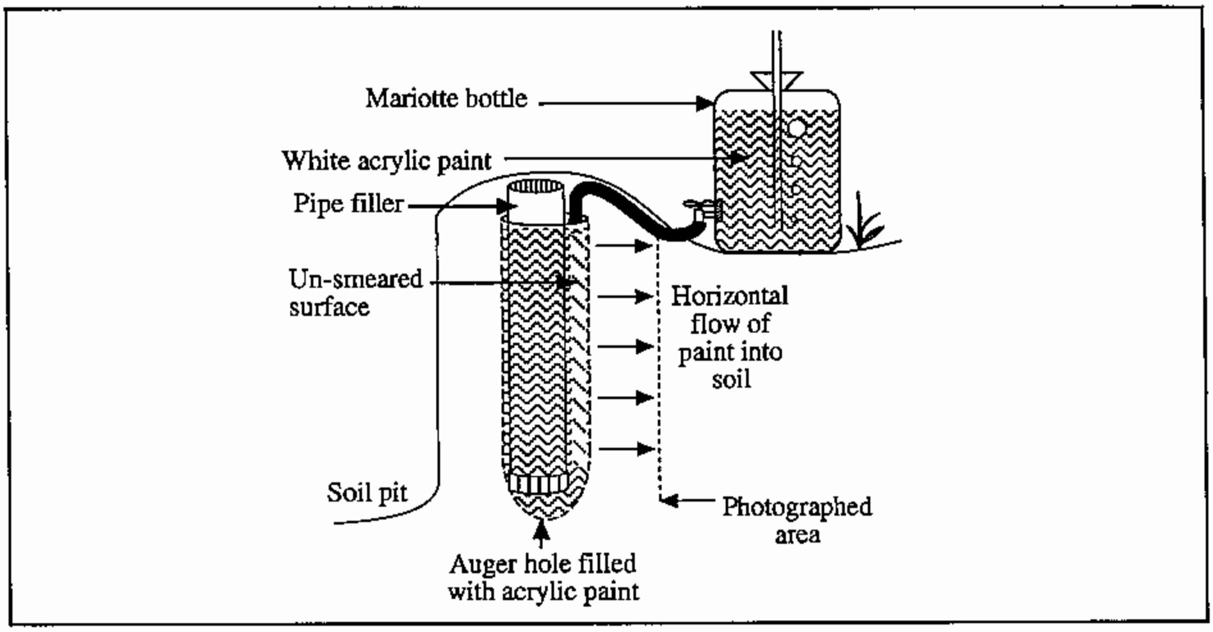

Figure 1. *Field layout for Vertical Paint method showing set up of equipment and position of photographed area.*

Paint Method – Horizontal

The horizontal method is simpler than the vertical method when taken close to the surface because little digging is required. Square frames (250×250×150 mm deep) were pressed into a cleared, unsmeared surface within the ridge. Diluted paint solution was poured into these frames and left to infiltrate overnight. The saturated layer was removed, and the soil unsmeared to obtain a photograph (in the shade) of the paint-infiltrated soil surface.

Image capture

Photographs were taken using Ektachrome ASA 100 slide film. All photographs of the pore-stained soil had a scale 200 mm for horizontals and 400 mm for verticals. The slides were scanned into the computer at the same relative scale using a digital slide scanner. Vertical images are represented by 1688 × 422 pixels and horizontals by 1022 × 1022 pixels.

Segmenting digital images

The images were segmented with new software developed to improve the binary image output. Previously, software used grey-level images with a single threshold for large elements and a "top-hat" transformation to estimate smaller elements of the image (3). The new segmentation procedure involves the use of colour digital images. Areas of the colour image representing either pore or solid were selected and identified as either part of a "pore" or "solid" class. The programme automatically finds the threshold between the two classes and converts the image to black and white. These binary images are realistic when compared to the original photograph.

Analysis of binary images
The binary images are analysed to give the quantitative data relating to the soil macroporosity, surface area, solid and pore sizes. The analyses described below are detailed elsewhere (4).

For vertical analysis, the raw data is taken from the binary 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, with an assumption of isotropy, i.e., the structure is isotropic in any plane normal to the vertical. In this way the structural attributes are analysed as functions of depth.

Macroporosity ($mm^3\ mm^{-3}$) was estimated as the proportion of pore pixels along each line. The surface area ($mm^2\ mm^{-3}$) is an estimate of interfacial area between pore and solid in a given volume of soil. Surface area is estimated from the number of intercepts 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 is given elsewhere (4).

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

Results
Vertical Results
The images shown in Fig. 2 are representative binary images produced from the vertical methods in the compacted and uncompacted sample areas. The images represent 400× 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 star lengths generally showed significant differences between compacted and uncompacted treatments but not for the differences between paint and resin, thereby suggesting that either method can be used distinguish between the soil structures. The only exception was with the pore star lengths where no differences were found between samples, indicating that pores are of a similar size.

Fig. 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 uncompacted treatments (they show the probability of treatments being the same, where 1 = same, and the the vertical line shows the 95%

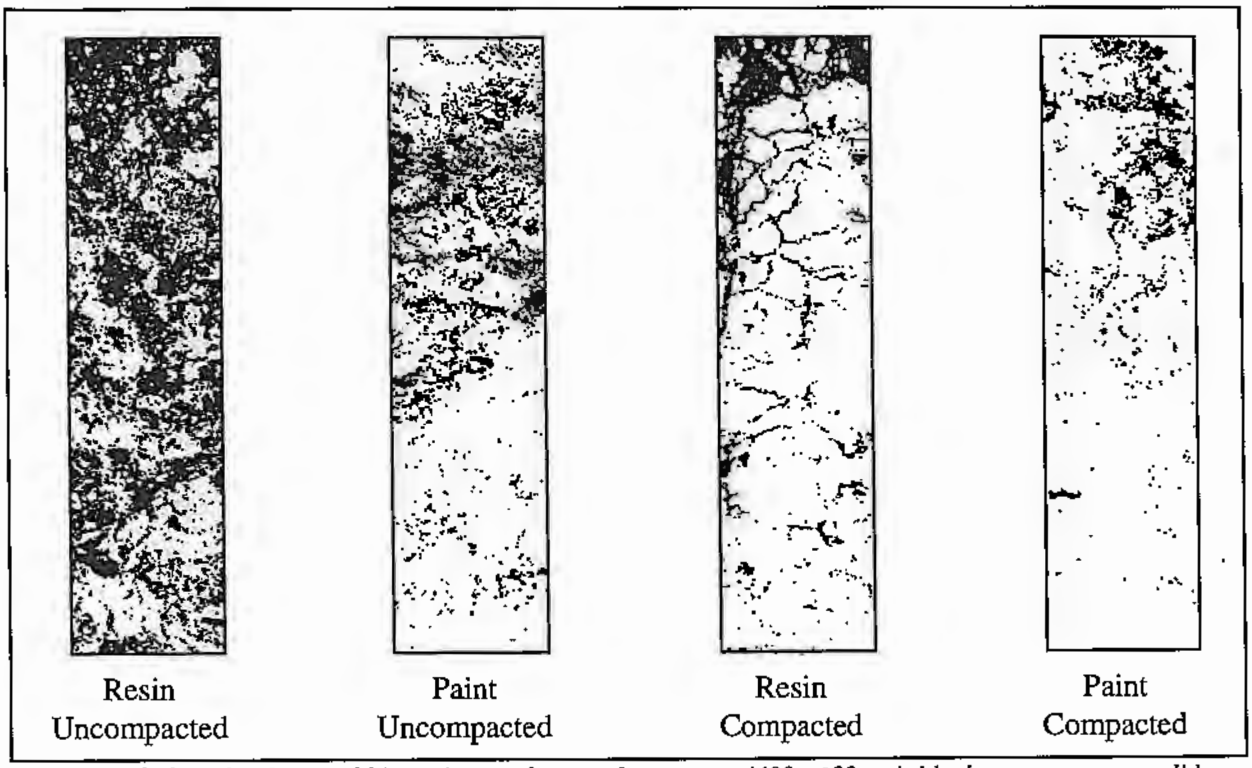

Figure 2. *Sample of vertical binary images from each treatment (400 x 100mm), black = pore, grey = solid*

confidence interval). Here the paint technique does not tend to detect the difference between compacted and uncompacted 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 that had a lot of resin throughout. By removing this one sample from the analysis, more significant results were obtained.

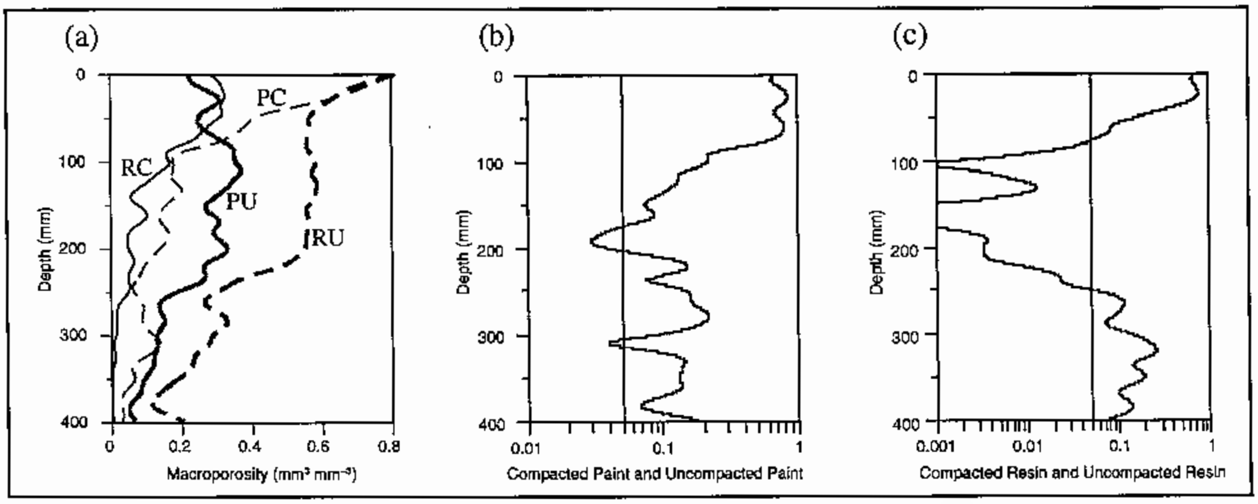

Figure 3. *Analysis of vertical macroporosity* (a) *Means of two field techniques on compacted and uncompacted treatments;* – – *Compacted paint (PC) method;* —— *Uncompacted paint (PU) method;* —— *Compacted resin (RC) technique;* – - *Uncompacted resin (RU) technique.* (a) & (c) *Probability graphs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

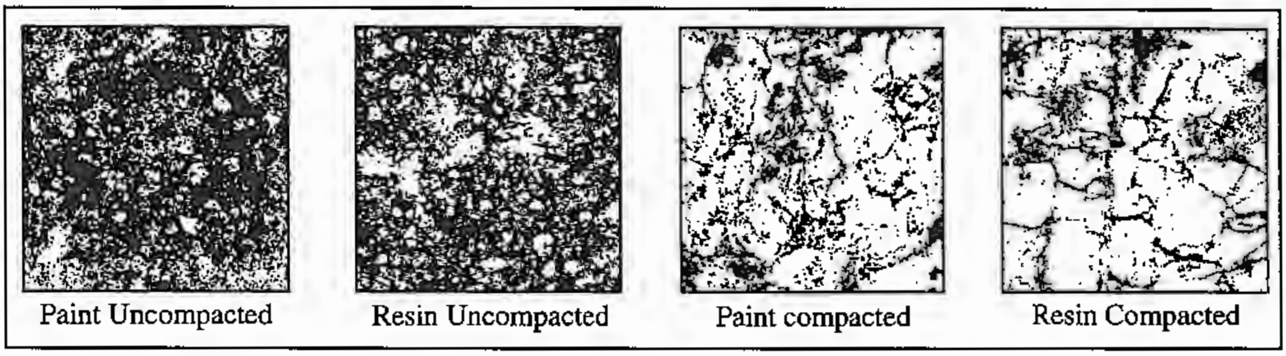

Figure 4. *Sample of horizontal binary images from each treatment (20 cm x 20 cm), black = pore, white = solid.*

Horizontal Results

Fig. 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. Also that 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 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.

Neither the paint or resin method attempt to quantify soil pore structure fully but aim to recognise and measure aspects of soil 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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