NSW GOVERNMENT Department of Primary Industries

Australian Government
Cotton Research and Development Corporation

An evaluation of the current understanding of cotton-growing soils and soil management practice issues in Southern NSW (DAN1408)

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September 2014

Acknowledgements

Dr Mark Conyers, NSW Department of Primary Industries
Mr Bin Wang, NSW Department of Primary Industries
Mr Kieran O'Keeffe, Regional Development Officer, CottonInfo
Mr Jorian Millyard, Cotton Seed Distributors
Dr Warwick Dougherty, NSW Department of Primary Industries
Mr Allan Williams, Cotton Research and Development Corporation

The authors of this scoping study are very grateful to the (anonymous) 13 growers and 5 consultants from across Southern NSW who generously gave of their time to be surveyed and interviewed for this project. We would also like to thank the Research Focus Group for their valuable input to the project. The Research Focus Group included A. Ringrose-Voase, D. McKenzie, I. Rochester, J. Triantafilis, M. Bell, N. Hulugalle, S. Cattle, S. North, W. Muirhead and K. O'Keeffe.

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Executive Summary

Cotton is a relatively new irrigated crop in Southern NSW and has proven to be financially profitable. The cotton growers in Southern NSW need to know more about their soils so that they are able to refine soil-related management practices. The growers are facing a number of soil-related challenges and need improved local soils information. The irrigated cotton soils of Southern NSW are quite different from the cotton soils in the northern cotton regions. In Southern NSW the soils are highly variable and also the region has a distinctively shorter growing season which causes other management problems. Parts of the region include rice cropping or have a history of growing rice and this has unique implications on the soil for growing cotton. This scoping study was commissioned by CRDC because there was a recognised lack of understanding on the cotton growing soils and the associated soil management practices in Southern NSW. It was recognised that there was a need to identify knowledge gaps, to establish research questions that relate to the cotton soils and their management in Southern NSW and to report on the current information available on cotton soils.

The approach taken in this study involved two main components as follows: (*i*) surveys and interviews with growers and consultants and (*ii*) a desktop study of data and literature for soils and soil management practices. Initially a research focus group was formed to formally receive expert opinion on the level of understanding of irrigated soils in Southern NSW and also to identify some research priorities. Written surveys were completed by the 13 growers and 5 consultants that were interviewed one-to-one. This ensured that the study thoroughly engaged with the local cotton industry. The interviews were semi-structured as they were guided by 9 primary questions. Each interview lasted between 40-60 minutes, was recorded and transcribed. Growers and consultants were selected to cover differences in terms of experience, cotton area, soil type and location. The desktop component of the study involved reviewing and evaluating soils/ soil management practice data and information from Southern NSW and other regions where cotton is grown.

The interview responses indicated that most growers were using high levels of nitrogen in their cotton systems which appeared to be based on a risk management approach. The use of manures and stubble was fairly widespread among those interviewed, however many growers were uncertain about the nutrients supplied from manures. Issues relating to the short growing season were acknowledged by growers; with soil temperature and establishment issues at the start of the season and soil compaction concerns at harvest. The pressure and challenges associated with back-to-back cotton were frequently mentioned, although this may relate to the current water availability and cotton prices. Regardless of the reason there were several soil issues associated with crop rotation such as stubble management, cultivation and compaction which were raised as problematic. On stubble there were issues around getting sufficient breakdown before the next crop and the tie-up of nitrogen. With cultivation the challenge was related to the time pressure for activities such as pupae busting, stubble incorporation and bed formation. Compaction was mentioned as a serious issue by growers/ consultants from all districts in Southern NSW. Several scenarios were identified as high risk for compaction and some respondents provided options to avoid compaction, but there was uncertainty regarding the extent of or impacts from compaction. Comments on irrigation primarily centred around setting start date, and the decisions around irrigation interval during the season. When irrigating most growers described as though there was system (or layout) ‘lock-in’ and once they

started irrigating there was very little opportunity for flexibility. Some soil issues such as acidity and salinity do not seem to be widespread, but more spatially isolated to specific cotton soils in Southern NSW. As cotton is a relatively new crop for some growers it appeared as though some respondents were learning through experience. Growers mentioned several different sources of soils information with advice from consultants and information from other growers being very important.

A review of the current soil survey data for Southern NSW was undertaken. The two main on-line databases are: eSpade/ SALIS (NSW Office of Environment and Heritage) and ASRIS (CSIRO). Areal estimates of soil order in Southern NSW showed that Vertosols are the dominant soil in the Murrumbidgee valley and cover 43% of the Lachlan valley. These are very approximate estimates because they are based on very limited soils and landscape data.

Assessment of previous cotton soils research (mostly from Northern NSW) reveals that there are opportunities to utilise results and translate them to Southern NSW. We established that there are limitations to utilising research from elsewhere; however as a guide we identified some key regional factors such as mineralogy or soil pH which strongly influence major soil processes. Likewise the same approach was applied to soil management practices. Again a series of different regional factors was found which have a large influence on the effectiveness or difficulty associated with implementing soil management practices.

The evaluation of databases and literature on soils and soil management practices also identified gaps in understanding for the cotton soils in Southern NSW. Exploration of soil survey databases indicated there are large differences in the coverage and quality of soils spatial data across Southern NSW. Major soil degradation processes including acidity, erosion, salinity and sodicity were each selected with research areas described which relate directly to the soils in this region. Soil chemical properties were examined and in many cases there is no published data available. A lack of understanding on the impact of different management practices on soil physical and hydraulic properties was evident. Quantification of soil hydrology on cotton soils and soil water properties is required. Very little information is available on the soil biological condition of the cotton soils in the region. At the farm scale there is a lot of uncertainty on issues such as compaction, stubble, tillage and crop rotations.

From this scoping study recommendations are made for future research and development activities. We suggest that a soil management practice case study is undertaken to improve understanding on the how and why growers make decisions in four areas: sowing and crop establishment, nitrogen fertilizer applications, irrigation scheduling and with picking and cultivation. We recommend that work is commenced to improve the soil spatial data for the cotton soils of Southern NSW with the highest priority on determining the extent of sodicity. A soil nutrient database is recommended as a means to increase industry confidence on the levels of critical soil test values. Such a database could enable benchmarking and also contain established crop nutrient response curves. Attention on soil physical condition is advised because of the unique soils found in the region and the uncertainty with the impacts from soil management practices. Finally, all future cotton soils research and development undertaken in Southern NSW should aim to produce soil management guidelines to identify and encourage the adoption of best practices.

1. Background

The irrigated soils across Southern NSW have been intensively cropped to support a wide range of annual and perennial cropping industries. Cotton was first grown in the Murrumbidgee Irrigation Area (MIA) in the 1960's and was described as the "Lusty New Infant of New South Wales Agriculture" (Anon. 1964). Recently cotton has made a resurgence as a very profitable and attractive crop to grow in Southern NSW. There are however several challenges to growing cotton in this region; namely the climate (i.e. the short growing season) and the challenging and diverse soil types.

Between 40,000 to 50,000 ha (per annum) of cotton have been grown in Southern NSW over the past few seasons (O'Keeffe, Pers. Comm.). This area varies each year according to water availability, although the area grown still represents a significant contribution to the national cotton crop. The areas where cotton has been grown in Southern NSW are shown in Figure 1. The major sub-regions include the Lachlan valley (near Hillston), the Murrumbidgee Irrigation Area (MIA), the Coleambally Irrigation Area (CIA) and the Hay district. There remains potential for the area of cotton to increase in future years (Millyard, Pers. Comm.). For instance, there continues to be an expansion southwards with crops being recently grown around Finley and Swan Hill in Victoria.

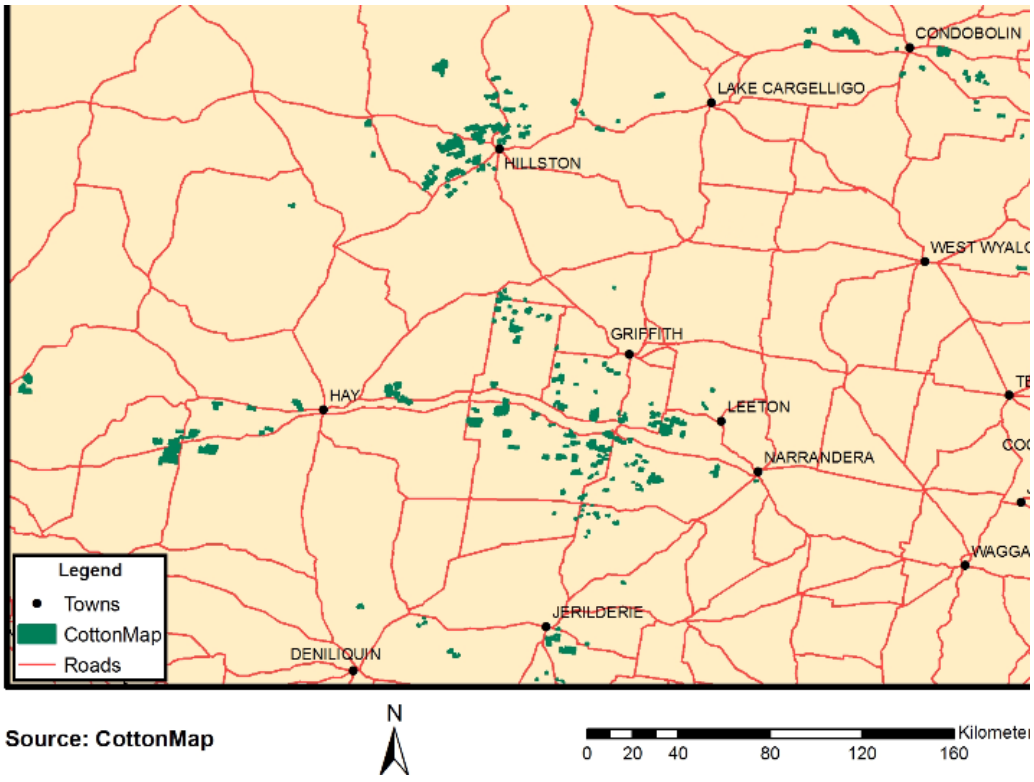

Figure 1. The area of cotton grown from 2009 – 2014 in Southern NSW (Source: Cotton Australia)

In comparison to the well established cotton industry in Northern NSW there remains a lot to be learnt about growing cotton in Southern NSW. Cotton production in this region has recorded some high yields being which is very promising for the future of the industry. The area includes a great diversity of soil types that have different chemical and physical properties. For example, the red alkaline soils found near to

Hillston behave very differently from the sodic grey soils near Hay or the acidic heavy clay soils near Darlington Point. Managing and working with these soils is an on-going challenge facing cotton growers.

There are a number of soil-related “unknowns” and some significant gaps in current understanding regarding appropriate soil management practices of the cotton soils in Southern NSW. The irrigation production area where cotton is grown also includes numerous other crops. Other irrigated summer crops include rice, soybeans and maize, while several different winter crops such as wheat, canola, barley and faba beans are grown too. There is limited knowledge of the benefits and drawbacks of various crop rotations and the possible soil effects. Because there has been little independent research in this region there are numerous questions on soil fertility. Consequently, there are several questions that growers have on nitrogen (N) fertilizer management, especially relating to the total N budget and N type. Improvements in N fertilizer use efficiency will be hampered while so many questions remain unanswered for growers. Other nutrition problems relating to potassium and zinc exist and there is also interest in the role and contribution of applying manures for cotton crop nutrition. The cotton gins are now composting gin trash so best management practices of compost are needed. Because of the great diversity of different soil types across Southern NSW the management of sodic and acidic soils are also other challenging issues. Concern about the impact of soil compaction and the risk of damaging the soil at picking is becoming an increasing problem.

Because there is potential for the area of cotton in Southern NSW to increase, there is a need for quality spatial soils data for the cotton soils. We believe that the information collected in this region should at least match what is available for the cotton districts in Northern NSW. For example, in Central and Northern NSW well developed spatial information for soils in seven irrigated cotton-growing regions is available from TerraGIS (Figure 2). Figure 2 shows a snapshot example from the Wee Waa district of spatial biophysical soils data which is currently available. In this example the exchangeable sodium percentage (ESP%) is given. TerraGIS can provide a wide range of spatial data such as cadastral, geophysical, soil properties and hydrological properties. Future research activities which develop TerraGIS in Southern NSW will assist growers to better evaluate soil constraints such as sodicity or salinity.

Soil degrading processes are recognised as a threat to cotton production. For instance, cotton is very sensitive to acidic conditions. In Southern NSW acidic soils are often found where there has been a previous history of growing rice. Moreover reduced nutrient availability is associated with acidic soils. Fertilizer expenses are the largest variable input cost for growing cotton. In 2013 cotton growers (on average) spent $546 per hectare on fertilizer (Boyce Chartered Accountants and CRDC 2014). There are potential financial savings for cotton growers if they are able to increase their efficiency with fertilizer applications such as nitrogen. Improvements in nutrient use efficiency can lead to higher yields and improved profitability. Sound crop nutrition has a bearing on crop maturity which can affect the timeliness of harvest. An understanding of soil nutrient status is required for sound environmental stewardship and to minimise the off-site impact of growing cotton. Growers in Southern NSW need more soils information that relates to their soil types. This also requires consideration of both short and long term impacts from management practices. Soil management practices that maintain optimum soil health should be implemented so that cotton is grown in a sustainable manner.

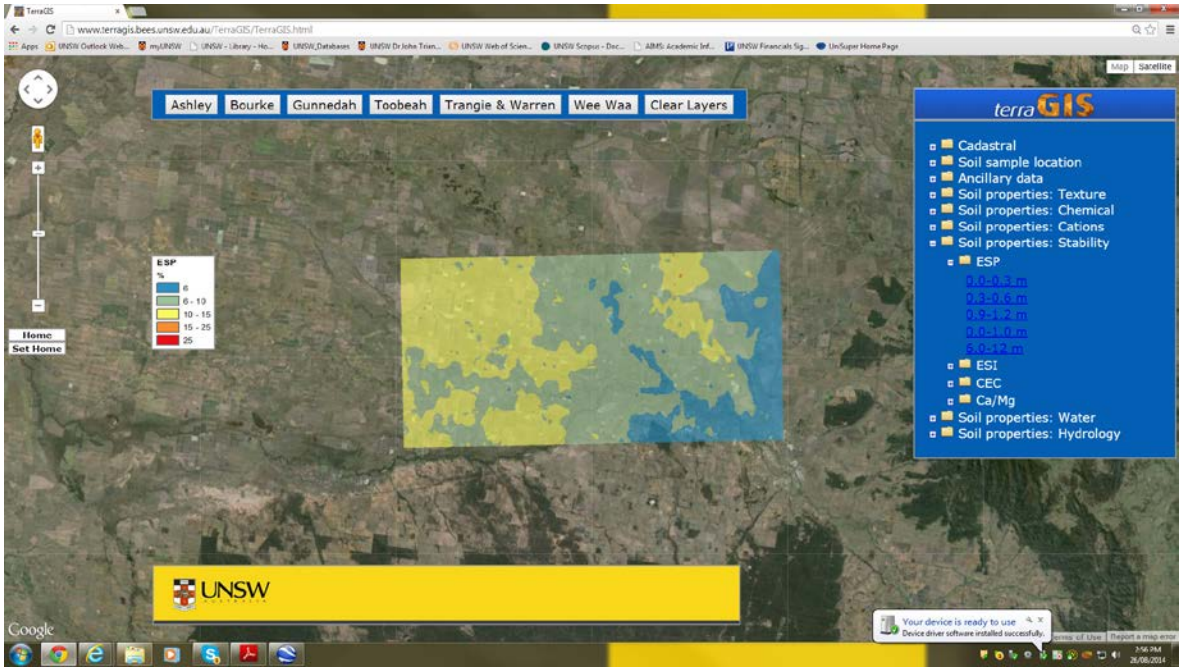

Figure 2. An example of the biophysical data available with TerraGIS showing the exchangeable sodium percentage (ESP%) for the Wee Waa region
(Source: TerraGIS http://www.terragis.bees.unsw.edu.au/TerraGIS/TerraGIS.html)

The issues given above are just a selection of the current soil issues and soil management practices that need thorough investigation in Southern NSW. This study was undertaken because of the recognised lack of understanding of soils in this region, to identify the nature of these issues and to make recommendations for future research.

2. Project Aim

Cotton growers in Southern NSW need to know more about their soils so that they are able to refine soil-related management practices. This project was designed to engage with important industry representatives (growers, consultants, researchers) to determine their current level of understanding on soils. In addition, the project evaluated previous relevant studies to identify knowledge gaps and to establish research questions that relate to the soils and their management in Southern NSW. Therefore, the main project aims were:

(*i*) to assess the current industry understanding of the cotton-growing soils in Southern NSW;

(*ii*) to identify the most important challenges for soils management practices in Southern NSW.

3. Study Approach

This scoping study used a mixed method approach in order to make a thorough assessment of the soil issues and the associated management practice challenges for cotton growers in Southern NSW. While close to the Southern NSW region, due to the short duration of this study we have not covered the cotton growing soils near the Menindee Lakes (i.e. Tandou Ltd). The two main components were: (*i*) undertaking surveys and interviews with growers and consultants and (*ii*) a desktop study of soils data and literature.

3.1. Industry survey and interviews

Initially the approach taken in this study was quite exploratory in order to understand about the cotton-growing soils of Southern NSW without preconceptions. The local cotton industry was engaged in this study. Therefore, we had discussion with a broad range of personnel who are active in the cotton industry including growers, consultants, suppliers, extension/ development staff and researchers. Engagement with the cotton industry was undertaken to assess the current understanding of cotton-growing soils and to identify the most important challenges for soil management practices in Southern NSW.

Research focus group

The first step was the formation of a research focus group to gather expert opinion on the level of understanding on irrigated soils in Southern NSW and identify research priorities. The research focus group included 9 soil scientists and 1 development officer. This group included some soil scientists with >30 years experience in research and others with many years of experience of the soils in Southern NSW. The research focus group engaged in a structured discussion which was focused on two main subjects (*i*) the soils found in Southern NSW and (*ii*) the effect on/ impact on/ consideration regarding soil and growing cotton. Feedback from the research focus group guided development of questions for the subsequent surveys and interviews with the growers and consultants; in addition provided insights for the direction of the project.

Written surveys

Written surveys were undertaken by each grower and consultant that was interviewed (see Appendix 1). The surveys included 15 questions focused on the unique features of the farm for each grower. The surveys for the consultants were similar, but the focus was on the range of different soils of the grower clients. Details on the experience and operational size of each grower/ consultant were surveyed. The surveys were useful as a means to record other details such as business type and were designed to be supporting information for the one-to-one interviews.

One-to-one interviews

Interviews were used to gather experience and insights from the industry and to gain deeper understanding about soil issues and management practices. One-to-one interviews were conducted with 13 growers and 5 consultants. Participants were selected through personal contacts of the researchers and through ‘snowball’ sampling where participants are asked to suggest other contacts. The aim was to interview a range of growers in terms of experience in growing cotton and location/soil types. The

interviews were semi-structured and involved 9 primary questions so that a broad range of topics and issues were discussed in each interview (see Appendix 2). To keep the discussion flowing, a series of prompting questions were asked to allow the respondents to expand on their perspective or understanding of an issue.

Across the Southern NSW region there are large differences in terms of grower experience. The study area includes a wide range of different size cotton farms and there are major differences in the soils and their properties. Consequently, special care was taken in the selection (in terms of experience, cotton area, soil type and location) of the growers and consultants for the interviews.

Each interview lasted between 40-60 minutes and was recorded using a portable stereo recorder (Olympus WS-831). The audio recordings were stored in an MP3 file format and transcribed using a professional transcription service (SmartDocs Pty Ltd). The interview transcriptions were analysed to identify key themes and common issues (Bryman 2008) using qualitative analysis software (NVivo10) (QSR International Pty Ltd 2012).

The themes are presented in section 4.2. In this section the experiences and insights from interview respondents are presented either verbatim as quotes, or paraphrased by the researchers. Specific quotes have been chosen to represent different points of view, or where a respondent may have summed up the issue clearly and succinctly (Kvale and Brinkmann 2009).

3.2. Soil survey data and other soils information

The soils data and information gathering component of this study was undertaken in order to establish and to collate the current knowledge and data on the cotton-growing soils of Southern NSW. The approach taken was to search through and identify relevant previous research papers, technical reports and other publications on soils and soil management practices. Studies on related areas such as geomorphology, hydrology, irrigation, agronomy and crop production were also consulted. The main organisations involved in soil survey and soils research in Southern NSW have been the CSIRO, the NSW Department of Primary Industries and the NSW Office of Environment and Heritage. Thus, the libraries and databases of these organisations are major sources of soils data and information. Researchers from other organisations such as the University of Sydney have also been active in the region. Evaluation of the data and information collected was also undertaken to identify the gaps in understanding on soils and soil management practices for cotton production in Southern NSW. In addition, some exploration and analysis of soil spatial data was undertaken using ArcGIS software.

4. Results and Discussion

4.1. Industry survey

The approximate location and the numbers of growers and consultants who were surveyed and interviewed from across Southern NSW are shown in Figure 3.

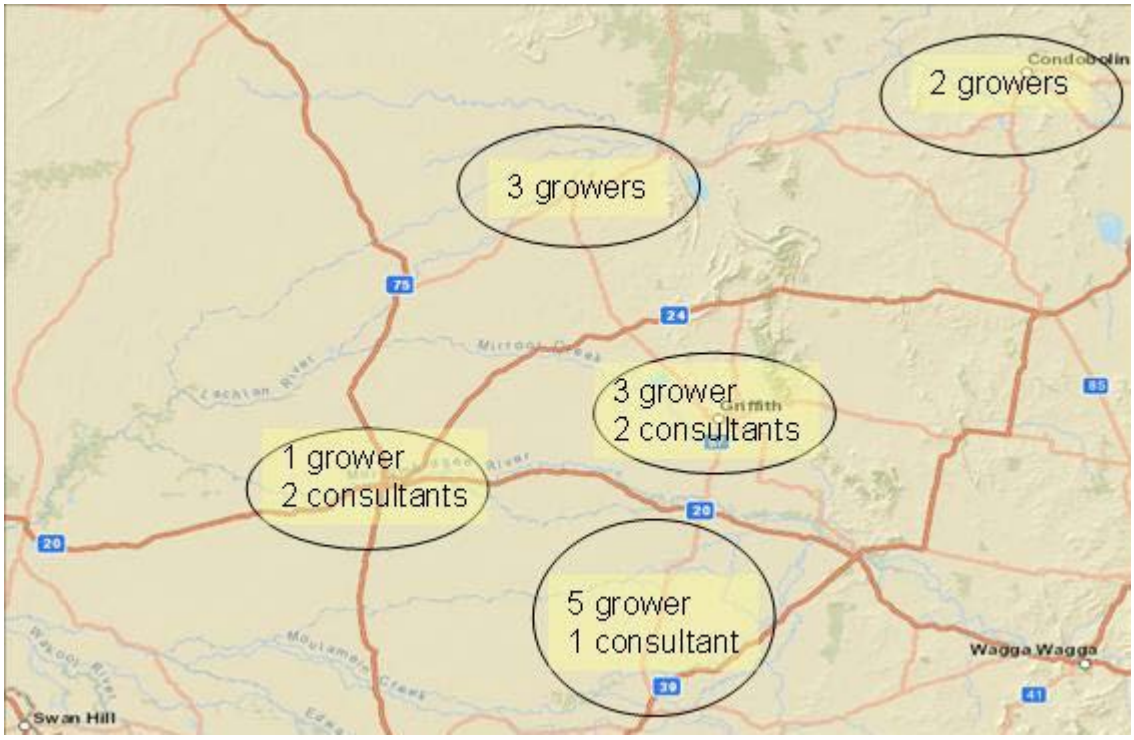

Figure 3. The districts where cotton growers and consultants were surveyed and interviewed from across Southern NSW. (NB. Consultants have clients in more than one district)

The survey data showed that the 13 growers with a widely different experience with growing cotton responded. The least experienced growers had only grown cotton for 3 years, while the most experienced had grown cotton for 30 years (including 12 years in Southern NSW). The growers surveyed were from a broad range of different size cotton farms with different production related attributes or characteristics (Table 1).

Table 1. Survey responses (production related attributes or characteristics) for the cotton growers who were interviewed in Southern NSW[A]

Grower attribute/ characteristic	Response
Area of cotton grown	120 to > 3,000 ha[B]
Average area of cotton	892 ha
Average cotton yields	7.3 to 12 bales/ ha
Best recorded cotton yield	10 to 15 bales/ ha
Worst recorded cotton yield	2 to 10 bales/ ha
Average water use	7.5 to 12 ML/ ha
Irrigation water source	2 growers channel only 3 growers river only 8 growers mixture (channel, groundwater, river)
Groundwater	6/ 13 growers have groundwater at 30-40 m depth 5/ 13 growers with groundwater of good quality
Irrigation scheduling	most (11/ 13) growers use soil water monitoring
Starting sowing date	15 September to 1 October
Starting harvest date	15 April to 15 May
Soil type	red loams, red brown clays, grey clays, heavy clays
N budget	180 to 330 kg N/ ha[C]
Soil / plant tissue testing	12/ 13 growers undertake soil testing 9/ 13 growers undertake plant tissue testing

[A] The survey was completed by all (13) of the growers that were interviewed.
[B] The area of cotton by the surveyed growers was 11,600 ha (for the 2013/14 season) which is a significant proportion of the total area grown in Southern NSW.
[C] 9 out of 13 growers use manure as part of their soil fertility program.

Most growers also grow wheat or another cereal in rotation with cotton, while the most popular other irrigated crops included corn and soybeans. Just over half of the growers have in the past or still do grow rice. The growers interviewed represented both private companies and agribusiness corporations. All of the growers use consultants to assist in decision making and a variety of different sources of information are used to manage soils e.g. field days, magazines, internet, own experience, neighbours experience.

There were 5 consultants surveyed who covered different parts of the Southern NSW cotton production area. These consultants ranged in their experience (from 1 to 16 years) with working on cotton in Southern NSW. The consultants surveyed were operating different size and types of businesses to support cotton growers. Some production related attributes or characteristics for the grower clients of these consultants are given in Table 2. As expected a diverse suite of different soil types were covered and a mixture of different irrigation water sources were also reported. The consultants included independent sole traders (i.e. providing advice only) as well as corporate agribusiness companies (i.e. providing advice and selling products). Overall, the consultants represent a mixture of different experience, business types and varying involvement with growers.

Table 2. Survey responses (production related attributes) for the clients of the cotton consultants who were interviewed in Southern NSW[A]

Client attribute/ characteristic	Response[B]
Average client cotton yield	8 to 11 bales/ ha
Best recorded client cotton yield	12 to 16 bales/ ha
Worst recorded client cotton yield	5 to 7.5 bales/ ha
Average client water use	7 to 12 ML/ ha
Client N budget	230 to 310 kg N/ ha

[A] The area of cotton consulted was 22,500 ha representing 55 growers in 2013/14
[B] Range given is from minimum to maximum value

4.2. Analysis of interview issues and themes

Research focus group

A panel of research experts were gathered via teleconference to provide input into the development of questions for the grower/consultant survey and interviews (see methods section 3.1.). The experts had extensive experience in soil science and on soil/ cotton interactions. A summary of the highlights from the discussion is provided below.

The focus group participants indicated a range of potential issues for further investigation. One participant identified that in the Hillston area (the highest yielding Southern cotton area) sodicity was the most compelling subsoil issue, which has implications for soil water storage. Irrigating from bore water and the potential effects from salt loading was raised as a concern in this area.

Grey and black soils where seen as the best for cotton, while red soils presented the most difficulties due to low organic matter and restricted plant available water content. More knowledge was needed on how surface soils interacted with the subsoil, and the implications for cotton. The red soils can suffer from 'melting down' or dispersion. Compaction is particularly a problem on Vertosols but can be an issue anywhere with large machinery and an early wet period. Pupae busting can also lead to deterioration of soil organic matter in the red soils.

Cotton is a crop that doesn't like concentrated sources of nutrients and is a good forager, with roots 10-30cm deep in northern Australia cotton growing areas. In southern NSW sodicity may have an impact on this rooting depth. One participant identified that cotton was inefficient at uptake of phosphorus and potassium for the topsoil while more efficient at accessing these nutrients from subsoil reserves. Foliar applications were not considered to be effective for solving this issue. Phosphorus was identified as an issue when cotton follows rice and nitrogen issues can occur if following a summer crop.

Seedling emergence was seen to be an issue, especially in heavier soils. The seed can get a cold shock from early irrigation and potentially be impacted by waterlogging on the second irrigation. One participant questioned the impact of soil variability on irrigation practices. Rotation practices were also seen as important as further south it is difficult to get double cropping rotations and back-to-back cotton can cause problems. Introducing a legume, such as Faba beans, into the rotation was suggested as a favourable option. Rice and cotton were seen as a economically favourable, but physically questionable to grow in rotation.

From the focus group a range of areas for investigation were proposed:

- How are growers managing their soils, what challenges are they facing?
    - How are they managing nutrients, compaction, irrigation
- How are growers approaching timing of planting?
- What are the current practices for building/maintaining soil organic matter?
    - Use of manures, permanent beds, reduced tillage, store/retaining carbon
- How are growers managing their rotations?
- Gather specific data from growers
    - for example: average paddock water use, nutrient practices (NPK), Soil tests, Irrigation rates
- Where do growers source information for decision making?

  - role of advisors
  - interaction with information from industry organisations (e.g. CRDC and Cotton Australia)
  - interaction with other growers
- How do consultants build their knowledge (training, knowledge from industry organisations etc)

Results from grower and consultant interviews

Responses from interviews of cotton growers and consultants are summarised below, the analysis process is described in the methods section of this report. The themes identified in the interview responses are listed in Table 3; each theme is classified by type and these themes are then discussed in general. Direct quotations are used where possible in relation to the issues discussed to highlight respondent opinions. Each respondent was given a pseudonym to protect their privacy. Due to the difficulty to be quantitative in such interviews, we used indicative terms such as 'some' (approx 2-5 growers), 'many' (6-9 growers) and 'most' (10-12).

Table 3. The themes identified from the interviews with the growers and consultants according to theme type

No.	Themes	Theme type
1	Soil acidity and salinity	soil property
2	Sodicity	soil property
3	Nitrogen management	management practice
4	Nutrient (non-nitrogen) management	management practice
5	Use of manures and stubble	management practice
6	Variability and Precision Agriculture	management practice
7	Disease and pest management	management practice
8	Soil temperature and seedling establishment	management practice
9	Crop rotations and back-to-back seasons	management practice
10	Compaction	management practice
11	Irrigation	management practice
12	Grower information sources and learning	development issue
13	Research opportunities and grower questions	development issue

Soil acidity and salinity

Around half of respondents listed acidity as an issue (either too high or too low), but mostly saw it as manageable by lime application. According to some growers a pH of below 5.5 can cause problems with cotton and one grower attributed a yield of 5 bales/ha to low pH which took 2-3 seasons to remedy through lime applications. Acidity was identified as a potential issue when following rice with cotton.

Salinity was not viewed as a problem by most respondents, although two growers identified some salinity problems. One respondent said that this was due to water tables not being as high as they used to be. There was a potential salinity risk from groundwater and reticulated irrigation systems.

Sodicity

A major soil-related issue identified by respondents was the occurrence of sodicity causing slumping and crusting and subsequent reduced infiltration. Growth of more

compact plants with shorter nodal length in sodic areas was noticed by one respondent while another cited a 2-3 bale/ha reduction in production on sodic areas. Another stated:

"Sodicity is probably the main cause of any yield decrease. We've got certain paddocks where ... there's no sodic soils in them at all and we're constantly averaging over a bale if not more per hectare" Respondent 5

Sodic subsoils could also cause problems for root growth according to one grower interviewed:

"Following a water-up event, we tend to see … if we have very dispersive subsoils that they tend to disperse out and almost self-compact. And then we seem to have trouble then getting cotton roots to grow through that zone in the early stage of the season" Respondent 8

While the sodicity problem was seen to occur across most soil types in the region, respondents highlighted several practices which can exacerbate sodicity. The cut and fill associated with lasering paddocks for irrigation uncovered highly sodic patches. Some growers interviewed were highly conscious of minimising the effects from cut areas and held concerns over the amount of soil needing to be moved, for example to change to a bankless irrigation systems. A respondent suggested that relying on groundwater with a high sodium load may act to exacerbate sodicity issues which suggest that irrigation water quality is an issue.

Strategies that growers took to alleviate sodicity included focussing on a good irrigation layout which minimised waterlogging and focussing gypsum application on the cut or sodic areas.

Nitrogen management

There was a wide range in the rates of nitrogen applied across the growers interviewed (see Table 1). Most growers applied two-thirds of their nitrogen prior to sowing to give the crop a good start but also because they found it difficult to apply the N when the crop was established. However there was a lot of variation, one grower applied 80-85% of N up front, while another applied 30%. Initial N was applied by some growers as anhydrous ammonia, while others used urea. One consultant thought 20% of growers were using the anhydrous method. A grower commented that they would avoid using anhydrous gas application if they had achieved a fine seedbed, as the application method often dug up large soil clods.

Follow-up applications of N were delivered via a variety of methods including water-running with irrigation, and foliar applications. Back-to-back cotton crops were frequently provided with extra N, up to 50kgN/ha more in one case. N was applied through manures, but there was uncertainty about the exact contribution from this source. Overall, the high rates of N application seemed to be used as a risk management strategy with one respondent thought that applying too much N causes excess plant growth and poorer fruiting. Another commented:

"We're not getting more yield by just applying more fertiliser. What we're getting is more yield if we're growing a crop on a rotation. There's more to it than nutrients, put it that way, more to high yielding cotton than just fertilising." Respondent 10

Additional comments on nitrogen management are given below as part of the 'Use of manures and stubble' theme.

Nutrient (non-nitrogen) management

Of the other macro nutrients some growers were applying P, one was applying 45kg/ha in order to build soil reserves and a consultant suggested there were others applying between 30-40kg/ha. Chicken manure was seen to be a good source of P. For instance one grower commented:

"Phosphorus, as I said, we're not putting out any MAP or anything like that. No granulated stuff at the moment because our phosphorus levels are very, very high from chicken manure. We're finding we're getting lots of phosphorus and we're getting lots of potassium out of manure. We're actually probably finding that maybe our soil is too high in everything and it might actually be affecting our cotton yields slightly." Respondent 17

Many growers thought that soils in the region were said to be high in potassium (K), however one grower was applying up to 12kg/ha as a foliar fertiliser at mid-flowering to help finish off the crop. Some growers appeared to be uncomfortable or confused about K. One grower mentioned:

"I don't know how far we can push the cotton with more potash or whether we actually need the potash we're putting on. It's a mystery, the potash, to me. The soil test would suggest that we've got a reasonable level of potash in the soil but we're worried about dropping it out of the programme and having a senescence issue later on." Respondent 7

Some growers noted that from late-December to mid-January they focussed on additional N, P, and K to ensure the crop met its potential. Gypsum was widely used to address sodicity and surface crusting of soils, for example one grower applied 1t/ha gypsum pre-planting to address crusting. Most growers did not report any concerns regarding their soil sulphur levels and gypsum was the dominant source of sulphur supplied.

There seemed to be an inherent uncertainty about the requirements for trace elements in cotton systems. There was variability across soil types in respect to responses to trace elements. Zinc was commonly applied by growers, some saw manure as a major source of zinc while one grower was applying 6kg/ha zinc in his fertiliser program, and another was applying a mix of copper, boron and zinc.

Use of manures and stubble

Most (nine) of the growers interviewed used manures in their cropping system, and eight of these used it regularly. One grower used a compost mix composed of gin trash, cow manure, gypsum, and clay. Another grower spread manure before pupae busting or stubble incorporation to improve mixing within the soil profile, while another applied the manure between crops. Manure used was primarily as a by-product from chicken production however some cattle manure was used. One respondent commented:

"Around Griffith, Darlington Point, Coleambally, (there is) quite a bit and that would be probably about 30 per cent of the area would use manures. Those sort of rates,

around about that five to seven tons to the hectare, depending on what (the) cropping history's been" Respondent 12

Benefits were seen to include a cheap source of N, P, K and S along with some micro nutrients, and improved biological health of soil. One respondent saw manure as a good source of K, and another said it was high in P. There appeared to be general uncertainty over the actual composition of manure brought onto farms and that sometimes the analysis provided by suppliers didn't match with the product received. In addition to uncertainty over the supply of macro nutrients from manure, growers had questions about the time for nutrients to be plant available, and how much zinc may be provided by manure. In terms of manure as a supply of N, a consultant commented:

"A typical rate for growers anyway, they'll put two tonnes of chook manure on. It's only a component of their nitrogen budget, it might only amount to 10% of their nitrogen budget, so the mystery of whether it's there or whether it's not there in terms of nitrogen, it's neither here nor there in terms of how the crop's going to react, we're not going to get caught out" Respondent 4

"We like to rely on synthetic nitrogen and know what we're doing there because it's too unpredictable, it's a bit of an unknown what you're getting. Some of the manure piles that you get delivered, particularly after a wet season, they'll be sitting there, you can smell the ammonia coming off these piles, they probably have been sitting around the chook sheds for months, then they're on farm for months waiting to be spread and then how quickly do they incorporate them once they've been spread? There's all these unknowns of how many losses we're getting and then we're seeing it or we're not seeing it in the cotton crops in terms of nitrogen" Respondent 4

One who didn't use manure commented that he found it more convenient to use artificial fertilisers in his system because of the large volume of bulk product and cartage costs. Cartage was seen as a factor for another respondent (consultant) who said:

"it depends on the location of the farm in regards to freight. If it is, for example, west of Hay, the freight components are significant compared to if you're at Darling Point." Respondent 18

The incorporation of crop stubble as a method for increasing soil organic matter, especially in lighter soils, was another major talking point for growers. One respondent noted improvements in soil structure, along with better water holding capacity and crop establishment, after 8-10 years of stubble incorporation. However, growers commented that retention of stubble brought challenges such as:

- needing to 'be on the ball' to make N available for microbial activity;
- dealing with the volume of stubble can be difficult when there is a short turnaround to the next crop;
- wireworm issues with increased stubble (along with other pests).

The use of nitrogen during stubble decomposition was addressed by one respondent:

"Then we put 120 kilos of urea, so that's, I don't know, 55, let's say 55 kilos of nitrogen in that first side dress, and we didn't get a response to it. But it was the tie up of that trash. It had just tied all the nitrogen up, because it was the first opportunity that we'd had to actually break any of that material down" Respondent 11

A consultant commented on the risks associated with stubble:

"If you've got a grower that's hell bent on incorporating an eight tonne wheat stubble then we're almost shaking our heads saying 'You're really setting yourself up here with a lot of risk.' We just see it every year that some growers test that out and quite often they're getting eaten out by wireworm because of the huge wireworm pressure and also the disease and just not getting seed soil contact." Respondent 4

Potential responses to deal with stubble suggested by respondents were:

- increase N application to account for stubble, possibly up to 30 units of additional N/ha;
- burn stubble if there is a short turnaround time;
- disc in the stubble to encourage incorporation, or undertake root cutting;
- timing e.g. in a wheat crop before cotton, don't push the wheat crop too hard to minimise stubble.

Variability and Precision Agriculture

The concept of precision agriculture was not included as a specific question in the interviews, however within paddock variability and precision agriculture approaches were discussed by some growers. While acknowledging variation, one respondent noted that he couldn't spend time and effort planting different areas within the field at different times. Some growers had altered their application of gypsum, lime or manure across a paddock based on experience or yield maps. One grower commented:

"We aren't variably rate applying out fertilisers. At the moment we're slowly identifying those weaker areas in our fields and maybe looking at our irrigation scheduling to limit the detrimental effects of those areas." Respondent 8

Disease and pest management

Respondents were cautious about cotton disease and pests, but no major issues were identified. As cotton growing is relatively new in the region some of the pests and diseases have yet to build up. Wireworm was mentioned by several respondents, one noted it occurring after a barley crop while another experienced wireworm in early December when the crop was at the 3-4 leaf stage. Back-to-back cotton could be susceptible to black root rot, however it was not yet prevalent in areas such as the Murray Irrigation Area. One grower burnt stubble to prevent it acting as a disease vector for things such as black root rot.

Having a summer and winter crop was identified as useful in breaking the weed cycle, and cleaning cotton pickers on and off the property was identified as vital by one respondent. Increasing Roundup resistance was noted by several respondents, and cotton volunteer plants were also an issue, particularly in back-to-back cotton.

Soil temperature and seedling establishment

Getting good establishment in cold soils with an early (and wet) start to the season can be difficult according to the growers and consultants in this study. In cold, wet soil growers described experiences of slow seedling emergence, and weak seedlings susceptible to disease or which 'run out of puff' by the time they get to the surface. At worse some growers have experienced high number of plant deaths and needed to replant, a costly exercise which also has implications at the end of the season. Replants often lead to significant yield penalty which is often at least 2 bales/ ha. Most growers acknowledged the industry advice of waiting until a set soil temperature and planting on a rising plane, but many felt they could not always wait for the ideal temperature for planting and needed to plant in the window of mid-September to mid-October. Missing that window could mean growers ended up harvesting in June or later. Late picking was associated with poor defoliation resulting in leaf in the lint and increases the chance of a wet pick.

In operating within such a short growing season, growers were sensitive to the cooling effect of early irrigation or rainfall after sowing. While they did try to wait for a soil temperature of 12-14 degrees and rising, many of the growers planted before this as they felt they couldn't afford to wait. One commented that he monitored soil temperature with a thermometer, trying to plant as the soil temperature is rising and not planting to a specific date, but his overall aim is to get crop in as early as possible. Others said once they have started they keep planting regardless of soil temperature.

Growers cited several approaches to improve establishment of their cotton crop:

- Get ground as warm and firm as possible for the crop;
- Get the seedbed ready before the winter rains, so frost and rain can break up and consolidate the seedbed;
- Pre-irrigating to drop the soil temperature before sowing, so there is not a sudden temperature drop in the first irrigation after sowing;
- One grower looked to put on less water to improve establishment;
- A grower tries to improve the tilth, then using a roller to get it nice and even, and attempts to get better soil placement;
- Forming up hills earlier in winter to allow time for consolidation and less air in the profile;
- Targeting north-south rows first;
- Altering layouts of rows to enhance warming, making rows narrower, or adding a small groove in the middle of beds to catch the sun (but expensive to change layouts);
- Planting the heavier clay soils toward end of planting window;
- If a warming trend is missed, being patient and waiting until temp is warming again;
- Incorporating stubble to act as insulation;
- Some growers were using the seedling vigour index (SVI) to at least chose higher SVI seed to use in their early plantings;
- Using plastic film on early planting areas.

One grower was attempting to influence soil temperature:

"We'll look at it and say righto we're going to plant more south rows. We plant those first. We plant our east-west rows when it warms up, generally...and what we're finding is that we're actually just maybe shaping the bed just a little bit to give us a

little bit of a hill on each side, make the centre of the bed hollow a little bit, that gives us a bit of heating as well and trying to get temperature control" Respondent 17

The use of plastics was not common. One grower who did use plastics thought that it increased soil temperature by 2-2.5 degrees, and that under the film seedlings took 6-8 days to emerge as opposed to 13-20 days in seedlings not protected by film. Results showed earlier emergence and better root development, however the film can also allow better weed growth too which needed to be controlled with a pre emergence herbicide. But the cost and logistics of plastics was prohibitive for most growers, and one consultant commented:

"Plastic is just not going to happen. They're too expensive and it leaves plastic everywhere and it, you know, it's a difficult thing to do. So I encourage my growers to grow rows rather than beds because you've got to grow surface area. We are rapidly coming to the conclusion that it's better to wait for warm beds and sow a little bit later because your cotton tends to pick up." Respondent 14

Crop rotations and back-to-back seasons

There was a wide variety of approaches to crop rotation amongst the growers interviewed. At the time of interviewing the southern NSW region was in a period of good water allocation for growers and they were therefore focussed on taking advantage of this, and viewed cotton as the premier crop in terms of profitability. Therefore rotations were focussed around maximising cotton crops.

Wheat was seen as a good partner crop for cotton as it tends to have a different root system which can break up the soil, however dealing with the stubble was identified as a challenge. Planting wheat depended on the timeliness of cotton picking, too late in May and it might not be worth planting a wheat crop. Corn was identified by some growers as being more profitable than wheat, but may not fit as easily into the rotation.

A rice/cotton rotation was not seen to be viable due to compaction issues after rice, and potential issues with phosphorus. Other crops also were seen to be unviable, such as canola. Vetch was tried as a green manure crop between cotton as it also breaks up the soil and is tolerant of sodic soils. One respondent said that faba beans, while good with cotton, are difficult to make money from and need to be in earlier than wheat.

A grower highlighted the required stages of a cotton/ wheat rotation:

"From a September-early October cotton sowing, the cotton would be expected to be finished in April/May. It gets picked, mulched, cultivated for pupae bust, and then the wheat will go in starting late May through June with quick-maturing varieties. And that will grow through until the end of October-ish and then dry down to a November or December harvest. And following that you'd go into bed preparation for next cotton in about February, and back into beds and furrows and pre-plant fertilisers, have a seedbed ready on a portion of the farm before the winter rains, because that sticky nature of the magnesium clays makes it hard to work when it's wet, and finishing off in August, early September ready for the next September planting on rising soil temperature." Respondent 7

Growers were taking advantage of the favourable conditions for cotton by growing back-to-back crops, up to four years in some cases. This produces potential

issues due to the relatively fast turnaround time required over winter and the need for significant cultivation for activities such as pupae busting, stubble incorporation, bed formation and weed control. Back-to-back cotton can increase the risk of disease. Some growers planting back-to-back cotton crops also experienced loss of yield with each subsequent year. Comments by a consultant and grower, respectively, are below:

"You have challenges of getting a decent soil seed bed because we're working country late, you know, the moisture content's wetter than ideal. We're ending up with some fairly course aggregates to plant into and the gypsum's sort of a quick fix there but that's just part of growing cotton here at the moment." Respondent 4

"With our shorter seasons and wet weather and in the wintertime, you know, back to back cotton is not going to be the way to go. I think that eventually it will catch up with us. You know, we obviously need to keep an eye on that. It's working for us at the moment. We're getting away with it but it's something that I'm very mindful of." Respondent 17

Compaction

Soil compaction from cotton cropping operations was mentioned by many of the respondents. While compaction can happen in any cropping system there were particular aspects of the cotton production system in southern NSW identified which heightened the risk of soil damage. These included:

- Fitting the longer season of cotton (compared to other crops) into a short growing season means risk of working with wet soils during seedbed preparation, sowing, and picking;
- Large cotton pickers can cause compaction, and often run outside of controlled traffic tramlines;
- Compaction can be a carryover from paddocks coming out of rice;
- Pupae busting can cause soil damage and compaction;
- Short timelines when trying to turnaround soil for a summer crop following a cotton crop;
- Compaction happening particularly in wheel tracks;
- Sodicity can exacerbate compaction risk.

One grower commented:

"They're six row pickers and we're an eight row configuration. They'll end up tramping on country that hasn't had a wheel track on it but we haven't had a wet pick and I'm comfortable with that. I'm really conscious of it that I'm managing for earliness and that is one of the reasons I do it, is that I don't want to have a wet pick." Respondent 10

There were a variety of methods suggested by growers to minimise compactions, including:

- Trying to time the final irrigation to minimise risk of wet soil at picking time, especially if rain is forecast;
- Aiming for a late April or early May pick to avoid wet soils;
- Minimising cultivation on wet soils, leaving a more 'cloddy' seedbed;
- Using wheat in the rotation to break up soil;
- Spraying from a plane rather than by land;

- Focussing on controlled traffic fertiliser spreading and spraying.

Aside from compaction, respondents commented on issues around soil structure in general:

- Soils can get a crust on surface after planting and seedling are not able to push through; thus, one grower applied gypsum after the planter to soften crust;
- Soils in the Lachlan area can be quite variable so achieving crop uniformity across paddocks can be difficult;
- Lasering and landforming can impact the soil structure significantly and can take a long time to recover from;
- One grower is trying to build organic matter through the cropping process, as soils in his area naturally had little organic matter;
- Instead of sprinkling gypsum on the top, spreading it before pulling up the hills to address subsoil issues;
- When pulling up hills every year, one grower uses deep ripping and then offset discs to incorporate stubble into soil;
- Soil after cotton can be quite cloddy, pupae busting can bring up big clods;

Waterlogging can be a big issue for cotton, particularly in the establishment phase when respondents noted the seed is quite vulnerable. When asked about waterlogging and infiltration issues, most of the growers didn't see a major problem on their properties. Some saw the potential for waterlogging issues if there was the wrong grade on their irrigation systems, poor recycling systems for irrigation drainage, or wrong heights of hills/beds. Compaction on wheel tracks had lead to infiltration issues and faster movement of water down the rows. Growers had worked to improve infiltration through management techniques such as building organic matter levels, deep ripping, and incorporation of stubble.

Irrigation

The discussion around irrigation was focussed on timing of irrigation at the start of the season, type of irrigation layout, irrigation scheduling, and methods for assessing soil moisture status.

Growers were using a variety of methods to assess soil moisture status, and many used tools for soil moisture monitoring as shown in Table 1. Some used third party companies to administer capacitance probes, while another used GDots for their ease of use, but many growers also relied on visual assessments and 'use of a shovel'. Assessments of evapotranspiration (ET) were important to growers, along with short term forecasts. In several cases the decision to irrigate was driven by these last two factors.

Many growers commented that once they started irrigating there was little room for adjustment and they were locked into an irrigation cycle to cover the whole farm within an appropriate return time. There were fixed rotations however individual paddocks may have different return times due to soil type or crop growth stage differences. One grower was irrigating paddocks every 8-10 days in summer, while another felt he could go out to a 15-day interval sometimes on cotton. Aspects such as machinery capacity, water availability or flow rate, or availability of skilled staff were often key criteria determining the irrigation schedule. When hot weather was forecast growers might act to speed up the rotation or get water on earlier, as one grower commented:

"I look at the weather that's coming up in front of me. I manage it around timing as best I can in regards to the crop, but by same token, if there's a heat wave coming, I start early, get going early generally, in front of the evaporation" Respondent 15

A consultant also stated:

"Once you're into the cycle of the season, you're not really going to go on the probe data as much. You're really going on the capacity of your irrigation system because you just don't want to get behind. So it's fine to say, yes we know we watered in a day or two days earlier, but often the reason for that is, it might be a heat wave coming or we might have a pump that we just know that we just can't afford to have it go down" Respondent 18

The form of irrigation layout was discussed by respondents, with many suggesting that bankless irrigation systems had benefits over a traditional siphon/ furrow layout. Bankless was seen by one respondent as having a small benefit in terms of water use efficiency, but a significant labour saving component. There was some conversion to bankless systems and respondents noted that new irrigation was often being laid as bankless, however it requires a steeper slope to minimise waterlogging and this can mean moving a lot of soil, as noted by one grower:

"The biggest issue I see with changing to bankless is the integrity of our soil. We really can't afford to go back to scratch and start digging up the ground all over again and losing the integrity that we've got as far as our topsoil - and basically then on average I suppose you're looking at least at one-third of your land becoming unproductive again until it gets its structure back." Respondent 3

In terms of other irrigation methods, one respondent saw benefits in spray irrigation in terms of efficiency but noted that it has higher energy costs which may be a factor with rising energy prices. Sub-surface drip irrigation also was seen to have higher efficiency but had a prohibitive capital cost for installation. A grower commented that he saw a risk that plants could go 'rank' under excessive rates of spray/drip irrigation, and another noted that high pressure spray droplets could cause soil surface damage and care needed to be taken to ensure a vegetative cover. Growers also discussed the orientation of beds to maximise light interception and warmth early in the season, as covered in the 'soil temperature' section above.

Grower information sources and learning

Cotton was a relatively new crop in the study area and many respondents were learning through experience. It is worthwhile to note that the growers interviewed ranged in their experience growing cotton from 3 to 16 years (Table 1). In most cases growers were learning about nutrition based on advice from agronomists/ consultants, results from soil/plant tests, and their own visual observations from year to year. Information from other growers appeared very important, especially to those with limited experience in cotton production. This interaction was achieved through one-on-one discussion and discussions during grower meetings.

Most of the growers used soil tests (see Table 1), although the intensity of these varied from every 2 years in selected paddocks, to soil testing before and after cotton crops. The value of soil tests was augmented by advice and interpretation from agronomists, other consultants and representatives of fertiliser companies.

Plant tissue testing was also relatively common amongst respondents, however they varied in opinions about the value of the tests. Some growers thought the plant tests were too variable and were influenced by environmental factors such as time of day, temperature, stage of crop and soil moisture content. They used the tissue test results as a general guide for within season nutrition planning. One grower used 4 tissue test per paddock per season, another tested 30% of his crops twice a year, whereas another grower didn't use plant tissue sampling because it was 'in the past and too variable'.

One grower used management software (Back Paddock^{TM}) to help record and manage soil and crop data. No other growers mentioned use of software, however this was not a specific question in the interviews or survey. Sources of information for irrigation scheduling have been discussed previously and included capacitance probes, GDots, ET, weather forecasts and physical soil and plant examination.

Other sources of information noted by respondents included industry publications, information on the internet, CRDC and Cotton Australia publications and workshops, CRC Soil Pack, and researchers. One respondent had completed a cotton production course at UNE. Another commented that they saw DPI work on soils in the region as a little outdated.

Research opportunities and grower questions

Throughout the interviews respondents identified areas of uncertainty or specifically suggested research topics. The questions of respondents are paraphrased below, in no particular order of importance:

- What is the impact of cultivation and vehicle traffic in cotton production systems? (especially in regard to the wet crop establishment and picking phases);
- What is the nutrient value of the stubble when it's worked back into the soil?
- What are the economics of precision agriculture within cotton systems to address higher or lower yielding areas within paddocks?
- What happens with nitrogen tie-up when incorporating stubble?
- Are the rates of nitrogen too high? Is there an impact of high N on the crop or environment?
- What is the nutrient value of manure and stubble?
- What is the role and requirements for potassium in cotton crops in this region? (particularly in respect to senescence)
- What is the role of fungi and soil microbes in cotton systems, and how can their growth be promoted?
- What is the role and requirement for minor elements?
- What is the phosphorus availability in these soils and what is the ideal form of application?
- How much potassium is required, what is its availability to cotton?

Selected quotes made by respondents around the questions they had are listed according to major theme areas or soil issues below.

Potassium and phosphorus

"I saw this premature senescence in the crop as well and we sent PDL tests and leaf blade analysis tests away and it came back with low levels of potassium, which is pretty typical of premature senescence. But you do some soil tests and all our soils here are quite high." Respondent 12

"I'm not so sure about potassium. I'm not a hundred per cent of whether we need the amount of potassium that we're putting on and I'm not a hundred percent sure if we don't need any more potassium (than) we're putting on as well." Respondent 10

"Should we be putting out some granulated phosphorus so that it's available? Is our phosphorus that's in the ground readily available? Is the cotton plant able to suck it up? Is the potassium that it's getting coming through the chicken manure, is that useful to the cotton plant, you know, during flowering and all that sort of stuff?" Respondent 17

"I'd love to see a researcher actually do some more of that because there's a lot of muck and mystery fertiliser companies trying to sell potassium but we can't get a response to it. Respondent 4" (consultant)

Nitrogen
"Are we going too heavy on our nitrogen rates and nutrient rates?" Respondent 12

"I believe we've gone too high on the nitrogen now, especially on a well structured soil where there's been a manure program in place. I think we're getting a bit of an adverse reaction to the high amounts of N. But I don't know enough about the science behind it" Respondent 18

"It'd be great to see some more work done on where that nitrogen is ending up in the soil profile. And whether things like, say, the nitrogen from a veg crop or a legume crop, whether that is a more stable source." Respondent 8

If you've grown X amount of crop the nutrient value then in that stubble is worth so much to you over what timeframe. That would be something we're always asking people and not really - no one can give you much in the way of an answer on it. Respondent 3

"I think the interest I have in this area is looking at the nitrogen potential losses in our soil and how we can manage that or at least measure what's happening in our part of the world. Because I think there's some good data about the Moree and Narrabri type soils, but it'd be good to understand what happens in our environment." Respondent 8

Sodicity and compaction/infiltration
"I'm very interested in knowing that actual level of damage we're causing to these soils at this time of year when we're picking them wet." Respondent 12

"I'm more sort of looking down the irrigation pathway and I like to know whether there's a change in infiltration and those sorts of things on a back to back system versus winter crop/fallow rotation" Respondent 12

"And then also the other thing that I didn't point out was our sodic subsoils that we have here and how we address them" Respondent 8

"One thing I'm not really understanding yet is why we get this compaction layer, this natural compaction layer forming, because it is quite a bit constraint in the system and it is partly why we seem to be irrigating so frequently. And that develops sort of three or four irrigations and once it's there, it's there in the flood systems" Respondent 9

Summary of interviews

The interviews involved discussion on a wide range of topics from soil and plant nutrition, to soil physical health, irrigation methods and crop rotation planning. As highlighted in the results section, major issues for growers and consultants were sodicity, soil compaction, crop establishment, and nutrient management.

Most growers were using high levels of nitrogen in their cotton systems. This appeared to be based on a risk management approach. This may be due to the fact that currently cotton is a premier crop in terms of profit or because of uncertainty about nitrogen budgeting. Growers and consultants asked questions about how much N is actually required, and whether there were impacts from current levels of use. A survey of growers in Southern NSW conducted by O'Keeffe (unpublished) in mid 2014 found there were large differences in the total N use between growers. O'Keeffe reported larger differences between growers than this study (Table 1); with one applying 450 kg N per hectare, while others it was less than half that amount. There are several potential reasons for this and from O'Keeffe's survey it was evident that most growers do not know how much nitrogen they have stored in the soil at the start of the growing season. Another reason was the uncertainty about how to split nitrogen applications or the appropriate amount to apply in the growing season. In this context a useful measure is to evaluate the nitrogen use efficiency (NUE). The NUE was calculated as the amount of lint harvested per unit of applied nitrogen. O'Keeffe reported that a wide range in the responses on NUE with the best grower recording 14.6 kg lint/ kg N, however 6 out of 10 growers achieved less than 10 kg lint/ kg N. Another reason which can be established from this survey is because most growers who apply manures do not know how much nitrogen they are supplying. O'Keeffe's survey provides confirmation with the interview responses in this study that there is a great lack of understanding on nitrogen management amongst a large number of growers.

Both growers and consultants appeared to be uncertain over the role of other nutrients (non-nitrogen) in the cotton/ soil system. Some respondents saw a need for phosphorus and potassium in their nutrient strategy, while others felt their systems had enough of these nutrients but that there were some issues with plant availability.

The use of manures and stubble was fairly widespread among those interviewed, however there were some questions about their use. The nutrient component of manures was difficult for growers to determine, so many discounted it in their nutrient balances. Stubble and organic matter were acknowledged by most to be important for sustainable and healthy soils, but there were issues around getting sufficient breakdown before the next crop and the tie-up of nitrogen.

The short growing season in this region was felt by growers at both ends of the season; with soil temperature and establishment issues, along with soil compaction concerns. Back-to-back cotton crops were exacerbating these concerns with pressure to get the most out of the current water availability and cotton prices. If this situation persists then there may be more issues around season-to-season yields and soil health. Based upon these grower and consultant responses future research could centre on soil health/ compaction issues and the impact of early season crop management on cotton

production or end of season results. Growers often described their rotations as being geared around maximising cotton production potential, while in some cases soil health takes a back seat. Growers are trying to select crops such as wheat, corn or legumes to work in tandem with cotton in the rotation, but sometimes have to select the best option relative to the date cotton was picked and timing of the planned future cotton crop.

Discussion around irrigation primarily centred around setting start date, and the decisions around irrigation interval during the season. There was evidence of system 'lock-in' with irrigation methods because even though growers may express interest in changing irrigation layout it is too expensive or unfeasible to do so.

Surprisingly salinity was not listed as a major issue for respondents. There may be a genuine lack of salinity issues amongst those interviewed, or it may represent a point in time where water tables are low and higher levels of rainfall have acted to flush salts from the soil profile. The practice of recirculating irrigation water, and changes in groundwater levels could lead to an increase in salinity over time.

4.3. Assessment of soil survey and other soils related research

Evaluation of current soil survey data

Southern NSW has been fortunate to have been host to several intensive soil surveys over the past 60 years. Today we have access to a wealth of soils data and numerous maps and reports from across the region, however the reliability of the soils data is highly spatially variable. Some districts have been intensively surveyed and the soil is mapped at a fine scale (1: 100,000) such as the Berriquin Irrigation District (Smith 1945). In contrast, other parts of the region have been surveyed in a more extensive manner and were covered at the Soil Landscapes or Land Systems level (1: 250,000 (Walker 1991).

The most detailed soil survey data for cotton growing soils is found in the following sub-regions: the MIA, the Coleambally Irrigation Area and the Murray Valley Irrigation Area. The area covered with very good soil survey data is shown in Figure 4 and is accessible from the following website http://irrigateway.net/tools/soilmaps/ (Hornbuckle *et al.* 2008).

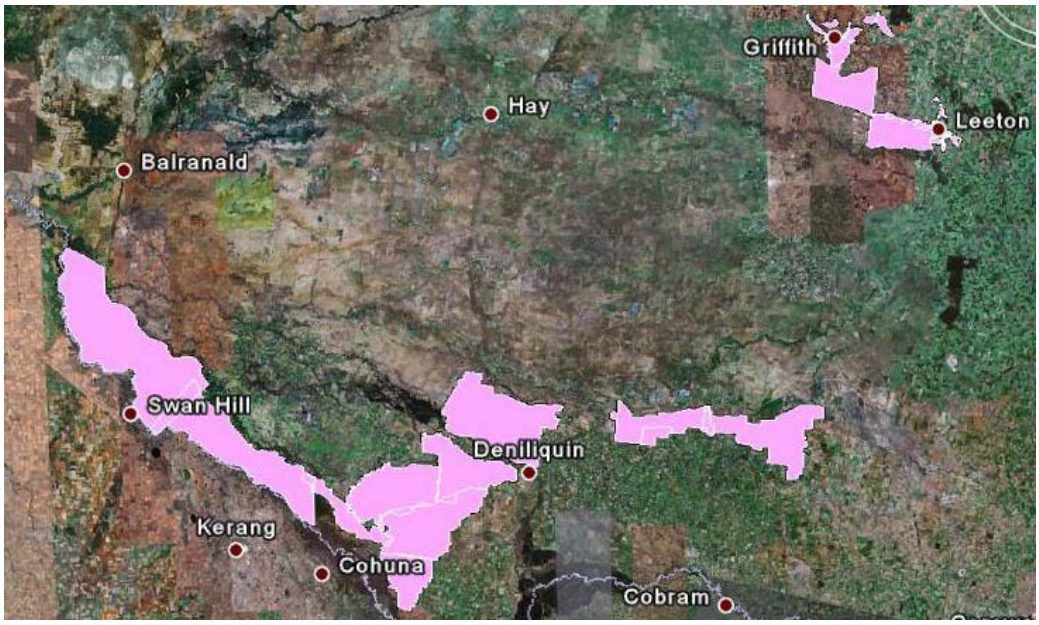

Figure 4. The area of soil survey coverage across Southern NSW (Hornbuckle *et al.* 2008)

Additional soils profile data is available from eSpade which is a Google Maps-based information system that allows easy access to all public soil and land information in the NSW Soil and Land Information System. The eSpade website (http://www.environment.nsw.gov.au/eSpadeWebApp/) is helpful for accessing soil profile information from past survey points and hence may be useful for assessing land that is new to growing cotton. The CSIRO's ASRIS website (http://www.asris.csiro.au/) is another useful source of soils data and is especially good at making a district scale evaluation of the soils which are present. ASRIS provides information in 7 different scales from the landform scale to a soil profile (Johnston *et al.* 2003). Other soils profile data is provided by CSIRO with APSoil

(http://www.apsim.info/Products/APSoil.aspx) and an alternative soils information source is SoilMapp (http://www.csiro.au/soilmapp). Some parts of Southern NSW have been surveyed in a project-based approach such as in the Lachlan valley e.g. in 2003 the soils of the lower Lachlan valley (Hillston district) were surveyed by the University of Sydney (University of Sydney 2006); while the mid Lachlan valley (Condobolin district) was surveyed by the Soil Conservation Service of NSW (Soil Conservation Service of NSW 1974). The amount and quality of soil survey data varies greatly across the cotton growing regions of Southern NSW. A list of published soil surveys and other spatial data from across Southern NSW is given in Appendix 3.

We explored the spatial soils data available using the eSpade system for the cotton growing regions in Southern NSW. This involved creating two areas representing (*i*) the Lachlan valley and (*ii*) the Murrumbidgee valley (including the MIA, CIA, Hay and other nearby areas). The selected areas include land used for growing cotton and other land along these valleys; thus, each area (polygon) was not restricted to irrigated cotton soils only. The spatial composition of the soils in these two areas was very interesting and the values calculated for each soil order are shown in Table 4. It is important to note that the Vertosols in Southern NSW have been formed on different parent material compared with the Vertosols found in Northern NSW. Therefore, the Vertosols found in the Lachlan and Murrumbidgee valleys contain a different suite of clay minerals and will have quite different behaviour characteristics.

Table 4. The areal extent (%) of soils[A] according to soil order found in the Lachlan and Murrumbidgee valleys using a Soil Type map of NSW[B]

Soil order[C]	Lachlan valley (% area)	Murrumbidgee valley (% area)
Vertosols	43	96
Chromosols	25	1
Calcarosols	24	2
Kandosols	8	<1
Kurosols, Rudosols, Dermosols, Ferrosols Sodosol, Tenosol	<1	<1

[A] These are estimated values are based on very limited soils and landscape data. See further discussion below in section 4.5 under Soil survey data.
[B] Spatial data from the NSW Office of Environment and Heritage (OEH 2013).
[C] Based upon the Australian Soil Classification (Isbell 2002).

Utilisation of previous cotton soils research

Understanding the fundamental controls to and limitations of soil processes allows us to at least partly translate the findings from research at other locations to southern NSW. This approach can provide a useful first step in adapting management recommendations from elsewhere. Importantly, advisors and growers have already started doing this. At a global level there are some fundamental processes or principles which have become established and accepted. At this level our knowledge can be applied elsewhere with confidence. For instance, there has been much work on the N cycle and a lot is known about the various pathways and transformations of N. Thus, given the current information on N losses how can understanding on this be

applied elsewhere? Likewise, there is considerable information on the hydrologic cycle, the acidification process and the dynamics of soil organic matter, but how can research in these different areas be used or applied for the cotton growing soils of Southern NSW? There are no simple answers or means by which research results can be locally applied, but rather there are numerous regional or site specific factors which influence the rate or magnitude of a particular soil process or property (Table 5). Future research in Southern NSW should be focused on the regional or site specific factors which are unique or different from the soils in Northern NSW and thereby extend understanding of soil processes in a new sphere which is directly relevant to local soil conditions.

The dominant regional factors which influence the rate or the strength of major soil processes are listed in Table 5. Many other soil properties have influence on these processes such as the soil water content and soil temperature. Table 5 is an initial guide and provides just two influencing factors. Thus previous research findings can be related to the cotton soils in Southern NSW if attention is taken of regional or site specific factors. Cattle and Field (2013) reviewed nearly two decades of soils research (which was mostly undertaken on Vertosols in Northern NSW and Queensland) and reported on the most significant outcomes of recent research on cotton soils. Review and evaluation of previous research highlights is relevant for cotton growers in Southern NSW, however there is often a challenge in identifying the particular regional soil factor(s) and deciding how to utilise or apply such information to the particular soil of interest.

Table 5. Selected major soil processes or soil properties with two key regional or site specific influencing factors with a helpful reference from previous research

Soil process/ soil property	Regional factors[A]	Useful reference
Acidification	initial soil pH, H+ inputs	(Singh *et al.* 2003)
Erosion	soil texture, land use/ rotation	(Hulugalle *et al.* 2002)
Salinity	groundwater level, irrigation water quality	(Triantafilis *et al.* 2004)
Sodicity	mineralogy, organic matter level	(Ghosh *et al.* 2010)
Nitrogen cycle	micro-organism composition, organic matter	(Rochester 2011)
Phosphorus (availability)	mycorrhiza, initial soil pH,	(Dorahy *et al.* 2004)
Potassium (availability)	mineralogy, soil texture,	(Bedrossian and Singh 2004)
Deep drainage	mineralogy, soil texture,	(Ringrose-Voase and Nadelko 2013)
Hydraulic properties	sodicity, overburden pressure	(Vervoort *et al.* 2003)
Organic carbon dynamics	rotation, annual rainfall,	(Hulugalle *et al.* 2012)

[A] Several other factors could be listed which have significant influence, however we have restricted the number of factors for simplicity.

Assessment of soil management practice information

Over the past few decades there has been a considerable amount of research and development undertaken on the soils across the region, but most of the existing soils data and understanding on soils has been for other crops (e.g. rice, maize). For example, the SoilPak for southern irrigators (Hughes 1999) has a strong rice focus and does not consider cotton. Our understanding about soils for cotton growing can partially be informed from previous soils research on other crops such as rice, but there are some distinct differences with cotton production and so there are limits to the value of such soils research. Utilising existing information on soil management practices is a challenge, but it should still be considered as a worthwhile source.

There is an extensive amount of soil management practice information from the established cotton growing regions of Central and Northern NSW and Queensland. The soil management practices from these longer established regions should be evaluated. Recommended management guidelines include: SoilPak for cotton growers (McKenzie 1998), NutriPak (Constable *et al.* 2001) and MachinePak (Schoenfisch 1999). Information in these publications is potentially useful for cotton growers in Southern NSW, however all these publications are more than 10 years old and some recent details are lacking. Soils management information from northern cotton growing regions should not be ignored and instead be used or adapted where appropriate for the conditions found in Southern NSW. A selected number of soil management practices are presented in Table 6 with two significant influencing factors which vary between regions and should be taken into account when trying to apply the research findings to a different location such as in Southern NSW.

Table 6. The identification of soil management practices or soil problem and two important regional factors with a useful reference

Soil management practice/ soil problem	Regional factors	Reference
Compaction	soil water content, soil texture	(McKenzie and McBratney 2001)
Manure	sodicity, mineralogy	(Ghosh *et al.* 2008)
Stubble	crop rotation, micro-organisms	(Rochester *et al.* 1997)
Tillage	sodicity, soil water content,	(Chan and Hulugalle 1999)
Irrigation water quality	mineralogy, cation exchange capacity	(Speirs *et al.* 2011)

We recommend that cotton consultants and researchers in Southern NSW review and evaluate of the recent soils research that is available from the northern regions of the cotton industry. We also suggest that cotton growers and consultants recognise the regional or site specific factors which they are facing with their soils. In the short term effective utilisation of previous soils research results is the best way in which to overcome the gaps in understanding of that exist in Southern NSW.

4.5. Gaps in soils and soil management practice understanding

Here we indicate the gaps in understanding on soils and soil management practices based upon our review of published reports, papers and databases.

Soil survey data

There are very large differences in the quality of spatial soils data for Southern NSW. The eSpade system provided by the NSW Office of Environment and Heritage shows most of the cotton growing regions in Southern NSW with a very low confidence class for soil mapping because of the limited amount of soil and landscape data available (OEH 2013). The reliability of the spatial soils data available from ASRIS (CSIRO) is also limited. ASRIS reports on the dataset reliability (CSIRO 2014) and indicates that large parts of Southern NSW is extrapolated using air photos and/or geological, topographical, or ecological maps, restricted field inspection, and general knowledge. Some areas are based soil correlations with reconnaissance soil surveys or integrating different sources of spatial data. Consequently despite the soil surveys which have been undertaken in Southern NSW there are significant issues with the reliability of spatial soils data in certain areas. The greatest lack of soil survey data exists in the cotton growing areas in the Hay district along the Murrumbidgee River and also in the mid Lachlan valley district near to Condobolin. The soils data for these areas is more limited compared to other parts of Southern NSW. Overall further soil surveying is required for the cotton soils right across Southern NSW in order to increase the confidence and the quality of spatial soils information. Therefore, we recommend that the soil spatial data and soil maps by eSpade and ASRIS for Southern NSW should be only used as a general guide.

Soil degradation – acidity, erosion, salinity and sodicity

Acidity

Soil acidity is a relatively new problem for the Australian cotton industry. The presence of acidic soils is mostly found on the soils of MIA, CIA and Murray valley. There is a need for better understanding on the management of acidic soils and suitable lime application for a cotton farming system. There are some risks with continuing acidification of soils due to the high levels of N fertilizer being applied. Research is needed:

- *(i)* to quantify the extent of acidic soils being used to grow cotton;
- *(ii)* to determine the effect of soil acidity on nutrient availability e.g. P and Zn;
- *(iii)* to develop improved lime management practices for cotton based cropping systems.

Erosion

There is little information on the water erosion caused by traffic or tillage. There is no data on the impact of cotton growing as a land use on the risk of wind erosion. Wind erosion is especially relevant in the western cotton growing areas in Southern NSW. Previous research has shown that management practices influence the level of soil loss from both water and wind erosion. Investigation is required:

- *(i)* to understand the effect of traffic and tillage on the cotton cropping soils of southern NSW;

(ii) to investigate the effect of different management practices and rotational practices (including fallow land groundcover) to develop best management practices protect the soil from wind erosion.

Salinity

Salinity has already been identified as a serious issue for irrigated cropping in Southern NSW. Fortunately, at this point there have only been relatively small areas of cotton soils which have been impacted negatively by salinity. While cotton is relatively tolerant of salinity, the crops grown in rotation with cotton are less tolerant. Consequently additional understanding is required on:

(i) the salinity risk for cotton-growing soils across Southern NSW;
(ii) the effect of different management practices on treating saline-prone areas;
(iii) the dynamics of groundwater levels under irrigation cotton and the mobilisation/ movement of salt stores.

Sodicity

Large areas of cotton soils in Southern NSW are sodic and this presents some major challenges. In particular there are numerous structural issues associated with sodic soils. Thus, there is a need to understand how to best manage sodic soils in this region. The major research and development questions are:

(i) to determine the spatial extent of sodic soils;
(ii) to evaluate the impact of hard-setting soils and investigate the crusting mechanism;
(iii) to assess the effect of applying organic amendments on sodic soils;

Soil chemical fertility

A snap-shot type summary of the soil chemical fertility information available is given in Table 7. Further specific details on the gaps in understanding or the research questions which are required are given below. For instance, in addition to strengthening the confidence on soil nutrient availability, it is also important to know about the timing and uptake of nutrients by cotton for soils in Southern NSW.

Table 7. Qualitative assessment of amount of information available for different soil chemical fertility issues for cotton-growing soils in Southern NSW compared with Northern NSW and Queensland

Soil nutrients	S. NSW	N. NSW/ Qld
Nitrogen	Limited/ little	Extensive
Phosphorus	No published data	Extensive
Potassium	No published data	Limited/ little
Manure	No published data	Limited/ little
Zinc/ trace elements	No published data	Limited/ little
Interactive effects	No published data	Limited/ little

Nitrogen

Nitrogen (N) fertilizer use is high by Southern cotton growers and there seem to be many crops which receive too much N. There is a need to lower N application rates and to improve N fertilizer use efficiency (Rochester 2011). Several areas of understanding are required on N management including:

(i) N budget requirements after a previous cotton crop compared with other crops such as an irrigated maize crop;
(ii) an evaluation of the timing and placement effects of N fertilizer;
(iii) reducing N fertilizer losses and better understanding on the contribution from manure N;
(iv) the role and N benefit of legume crops as part of a Southern cotton rotation.

Phosphorus

Phosphorus (P) nutrition is a significant component of the cotton nutrition program. Previous experience with irrigated crops such as rice in Southern NSW has shown that there are challenges to optimising P nutrition on these soils. Nearly every cotton grower applies some P fertilizer before sowing, but there is some uncertainty about the appropriate level of P fertilizer to apply or regarding the P contribution from manure. Research on P is required in the following areas:

(i) to better understand P uptake for Southern NSW cotton soils and to investigate the P use efficiency for the different soils;
(ii) to evaluate the effectiveness of different P application methods (banding or broadcasting);
(iii) the dynamics and effect of P supplied from Riverina sourced manures;
(iv) the effect of sodicity on crop P uptake (this is already identified as important for cotton soils elsewhere (Rochester 2010).

Potassium

Responses from the interviews and other collected data indicate that there is a lack of confidence and uncertainty with some growers regarding potassium (K) nutrition. While most growers do not apply any K fertilizer there are growers that apply K before sowing or as a foliar spray. Research on soils in Northern NSW has identified the effect that K has on premature senescence (Bedrossian and Singh 2004) which confirms the need to improve on K nutrition for cotton. Thus, the research requirements are:

(i) to undertake thorough research on the crop K uptake and increase confidence of the critical soil test values for cotton production;
(ii) to identify the soil types most at risk of K deficiency;
(iii) to evaluate different methods of applying K fertilizers and compare the effectiveness of different K fertilizer products.

Manure

A significant number of cotton growers apply either chicken or cattle manure as part of their crop nutrition program. Few growers were completely confident with the nutritional contribution and all of the beneficial effects which are provided from manures. A range of different manure rates are being used and the frequency of application also varies. Therefore, research is needed on:

(*i*) the nutritional benefits and drawbacks from applying manures, including modifying/ enhancing manure blends;
(*ii*) the physical benefits from manures on soils which have been heavily laser cut or are sodic;
(*iii*) to develop industry best practice guidelines on applying manures for cotton growers.

Trace elements
Zinc (Zn) has received the most attention for cotton nutritional requirements. Cotton growers have considered the importance of Zn nutrition for more than 25 years (Constable *et al.* 1988). Most of the growers interviewed apply Zn as a starter fertilizer, however there is no independent published research on the requirements of Zn for the cotton growing soils in Southern NSW. Therefore, research on trace elements is required:

- *(i)* on the cotton crop requirements for Zn according to soil pH, especially for acidic soils;
- *(ii)* to investigate the risk of deficiency from copper on highly alkaline soils, molybdenum deficiency on acidic soils and boron.

Interactive effects
There is a need for the interactive or combined effect of nutrient levels to be understood. For instance, there is evidence of the relation between P and Zn and between K and Na, while there are links between N and the use of plant growth regulator. Furthermore, the relation between P availability and mycorrhizae has not been studied on the cotton soils of Southern NSW.

Soil physical and hydraulic properties

Structure
Well developed soil structure is vital for soil health and function. The soil management practices implemented in Southern NSW should actively maintain soil structure. Because of the unique characteristics of the soils in Southern NSW there is a requirement to better understand the impacts on soil structure from crop rotations and the different management practices. Such research should be related to the effects on soil organic matter/ soil carbon. The gap in understanding here is on the soil structural dynamics of a typical cotton based farming system in Southern NSW. Work in this area should identify both the poor and good management practices and thus provide valuable information for growers.

Infiltration
Soil hydraulic properties indicate the ability of a soil to drain. Due to the intensive tillage practices associated with preparing a seedbed there is a risk that internal drainage of some soils may be compromised. Traffic and tillage effects are not fully understood and effects on soil infiltration properties are required. This has implications on reducing the incidence of waterlogging.

Irrigation and hydrology

The efficient use of water is a critical part of a profitable cotton production system. Intensive measurement and monitoring of water use and soil water properties are required to better understand the dynamics of the system. Several different irrigation methods (furrow, overhead sprinkler and bankless or ‘beds in bays’) are currently being used, but overall there is a lack of data to adequately compare these systems and the merits of each according to soil type and slope. Thus, a strong soils component of irrigation research is recommended. Research and development is need to assist with irrigation scheduling and the decision making of water use. Growers need information to improve their water use efficiency and this will be best achieved by determining the

relationship between the major soil types of Southern NSW and their water use characteristics. It is essential that the soil water balance is quantified for the major soil types in Southern NSW, in particular the amount, rate and risk of deep drainage should be measured.

Cotton growers in Southern NSW use water from three sources: river, channel and groundwater. Poor groundwater quality can have a detrimental effect on the soil and crop growth, but there is insufficient data on the effects of irrigating with such water for some soil types. Studies on the dynamics of groundwater levels as a consequence of irrigating cotton are needed.

Soil biological condition and seedling diseases

Recently there has been a significant amount of research on soil carbon on the cotton growing soils of N. NSW and Queensland. The lessons learned from that research indicate the importance of soil carbon and the effect of different management practices on soil carbon levels. Future soils research in Southern NSW should continue to monitor the dynamics of soil carbon and the effects of soil management practices on carbon stocks.

Soil-borne diseases can have a potentially very damaging effect on crop establishment and plant growth. More understanding is required on the factors which cause seedling diseases in the Southern NSW environment. The main research priorities are:

(i) to quantify the dominant soil factors which cause the development of diseases;

(ii) to understand the effect of various management strategies on reducing the risk of seedling diseases such as Black root rot;

(iii) evaluate the relationship between pathogens and hosts found in the cotton based farming rotation in Southern NSW.

System level factors

Soil temperature

The short season length in Southern NSW cause major challenges that can relate to the soil at the start and the end of the growing season. At the start of the season there is a narrow sowing window and there is a strong focus on soil temperature. Further understanding is required on the effect of different management practices and crop rotations on soil temperature. This investigation should also consider irrigation management (e.g. pre-watering vs. watering up) and seedbed layout. Improved understanding in this area should lead to better seedling establishment which has implications on the final plant population and crop yield potential.

Compaction

Soil compaction is a serious challenge at the end of the growing season, especially when picking cotton if the soil is wet. The challenge of this issue varies from year to year, but given the short length of the growing season it is often a problem in Southern NSW. Research is greatly needed to determine the risk of compaction from a range of different management practices for the cotton soils in Southern NSW. This is an issue which can build on the research undertaken on Vertosols in Northern NSW and investigate other soils which have different soil properties and behaviour compared to Vertosols. With the introduction of the large, heavy cotton pickers there

is a challenge to develop fully matched controlled traffic systems as well as the investigation of how to manage or ameliorate subsoil structural degradation. Most growers interviewed stated that compaction was a major problem.

Stubble/ tillage
The management of stubble has subsequent implications on nutrient management and soil physical condition. There is a need to thoroughly test the most common stubble management techniques in order to assess the effects of each and determine the associated benefits/ drawbacks. The timing and effectiveness of different tillage operations has not been investigated for the cotton soils in Southern NSW. Research is needed to evaluate the impacts of different tillage practices as well as to investigate options to cope with the significant time pressure associated with tillage/ seed-bed preparation.

Crop Rotation
The crop rotation selected has major implications on soil nutrient levels, soil physical condition and biological diversity. The cotton-based farming rotation in Southern NSW is not the same as northern areas of the cotton industry. It is essential that the potential impacts arising from the different common rotations are investigated. From the interviews we found that some growers were not confident with their current rotation. There is a need to better understand the dynamics of important soil properties and for information gathered on the merits of each rotation program with the associated management practices.

5. Recommendations

Based upon the grower and consultant surveys and interviews and the evaluation of previous published studies we make the following recommendations:

(i) Soil management practice case study

This scoping study has reported on the insights of growers and consultants at just one point in time. Because of this our understanding on the decision making and the implementation of management practices is limited. In this instance longitudinal case studies are valuable in gathering more interview data and following growers over a longer period. Previous studies on the evaluation of management practices have shown great benefit in improved understanding management practices e.g. dairy farmers in Eastwood *et al.* (2012). In Southern NSW, there is a great opportunity for a case study research project to build on the survey and interviews which have been undertaken in this scoping study. Therefore, we recommend that case studies are undertaken to improve understanding in the how and why growers make decisions in the following four areas:

- sowing and crop establishment
- nitrogen fertilizer applications;
- irrigation scheduling;
- practices which can cause compaction (namely picking and cultivation).

(ii) Soil spatial information

The lack of soil survey data and the subsequent poor reliability of the soil maps and soil spatial information is a significant disadvantage to the cotton industry in Southern NSW. A specific and targeted program of analysing/ describing soils would build on the existing data and improve the reliability of the current soil maps. Improved spatial information on soils would have flow-on benefits for growers. Attention should aim to increase the coverage and quality of soils spatial data. We recommend that work in this area should be focused on the following 3 soil properties:

- sodicity (highest priority);
- salinity;
- soil pH (both for acidic soils and alkaline soils)

(iii) Soil nutrient database

Soils are drivers of agricultural production system performance so it is important that growers know the key soil indicators. A cotton soils database needs to be established. The development of such a database could enable threshold values and optimum ranges to be determined. The database could also contain crop nutrient response curves which increase knowledge of critical soil test values. A wide suite of related data could be included such as crop rotation history, soil type and location details. An example of this type of database has been established for the grains industry and is called the Better Fertiliser Decisions for Cropping Systems interrogator (Speirs *et al.* 2013). A similar type of database could be developed for cotton soils. We estimate that this type of database would lead to an increase in the efficiency of nutrient applications. It would enable benchmarking between growers and for growers to make their own on-farm inter field comparisons. This proposed database would be useful now and it could be added to in the future. This type of database is likely to further identify where there is a lack of nutrient data for cotton soils across Australia.

(iv) Soil physical condition evaluation

The neglect of soil physical condition is perilous to any agricultural enterprise. Investigation of the changes to soil physical properties is required so that understanding is developed on the impact of different management practices. Several potential negative effects are possible on water use efficiency which influences profitability or on structure which can influence yield. Information on soil physical properties needs to be established for the cotton growing soils in Southern NSW because of the unique soil characteristics found in this region. We recommend that research on cotton soils in Southern NSW is targeted in the following 3 areas:

- soil structural properties;
- soil water holding capacity.

(v) Soil management practice guidelines

The development of best management practice guidelines which are suited to the irrigated soils of Southern NSW are recommended as a medium term goal for forthcoming research and development activities. Previous guidelines such as SoilPak for cotton growers were not prepared with consideration of all the soils in Southern NSW (e.g. Hillston was only district included), while other locally developed guidelines like SoilPak for southern irrigators did not include cotton. Furthermore, there is a need for this type of extension literature to include recently published research information. The practical benefits of research in this area will be to ensure that sustainable management practices are identified and in the future these can be encouraged. We recommend that future research and development activities are involved in the identification and description of best management practices for the cotton soils of Southern NSW for the following issues:

- cultivation/ seedbed preparation;
- stubble;
- waterlogging;
- nutrient application;
- sodicity;
- acidity;
- erosion;
- salinity.

6. Conclusions

The role of soils is widely acknowledged as a very significant component of profitable and efficient cotton production systems. This scoping study was undertaken due to the lack of understanding on the cotton growing soils of Southern NSW. This study identifies the most serious soil and soil management practices issues present.

This scoping study engaged with different players in the cotton industry including growers and consultants in Southern NSW and researchers from across Australia. Interview responses indicated showed that nitrogen was nitrogen applied according to a risk management policy. We conclude that there is opportunity for nitrogen to be applied more efficiently. There was uncertainty about manure use, in particular regarding the supply of nutrients from manure. Nevertheless manure was a popular input used by well over half of the growers. For other nutrients such as potassium and phosphorus growers were not completely comfortable with their level of understanding or the amount of nutrient to apply. There were serious concerns raised on sodicity and compaction, but a lack of confidence with how to deal with these issues. Other issues such as acidity and salinity were not so widespread and more localised problems. On the issue of sowing, growers seemed to have a stronger focus on the calendar date rather than on the actual soil conditions and this has implications on seedling establishment. On the issue of irrigation, many growers indicated that once the season got going they had limited options and had to keep the irrigation schedule going. On the issue of cultivation, many growers commented that they were very constrained due to the short growing season which meant that there was little time to cultivate at the appropriate soil moisture content. Big differences in the responses on certain issues like stubble and crop rotation suggests that individual grower experience and soil type play a strong role with these issues. Overall, the interviews indicate that cotton growers in Southern NSW need better understanding of their soils in four main areas; these are for: (*i*) crop establishment (*ii*) nutrient management, (*iii*) irrigation management, and (*iv*) compaction.

An evaluation of published reports and literature on the cotton soils of Southern NSW found that there are large differences in the availability and quality of soil spatial data across Southern NSW. In some districts e.g. Hay there is very limited soil survey data. A significant implication of the lack of basic spatial soils data is that there are only poor or very partial estimates of important soil properties such as sodicity. It is suggested that previous research results on cotton soils and soil management practice can be utilised to a limited extent, however careful note should be taken of significant regional factors which influence both the rate of soil processes and the effectiveness of soil management practices.

The identification of specific gaps in understanding of cotton soils showed that there are significant areas of research required in the following major areas: soil degrading issues (such as acidity and sodicity), soil nutrient dynamics (especially nitrogen), soil physical and hydraulic properties (structure), irrigation and hydrology, soil biological condition and seedling diseases and system type factors such as on temperature, tillage, stubble and rotations. Most of these soil issues relate to a specific soil management practice and we also found uncertainty regarding the effectiveness of some management practices for the cotton soils in Southern NSW. We recommend that future research and development activities are undertaken to: better understand decision making of growers, improving the spatial data on soils, developing a cotton soils database, investigate specific soil physical/ hydraulic properties and establish best management practice guidelines for key issues for soils in Southern NSW.

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Appendices

Appendix 1 – Grower Survey for Cotton Soil Scoping Study for Southern NSW

This brief survey is being conducted as part of the scoping study on cotton-growing soils of Southern NSW. These questions can be answered either before or after the interview has been conducted. All responses will remain confidential.

NAME: _____

1. (a) How many years have you been growing cotton on your **current** property? _____
(b) In **total** how many years have you managed/ grown cotton? _____

2. (a) In the 2013/14 growing season how many hectares of cotton did you grow? _____
(b) What is the average area of cotton which you grow each year (ha)? _____

3. (a) What is your average cotton yield (bales/ ha) across your farm? _____
(b) In the field that has performed the best in the past 5 years what has been the yield (bales/ ha)? Which season/ year was it? _____ _____
(c) In the field that has performed the worst in the past 5 years what has been the yield (bales/ ha)? Which season/ year was it? _____ _____

4. On average how much water (ML/ ha) do you use to grow cotton per season? _____

5. What is your source (and percentage if more than one source) of irrigation water on your farm? _____
(*i*) river; _____
(*ii*) irrigation scheme/ channel; _____
(*iii*) groundwater; _____

6. (a) Do you know the depth of the groundwater on your farm? If yes, what is it? _____
(b) What is the quality (in terms of saltiness) of the local groundwater? (Please circle your response)
e.g. good, average, poor

7. (a) To assist with irrigation scheduling do you measure soil moisture? (Please circle your response) Yes/ No
(b) What tools do you use to schedule irrigation?

8. Apart from cotton which other crops do you grow?

9. (a) What is your target sowing period? (include both starting and finishing dates) _____

(b) What is your target (or average) picking date? (include both starting and finishing dates) _____

10. Using generalised terms for colour and texture (such as Red or black; clay, loam or sand) how would you describe the soil used for growing cotton on your farm?

11. (a) Do you undertake soil testing on the fields where you grow cotton? (Please circle your response) Yes/ No

(b) Do you take plant tissue/ petiole samples for nutrient analysis? (Please circle your response) Yes/ No

12. (a) What is your average N budget (kg/ ha)? _____

(b) What form of N do you apply and how is it applied?

13. (a) Do you manures in your nutrition program? (Please circle your response) Yes/ No

(b) If yes, what type of manure and what rates do you apply?

14. Where do you gather most of your information to manage soils?

(a) consultants/ advisors
(b) internet;
(c) industry magazines/ journals;
(d) field days/ workshops;
(e) other source (please specify)

15. What is your business structure? (Please circle response below)

(a) sole trader/ private;
(b) corporate business;
(c) other business structure (please specify)

Appendix 2 – Questions for One-to-one interviews

The following questions are being asked as part of the scoping study on cotton-growing soils of Southern NSW. The formal length of this interview will not exceed 40 minutes. All responses will be confidential and your anonymity protected.

1. What are the most important soil related issues for cotton production on your farm?

2. Can you talk about the most important soil limitations or soil constraints which are specific to your farm?
   (By constraint we mean issues such as sodicity, salinity, acidity, waterlogging etc.. or whatever else is important to you).

3. Can you describe your typical crop rotation when growing cotton?

4. Describe your crop nutrition program and how you make decisions to use fertilizers on your farm?

5. Describe your irrigation scheduling and drainage management;

6. Which management practices do you currently implement to specifically “look after” the condition of your soil?

7. Tell me about the structural condition of the soil where you grow cotton? Are you noticing any changes in the soil structure over time?

8. From where do you get most of your advice or information on soil management?

9. Is there anything else that you would like to mention regarding your soils or soil management which has not been covered?

NB. The questions above were slightly modified for the interviews undertaken with the consultants. Thus, the consultants were asked to give a response in relation to their clients and the range of different soils which are found on the farms of their clients.

Appendix 3 – Soil survey reports for Southern NSW

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