Australian Government
Cotton Research and Development Corporation

Cotton Catchment Communities CRC

FINAL REPORT 2006

If you are participating in the presentations this year, please provide a written report and a copy of your final report presentation by 31 October.
If not, please provide a written report by 30 September.

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number:
OR Cotton CRC Project Number: **1.1.28**

Project Title: Maintaining a functional soil system for cotton production

Project Commencement Date: 1 July 2004 **Project Completion Date:** 30 Jun 2006
CRDC Program:
OR CRC Program: The Farm

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Part 3 – Final Report Guide (due 31 October 2006)

(The points below are to be used as a guideline when completing your final report.)

Background

The drive behind this project was based on previous research on soil utilised for cotton production which identified that soil factors likely to restrict cotton growth may be broadly categorised into soil structural and pH limitations (CRDC reports DAN 111C, MCK 1C & MCK 2C), organic carbon decline (CRC project 3.1.11AC), localised potential for salinisation and/or sodification, and the availability of soil water. Concern has also been raised regarding the lack of information on how changes in soil microbial diversity may influence cotton production (CRDC, Soil Health Workshop). Some recent work suggests that the reduction of the species forming the soil biomass below a threshold point will compromise the functioning of the soil system. Understanding and managing the optimal function of a soil for cotton production, in part, requires the assessment of soil physical, chemical and biological properties. At present, an approach is being developed using a framewrok that accounts for the interrelationships and dynamics of soil properties and be able to predict the resulting changes in soil factors, i.e. soil function framework. Using this framework it should be possible to develop a set of indicators that can monitor, predict changes in, and ultimately enable management soil function for cotton production.

Based on the work to date the postulated soil function framework should incorporate the interrelationships between the soil physical, chemical and biological properties and is represented in Figure 1. These soil properties influencing the soil's ability to function can be viewed as indicators. These indicators form a '*minimum data set*' (MDS), which is need for the assessment of the required soil function. The indicators are feed through a '*rule base*' which houses the potential interactions that may occur between the utilised soil indicators. Using the output from the rule base it is possible to predict changes in '*soil function*' at a point in time. Also, it has been established that unknown or hard to measure indicators can be estimated from known/measured data using the soil inference system (SINFERs), which was developed in CRC project 3.2.08 and will be incorporated into the soil function framework.

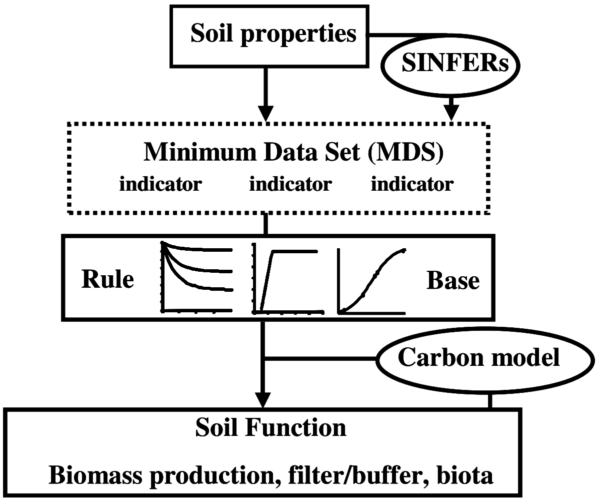

Figure 1. A framework for assessing soil function

In addition to soil sodicity, aggregate failure and the formation of a temporary surface crust that may impede seedling emergence is also exacerbated by the lack of particulate soil organic matter (Field, 2000). Current opinion suggests that the maintenance of stable soil surface aggregates is dependant on the continued input of sufficient POM that can supply substrate for the microbial biomass (BIO), whose degradation products contribute to aggregation. To investigate this, work is being undertaken and needs to be developed further, to assess the how interrelationships between the dynamics of soil carbon, gauged from the soil carbon turnover modelling, and other influential soil properties influence changes surface aggregate stability.

Little is known about the affect cotton soil properties and variations in soil carbon types have on the microbial biomass/diversity and *vice versa*. It is has been demonstrated that decreases in soil organic matter and alkaline pH conditions may cause a reduction in microbial biomass, but the less is known about the affect on the biodiversity. Assuming the importance of functional microbial diversity in maintaining soil function, research is required to resolve what interacting soil properties influence changes in microbial diversity. This is a first step to establishing the role of microbial input in maintaining soil function, which has the potential to be incorporated as part of the rule base in the soil function model.

Multicompartmental models that predict carbon turnover have successfully been used in a number of agricultural industries. These models take into account the type of carbon input (POM), fractions the carbon into available and inert forms, and reports how these additions result in beneficial/negative changes in the soil biomass over time. Considering the potential interactions between soil surface stability and the affects on the soil biology outlined the incorporation of a soil carbon turnover model enable the changes in soil function to be monitored over time when incorporated into the rule base of the soil function model.

Once a soil function framework is established it should be possible to develop a minimum set of indicators that can be used to monitor changes and enable management of soil function for cotton production. Further to this, these findings need to be incorporated into decision support systems that have been developed by the Australian Cotton industry, e.g. such as SOILpak, and be used to benchmark if soil used for cotton production is in a good functional condition.

Objectives

> To determine trigger amount/ratios for various indicators, which signify changes in cotton soil function,
>
> To determine the dynamics of the interrelationships between various indicators that will signify changes in cotton soil function
>
> Use information from the soil function model to determine if soil is in a good functional condition and incorporate findings into decision support materials

Methods

In order to identify benchmark indicators of soil function and incorporate these into a preliminary soil function model a selection o soil profiles have been strategically collected from the Namoi Valley and the Lower Lachlan River Valley. As from June 2005 the analysis of fundamental soil properties for these samples will be completed including; soil texture, ph electrical conductivity (EC), cation exchange capacity (CEC) and exchangeable cations, and soil organic carbon. From these other soil properties related to soil stability and sodicity such as exchangeable sodium percentage (ESP), electrochemical stability indexes (ESI) and Ca/Mg ratios will be established. These fundamental soil properties are being measured using conventional soil analysis techniques and estimated from mid-infrared spectrometer scans.

This data will be incorporated into the soil function model and the interrelationships between these and other measures of soil function will be established.

It is envisaged that a soil carbon turnover model will form part of the basic framework from which to assess changes in soil function. Field (2000) has already presented some initial work on carbon turnover model incorporated into a standard quality model. Work is being undertaken in collaboration with Jan Skjemstad (CSIRO, Adelaide). This involves estimating various carbon fractions such as; particulate organic matter (POM), inert organic matter (IOM), using mid-infrared spectrometry. This information is required for the various pools in the carbon model.

To determine the effect changes in POM inputs have on the microbial biomass and functional biodiversity the relationships between soil carbon content and soil microbial biomass and functional biodiversity is being established using the approach described by Yan *et al* (2000). This involves the extraction of soil using KCl and subsequently the extract is added to bio-plates containing a range of organic substrates. The change in colour and rate of change can be sued to assess the degree of diversity (Shannon's index) and their interactions (using parameters in logistic models using to describe substrate breakdown).

Building on the findings of Field (2000), work was undertaken to model the kinetics of aggregate breakdown of the cotton soil samples collected. This involves the use of an end-over-end procedure over a series of shaking times and the aggregate slaking (100 µm) and dispersed material (2 µm) being determined. This information needs to be interrelated to the other measures of the chemical, physical and biological factors used in the soil function model. The hydraulic properties of the surface samples are assessed using the evaporation method, which can be interrelated to the surface soil condition. Analysis of this data involves inverse modelling and the adoption of the generalised likelihood uncertainty estimation (GLUE) concept.

Using the data from the procedures above a set of indicators that can be used to signify if soil is in a good functional condition will be identified. Understanding the interrelationships and dynamics between various indicators and identifying trigger ratios will form part of the framework of the soil function model.

Results

Milestone: Characterise soil physical, chemical and biological properties.

In order to satisfy this milestone soil profiles that encompass the variation found in basic soil properties needed to be strategically sampled. The profiles sampled represented cotton growing regions in northern and southern NSW. The Latin Hypercube sampling (LHS), a stratified-random procedure, was employed to help identify potential sampling sites. This is achieved by sampling a known distribution of soil properties and associated attributes that is housed in the Australian Cotton Cooperative Research Centres Database Assistant. The database attributes that were used in the LHS were clay content, total carbon, exchangeable sodium percentage (ESP), and pH. These attributes have previously been identified as influencing cotton production. In addition, attributes such as cation exchange capacity (CEC), C/N ratio and landuse (e.g. cotton rotations or native vegetation) have also been included as they may be indicative of changes in mineralogy, quality of organic matter and land use history.

One way to account for the variation when presented with many attributes is to summarise using principle component analysis. This was performed on the attributes chosen and is represented graphically in the biplot presented in Figure 2. The spatial distribution and orientation of the rays in the biplot demonstrates the relationships between individual samples and the attributes measured. The distribution of data points in the biplot indicates there is very little clustering of the data which is desirable when trying to account for the potential variation of the soil attributes. The numbered data points in the biplot are the sampling sites chosen. Using the grid it appears that the potential sites are not clustered with most individual cells containing a sampling point suggesting that the variation is well accommodated.

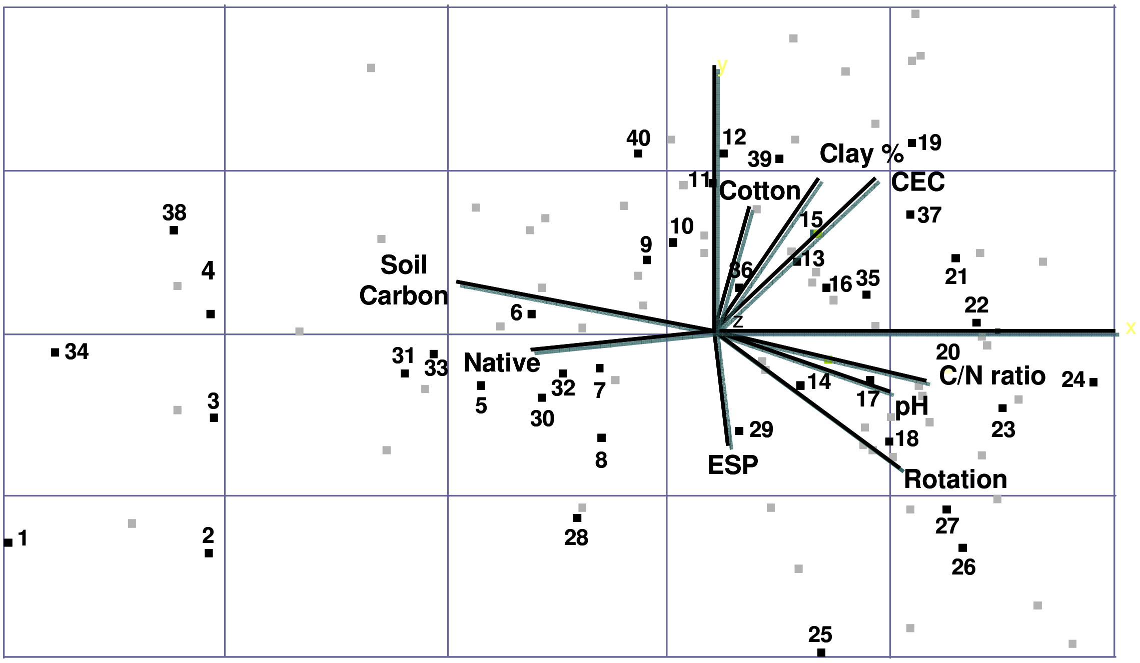

Figure 2. A biplot showing the distribution of individual soil properties sampled from the Australian Cotton Cooperative Research Centre Soil Database Assistant using Latin Hypercube Sampling. The black dotes represent those profiles that were actually sampled.

Once the profiles were sampled they were divided into 4 depths and their basic soil properties were quantified using conventional soil analysis techniques. The soil samples were also analysed using mid-infrared spectroscopy (MIR) which has also proved useful as a technique to estimate the basic soil properties simultaneously, and in a timely cost effective manner. The MIR approach also enabled for the quantification of various soil carbon fractions, e.g. particulate organic matter (POC) and the inert soil carbon (IOM). Other studies, including this work as will be described later, have found that these carbon fractions are more effective in predicting factors affecting soil function then total soil carbon.

Milestone: Identify potential relationships that can form the rule base

To illustrate how rule bases are identified the project concentrated on measures of soil surface stability, protocol to assess soil water retention and a measure of soil biology. Soil structural decline may be potentially one of the limiting factors restricting cotton growth and is due to the surface soil aggregates slaking and/or dispersing in water. If slaking is excessive, resulting in aggregates < 100 µm in diameter, there is a chance that a temporary surface crust may form (Loch, 1995). Further, the dispersion of these slaked aggregates producing excessive amounts of clay (< 2 µm) would also result in the development of a soil surface crust. In order to quantify the potential for surface soil structural decline and end-over-end procedure was employed that enabled the rate at which surface soil slakes (< 100 µm) and/or disperses (< 2 µm). The resulting aggregate slaking (100 µm) and dispersion (2 µm) curves were modelled by using an exponential increase function.. This was achieved by fitting the data using a non-linear least squares method which minimises the sum of squares of the residuals of the observed data and predicted values, presented in Figure (3a). In order to compare the relative stability of

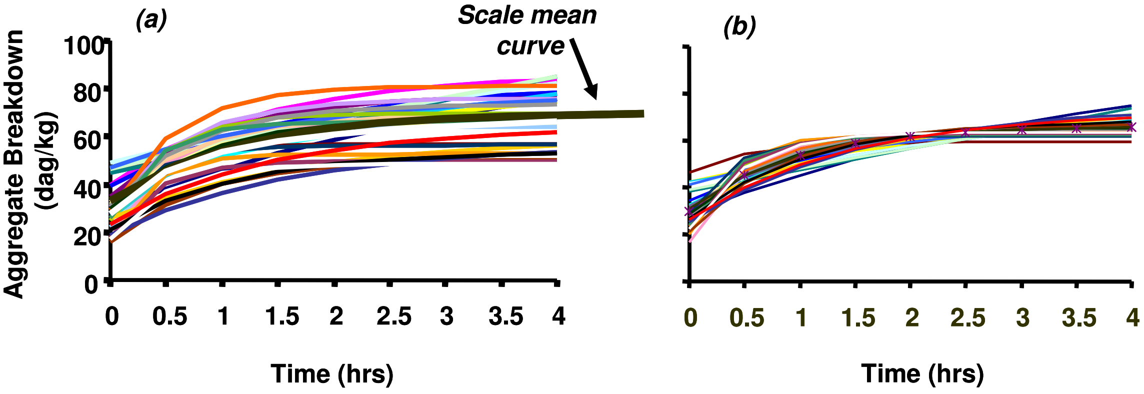

Figure 3. Comparison of individual breakdown curves of the (*a*) < 100 μm aggregates (λ_{100}) with the scale mean curve and (*b*) the effect of using the λ_{100} scaling factor resulting in their coalesce while maintaining each curves uniqueness.

each of the surface soil samples used an approach was adopted to describe the dynamics of aggregate breakdown or dispersion curves by a single scale factor while maintaining each curves uniqueness (Zanini *et al*, 1998). This procedure involves seeking a scale mean curve computed for a set of aggregate breakdown or dispersion curves and subsequently identifying a scale factor that would coalesce that individual curves. A scaling factor less then one would indicate a weakly aggregated sample, whereas a scaling factor grater than one would indicate a strongly aggregated sample, and the multiplication of the curves by the scaling factor would translate the curves to the position of the scale mean curve, illustrated in Figure (3b). The simplification of the aggregate breakdown and dispersion curves using the scale factor has successfully modelled the relative stability of the surface soil samples.

The relationship between the relative stability for the <100 μm aggregates (λ_{100}) and the dispersed < 2 μm material (λ_2) is presented in Figure (4). Looking at the distribution of the data there appear to be some clustering present, which was analysed using a k-means approach. It can be seen in the graph that one of clusters has λ_{100} and λ_2 values < 1, which would describe soils that are highly dispersive. There is also a clustered population that has λ_{100} values < 1 but λ_2 values > 1, indicating surface soils that excessively slake and therefore may be crusting prone. To identify the potential relationships between the routinely measured soil properties and the samples represented in the clusters a principle component analysis was once again employed, presented in Figure (5). There appears to be a positive relationship between the Ca/Mg ratio and λ_2, whereas the ray for exchangeable sodium percentage (ESP) is orthogonally opposed indicating that a greater

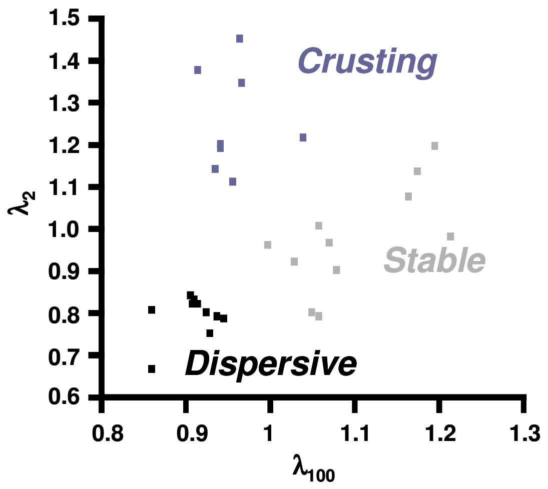

Figure 4. Relationship between the excessive slaking (λ_{100}) and dispersion (λ_2) values of the surface soil samples form the cotton growing areas.

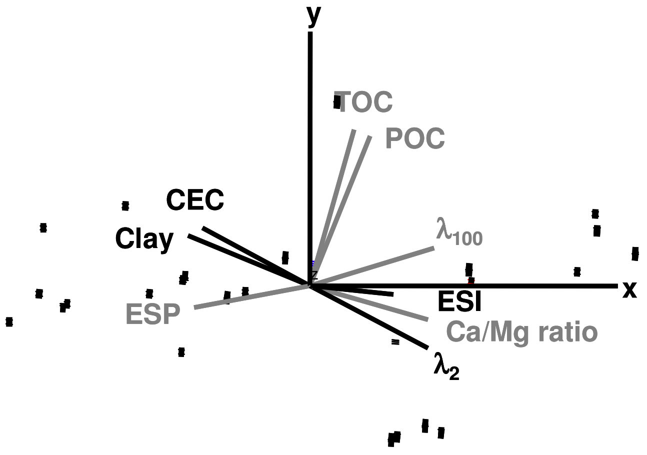

Figure 5. Biplot showing the relationships of selected soil properties with the measures of excessive slaking (λ_{100}) and dispersion (λ_2).

ESP value results in a more dispersive soil ($\lambda_2 < 1$). For the λ_{100} the rays for the organic carbon fractions (TOC, POC) lie in the same plain whereas a negative relationship can be observed for larger clay contents (Figure 5), indicating that the interaction between these two soil properties may influence the surface soil propensity to excessively slake.

Conventionally, when developing rules that describe the relationship between influential soil properties critical values, linear and/or curve linear relationships are used. An alternative approach is to use classification trees, which enables the interrelationships of several influential soil properties to be observed. The classification tree developed to describe the potential for surface soil crusting is presented in Figure (6). The terminating nodes categorise the soil into dispersion prone, crusting prone and stable (unlikely to crust or disperse). Working through the classification tree it is apparent that soil samples with an ESP of > 5 are more then likely prone to disperse. If the surface soil samples have a low ESP (< 5) and have a particulate organic carbon content > 0.35 dag/kg these soils are more then likely not prone to develop a surface crust from excessive slaking and/or dispersion. It is suggested that the particulate organic carbon represents the relatively younger organic matter in the soil system that has undergone a small degree of decomposition. More importantly this carbon is customarily implicated in the formation and maintenance of soil aggregates that resist slaking. If the clay content of the surface soil is > 50 % but the POC is < 0.35 dag/kg the soil is likely to form a surface crust. The rationale offered is that the lack of organic matter does not enable it to effectively enmesh the clay rich aggregates increasing the potential for excessive slaking. Table 1 illustrates how the rule base that has been developed could be used to predict the surface soil condition. It can be seen that for the sample NM130 that the soil property ESP governs the propensity for this soil to disperse. Whereas, for the samples NM143 and NM138 the potential for the soil surface to either remain stable or crust respectively, is governed by the interaction of three basic soil properties.

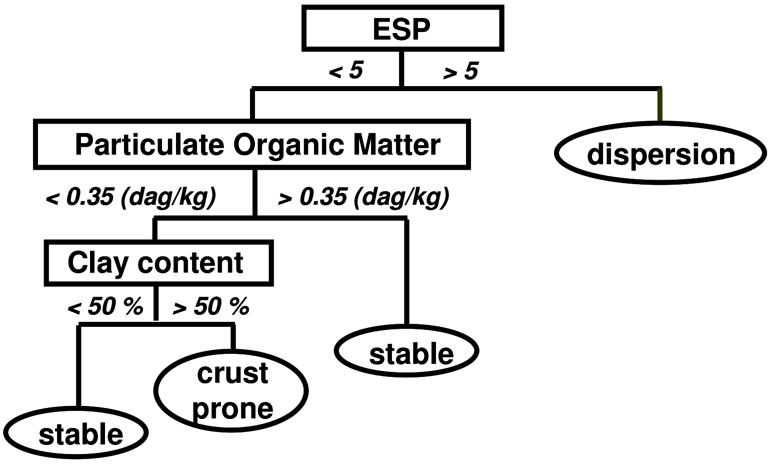

Figure 6. Surface crusting classification tree defining the critical limits and illustrating the interrelationships of influential soil properties terminating at nodes characterising the soil into dispersion prone, crusting prone and stable (unlikely to crust or disperse).

Table 1. Illustrates the prediction of surface condition using the basic soil data and the classification tree. The influential soil properties used in prediction in bold. Identifying the limiting soil properties may prove useful in identifying appropriate ameliorants.

Profile	Clay Content (%)	pH	EC dS/m	CEC cmol(+)/kg	ESP (%)	Soil (residual) (%)	Carbon (inert) (%)	Bulk Density g/cm^3	***SFM*** Surface condition
NM130	55	7.5	0.22	56	**7.5**	0.25	0.21	1.4	***Dispersion***
NM143	**47**	8	0.15	35	**2.9**	**0.28**	0.17	1.2	***Stable***
NM138	**56**	8.6	0.18	40	**3.2**	**0.30**	0.22	1.3	***Crusting***

Appreciating the interrelationships demonstrated by the classification tree managers can identify the potential causes of poor surface soil stability targeting these with appropriate amelioration strategies.

As described in WATERpak (Dugdale *et al.*, 2004, p. 96) there are many means by which soil water data can be estimated and expressed. Not only are we concerned with the total water in the soil but what is available to the plant (PAWC) and how much needs to be added to top up the amount of water used. In the industry these limits, also known as critical soil water potentials, are often defined as the drainage upper limit (DUL), the crop lower limit (CLL) and the refill point or readily available water (RAW). The PAWC is determined by the difference between the DUL and CLL, whereas the RAW is the difference between the DUL and refill point. Depending on the timing in the growing season irrigations will be scheduled to maintain the soil water at either of these contents. In the industry these values are often determined using field trials in various regions throughout the cotton growing areas. An alternate method used in estimating these critical parameters is the production of a soil water retention curve. Simply the soil retention curve is a means to express how much water is present in a sample at different energy levels i.e. soil water potentials.

The measurement of a complete soil water retention curve is among the most difficult and time-consuming tasks. Quite often this involves equilibrating the soil under a range of potentials using a range of specialised equipment. The evaporation method (equipment funded by the CRDC, US60C) is a reliable procedure for measuring the water retention of a soil between the ranges of -5 to -60 kPa. This range represents the wet end of the soil water characteristics or a good approximation of the RAW. By modelling the evaporation method data is should be possible to estimate the water retention curves towards the CLL and thus saves time by avoiding the conventional further experimentation. This involves using inverse modelling to predict the complete retention curve from the soil evaporation data. This involves identifying a parametric model that can describes the soil-water relationship, the use of an objective function that describes the target variable we want to match between the experimental data and simulated data, and an optimisation procedure, which finds parameters that minimise the objective function. The conventional approach to solve the inverse solution is the use of the nonlinear least squares (NLLS) technique. A major problem with using such technique is that many parameter sets within a model will give similar outputs to satisfy the objective function. This is called the equifinality problem (similar to nonuniqueness), which realises that no single optimum set of parameters will be identifiable. Thus, it is only possible to assign the likelihood of each parameter set to be able to predict the system. The discrepancies of the NLLS approach may be alleviated by adopting the concept of a generalised likelihood uncertainty estimation (GLUE). The GLUE method is summarised as follows;

1. Define the feasible range of parameters that are required to describe the soil-water relationship
2. Sample the parameter space uniformly within prescribe range N_s times using Latin Hypercube Sampling (LHS).
3. Run the simulation program N_s times, each time using random parameter and calculating the modelling efficiency E_a.
4. Rank E_a values and determine the threshold value E_T. Then accept the parameters that give E_a values greater then E_T, which are known as the behavioural parameter.
5. For each behavioural parameter, calculate the soil water retention curve from 0 to -100 kPa.

The prediction of the water retention curve using the GLUE technique was found to be comparable with estimates using the conventional NLLS. When using the NLLS technique if a good estimate of the staring parameters is not supplied the NLLS approach fails to find a solution, whereas this is not a problem for the GLUE approach. The GLUE does not attempt to find the best solution but selects an acceptable parameter set to provide a solution. In doing so it has the added advantage of being able to model the uncertainty associated with modelling the soil water potential curve (Minasny and Field *et al.*, 2005). It has also been demonstrated that the prediction of the soil water retention curve using the GLUE approach is quite accurate, but beyond the refill point the uncertainty increases. However the values are still within a 95 % confidence interval and therefore given the level of confidence the prediction of the available water capacity it should be possible to define manageable profile water storage. For a more in-depth discussion of this work see Minasny and Field *et al* (2005).

In response to concerns raised within the cotton industry this work was undertaken to establish if there is a critical level of soil organic carbon below which the functioning of cotton soil is beginning to be compromised. The indicator used for this declining function was a measure of the biodiversity using the Biolog plate approach as described in the methods section. In order to evaluate the comparative biodiversity of the samples from the northern and southern cotton regions the substrate utilisation data was processed using the following logistic model;

$$H^{'} = \frac{\theta_1}{1+\theta_2 e^{-\theta_3 t}} \qquad (1)$$

where θ_1, $\theta_{2,}$ θ_3 are parameters and t is time in hours after inoculation. Of the parameters θ_1 represents the asymptote of the curve, and the actual measured values of θ_1 have been reported as the final diversity and is independent of the inoculation density. The parameter θ_3 is responsible for the shape of the curve and is meant to represent that part of the colour change determined by the microbial community characteristics and therefore is meant to represent the structure of the community. The results for the northern and southern NSW samples are presented in Figure 7. Looking at the curves it does not appear that there is any clear separation or clustering of the samples. Considering the samples were located in different regions of the state and have experienced different management systems (e.g. native vegetation, various crop rotation schedules) some separation would have been expected.

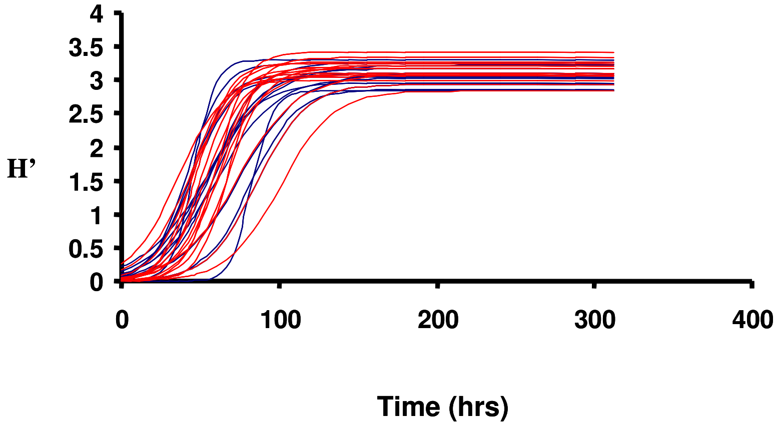

Figure 7. Fitted curves for substrate diversity (*H'*) over time.

Previous work has shown that microbial biomass and activity are strongly correlated with changes in the amount and type of soil organic matter, and to a lesser extent some evidence has been presented showing a correlation between soil organic matter and diversity (Yan *et al.*, 2000). This relationship was not observed in this study as illustrated in Figure 8. There appears to be no relationship between the amount of soil organic carbon and the diversity measured using the Biolog system. Considering the relationship seen in Figure 7 this is not surprising. It is not clear at this point in time why this data does not reflect what has been reported previously in the literature. The samples were stored for a period of time after sampling in cool conditions before the analysis could be performed. It could be suggested that the storage of the samples may have compromised the viability of some microorganism communities present creating what appears to be a more homogenous set of samples, i.e. the diversity profile of the organisms will reflect the new environment they are being stored. This result is unfortunate as it has not enabled to establish if there is a critical level of soil organic carbon below which the soil function is compromised as assessed using the Biolog technique as the indicator.

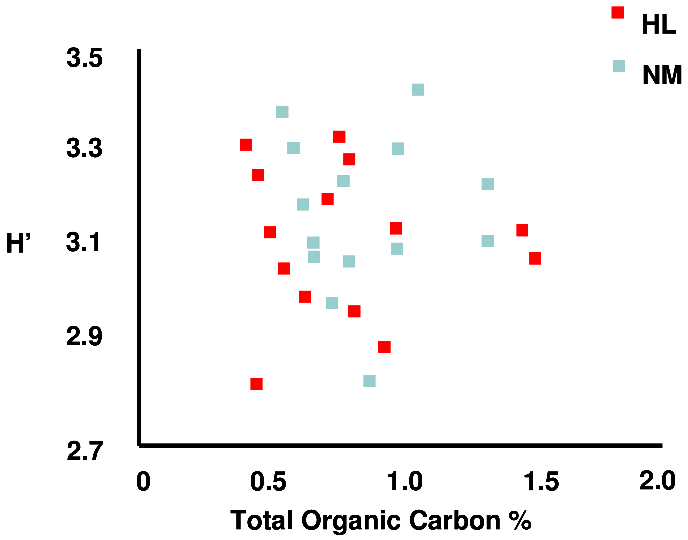

Figure 8. Relationship between the total soil organic carbon (%) and the functional microbial diversity for the samples from Namoi (NM) and Hillston (HL).

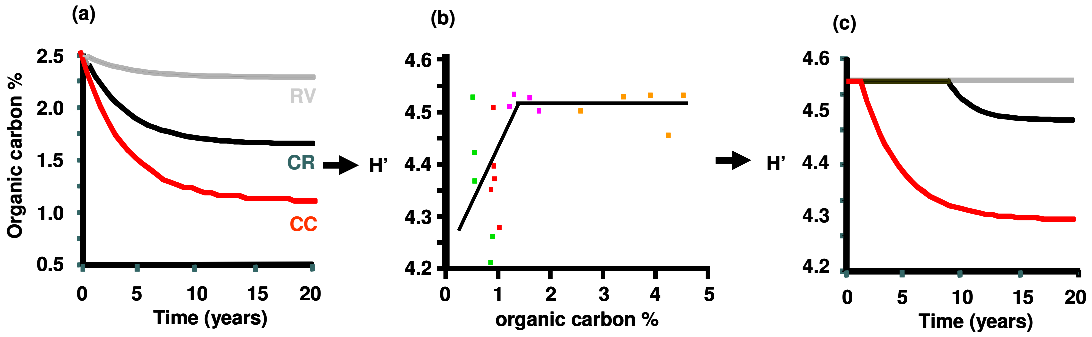

Figure 9. Using an indicator (*b*)of changes in functional soil microbial biomass to predict the decline in soil microbial biomass (*c*) responding to a decline in soil organic carbon (*a*).

The inability to identify any relationships using the Biolog technique has also hampered the development of a compartment in the soil function framework that would be used to predict how changes in soil carbon resulting from differing management systems affect the functional biodiversity (Figure 9). In Figure 9a it is apparent that different management strategies, illustrated by remnant vegetation (RV), cotton rotations (CR) and continuous cotton (CC), result in a change in the soil organic carbon over time to a new equilibrium. If an indicator of soil microbial diversity, such as the Biolog (Figure 9b), was successful it would be possible to predict the subsequent changes in the soil biodiversity (Figure 9c). To turn around this decrease it would require the injection of organic matter into the system increasing the soil carbon to levels that promote or sustain the soil microbial populations.

Given the current research within the cotton industry there is still potential to develop this area.

Milestone: *Critical finds from the postulated framework affecting soil function identified*

The final milestone of this work is to postulate a framework that would enable the function of the soil to be established. In order to do this the framework needs o consist of three components; the development of a data set of indicators of soil function, a collection of rules that score the affect of the indicators, and a means to aggregate these scores to establish if the soil is in a good functional condition.

The work in milestone one has established a collection of soil properties that can be used to monitor the present condition or changes in soil used for cotton production. This is evident from the relationships affecting the rule bases identified as part of milestone two. Thus these soil properties can be described as indicators of the soil's function and when collected together form a minimum data set of soil function indicators. It should be noted that the soil indicators identified in this work relate to the surface soil structure, ability of the soil to store water and the attempt to assess changes in the soil functional biodiversity. A minimum data set useful for other soil functions of interest to the cotton industry may consist of these, or more then likely require additional indicators. Also, based on previous work in the cotton industry, CRDC reports MCK 1C & MCK 2C, it is also expected that the soil properties affecting soil functions will be different for the different cotton growing regions. Thus, the development of a minimum data set should be modified to suite the region in which it is going to be used.

After establishing the indicators in the minimum data set a group of algorithms need to be identified that enable a score for each indicator to be developed. The rule bases developed in milestone two are difficult to aggregate as the resulting measures affect soil function are not presented on a common scale, thus the need to develop a collection of scoring algorithms. The measured indicators are converted to unitless values on a scale from 0 to 1. An indicator score of 1 represents an indicator that is not limiting to the soil function under question, whereas a score of 0 represents an indicator severely affecting the soil's ability to function. Although the critical limits may be different for different cotton growing regions it is expected that the relationship between indicators and soil function is generally the same. Some typical scoring functions that are excepted are presented in Figure 10. It can be seen that the scoring functions can; increase with increases in a soil indicator, decrease with increases in a soil indicator, or be presented as a mid-point optimum. For example, (Figure 10a) an increase in exchangeable sodium (ESP) is expected to increase the potential for a surface soil to be unstable and is represented be a less-is-better algorithm. Alternatively, a large cation exchange capacity (CEC) is associated with a soil having a greater shrink-swell capacity, which would ameliorate loss of surface soil structure. This is represented by a more-is-better algorithm (Figure 10b). The optimum soil pH for cotton growth is represented using a mid-point optimum. Continuing with the theme of surface soil structure it is possible to develop scoring algorithms that consider two interdependent soil indicators (Figure 10d). In this relationship the scores are represented by a series of curved algorithms. This relationship takes into account that the less clay in the soil the greater amount of soil organic matter (AGG) is required to maintain the integrity of soil structure. As with the choice of indictors the scoring functions need to be modified to suite the region in which they are going to be used. This modification would not only rely on the relationships identified in the previous reports to the cotton industry, such as CRDC reports MCK 1C & MCK 2C or SOILpak etc, but the local knowledge and expertise of growers and extension staff working in the regions. The development of the postulated framework using the scoring algorithms accommodates this flexibility.

Once each of the soil indicators ahs been scored these can be aggregated together give an overall score for the area of interest using the following function;

$$SF = \left(\frac{\sum_{i=1}^{n} S_i}{n} \right)$$

Where *S* is the individual indicator value and *n* the number of indicators. A possible use of this relationship is demonstrated for the Gwydir valley in Figure 11. Using the data from the Australian Cotton Cooperative Research Centres Database Assistant and the scoring functions illustrated in Figure 10 it is possible to map the soil function across the valley. In this example it can be seen that the CEC is quite high (>30 cmol$^{(+)}$/kg) resulting in a favourable soil function score across most of the valley (Figure 11a). Likewise, the ESP for the region is quite small once again resulting in a favourable soil function score across the valley (Figure 11b). Aggregating these two scores (Figure 11c) it is possible to discern an area of concern which corresponds to high ESP and a lower CEC. This would indicate that the soil is highly prone to damage and once this occurs the poor shrink-swell capacity would inhibit the soil's ability to bounce back.

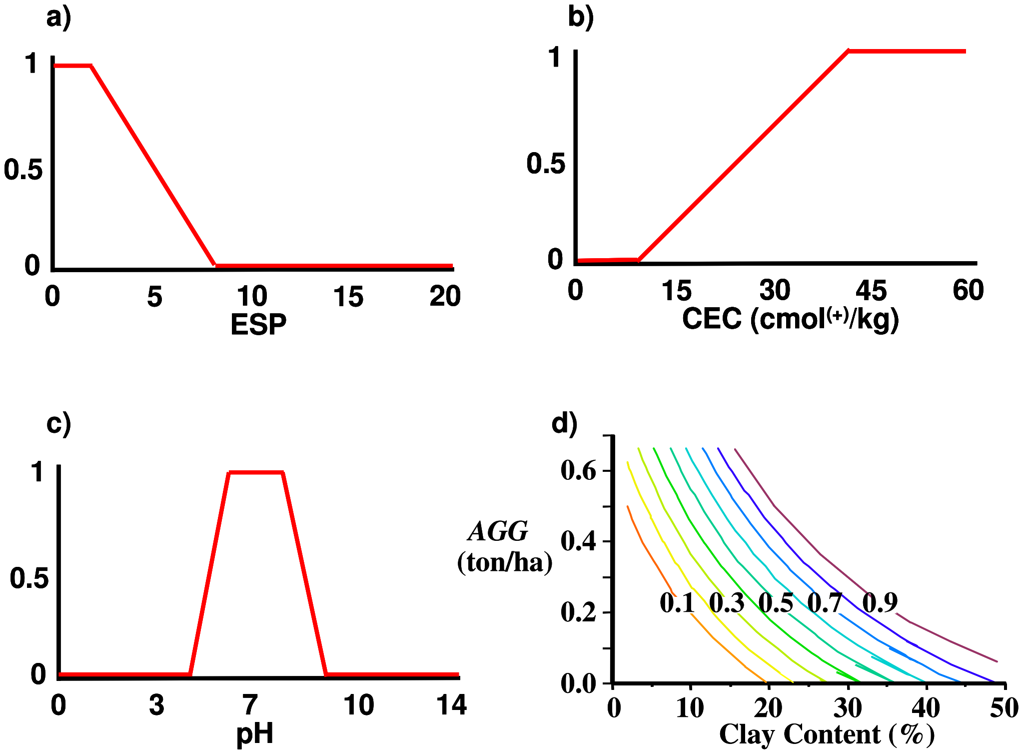

Figure 10. Algorithms used to translate soil indicators into scores for assessing soil function.

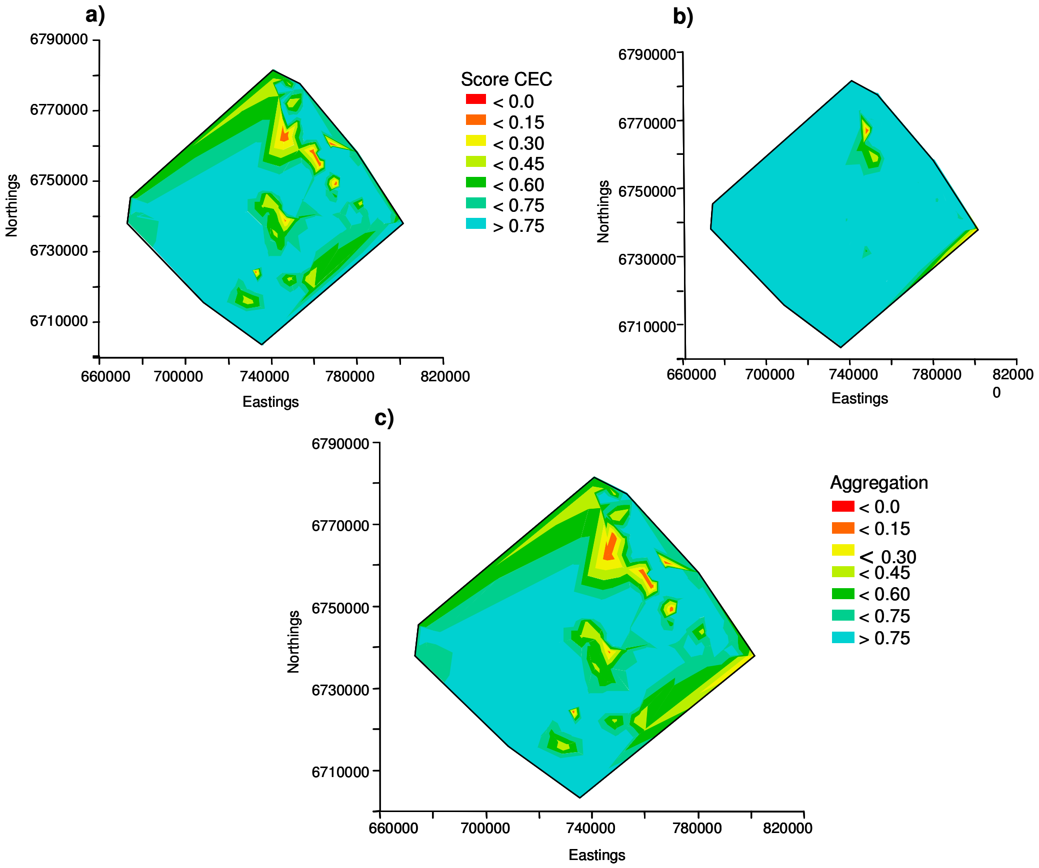

Figure 11. The spatial distribution of the scores for the soil functions of (*a*) cation exchange capacity (CEC), (*b*) exchangeable sodium percentage (ESP), and the resulting aggregated score (*c*) for the Gwydir region.

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Conclusion

The primary aim of this work was to postulate a framework in which the function of cotton soil could be assessed. To achieve this soil's were sampled and their properties were charactersied for cotton growing regions in northern and southern NSW. How these properties interacted affecting selected soil functions, namely soil stability and functional soil biodiversity where investigated. These relationships where then used to illustrate how a framework for measuring soil function can be developed. This involved three stages; the development of a data set of indicators of soil function, a collection of premises/rules that score the affect of the indicators, and a means to aggregate these scores to establish if the soil is in a good functional condition.

Extension Opportunities

1. Detail a plan for the activities or other steps that may be taken:

The use of mid-infrared spectroscopy to measure the soil properties demonstrated this as potential technology to analyse soil data. The advantage of such a technique is that in one scan many soil properties can be determined in less then a minute, rather then days using the conventional techniques. Further work would need to be undertaken to develop a calibration data set and which needs to be calibrated for the soils within the cotton growing regions. This work is currently being championed by the cotton industry.

Currently the cotton industry is undertaking the task of collating soil information as part of the healthy soil's initiative within the industry. This initiative may prove beneficial in developing the postulated soil function framework outlined in this project. There are several aspects of the healthy soil's initiative that could facilitate this. The collation of expert knowledge and data on how soil indicators are affecting soil function can be facilitated on a regional basis using this initiative. This would involve identifying what soil functions are of concern to the growers and stakeholders of the region. Once this has been established a number of workshops need to be held to identify what soil properties affect these soil functions. This needs to involve the growers as they can inform the industry what soil property data is routinely measured, and what additional soil property data are they willing to measure after considering the soil functions issues raised (a cost vs benefit issue). The resulting soil function framework can be incorporated into software such as EXCEL for use by the industry stakeholders. Once again this needs to be done in consultation with the growers as it has been demonstrated by the industry in the past that this inclusiveness results and a sense of ownership that encourages adoption.

8. A. List the publications arising from the research project and/or a publication plan.

Minasny B., Field D. J. 2005. Estimating soil hydraulic properties and their uncertainty: the use of stochastic simulation in the inverse modelling of the evaporation method. *Geoderma*, 126, 277-290

Field D. J., Minasny B., Gaggin M. 2006. Modelling aggregate liberation and dispersion of three soil types exposed to ultrasonic agitation. *Australian Journal of Soil Research*, 44, 497-502

B. Have you developed any online resources and what is the website address?

Not applicable

Part 4 – Final Report Executive Summary

Previous research of soil in cotton growing areas has highlighted that some of the soil functions likely to restrict cotton growth may be broadly categorised into soil structural limitations, soil salinity/sodicity, pH changes, organic carbon decline, and changes in soil microbial diversity. These restricting factors govern whether a soil is in good functional condition for cotton growth. At present routine analysis of soil supplies useful information for managing the soil properties that influence cotton growth yet, the interrelationships of the basic soil properties needs consideration. With this in mind this work was initiated to identify some of the physical, chemical and biological properties that can be used to identify indicators, which signify that soil is in a functional condition. The interrelationships between these indicators and how they influence the limiting soil factors can be used to develop a set of rules, which allow for the prediction of potential changes in a soil function.

Initial work involved the collection of soil samples that represented the variation that can be found in soil within the cotton growing regions. The soil properties were determined by using conventional soil analysis techniques and mid-infrared spectroscopy. The advantage of the mid-infrared techniques is that several soil properties can be assessed simultaneously with one scan in several minutes. Saving time and money compared to conventional soil analysis. Building on these findings the industry is currently undertaking further research into the use of this technique.

Subsequent work was undertaken to evaluate which soil properties influenced selected soil functions. This can be illustrated by considering how soil properties influence the surface soil stability. Analysis of the relationships found that the interrelationship between clay content, exchangeable sodium percentage and soil residual organic carbon affected soil surface stability (Table 1). The influence of a soil property depends on how it is interacting with other soil properties. Soil properties that are found to be influential are defined as indicators of soil function.

Table 1 Illustrating the prediction of surface condition from soil properties. The influential soil properties are in bold.

Profile	Clay Content (%)	pH	EC dS/m	CEC cmol(+)/kg	ESP (%)	Soil (residual) (%)	Carbon (inert) (%)	Bulk Density g/cm^3	***SFM*** Surface condition
NM130	55	7.5	0.22	56	**7.5**	0.25	0.21	1.4	***Dispersion***
NM143	**47**	8	0.15	35	**2.9**	**0.28**	0.17	1.2	***Stable***
NM138	**56**	8.6	0.18	40	**3.2**	**0.30**	0.22	1.3	***Crusting***

To help make comparison between indicators easier a procedure was adopted to convert the individual soil indicators onto a common scoring scale from 0 to 1. A score of 1 represents an indicator that is not limiting to the soil function under question, whereas a score of 0 represents an indicator severely affecting the soil's ability to function. It can be seen that the scoring functions can; increase with increases in a soil indicator, decrease with increases in a soil indicator, or be presented as a mid-point optimum (Figure 1). To give an indication of the overall soil function the individual scores for each indicator are added together and averaged, thus a soil with an overall score closer to 1 is functioning well whereas a score closer to 0 indicates investigation may be required. .

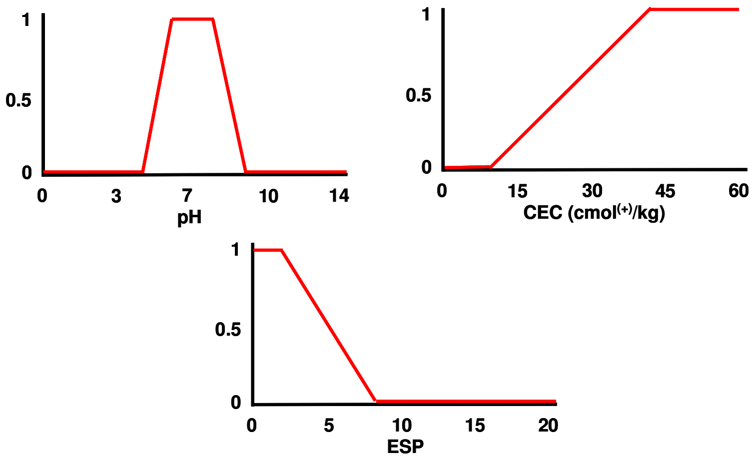

Figure 1. Example of scoring rules in the postulated soil function model