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Study tour report research on soil structure and its relationship with cultivation practices in south east Queensland

C W L Henderson
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Study Tour Report Research on Soil Structure and its Relationship with Cultivation Practices in South East Queensland

C.W.L. Henderson

Resource Management Technical Report No.40
Disclaimer

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1 Introduction

A five day study tour of the Queensland Wheat Research Institute (QWRI), Queensland Department of Primary Industry Toowoomba Regional Office and J. Bjelke—Petersen Research Station was conducted between the 21st and 25th January 1985. A visit to the University of Queensland (U of Q) was made On the 18th January 1985. A detailed itinerary is given in the Appendix.

The aim of the tour was to examine research into the effects of farming practices on soil physical characteristics, and to assess results and investigative techniques that may be applicable to the Western Australian situation. This report details research projects that were reviewed on the tour, with a short discussion of some of the ideas and results presented.
2 Research Areas

2.1 Surface structure development and stability of clay soils.

Research into the mechanisms and forces involved in the development of surface structure on the Black Earths (095.1) that make up a large proportion of the soils of the Eastern Darling Downs has been carried out by Drs G. Smith, K. Coughlan and others for many years.

Surface properties of some Darling Downs Black Earths are shown in Table 1 (from Smith et al 1984). Research results suggested that although organic matter was significantly correlated with aggregate porosity, it was not related to final aggregate size after a series of wetting and drying cycles (Coughlan and Loch 1984). The properties of the clay dominate the effects of organic matter on aggregate size distribution (Smith pers. comm.).

Table 1

<table>
<thead>
<tr>
<th>Soil</th>
<th>pH</th>
<th>EC</th>
<th>OC</th>
<th>CS</th>
<th>FS</th>
<th>S</th>
<th>C</th>
<th>CEC</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>WC_{0.33}</th>
<th>WC_{15}</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7.6</td>
<td>7</td>
<td>1.2</td>
<td>6</td>
<td>18</td>
<td>17</td>
<td>58</td>
<td>46</td>
<td>13.6</td>
<td>26.1</td>
<td>1.8</td>
<td>1.5</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>8.2</td>
<td>15</td>
<td>1.3</td>
<td>2</td>
<td>17</td>
<td>15</td>
<td>65</td>
<td>66</td>
<td>39.5</td>
<td>23.5</td>
<td>3.1</td>
<td>1.7</td>
<td>54</td>
<td>29</td>
</tr>
<tr>
<td>11</td>
<td>6.8</td>
<td>12</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>12</td>
<td>80</td>
<td>60</td>
<td>28.7</td>
<td>28.7</td>
<td>1.6</td>
<td>0.8</td>
<td>49</td>
<td>30</td>
</tr>
</tbody>
</table>

Some properties* of the 0—10ccm layer of selected Queensland Vertisols.

*pH = glass electrode, EC = electrical conductivity (ms/m) both in a 1:5 soil: water suspension.

OC = organic carbon (%), Walkley—black method.

CS = coarse sand (%); FS = fine sand (%); S = silt (%); C = clay (%).

CEC = cation exchange capacity (m equiv./100 g) at pH 8.5.

Ca, Mg, Na, K = exchangeable cations (m equiv./100 g).

WC_{0.33} = water content at —0.33 bar. WC_{15} = water content at —15 bar.

Yule et al (1976) correlated seedling establishment difficulties with the proportion of dry aggregates over 5mm in diameter, with more than 40% large aggregates causing problems. Coughlan and Loch (1984) developed predictive equations that related aggregate size distribution to exchangeable sodium percentage (ESP), cation exchange capacity and clay content. Conclusions drawn from this are that good seedbed conditions are favoured by highly active clay minerals, and that management
practices to mitigate cloddiness need to reduce ESP and/or clay dispersion (Smith et al 1984).

Considerable studies on aggregate stability and formation under different wetting and drying cycles have been conducted. Slaking is not thought to be of great importance in developing adverse soil conditions, unless breakdown products act as fillers and bonding agents between aggregates. Some slaking may in fact be desirable in breaking down large clods (Smith et al 1984). Coughlan et al (1973) developed a concept of a critical water content (the Disruptive Moisture Content DMC) above which clay is readily dispersed. This theory suggests that soils with a high CEC, which increases the DMC, should be more stable, a hypothesis supported by field observation. Trapped air effects on aggregate breakdown appear to be negligible, but rainfall energy is said to play a critical role in clay dispersion. Simulated rain reduced the percentage of aggregates > 1mm diameter to less than 10%, compared to 63% after gentle immersion, indicating the destructive effects of rainfall energy (Loch and Smith, unpublished).

Conditions favouring self mulching of these soils are gentle rainfall and rapid, intense drying (Coughlan 1984). Surface aggregation is due to differential swelling and shrinking, and the breakdown of large aggregates is considered beneficial, provided it is not accompanied by clay dispersion. Aggregation mechanisms are mainly governed by inherent soil properties, but there may be scope for influence by management. Stubble retention can reduce rain energy and hence clay dispersion, but could also reduce the rate of drying, and hence increase cloddiness (Loch and Coughlan 1984). Soil amendments such as gypsum show potential to counteract dispersion and hence reduce dry aggregate size (Smith et al 1984).

Current work is looking at developing tests to predict the behaviour of Slack Earths under different management practices. A test for gypsum responsiveness involving simulated laboratory rain is also under investigation, in conjunction with field trials looking at the effects of gypsum on drainage, infiltration, seedling emergence and the longevity of response. At present the decision to apply gypsum is based on field observation of surface structure and emergence problems.

Research into the effects of long term tillage on soil properties, both physical and chemical, is being conducted in association with the University of Queensland, primarily by Dr R. Dalal (QWRI) and Mr G. Cooke (U of Q). Work is still at an early stage, and is looking at soils that have been cultivated for a range of periods, varying from greater than 80 years to less than 5 years. The general technique is to regress a soil parameter against period of cultivation, to study rates of change as well as absolute difference. Dr Dalal is concentrating on chemical factors, such as organic matter, CEC, ESP etc, while Mr Cooke is investigating physical characteristics like dispersible clay, aggregate stability, bulk density, and others. Preliminary results suggest that the higher clay content soils such as the Black Earths have a much slower decline in organic matter content with years of cultivation than the sandier soils such as the Red—Brown Earths and Red Earths, which drop to a low equilibrium organic matter content after only a few years cultivation (Dalal pers comm.).
Dispersible clay also seems to increase with years of cultivation, particularly in the Black Earth soils of the Eastern Darling Downs (Cooke pers. comm.).

### 2.2 The process of soil compaction and its effects on crop growth.

Soil compaction was not thought to have been important on the cracking clay soils, because it was considered that the self mulching characteristic would naturally ameliorate any compacted layer that developed. Recent research on the Darling Downs has indicated that it can be a problem on heavily cropped soils, and where traffic on wet soils is frequent. Similar results are reported for the cotton growing areas of New South Wales (Ralph 1984). An investigation of the occurrence of soil compaction under cotton in the Emerald area of Queensland by Dr So from the University of Queensland showed evidence of compacted layers in these Black Earths, both by pedological appraisal and objective measurement. Root morphology also suggested a strong mechanical limitation to root growth, but the significance of this limitation to crop yield was not investigated, due to lack of funding.

A research program on soil compaction on the Darling Downs has been instigated by Dr So. An experiment conducted in 1984 examined the response of irrigated french beans to a compacted soil layer at one of three depths. Soil compaction lowered yield in all cases, except when a small amount of compaction was induced at the surface. This latter treatment gave maximum yield, possibly due to increased water and nutrient content per unit volume of soil, as well as better root/substrate contact.

Current research is investigating legume species and surface compaction interactions, in order to explain the poor performance of pigeon pea on the Black Earths. Three species, in ascending order of drought tolerance — pigeon pea, soy bean, and mung bean, are being assessed under a range of surface compaction conditions. It is hypothesised that a compaction effect on root growth may be inducing increased drought stress on the more sensitive pigeon pea plant.

The question of natural amelioration of compacted soil layers by a series of wetting and drying cycles is being examined. The development of a compaction problem depends on the relative rates of amelioration and reformation. An experiment consisting of five compaction levels at two depths (achieved by scraping and relayering, using a roller as the compacting implement) has been initiated in late 1984. Changes in structure and pediology over time, as well as plant characteristics such as germination, emergence, root growth, water extraction and yield will be assessed under irrigated and rainfed conditions (So pers. comm.). It is hoped that these investigations will reveal the level of soil compaction that is significant, and under what circumstances such conditions are likely to occur.

On a completely different soil type, a Krasnozem (Gn3.II) at Kingaroy, an investigation into the causes of deteriorating peanut yields is being conducted by Mr M Bell and others. Apart from disease and chemical fertility aspects, physical soil degradation factors, particularly compaction, are hypothesised as possible yield limiting agents. As
part of a crop rotation/ley experiment, development of compacted soil layers and amelioration by deep ripping, including residual effects, is being assessed.

Soil characteristics including pH, EC, CEC, exchangeable cations, plant available water content, bulk density, penetration resistance, aggregate structure, size, strength and stability, water movement parameters such as hydraulic conductivity and diffusivity are all to be monitored over time (Bell pers. comm.).

2.3 *Surface management effects on infiltration/runoff/soil erosion.*

The research into surface management and its effects on runoff and soil erosion being conducted by Mr D. Freebairn and colleagues is well known and widely reported. (Freebairn and Boughton 1982), and is only briefly summarised here. A series of contour bay catchments have been developed and monitored at a number of sites on the Darling Downs, as well as at Roma on the Western Downs and Emerald in the Central Highlands. Table 2 (from Smith et al 1984) given an indication of the results.

**Table 2**

The effect of fallow management practices on runoff, fallow efficiency, soil movement, and wheat yield on a Black Earth at Greenmount on the Darling Downs (mean 1978—1982).

<table>
<thead>
<tr>
<th>Management Practice</th>
<th>Bare Fallow</th>
<th>Stubble Incorporated</th>
<th>Stubble Mulching</th>
<th>Zero Tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff (mm)</td>
<td>81.8</td>
<td>53.3</td>
<td>39.7</td>
<td>53.6</td>
</tr>
<tr>
<td>Fallow efficiency (%)</td>
<td>16.0</td>
<td>17.5</td>
<td>23.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Soil movement (t/ha)</td>
<td>70</td>
<td>20</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>2.81</td>
<td>2.88</td>
<td>3.11</td>
<td>2.85</td>
</tr>
</tbody>
</table>

Bare Fallow - stubble burnt at harvest, tyne cultivation.

Stubble Incorporated - disc cultivation to incorporate stubble, then tyne cultivation.
Stubble Mulched - cultivation with wide spaced sweep tynes to maintain stubble on the surface.

Zero Tillage - stubble retained, weed control by herbicides.

Fallow Efficiency - percentage of rainfall during the fallow period that is still stored in the soil profile at sowing.

Stubble retention on the surface gave the best erosion control, with zero tillage being less efficient at reducing runoff (implying lower infiltration capacities) than stubble mulching. Stubble retention seemed to have little potential for reducing fallow evaporation unless rain came in low intensity but frequent intervals (Smith et al 1984). Results from the other contour bay experiments also indicate advantages of stubble retention in increasing fallow efficiency and reducing runoff and soil erosion.

Work on the Darling Downs contour bays has shifted in emphasis toward summer cropping, and particularly the management of sunflowers. This crop increases the erosion risk because of poor basal cover and the short life of sunflower stubble. Concentration of rain by the leaves into a continuous stream on the inter—row soil is also hypothesised as an erosion hazard. No till planting and undersowing with a pasture legume are both erosion control strategies under investigation.

The effects of surface management on erosion processes are being studied by Mr R. Loch and associates, and are reported by Loch and Donnollan (1983 a, b). They use a derivative of the rainulator described by Meyer and McCune (1958), which is capable of causing rilling, and hence is more suitable for erosion studies than a smaller simulator. Their results indicated that contour tillage increased total infiltration by up to 13mm compared with tillage up and down the slope (Loch and Donnollan 1983a). They also reported that the rills carried about five times as much sediment load as rain flow. Erodibility was related more to the density of the sedimentary particle than to their size (Loch and Donnollan 1983b).

Surface effects on infiltration are being studied by Mr S Glanville using a variety of modelling approaches. These include CREAMS (Knisel 1980) and Curve Numbers (Glanville et al 1984), deterministic infiltration equations (Collis—George and Green and Ampt type), and simple power function curves, to investigate the effects of surface management and soil properties on infiltration. Most of the models seem to work well, providing that the necessary parameters can be determined.

The surface management research is being co—ordinated so that results from the small rainfall simulator, rainulator and contour bay catchments can all be related, to compare and contrast results from the different investigative techniques. In this way it is hoped to be able to extend research results to other land types; using the more portable simulation methods for experimentation rather than having to develop contour bay trials for every land situation. So far, the smaller simulator has produced similar results to the larger catchment experiments in some, but not all, situations (Glanville pers. comm.).
2.4 Tillage effects on soil biology, crop establishment and yield.

(This work is only summarised briefly, as it is outside the actual scope of the report).

Stubble retention increases the organic matter levels in the soil, with the well known short term effect of nitrogen (N) inunobilisation as the increased microbial population degrades the N deficient substrate. In the long term, a higher equilibrium soil nitrogen level will be established, but this may take many years (Thompson 1984). There is also an indication of a build up of root lesion nematode in the soil in a continuous wheat — zero tillage system. There seems to be little evidence of phytotoxicity from stubble breakdown products in the Queensland situation (Thompson 1984).

Stubble retention increases the opportunities for planting by increasing infiltration and reducing short term evaporation after rain (Radford pers. comm.). Investigations of planting techniques and minimum tillage planting machinery have been carried out by Mr L. Ward and Mr B. Radford. On the heavy clay soils, a micro seedbed (i.e. creation of a disturbed strip in the seeding line) concept, rather than a minimum disturbance approach (eg triple disc drill) seems to give the best crop establishment results (Ward and Norris 1982). A coulter followed by a chisel opener/seeder and then a press wheel is thought to be the best zero till option at the present time (Ward pers. comm.).

Stubble retention has generally given equivalent or better yields, compared to conventional tillage, in most situations. Trials looking at a range of stubble retention and minimum tillage systems are being conducted at a number of sites on the Eastern and Western Downs. In particular, a trial at Billa Billa, just north of Goodiwindi, commenced in 1984, to investigate the effects of tillage method and frequency, (with a range of stubble management, gypsum addition and Paraplowing sub—treatments on soil physical properties, water relations and crop growth (Radford pers. comm.).

2.5 Erosion effects on productivity.

Dr P. White has initiated a series of trials to examine the effects of topsoil losses on wheat production. He is following a similar approach to Mr B Marsh, but using hand scraping or a bobcat to remove soil at 12 different erosion rates, the maximum being 2500 tonnes per hectare. To investigate the productivity effect mechanisms, the main erosion treatments are combined with irrigation and complete fertilizer addition treatments. The experiments are conducted at two sites, Millmerran and Roma.
3 Discussion

The processes involved in the formation and stabilization of surface aggregates on the Black Earth soils are a complete contrast to those on most of the soils of Western Australia (WA). With lower overall clay contents, and the dominance of the less active clay types such as kaolinite and illite, organic processes are much more important in aggregate formation and stabilization in WA soils than in the high clay content, montmorillonite dominated Darling Downs soils. Contrast the cation exchange capacities of the Queensland Black Earths at around 60 m equiv./100g with that of a Red Earth near Geraldton, with a CEC of about 4 m equiv./100g. In the WA soils, aggregates are generally formed by biological processes, including the activities of plant roots and soil flora and fauna such as lichens, fungi etc. Even though organic matter contents are generally lower in WA soils than in the Queensland Slack Earths, (organic carbon contents of about 0.6 and 1.3 per cent respectively), the small amounts of organic material that are present are critical for the stability of aggregates in WA soils.

Because of the relative importance of organic matter compared to Clay properties in determining structural stability of WA soils, there is much more scope for tillage and stubble management to affect (improve or degrade), their surface structure. Structural decline is very rapid in our fragile gradational and duplex soils when subjected to forces that disrupt and destroy organic bonding materials, because there is little inherent soil ability to reform aggregates. Gypsum has been shown to have a role in improving structure in localized situations, where a highly dispersed clay can be flocculated to reform micro—aggregates, but a minimum tillage practice can overcome the need for continual gypsum addition (Howell pers. comm.).
4 Recommendations

There is a need for research in Western Australia to define the types of surface structures needed to maximize water infiltration, air permeability and seedling emergence (both rate and percentage) and to resist wind and water erosion. The first stage should identify how we define structure, in terms of surface characteristics, such as aggregate size distributions and stability, porosity etc. Next we need to investigate which components of the soil system influence these surface characteristics, and then determine how we can manipulate these components for maximum benefit. At this stage there seems to be a more ad hoc approach, which is understandable given personnel, time and finance constraints. There appears to be some move to a more systematic approach with the establishment of soil structure investigation projects at Merredin and South Perth.

The recognition in Queensland of a compaction problem on a range of soil types, including those that were thought unlikely to develop a compacted layer because of inherent soil properties, indicates that we should also review our thoughts on the importance of compaction on soils other than the Earthy Sands, which have already been shown to have a severe problem. This need was very clearly demonstrated at a recent workshop on deep tillage, when our knowledge of the compaction situation and its importance on many Western Australian soils was shown to be virtually nonexistent. Developing techniques of identifying a compacted soil layer and determining if it is a serious problem is a major aim of the author’s future research program.

In all probability, determining the presence of compacted layers in soils with clay contents greater than about 15—20 percent will be more complex than simple penetrometer measurements. It could involve pedological examination of the soil profile, with hydraulic and/or air permeability measurements, as well as visual descriptions of plant root systems. This multiple parameter investigative method is being used in the Queensland studies at present.

Research similar to the Queensland work on surface management practices and their effects on hydrology is also being conducted in WA although rainfall simulators have been little used in this state. In Queensland, the integration of infiltration/runoff research including catchment monitoring, contour bay and rainfall simulator experiments is such that data collected from one source can be readily related to another. This spatial co—existence of the different research projects is an obvious objective for similar work planned in Western Australia.
5 Acknowledgements

The author thanks the Dept of Agriculture Western Australia for the generous allowance of time and travel costs for the six days in South—East Queensland. Sincere appreciation is extended to the personnel at the Queensland Wheat Research Institute, DPI office Toowoomba, J. Bjelke—Petersen Research Station and University of Queensland for their time and effort. Particular thanks to Dr George Smith who organized the itinerary and made me feel very welcome.
6 References


Appendix

18—1—85: University of Queensland. Reviewed experimental program of Dr. Bing So and Mr Gary Cooke.

21—1—85: Travelled to Toowoomba. Queensland Wheat Research Institute. Met Dr. Allan Clarke (Director) and reviewed research programs of Dr. George Smith, Dr. Peter White and Mr R. Loch.

22——1—85: Toowoomba DPI Office. Field trips to Greenmount contour bay experiment and soil conservation problem areas with Mr Bruce Carey. Review research programs of Mr Lindsay Ward, Mr Steve Glanville and Mr Cyril Ciesiolka.

23—1—85: Travel to Billa Billa tillage trial with Mr Bruce Radford and inspect rainulator and rainfall simulator in action en—route.

24—1—85: Queensland Wheat Research Institute. Review research programs of Mr Dave Freebairn, Mr Ram Dalal and Dr J Thompson. Shown DPI films on stubble retention.

25—1—85: Travel to Kingaroy. J. Bjelke—Petersen Research Station. Review research program of Mr Mike Bell, including visit to trial sites. Return to Brisbane.