HONOURS SCHOLARSHIP REPORT

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1. Project Title : Soil coalescence and compaction in southern NSW
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1. Executive Summary:

The physical condition of soil is a vital aspect of sustainable agricultural production systems and the inherent physico-chemical characteristics of soils are essential in determining the impact of irrigated agricultural systems on the soil physical condition. An understanding of these changes to the soil physical condition is important in making informed decisions on changes in production systems. This research assessed the changes to the soil physical condition following a conversion from rice to cotton production systems on a red and grey soil. The two soils, indicative of the NSW Riverina region, were selected to examine virgin and rice soil conditions as well as soils to have undergone recent and longer-term conversions to cotton. Soil morphological observations, in pits excavated to 30 cm, showed the rice soils to contain a massive sub-surface while the virgin soils exhibited coalescence and biopore development. Soil pedality improved on both cotton soils following changes out of rice production. These observations were consistent with penetration resistance measurements, whereby the rice soil exhibited resistance levels which would inhibit cotton root growth. Soil bulk density, as well as sorptivity and steady state infiltration, did not correlate with the observed soil morphology due to the high shrink-swell clay content. The morphological observations, in conjunction with penetration resistance, showed the grey soil to recover at a faster rate following a change from rice to cotton production. This was due to a higher Ca:Mg ratio and greater aggregate stability.

2. Background:

The physical condition of a soil temporally evolves through the interaction of management stresses with climate and natural soil physical, chemical and microbial properties. Changes to these factors will result in a disruption of the soil equilibrium and alter the physical condition, occurring naturally or through management practices. Extensive research has examined soil compaction, a management associated stress, identifying it to negatively affect almost all soil system properties by impacting plant growth, disrupting soil hydrology and increasing erosion susceptibility (Mooney and Nipattasuk, 2003; Nawaz et al., 2013). While causing similar problems for agricultural production, considerably less research has been targeted towards the natural phenomena of coalescence and hardsetting in soils. ‘Soil coalescence’ is the inevitable increase in soil hardness over time due to the disruption of soil aggregates from slaking and dispersion during wetting and drying cycles (Cockroft and Olsson, 2000; Grant et al., 2001; Daniells, 2012). Although resulting in similar long-term effects, coalescence occurs gradually as opposed to the abrupt onset of hardsetting whereby soils “set to a hard, structureless mass during drying and are thereafter difficult or impossible to cultivate until rewetted” (Mullins et al., 1990; Murray and Grant, 2007). The capacity for structural development of such soils under natural conditions is immediately destroyed following cultivation. The presence and extent of inherent hardsetting behaviours and induced compaction can be exacerbated in irrigated production systems. While degradation of irrigated soils will become increasingly important given the changing availability of water resulting from climate change, an understanding of this structural change relies largely on inferences from research on dryland agricultural systems. ‘Soil resilience’, the ability of a soil system to return to equilibrium following the removal of stresses, is critical if land is used for production systems requiring different conditions, such as rice and cotton (Lal, 1993).

Soil structural changes can positively or adversely affect plant growth and variations in plant requirements result in variations of the parameters for favourably structured soils. In southern New South Wales, dense subsoils susceptible to waterlogging and anaerobic conditions are successfully used for rice production as the crop requires periods of permanent water application (Dunn et al., 2013; North, 2018). As a consequence, methods identified to destroy soil structure, such as wet tillage, have been implemented to improve water use efficiencies (Hughes, 1999). Due to the conditions required by rice, waterlogging is a common yield constraint in alternate crops that are grown in these soils. Cotton, as opposed to rice, is highly susceptible to physical soil constraints and waterlogging, resulting in lower yields (Williams and Bange, 2013). Therefore, the identification of the soil characteristics present and whether soil degradation is inherent or induced is important in identifying soil suitability for irrigated cotton systems. This will affect the timeframe over which structural change occurs following a conversion from rice to cotton production systems.

3. Aims and Objectives:

This research aims to:

- To determine if there is a difference in soil condition under rice production compared to cotton and virgin soils;
- Identify how different soil types respond to the change in management, from extended periods of waterlogging, to irrigation systems reliant on fast application and removal of water; and,
- Understand how inherent soil characteristics impact soil responses to management changes.

To achieve this:

- Two farms will be identified with soils indicative of the area;
- Three sites, on four treatments, will be excavated and sampled on each farm;
- Soil physical characteristics of soil strength, bulk density and hydraulic conductivity will be measured at multiple depths and compared between treatments;
- Laboratory chemical analysis, particle size analysis and ASWAT scoring will be used to determine inherent differences between the soil types; and,
- Statistical analysis of all data will be used to determine significant differences between soil types, treatments and depths.

4. Materials and Methods:

Two farms were selected for this study with soils commonly used for broadacre irrigation within the Riverina; *Farm A*, a Grey Vertosol in the Murrumbidgee Irrigation Area (M.I.A.) and *Farm* B, a Red-Brown Chromosol in the Coleambally Irrigation Area (C.I.A.). Both farms contained the desired treatments transitioning from soils used to grow rice, to now producing cotton, as well as a virgin (control) soil. The treatments to be tested were; a soil still used for rice (R), a soil recently brought into cotton production (≤2 years) (RC1), a soil longer into cotton production (>2 years) (RC2), and, virgin soil as a control (CONT). Paddock histories from the three years prior to sampling were recorded for each treatment.

4.1. Soil sampling and field measurements

For each treatment, three sites were chosen, utilising yield data and previous cut and fill maps, with a small pit excavated allowing for soil morphological observations and samples to be taken to depth. Loose soil samples, at the surface and at depth (30-50 cm) were collected at each site for laboratory analysis. Soil bulk density was measured using the core method (Grossman et al., 2002), with three repetitions at depths of 0 cm, 20 cm and 30 cm. Penetration resistance was measured at 0, 20 and 30 cm in each put using a dynamic cone penetrometer in accordance with the modified method presented by Vanags et al. (2004). Soil hydraulic conductivity, sorptivity and steady state infiltration were estimated for the soil surface at each site using a ponded disc permeameter (White et al., 2002).

4.2. Laboratory soil analysis

Collected soil samples were separated, with one sub-sample kept aggregated, and the other dried and ground. Aggregate Stability in Water (ASWAT) tests were conducted on natural peds (air dried) and remoulded soil samples from 0 and 30 cm (Field et al., 1997). For each soil sample three replicates of soil pH and electrical conductivity were measured in a 1:5 soil to water suspension (Raymond and Lyons, 2011). Particle size analysis was conducted using the pipette method for each air-dried soil sample (Glendon et al., 2002). A modified manual colour method of Colwell (1963), presented by Rayment and Lyons (2011) was used to determine phosphorus content. Samples were sent for external analysis of cation exchange capacity, aluminium content and exchangeable calcium, magnesium, potassium and sodium. The high temperature (1150°C) combustion of further ground, 1 g, samples using a CN Elementar Vario MAX CNS analyser was used to determine carbon and nitrogen percent composition (Rayment and Lyons, 2011).

5. Results:

5.1. Soil morphology

The primary colour of the grey soil (*Farm A*) was 10YR 3/1 (dark grey) and the primary colour of the red soil (*Farm B*) was 7.5YR 4/4 (brown). The grey soil was strongly pedal, with large peds from the surface through to depth at all treatments. There were, however, still large pores from the surface to the depth excavated (30 cm). The two cotton treatments on the red soil, while strongly pedal, contained large, interconnected macropores. The rice soil on both the grey and red soil types had soft, epipedal surfaces. These transitioned to a massive, hardened sub surface from 15 cm depth. Both the grey and red soil control sites exhibited strong, blocky pedality which, in contrast to the rice soils, contained a larger number of pore spaces. Both cotton treatments on the grey soil contained a finer tilth and greater plasticity than the rice treatment and corresponding cotton treatments on the red soil.

5.2. Soil physical characteristics

Soil bulk density is significantly affected by depth, treatment and soil ($P<0.05$). On all treatments bulk density was greater at 20 and 30 cm than at the surface. There are no significant differences between treatments at any depth on the grey soil. On the red soil the bulk density of treatment RC1 is significantly less than the rice and RC2 at all depths. The grey soil exhibits significantly higher bulk density values for the control and treatment RC1 at all depths and treatment R at the surface compared to corresponding treatments on the red soil.

The control and RC2 treatments exhibited significantly higher penetration resistance on the red than the grey soil for the corresponding treatments at all depths. There is no significant difference between the two soil types at any depth for the rice and RC1 soils. On the grey soil, the rice treatment has a significantly higher penetration resistance than all other treatments at 20 and 30 cm. At the surface of the red soil, the rice and RC1 soils had a significantly lower penetration resistance than the control soil. The RC2 soil was not significantly different to any other treatments. At 20 cm depth on the red soil, the control site exhibited a significantly higher penetration resistance than the RC1 and RC2 soils. The rice and RC2 soils showed significantly higher penetration resistance than the RC1 treatment. At 30 cm on the red soil, the rice treatment exhibited a significantly higher penetration resistance than the RC1 and RC2 soils only. Both the RC2 and rice soils showed higher penetration resistance than the recently converted to cotton soil.

There are no significant interaction effects identified affecting sorptivity and steady state infiltration. Treatment and soil type had significant single effects on aggregate stability ($P<0.05$).

5.3 Soil chemical characteristics

There is a significant interaction effect between soil, treatment and depth for both pH and electrical conductivity (EC). The soil is more alkaline at depth for all treatments except the grey soil control and both red soil cotton treatments. The grey soil is more alkaline than the red soil at the surface of the control, rice and RC1 soils. There is no difference between treatments on the red soil. The rice treatment, on the grey soil type, is more alkaline than the control and cotton soils.

At 30 cm the EC of the control site is greater than all treatment soils on both the red and grey soil types. At the surface there is no variation between treatments on the red soil type. At the surface of the grey soil type, the control soil has a higher EC than the rice soil, however, neither are significantly different from both cotton treatment soils. At both depths, the grey control has a higher EC than the red control, however, there are no significant differences between the treatment soils on the two soil types.

There was a significant three-way interaction for all particle size fractions. The percentage of clay sized particles was greater at depth and clay content was higher on the red than the grey soil. The exchangeable sodium percentage and cation exchange capacity were greater at 30 cm than at the surface. Exchangeable magnesium concentration is higher in the red soil and at depth than in the grey soil and at the surface, respectively. The average Ca:Mg ratio is higher on the grey soil at both the surface (1.99) and 30 cm (1.31) compared to the red soil, 0.99 and 0.83 at 0 and 30 cm, respectively.

The grey soil contains higher levels of phosphorus than the red soil. For all treatments on the grey soil, and the rice treatment on the red soil, phosphorus levels are significantly greater at the surface than 30 cm. At the surface the rice and RC2 soils contain less phosphorus than the RC1 soil, which contains less phosphorus than the control on the grey soil. The rice soil, on the red soil type, contains significantly higher phosphorus at the surface than both cotton soils and the control.

6. Discussion and Conclusions:

Through examining pits to a depth of 30 cm, the red and grey rice soils exhibited massive subsurfaces. Soil penetration resistance was correlated to morphological observations, with the massive rice soils exhibiting penetration resistances which would inhibit root growth. A change to cotton production, however, resulted in decreases to penetration resistance and improved structure. This suggests that that increased wetting-drying cycles are resulting in aggregate disruption, reformation and bio-pore development (Cockroft and Olsson, 2002; Diel et al., 2019). The control soils, while exhibiting high penetration resistance and bulk density measurements, showed significant biopore development as stated by Cockroft and Olsson (2000), suggesting a loss of structure through management operations associated with rice production.

Due to differing plant requirements and the influence of soil wetness, penetration resistance values should not be considered in isolation. In an extensive study of a variety of plant species, Materachera et al. (1991) concluded that at a penetrometer resistance of 4.2 MPa would decrease cotton root elongation by 93.4% after 10 days of growth. The figures observed by Materachera et al. (1991) are considerably larger than those in the early research; Taylor et al. (1966) determined a penetration resistance of 2.5 MPa would cause cotton root growth to cease. As all penetration resistance values at depth were approaching or greater than 2.5 MPa, it is clear that other factors in these soils circumvent this growth restriction. The application of water during irrigation cycles lowers penetration resistance through softening aggregate cementing agents (Marshall et al., 1996).

There were poor relationships between field observations, penetration resistance and bulk density measurements. One reason for the differences between observed morphologies and bulk densities are the difficulties of using the invasive core method on porous soils with high clay contents (Grossman and Reinsch, 2002). Soil bulk density can be considered as a function of wetting (swelling) and drying (shrinking) cycles if, as on the sites examined, non-rigid clay content is high (Timm et al., 2005). As a result, there will be large temporal alterations to porosity and resulting bulk density. Further, during core collection the strong pedality on the control and cotton soils and massive subsurface on the rice soils resulted in difficulties extracting cores.

Expected increases in clay content, penetration resistance and bulk density were observed at depth. The grey soil exhibited an increased rate of structural improvement than the red soil. This was determined on the temporal scale comparing findings from the rice soil to a recently cotton soil and a longer-term cotton soil. Chemical analysis of the grey soil suggests that it is inherently capable of faster structural redevelopment through higher aggregate stability and a greater Ca:Mg ratio when compared to the red soil. As a result, alternate management practices may be needed between the two soil types despite their location within the same production region. The two soils sampled have previously been classed as exhibiting similar attributes. Given the differences noted in response to transitioning from rice-to-cotton systems, a review of this classification may be required.

7. Highlights:

There were a number of highlights throughout my CRDC sponsored honours year. The first of these was the opportunity to fully apply myself to my project, providing a valuable insight into research practices from planning, consultations with growers, sampling, lab work to statistical analysis and the writing of my thesis. Secondly, during my initial site visits I had the opportunity to attend a Soil Science Australia Riverina Branch workshop and networking evening. This presented the opportunity to discuss my work with a number of soil scientists vastly experienced with soils of the Riverine Plain. I envisage that a large number of these connections will be extremely valuable as I look to move forward into a PhD studying soil and cotton suitability in the region. Finally, the greatest highlight of my time conducting my CRDC supported honours project was the opportunity to attend the Australian Association of Cotton Scientists (AACS) 2019 conference in Armidale. This provided an invaluable opportunity to meet a diverse range of accomplished industry members and discuss their paths into research. The highlight of the conference was the opportunity to present my research and discuss the outcomes with others who had conducted work in the region.

8. Future Research:

Further research is required to improve the understanding of cotton-soil interactions within the Murrumbidgee. This was stated by Holland and Eastwood (2014) in their soil scoping study for cotton in the region, with the unique properties of Riverina soils causing them to be vastly different to those in other growing regions. As identified in research for this project, Riverina soils have a natural propensity to coalesce and hard-set, processes which are exacerbated by irrigation. This research showed that two soils, previously classified as similar, exhibited different inherent properties. Based on this, as well as differences in the physical condition, it is valid to suggest that certain soils will be more suited to sustainable cotton production than others. Identifying such soils, however, is challenging due to potential inaccuracies in previously conducted soil surveys. The soils sampled in this study, for example, exhibited different characteristics to those previous identified and mapped by Taylor and Hooper (1938) and van Dijk and Talsma (1961). Therefore, it would be valuable to re-assess previous data alongside new research to, where required, update soil maps using modern techniques. This process could also allow the suitability of the regions soils for cotton production to be classed using parameters identified in previous agronomic research.

9. Presentations and Public Relations:

This research has been presented at the AACS 2019 Conference and the Stepping Out with Fresh Ideas end of year conference at The University of Sydney. There is also a potential opportunity to present at a Soil Science Australia Riverina Branch cotton workshop in April 2020. Along with these presentations, I have also discussed the research project with a number of industry members at the Agronomy 2019 Conference and members of the Riverina Branch of Soil Science Australia.

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