Combating Subsoil Constraints

(SIP08: Northern Grains Region)

Project Results Book

2007

Queensland Government
Natural Resources and Water
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NSW DEPARTMENT OF PRIMARY INDUSTRIES

THE UNIVERSITY OF QUEENSLAND

CSIRO

University of Western Sydney

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GRDC
Grains Research and Development Corporation

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Edited by

Yash Dang
Stuart Buck
Ram Dalal
Phil Price
Graeme Schwenke
Zvi Hochman
Ian Daniells
Andrew Biggs
David Freebairn
Kristie Watling
Neil Cupples

Project Team

QNRW: Ram Dalal, Yash Dang, Andrew Biggs, Ben Harms, Greg Thomas, Geoff Titmarsh, Ian Heiner, Kristie Watling, Scott Irvine, Bodapati Naidu, Denis Orange, Dave Lyons, John Hegedon, Maria Harris, Kelvin Spann

QDPI&F: Richard Routley, Stuart Buck, Michael McDonald, Jai Singh, Rob Kelly, Michael Mann, Steven Griffiths, Brenda Leighton, Peter Agius, Vanessa Alsemgeest, Jack Christopher

NSW DPI: Graeme Schwenke, Hugh Allan (deceased), Ian Daniells, Nathan Ferguson, Bob Farquharson, Bill Manning, Giles Butler, David Mitchell, Simon Speirs, Jim Perferment, Lachlan Rowling, Russell Carty, Dougal Pottie, Tony Cox, Josh Gordon, Anthony Mitchell, Jayne Jenkins, Michael Honess, Ken Scott, Jennie Spenceley, Linda Heuke

CSIRO: Zvi Hochman, Neal Dalgliesh, Merv Probert, Anthony Whitbread

USQ: Neal Menzies, Anna Sheldon, Bing So

UWS: Peter Cornish, Shane Norrish, Harsharn Grewal, Linda Allanson, Basant Maheshwari

NSWDNR: Sheila Donaldson, Greg Chapman, Ross Beasley

GRDC: Phil Price, David Freebairn, Phil Bardsley, Bill Yeats, Bob Eisemann

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Preface

The northern grains cropping soils are predominantly Vertosols (cracking clay soils) which are generally uniform down to at least 1 m depth. Due to summer-dominant rainfall, winter crops largely rely on water stored in the soil profile during the previous summer-autumn fallow period. Although most soils of the region can store as much as 250 mm of water in their profiles, the presence of salts (salinity), sodium (sodicity) and chlorides in the subsoil effectively reduces rooting depths, increases osmotic potential and chloride toxicity, and nutrient imbalances. This reduces the amount of water a crop can access and utilise from the soil profile. These constraints cost growers around $80/ha over 1,400,000 ha or at least annually $112 million in the northern grains region in forgone grain income. Potential environmental damage may also occur due to salts mobilised in the landscape from increased runoff and deep drainage. It is, therefore, essential that the causal factors and the extent of subsoil constraints are investigated, management options evaluated and decision tools developed for growers.

The Results Book provides a comprehensive documentation of the 5-year project ‘SIP08 (North) Combating Subsoil Constraints’, funded by GRDC, Queensland Departments of Natural Resources and Water, and Primary Industries and Fisheries, Universities of Queensland and Western Sydney, NSW Departments of Primary Industries and Natural Resources, and CSIRO-APSRU. The diagnosis of the existence, extent and severity of subsoil constraints in the northern grains region soils was achieved using a combination of tools such as existing soil data, soil analysis, electromagnetic induction, remote-sensing, yield monitoring and numerous other techniques. Impact of subsoil constraints on grain yields, water use, runoff and leaching, and economic and environmental aspects were simulated by using APSIM. Field trials showed that grain yields of most winter cereal, pulse and oilseed crops decreased with increasing chloride levels in the subsoil. Pulses performed worst; however, cultivar differences were inconsistent on the subsoil constrained soils. In some of the highly constrained subsoils, it may be economic to shift from cropping land to forage crops or pastures (lucerne, lablab) or even agroforestry. It may also be economic to apply gypsum (sodic soils) and correct nutrient deficiencies such as for phosphorus and zinc.

Surveys of growers and advisors in the early stage of the project and at its completion clearly showed a significant increase in the knowledge, awareness and management of subsoil constraints, especially among advisors and advisor-linked growers. As the growers indicated in their early survey, we found that field days/soil pit days, workshops, and growers’ meetings were the most effective forms of two-way communication. A reference manual explaining subsoil constraints, and workshops with hands-on learning tools, proved to be most popular among advisors. We have prepared a decision tree and a toolkit to assist growers and advisors to identify and assess the severity of subsoil constraints on a farm, a paddock or part of a paddock and then decide on the best management option.

The project team thank GRDC and our agencies for funding the project. We sincerely thank numerous growers for establishing and managing the field trials, providing the land and other resources, including warm hospitality, sharing their trial results and ideas with the project team. We thank advisors and other growers, scientists, extension and development officers, Landcare and regional groups, and GRDC northern panel for their invaluable contributions.

Ram Dalal
Project Supervisor

Summary

Yash Dang

Subsoil constraints are those chemical, physical or biological properties in the subsoil, which limit the ability of plants to utilise soil water and nutrient resources, or otherwise have a detrimental effect on plant growth. These subsoil constraints include salinity, acidity, alkalinity, nutrient deficiencies and/or toxicities, sodicity (chemical), inherent high bulk density, compacted or gravel layers (physical) and low microbial activities or increase in pathogen/nematodes causing diseases (biological). Several of these constraints may occur together in some soils. Subsoil constraints have a significant impact on soil water storage and use, nutrient regime and crop growth.

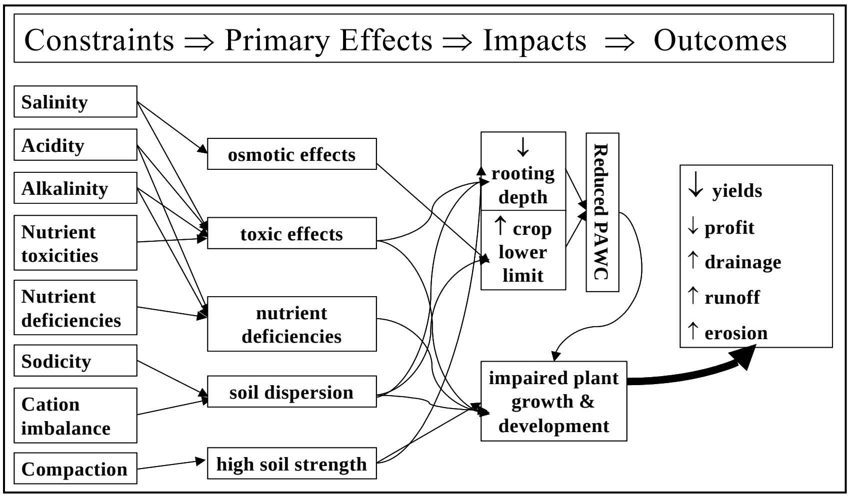


Figure 1. Impact of subsoil constraints on soil-plant, farming, landscape and environment.

The Grains Research and Development Corporation (GRDC) identified subsoil constraints as being an important limitation to crop production in the northern grains region of Australia. The GRDC in its investment strategy for 2002/03 invited tenders for potential research, development and extension (R, D & E) into improving farming outcomes from landscapes with subsoil constraints. The rationale behind this initiative was to determine the extent and location of subsoil constraints to farming and to develop strategies to manage and/or avoid these constraints. After scoping this initiative, a major project commenced targeting subsoils that constrain grain yield in the cracking clay cropping lands from Emerald in Queensland to Dubbo in New South Wales. A research consortium led by the Queensland Department of Natural Resources and Water in collaboration with the Department of Primary Industries & Fisheries, NSW Department of Primary Industries, NSW Department of Infrastructure Planning and Natural Resources, CSIRO, and the Universities of Western Sydney and Queensland successfully carried out R, D & E for this project over 5 years.

This result book provides a summary of R, D & E activities carried out within the project and our current knowledge about subsoil constraints in the northern cropping region, in particular:

- diagnosing their presence and severity
- their extent and distribution
- predicted impacts across regions, seasons and soil type
- management options
- extension activities including action learning tools
- preparing and distributing project products.

Diagnosing, distribution and impacts

The identification of the most limiting constraint, including that in the top soil layer, and its interaction with other factors is a first step to plan for sustainable, site-specific resource management. Chapter 1.1 provides an overview of information on biological, physical and chemical subsoil constraints and a step by step decision tree to identify the presence and severity of the most limiting constraint. The following symptoms would aid the on-farm identification of subsoil constraints:

- presence of unused soil water in the root zone after harvest, especially in the absence of recent rainfall, suggesting possible adverse impact of chemical constraints such as acidity, salinity, high chloride and sodium in subsoil,
- roots growing at right angle or presence of bent roots at shallow depth, suggesting an impenetrable compacted layer,
- presence of mottling and discolouration of the soil from waterlogging, suggesting poor drainage which could be due to subsoil sodicity.

For chemical soil analysis, take an approximately 500 g soil sample, using a small hand spade, separately at different depth intervals of 0-10, 10-30, 30-50, 50-70 and 70-100 cm. It is important to take and retain separate samples from different depths and sites (good or bad areas). These samples can then be tested for the constraints discussed below. At the paddock or farm scale, targeted soil sampling should be done by using EM survey, yield mapping or remote sensing (e.g. NDVI using biomass) to map areas suspected of subsoil constraints.

In the northern grains region, this project has identified the presence of high concentration of chloride (Cl) as key predictor of chemical subsoil constraints. We defined the levels of subsoil constraints based on Cl concentration in the top 1 m soil depth:

Cl < 400 mg/kg	Low subsoil constraints (no yield penalties)
Cl = 400-600 mg/kg	Mild subsoil constraints (legumes especially chickpea start to show yield penalties)
Cl = 600-1000 mg/kg	High subsoil constraints (most cereals e.g. durum wheat, bread wheat, barley and oilseed crops such as canola, mustard show yield penalties)
Cl > 1000 mg/kg	Very high subsoil constraints (low grain yields; crop production may not be economic)

In surface soil, the presence of high levels of exchangeable sodium percentage (ESP > 6%) is a major soil constraint (sodicity constraint), however, in the subsoil moderate to high ESP (6-25%) which is commonly occurring in the northern grains region, has been found to be less effective in identifying subsoil constraints. A pH value <5.5 would indicate acidity and a pH value >8.5 would indicate alkalinity as the potential constraints.

On the basis of these threshold values (ESP >15, EC_{se} >6 dS/m and Cl >1000 mg/kg soil), we estimated that more than 30% of the cropping land in Queensland alone is severely affected by one or more of the subsoil constraints. The spatial distribution of subsoil acidity (pH < 5.5) and alkalinity (pH > 8.5) represented 9% and 26%, respectively of the cropped area. Further, subsoil sodicity and subsoil salinity are more prevalent in southern Queensland compared to central Queensland. Insufficient soil survey data is so far available in northern NSW to allow subsoil constraints mapping, but it is expected the pattern will be similar to that of southern Queensland.

Modelling and simulation using the APSIM model showed that chemical subsoil constraints affect crop yields by reducing the amount of soil water that is available to crops (PAWC). The yield penalty due to subsoil constraints is seasonally variable; however, more in-season rainfall results in less impact from subsoil constraints**.** For wheat, management to take account of subsoil constraints (e.g. better matching inputs such as N fertiliser to yield expectations) is justified when Cl > 1000 mg/kg in the top 1m soil depth. In more marginal cropping regions with Cl > 1000 mg/kg in the top 1m soil depth, grain production may not be economically viable.

Management options

Various options to manage subsoil constraints were evaluated, including plant adaptation through breeding of tolerant cultivars, agronomic decisions, and chemical, mechanical and biological treatments. Briefly, different crop species showed differences in sensitivity to increasing subsoil Cl concentration. Grain yield of most species declined with increasing subsoil Cl. Barley and triticale yielded better than bread wheat at sites high in subsoil Cl. Durum wheat yields were more affected by low in-crop rainfall and high levels of subsoil Cl than bread wheat. Chickpea and field pea showed a clear decrease in yield with increasing Cl, and above average rainfall didn't mediate the effects of Cl. Field pea was less sensitive to subsoil Cl than chickpea. When sown on time, faba bean out-yielded chickpea, particularly at high subsoil Cl sites. Oilseed crops were less affected than cereals by increasing levels of subsoil Cl. Among oilseed crops, safflower yielded better than canola and mustard. Grain yields of summer crops did not show significant relationship with levels of subsoil constraints. We conclude that the range of constraints at each of our sites was insufficient to demonstrate a response, and differences between sites included other variables such as sowing date and rainfall. In general, the water extraction potential of millet, mung bean and sesame appear to be more sensitive to subsoil constraints as compared to sorghum and maize.

Cultivars of different crops also showed differences in sensitivity to increasing subsoil Cl. However, the differences in tolerance to subsoil constraints were minor. Within crop species, the following gives a guide to variety preferences in the presence of subsoil constraints:

- Bread wheat: Variation across sites was high so most varieties were no different to Baxter; Sunco and Rees tended to yield less than others on average.
- Durum wheat: no variety difference between Wollaroi and Bellaroi
- Barley: Binalong, Fitzroy, and Grout tended to yield better on high to very high subsoil Cl than Gairdner and Mackay.
- Triticale: in northwest NSW, Kosciuszko yielded equal or better than Everest; in CQ Treat yielded equal or better than Speedee (only 1 year data)
- Chickpea: in northwest NSW, Howzat outyielded Jimbour which was equal or better than Flipper and Genesis836; in CQ, Jimbour outyielded Moti
- Faba bean: Fiord outyielded Cairo at Garah and Bellata; but yielded less than Cairo at Spring Ridge
- Field pea: Yarrum outyielded Boreen at 9 of 11 trial sites in northwest NSW
- Lentil: CIPAL414 outyielded Digger at Bellata and Spring Ridge, but yielded less than Digger at Garah
- Canola: Ripper outyielded Rivette at Spring Ridge, but yielded less than Rivette at Bellata
- Mustard: Micky outyielded Kaye at 3 sites but was no different at another 6 sites
- Safflower: No difference between Gila and 555 in northwest

Simple agronomic practices such as wide row spacings or increasing length of the fallow period did not overcome the impact of subsoil constraints. Zero tillage with stubble retention increases water capture and can lead to higher deep drainage and chloride movement beyond the root zone if opportunity cropping is not practised. Drainage can be higher under cropping systems than pastures.

An adequate supply of phosphorus and zinc on paddocks with subsoil constraints improves the grain yield for wheat, chickpea, barley, canola and faba bean. Potassium is likely to increase the biomass yield, but not necessarily the grain yield for wheat. Surface application of gypsum to topsoil with ESP>6%, significantly increased wheat grain yield. Deep placement (20-30 cm) of gypsum did not affect grain yield in the first year, however, there appears to be some effect in the second year after application.

Use of pasture and tolerant forage crops are important alternative land use strategies for soils with high subsoil constraints. Actively growing plants would also reduce deep drainage. Mostly drought/salt tolerant pasture and forage species such as lucerne, buffel grass, and lablab and forage sorghum are recommended for southwest Queensland. Shallow cropping soils (only 60-70 cm deep) with moderate Cl concentrations do not suit perennial grass and legume pastures such as bambatsi, medic and lucerne. Annual pasture and forage crops (lablab, forage sorghum and oats, buffel grass) may be better suited. A potential alternative land use to cropping on highly constrained subsoils is commercial agroforestry using an Australian native species such as *Kalpa* (*Millettia* species).

Good agronomic management helps to minimise the water and other physiological stresses imposed by subsoil constraints. In paddocks with subsoil constraints, successful cropping can be achieved by:

- maximising fallow efficiency with short fallows
- effective weed control
- suitable rotations for disease minimisation
- matching nutrients to realistic yield expectations
- appropriate species and cultivar selection and
- timely crop sowing
- using zero till, stubble retention and controlled traffic

Dissemination of project outcomes

The project team coordinated and delivered multiple learning activities for growers and advisors across the northern grains region. Each activity was designed to disseminate practical information to (a) raise awareness and knowledge of subsoil constraints, (b) assist growers to evaluate whether subsoil constraints are an issue on their farm, and (c) determine what can be done to manage around these issues. More than 30 action learning workshops were conducted and more than 100 presentations or discussions delivered at grower group meetings in QLD and NSW. Research data from the project has also been disseminated through the field days, soil water, and crop sequencing ALMs (action learning modules) presented to advisers and growers throughout the northern grains region.

The project had strong linkages with farming systems projects (EFS-NSW, WFS-Qld, WFS-NSW, CQSFS) and other groups including CFI, Namoi CMA, Border Rivers Gwydir CMA, and Healthy Soils for Sustainable Farming and Land care groups.

The project team also published peer reviewed research papers, conference papers, technical notes (see list of publications, chapter 3.3) and various other written resources including:

- **Reference manual:** A detailed guide to subsoil constraints to crop production in north-eastern Australia
- **Decision tree:** Constraints to cropping soils in the northern grains region and management options
- **Crop note:** Subsoil constraints to crop production: impact, diagnosis and management options
- **Tool kit:** An instruction booklet for assembling and using a tool kit for identifying subsoil constraints in Australia's northern grains region.

Evaluation

At the commencement of the project (2003) a survey was undertaken to benchmark growers' and advisors' knowledge, attitudes, skills, aspirations and practices relating to subsoil constraints. A total of 421 growers and 93 advisors in the northern grains region responded to this survey. During the last 6 months of the project (2007) a final project survey was conducted in the same geographic location. A total of 392 growers and 49 advisors responded to this survey. Comparing the 2007 results to the 2003 survey provides information to determine the impact of the project. In brief:

- large numbers of growers and advisors throughout northern grain region have participated in project activities
- the project has increased knowledge of identification and impacts of subsoil constraints, with advisors gaining more knowledge than growers
- 39% of growers and 68% of advisors indicated in 2003 that they managed soils with subsoil constraints differently to those without, while in 2007 these responses have significantly increased to 68% of growers and 90% of advisors.

Grower case studies

The project commissioned Russ Boadle (Media unit officer) from the Department of Primary Industries & Fisheries and Bernie Reppel, an independent journalist to obtain information on grower's participation and learning activates with the subsoil constraints project. They selected 2 growers each from central Queensland, southwest Queensland and northern NSW and asked about their role and learning from the project.

Some of the key learnings included:

- Neville Boland believes identifying and measuring patches of subsoil constraints has provided confidence in the future productivity of his grain enterprise
- John Nolan believes association with the subsoil constraints project has lead to revising crop options, improved water use efficiency and profitability on his grain and cattle property.
- Lex Webb believes the 110 per cent support offered by staff from the Combating Subsoil Constraints Project was a major influence that had enabled them to identify and successfully manage the limitations imposed by subsoil constraints.
- When approached by the project, Joe Reddy didn't hesitate to investigate the crop performance impacts of subsoil constraints on his property.
- Andrew Crowe believes that local growers are now able to make better use of plant available water and maximise production on their country with subsoil constraints thanks to the EFS/SIP08 projects
- Drew Penberthy says the projects helped him to identify which crop and which variety would deliver the best gross margins on country with subsoil constraints

1.

Diagnosis, Distribution and Impacts

1.1 Diagnosing the presence and severity of subsoil constraints

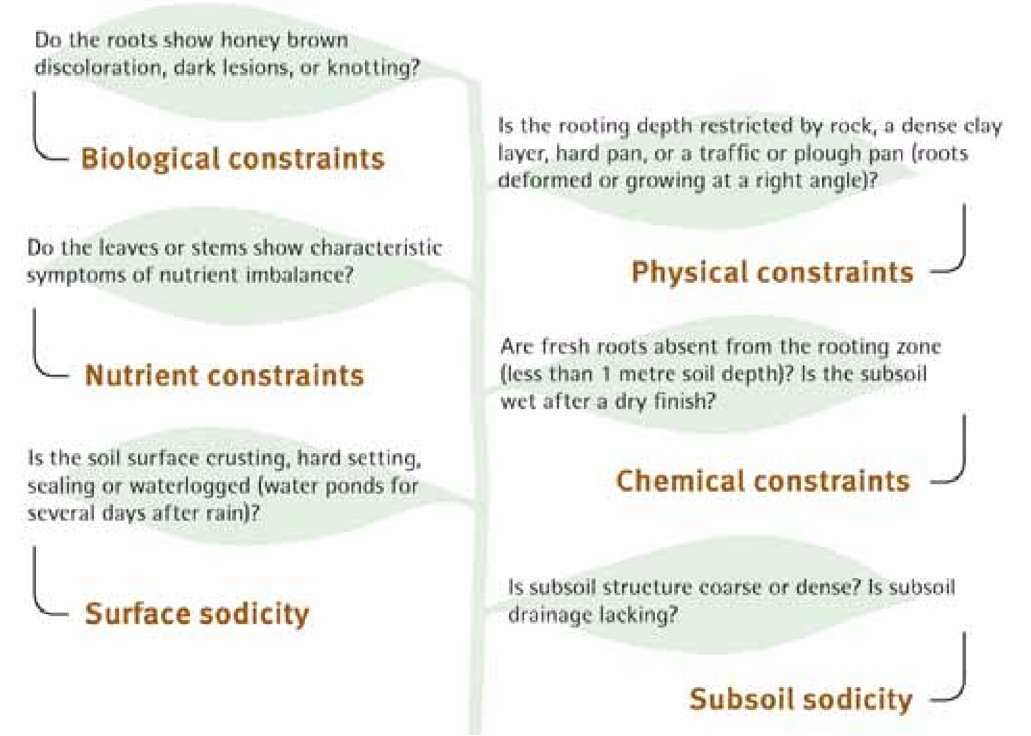
Yash Dang

Key messages:

- Chemical, physical or biological subsoil constraints limit the ability of plants to utilise soil water and nutrient resources.
- Identification of the most limiting subsoil constraint is a first step.
- Chemical constraints can be directly toxic to plants or restrict water uptake.
- Physical constraints decrease rates of root growth, oxygen diffusion and water movement into and within the soil.
- Biological constraints (organisms) invade roots and interrupt root functions.
- Targeted soil sampling and analysis, EM survey, yield mapping and remote sensing can be employed to locate areas suspected of subsoil constraints.

Subsoil constraints are those chemical, physical or biological properties in the subsoil, which limit the ability of plants to utilise soil water and nutrient resources, or otherwise have a detrimental effect on plant growth. These subsoil constraints include salinity, acidity, alkalinity, nutrient deficiencies and/or toxicities, sodicity (chemical), inherent high bulk density, compacted or gravel layers (physical) and low microbial activities or increase in pathogen/nematodes causing diseases (biological). Several of these constraints may occur together in some soils and may interact. Subsoil constraints have a significant impact on soil water storage and use, nutrient availability and crop growth. The identification of the most limiting constraint and its interaction with other factors is a first step to plan for sustainable site-specific resource management.

If a paddock or parts of a paddock show poor crop growth and yield, despite good soil moisture at sowing and adequate in-crop rainfall, look for the following: diseases, insect pests, nematodes, herbicide damage, weeds, or frost damage. If none of these are the obvious cause of poor/patchy growth or yield, then soil chemical, physical or biological properties may be limiting plant growth. Use the decision tree below to help identify the likely soil constraints.



Do the roots show honey brown discoloration, dark lesions, or knotting?

Do the leaves or stems show characteristic symptoms of nutrient imbalance?

Is the soil surface crusting, hard setting, sealing or waterlogged (water ponds for several days after rain)?

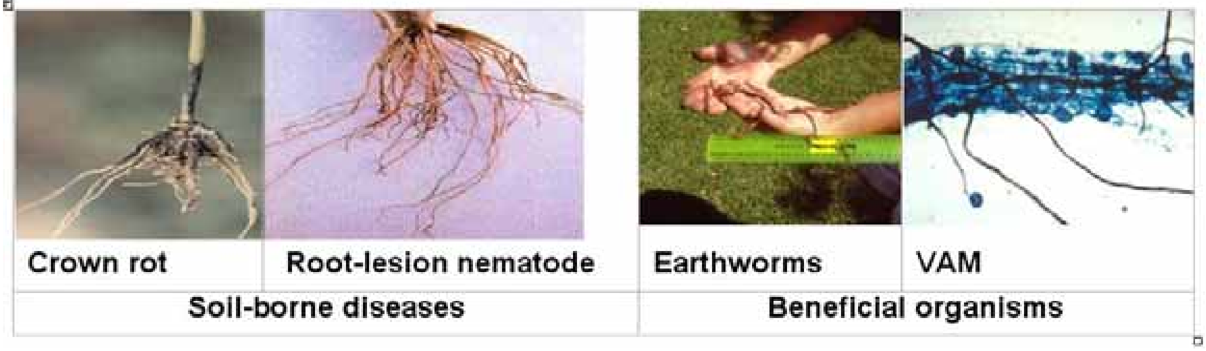
Is the rooting depth restricted by rock, a dense clay layer, hard pan, or a traffic or plough pan (roots deformed or growing at a right angle)?

Are fresh roots absent from the rooting zone (less than 1 metre soil depth)? Is the subsoil wet after a dry finish?

Is subsoil structure coarse or dense? Is subsoil drainage lacking?

1.1.1 Biological constraints

Good and bad soil organisms affect plant growth. Problems occur when there is a reduction in the activities of good organisms such as earthworms and VAM (mycorhizae), or an increase in pathogens or plant-parasitic nematodes. Pathogenic fungi and nematodes often build up in monoculture cereal cropping systems. These include crown rot and common root rot, as well as root-lesion nematodes that can be deep in the soil at or below 60 cm depths at peak times.

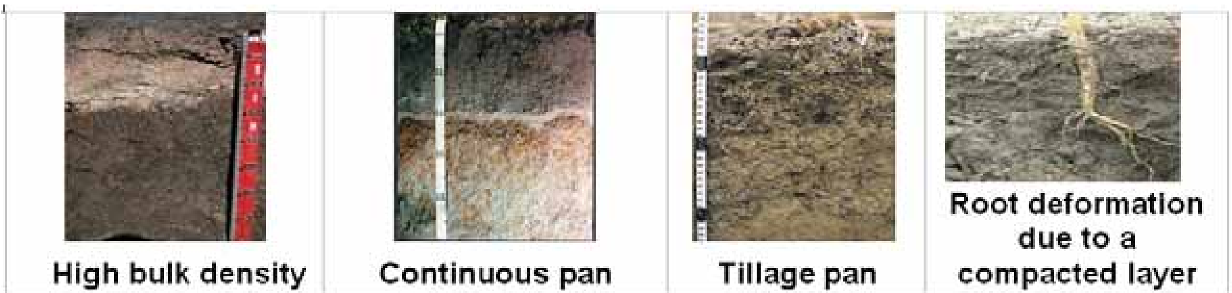


Crown rot | Root-lesion nematode | Earthworms | VAM

Soil-borne diseases | Beneficial organisms

1.1.2 Physical constraints

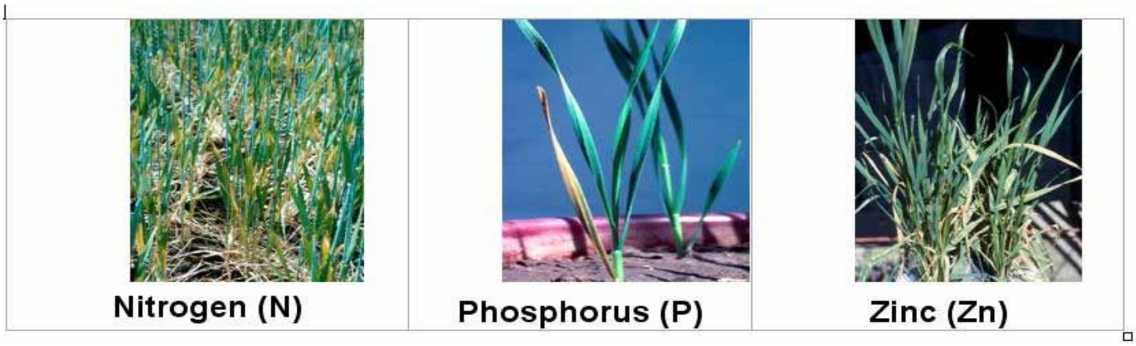
Physical constraints decrease oxygen and water movement in the soil. Compacted soil and soil with a high physical strength impede root growth. Compacted soil layers or layers of high bulk density (>1.5 g/cm^3) are widespread in the northern cropping region. Subsoil compaction may be natural but is also caused by heavy traffic and tillage on wet soils. Man-made compaction occurs mainly in the top 30 cm in most cropping soils, but can be deeper especially below wheel tracks. Compacted layers may be visible, or shown by high penetration resistance (>2 MPa), or indicated by distorted root growth.



High bulk density | Continuous pan | Tillage pan | Root deformation due to a compacted layer

1.1.3 Nutrient deficiencies

Better crop varieties, improved agronomy and higher yields, along with continuous cropping without adequate fertiliser, have resulted in widespread soil nutrient depletion—especially of nitrogen, phosphorus and zinc. Subsoils are generally lower in nutrients than the surface layer. This can reduce yield in dryland regions, where continued root growth and function are essential to enable crops to extract water and nutrients from the subsoil. Signs of nutrient deficiency include: pale yellow old leaves (lack of N), dark green foliage and purple old leaves (P), and water-soaked strips on young leaves (Zn).



Nitrogen (N) | Phosphorus (P) | Zinc (Zn)

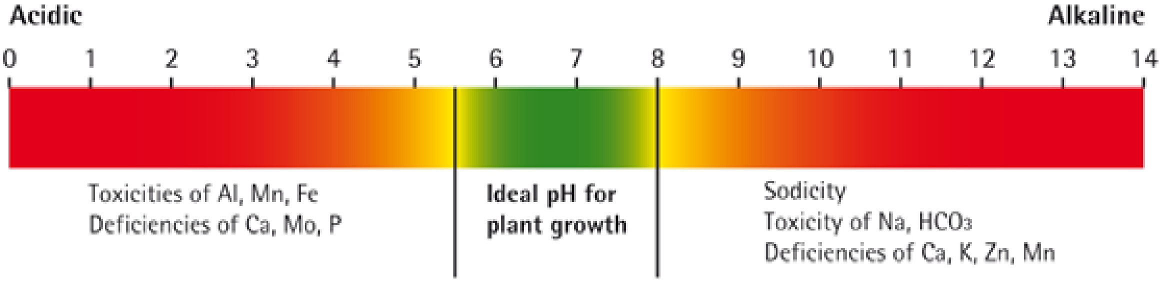
1.1.4 Chemical constraints

1.1.4.1 Acidity

In acid soils (pH <5.5), aluminium and manganese become more soluble; they may become toxic as their concentration in the soil water rises. Aluminium inhibits root growth in most plants and induces calcium, phosphorus and molybdenum deficiencies. In the northern grains region, subsoil acidity is common in soils dominated by N_2-fixing brigalow and belah trees.

1.1.4.2 Alkalinity

In alkaline soils, an abundance of anions such as carbonates and bicarbonates contribute to the high pH. At soil pH >8.0, especially pH >9.0, toxicity of carbonate and bicarbonate can reduce crop growth and yield, and/or induce nutrient deficiencies.



1.1.4.3 Salinity

Salinity is the presence of dissolved salts in soil or water. A high concentration of salts can cause ion toxicity, and due to osmotic effects can also reduce a plant's ability to absorb water. Several salts are found in northern region soils, including sodium chloride (common salt), calcium sulphate (gypsum) and calcium carbonate (lime). Different salts have different solubilities. Only highly soluble salts such as sodium chloride inhibit water extraction or are directly toxic to roots. Soil salinity is commonly measured as electrical conductivity (EC) in a 1:5 soil: water extract and expressed as dS/m. EC measurements do not discriminate between salt types.

Gypsum: EC values will be high if significant quantities of gypsum are present. If the high EC reading is due only to gypsum there are no concerns for crop growth. The dissolution of soluble gypsum will not restrict the roots from extracting water (low osmotic effect) unless other soluble salts are present. Gypsum is present as white bands in this photo of a soil profile.

***Chloride and sodium*:** Measuring sodium and particularly chloride concentrations in soil provides a better indicator of ion toxicity, and why a crop has problems extracting water (high osmotic effect). Chloride salts are highly soluble and can accumulate in toxic concentrations in plant tissue. Chloride accumulation in some species causes toxicity and a drop in grain yield.

Chloride affected wheat and chickpea

1.1.4.4 Sodicity

Sodicity is an excess of sodium ions relative to other cations (calcium, magnesium and potassium). A high proportion of sodium can lead to soil dispersion. Dispersion is the disintegration of clay aggregates into individual particles when wet, resulting in milky or cloudy water. In the paddock, the soil is likely to be poorly drained and the subsoil may remain saturated for long periods.

Salinity can mask the dispersive behaviour of sodic soil. Sodicity and salinity both occur together in many subsoils. Plant growth is primarily limited by salinity. However, sodic impermeable subsoil does not allow the drainage that would otherwise help to move salts out of the surface layers and root zone.

High surface soil sodicity leads to surface crusting, cloddy seedbed, poor water infiltration and increased water-logging. In subsoils, high sodicity often leads to a coarse or dense structure that restricts soil water and air movement. The subsoil may become oxygen deficient and take on a mottled "rusty" appearance. Crop roots cannot grow in a water-saturated soil (due to the lack of oxygen). Even though the subsoil is wet, this water is not really available to the crop due to high salinity and resulting high osmotic potential.

1.1.5 Paddock assessment for the presence of subsoil constraints

The severity of subsoil constraints can vary greatly within a paddock and their impact can be dependent on seasonal conditions. The soil should be sampled separately from good and bad areas and checked for soil properties in both the surface and subsoil.

Identify potential sites of concern for screening the areas suspected of soil constraints, which may limit the crop's ability to extract soil moisture and nutrients, based on the grower's own knowledge of a paddock. These areas may show symptoms such as poor germination, low yield, patchy growth, water logging, cloudy water, surface crusting and shallow rooting depth.

For a complete physical-chemical examination of the soil profile, dig or excavate a 1 m deep hole. The hole should be large enough to enable examination of the profile, collection of samples and be safe to access. Examine the soil profile and record at each depth interval for the presence of fresh roots, presence of moisture, and any layer of hard pan or plough pan, mottling, presence of beneficial organisms (e.g. earthworms) or root diseases.

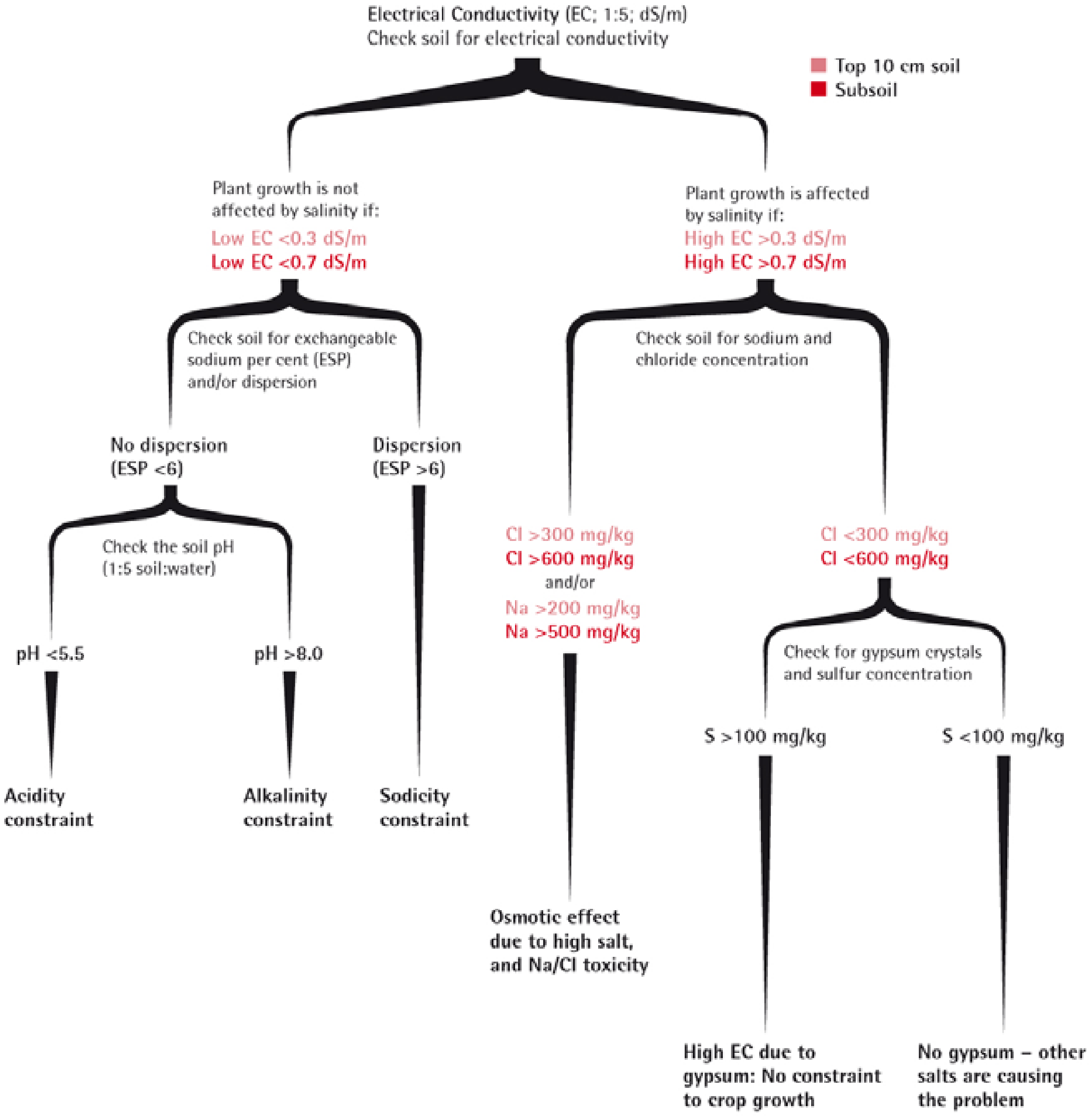
Symptoms of subsoil constraints to look for in the soil pit include:

- presence of unused soil water in the root zone after harvest even though it hasn't rained recently, suggesting possible impact of chemical constraints such as acidity, salinity, high chloride and sodium in subsoil,
- roots growing at right angle or presence of bent roots at shallow depth, suggesting an impenetrable compacted layer,
- presence of mottling and discolouration of the soil from waterlogging, suggesting poor drainage which could be due to subsoil sodicity.

For chemical soil analysis, take an approximate 500 g soil sample separately at each different depth interval of 0-10, 10-30, 30-50, 50-70, 70-90, and 90-110 cm, using a small hand spade Soil samples can also be obtained with a soil corer at different depth intervals if you cannot dig a pit. Traditional soil samples taken for nutrient assessment were often mixed across the whole paddock. When trying to define subsoil constraints, it is important to take and retain separate samples from different depths and sites. Each sample should be clearly labelled with location in the paddock, depth, date and other relevant information prior to sending for analysis.

1.1.6 Interpreting soil test results

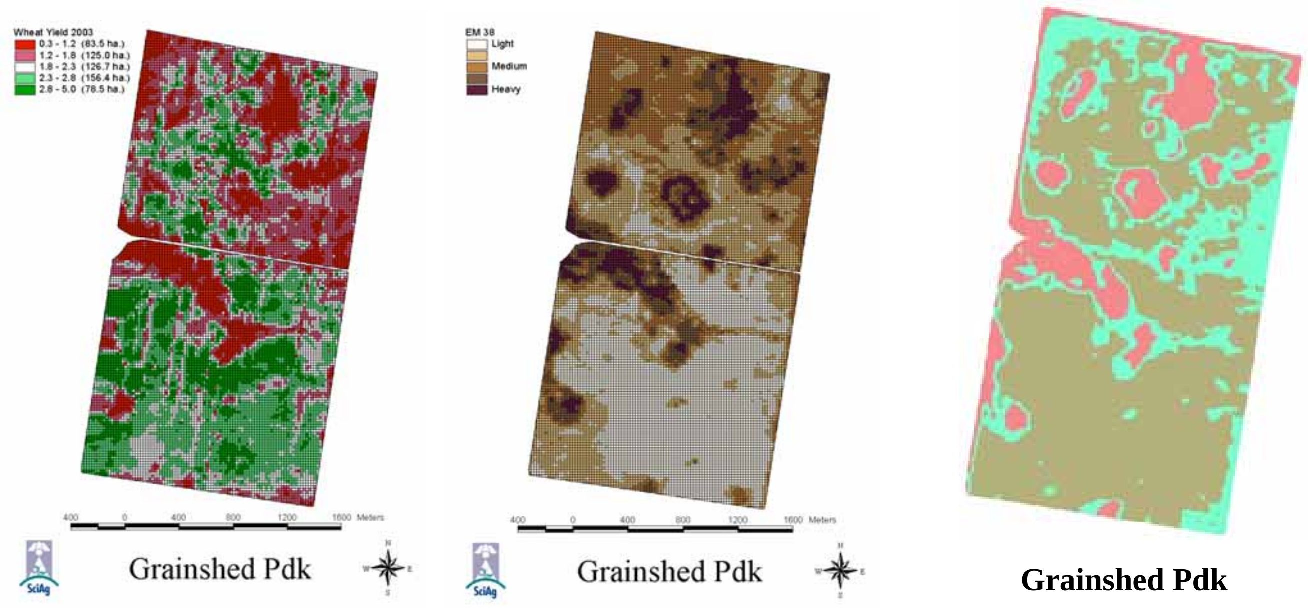
The decision tree given below helps the advisor and agronomist to use grower's test results and work through the alternatives to decide which chemical subsoil constraint occurs in grower soil sample, and which is likely to have the most effect on growth and yield of crops.



1.1.7 EM and yield maps

Grid sampling of soil to test for variable distribution of possible subsoil constraints, both spatially across the landscape, and within the soil profile would be time consuming and expensive. However, sensing technologies have made the capacity to monitor and locate areas of potential subsoil constraints both practical and economic. There are three types of sensors that can be used to help identify subsoil constraints, namely electrical conductivity sensor, electromagnetic (EM) induction sensors and gamma radiometric sensor. EM38 technology uses electromagnetic induction to provide measurements of bulk soil EC (apparent), which is a function of salt concentration, soil water content, and soil clay content. Taking EM readings when the soil moisture profile is close to field capacity removes one of these variables. Ground-truthing by soil sampling and analysis of salts is necessary to convert apparent EC to actual EC.

Beside EM surveys, yield maps, aerial photographs and remote sensing for biomass (using NDVI data) can be used to delineate the areas of possible subsoil constraints. We examined the feasibility of using mobile EM38 coupled with a yield map and NDVI map to identify areas with possible subsoil constraints (Figure 1). High yielding areas in yield map of the paddock closely matches with low EM38 values in EM38 map and also with dark brown areas in NDVI map. Preliminary results suggest that using EM38 maps together with yield map, and remote sensing may offer an affordable method to identify areas with suspected subsoil constraints.



Yield map **EM38 map** **NDVI map**

Figure 1.1.1. Comparison of wheat yield map with EM38 map and NDVI map derived from satellite imagery.

1.2 Extent and distribution

Ben Harms

Key messages[1]:

- A large proportion of the land used for dryland cropping in Queensland is affected by subsoil constraints:
    - 41% has strongly sodic subsoils (ESP >15)
    - 27% has chloride levels that constitute a severe subsoil constraint (>1000 mg Cl/kg)
    - 31% has severe subsoil salinity (EC_{se} >6 dS/m)
    - 26% has high subsoil alkalinity
- 40% of the cropped land is severely affected by at least one of the subsoil constraints.
- 10% of the cropped land is affected by all three of the sodicity, soil chloride and alkalinity subsoil constraints.
- Sodicity and soil salinity are more prevalent in southern Queensland compared to central Queensland.
- Insufficient soil survey data is so far available in northern NSW to allow subsoil constraints mapping but it is expected to be a similar pattern to southern Queensland.

Regional mapping of subsoil constraints in Queensland has been undertaken using the best available land resource mapping and the data available in Queensland's Soil and Land Information (SALI) database. The Queensland maps of subsoil constraints have been adapted from the ASRIS (Australian Soil Resource Information System http://www.asris.csiro.au) 'attribute surfaces'. ASRIS soil attribute surfaces are derived by allocating soil properties to map units (or polygons), using the finest scale mapping available and a codified attribution process. Soil properties incorporated into ASRIS include ESP, EC, pH and clay content.

The first level of attribution is based on actual site data (laboratory analysis and field observations). The second level uses soil profile class (SPC) within a soil mapping project. The third level incorporates information obtained from reconnaissance or 'land system' mapping. The derivation of these attribute surfaces is discussed by Brough *et al.* (2006). A unique feature of the 'ASRIS surfaces' is that they are based on soil profile 'control sections' rather than specific soil depths. For example, control section four (CS4) corresponds to the middle of the B (subsoil) horizon. In the cereal growing region of Queensland, CS4 has an average lower depth of 1.2 m.

The subsoil constraints mapped in this project are *salinity*, *sodicity*, *acidity* and *alkalinity*. Chloride (Cl) toxicity has been shown to be a prime causal agent of salinity effects on plant growth. Cl concentration is not an 'ASRIS attribute', but has been included in the Queensland data set because of its relevance as an indicator of salinity. In addition, the saturation extract of EC (EC_{se}) is widely regarded as an indicator of salinity that relates to plant response and accounts for soil texture differences (Shaw, 1999). . An equation (Shaw, 1999) has been used in this project to obtain estimated values of EC_{se} for each map unit (polygon). The sodicity limitation has been established using values of exchangeable sodium percentage (ESP). Acidity and alkalinity limitations have been obtained from soil $pH_{1:5}$ measurements.

Effects of any soil attribute on plant root growth depend on many factors, especially crop species and soil moisture levels. Therefore the critical thresholds adopted in mapping subsoil constraints are somewhat arbitrary. The 'constraint ratings' adopted for each attribute are shown in Table 1.2.1.

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[1] Statistics in the key message box are estimated proportions of the dryland cropping land within the cereal growing region of Queensland.

The subsoil constraints maps have an accuracy that reflects the scale of the source data used, which in the project area ranges from 1:50,000 to 1:500,000. Because the attribute surfaces are based on averages or estimates for each soil property within particular mapping units, they must be regarded as indicative only. Therefore they are suitable only for regional scale estimates and not applicable at a ‘paddock scale’.

Subsoil constraints maps have been produced for the cereal growing region of Queensland (Fig. 1; Fig. 2). Statistics of the area affected by subsoil constraints have been prepared for both the total cereal growing region (31 Mha) and for the area of land actually used for dryland cropping. Land use mapping (Witte et al., 2006) shows that within the cereal growing region, 2.5 Mha or 8% of the total area was used for dryland cropping in 1999.

Table 1.2.1 shows that a large proportion of the land used for dryland cropping is affected by subsoil constraints. The proportion of cropped land affected by salinity (Cl and EC_{se} constraints) is much greater than the proportion of all land affected (59% compared with 42% for Cl; 74% compared with 57% for EC_{se}). Conversely, the proportion of cropped land affected by the alkalinity constraint is much lower than the total proportion of land affected (26% compared with 77%).

Further analysis has shown that different subsoil constraints often occur together, with 57% of the land used for dryland cropping affected by a combination of both sodicity ($ESP \geq 6$) and salinity (Cl conc. ≥ 400 ppm). 10% of the cropping land is affected by sodicity, salinity and alkalinity ($pH > 8.5$) together.

Table 1.2.1 Subsoil constraints and the proportion of land affected by each in Queensland’s cereal cropping region.

Attribute	Attribute Level	Constraint rating	% of cereal cropping region[a] affected	% of cropped land[b] affected
ESP	6-15	Moderate	40	47
	15-30	Severe	30	34
	> 30	Very severe	12	7
		TOTAL	**82**	**88**
Chloride (Cl) (mg/kg)	400-600	Minor	11	9
	600-1000	Moderate	15	34
	> 1000	Severe	16	27
		TOTAL	**42**	**59**
EC_{se} (dS/m)	2-4	Minor	19	23
	4-6	Moderate	17	21
	> 6	Severe	21	31
		TOTAL	**57**	**74**
Alkalinity	pH > 8.5	Moderate	77	26
Acidity	pH < 5.5	Severe	8	9
		TOTAL	**85**	**35**

[a] total area = 31,192,045 ha. [b] total area (cropped in1999) = 2,480,195 ha

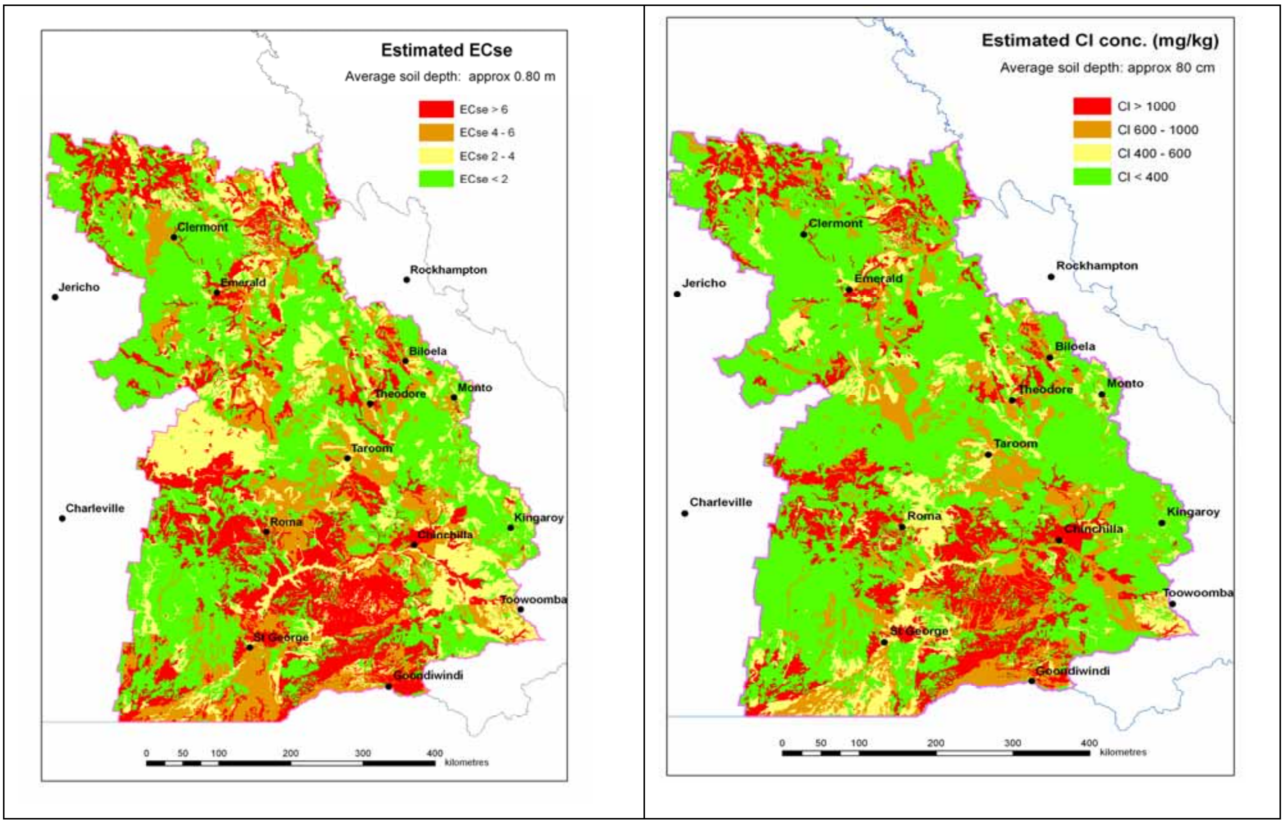

Fig. 1.2.1 The estimated distribution of the subsoil *salinity* constraint in the cereal growing region as shown by saturation extract electrical conductivity (EC_{se}) and Chloride (Cl) concentration. Estimations based on ASRIS control section 4 (middle of B horizon).

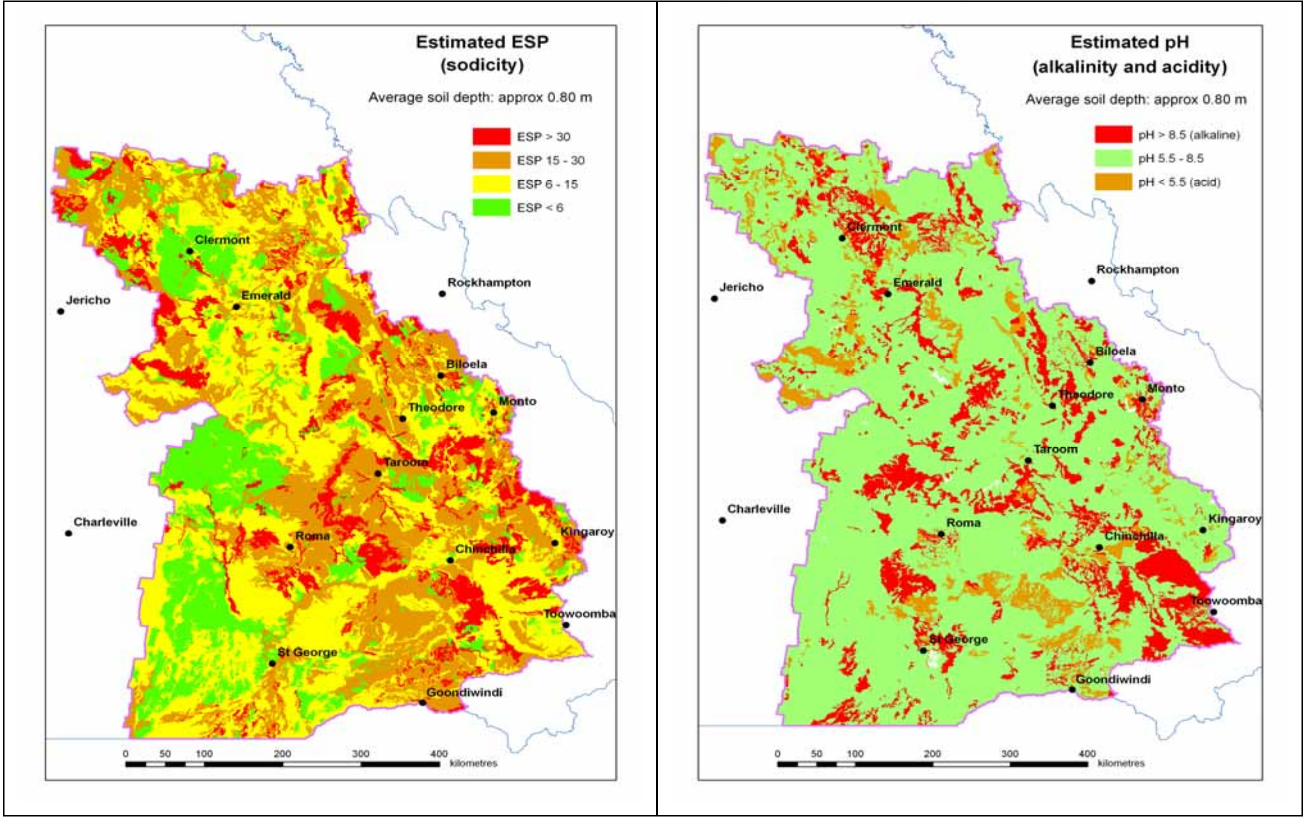

Fig. 1.2.2. Maps of estimated ESP (subsoil sodicity constraint) and estimated pH (subsoil alkalinity and acidity constraints) in the cereal growing region. Estimations based on ASRIS control section 4 (middle of B horizon).

An arbitrary line (passing approximately through Taroom) was drawn across the cereal growing region to separate it into northern and southern sections. Table 1.2.2 shows the proportion of land affected by subsoil constraints in each of these sections, illustrating that sodicity and salinity are more prevalent in the southern section of the region. This is probably due to the geology and landscapes on which the cropping land is found. In southern Queensland, the majority of cropping land (85%) is located on soils derived from fine grained sedimentary rocks (eg mudstone) and alluvial sediments, both of which have higher salt and sodium concentrations. In central Queensland, a much larger proportion of cropping land (approx. 55%) is located on soils derived from basalt, and alluvium both of which have lower salt and sodium concentrations.

Table 1.2.2. The proportion of cropped land affected by subsoil constraints in the northern and southern sections of the cereal cropping region.

Attribute	Attribute Level	% of cropped land affected in the north (CQ)	% of cropped land affected in the south (SQ)
ESP	> 6	75	94
	> 15	22	51
Chloride (Cl) (mg/kg)	> 400	39	69
	> 1000	11	34
EC_{se} (dS/m)	> 2	51	86
	> 6	17	38
pH	> 8.5	31	24
	< 5.5	2	12

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Witte C, Van den Berg D, Rowland T, O'Donnell T, Denham R, Pitt G, Simpson J (2006) Mapping Land Use in Queensland: Technical report on the 1999 land use map for Queensland. Department of Natural Resources, Mines and Water, QNRM06185, Brisbane.

1.3 Predicted impacts of subsoil constraints across regions, seasons and soil types

Zvi Hochman and Bob Farquharson

Key messages:

- Modelling and simulation show that chemical subsoil constraints affect crop yields by reducing the amount of soil water that is available to crops (PAWC).
- Cl concentration is the best and cheapest indicator of potential impacts of SSC on wheat yields.
- Yield penalty due to subsoil constraints is seasonally variable: However, more in-season rainfall results in less impacts from subsoil constraints.
- For wheat, management of areas affected by subsoil constraints (e.g. reduced N inputs) is justified when Cl > 1000 mg/kg anywhere in the top 1m soil depth.
- In more marginal cropping regions with Cl > 1000 mg/kg anywhere in the top 1m soil depth, grain production is severely affected and may not be viable.

1.3.1 Testing the proposition that chemical subsoil constraints affect crop yields by reducing the amount of soil water that is available to crops

There is growing evidence that chemical subsoil constraints (salinity and sodicity) impact wheat yields by increasing the lower limit of wheat's available soil water (CLL) and thus reducing the soil's plant available water capacity (PAWC). This proposal was tested by using the APSIM model (Keating *et al.* 2003) and specifying subsoil constraints only in terms of the measured PAWC characteristics, to simulate 33 farmers' paddocks in southwest Queensland and northwest NSW. The simulated results accounted for 79% of observed variation in grain yield with a root mean squared deviation (RMSD) of 0.50 t/ha. This result was as close as any achieved from sites without subsoil constraints, thus, providing strong support for the proposed mechanism that SSCs impact on wheat yields by increasing the CLL and thus reducing the soil's PAWC.

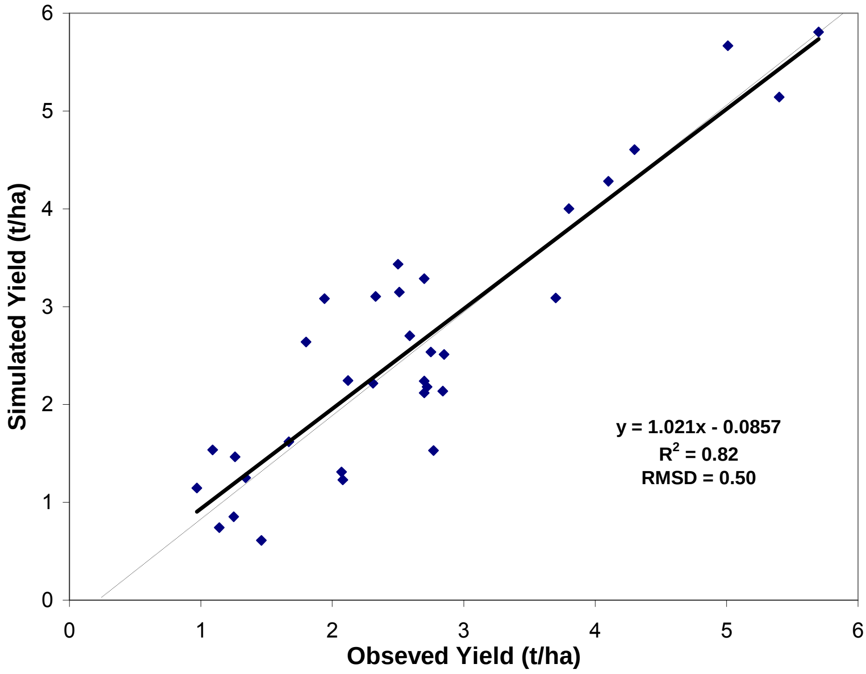


Figure 1.3.1. Simulated and observed wheat yields at 33 sites with various levels of EC, Cl^-, exchangeable Na and ESP in the northern grains region using CLL to account for the impact of the SSCs.

1.3.2 Deriving response functions to identify and quantify the chemical factors limiting crop performance

A cost effective means of accounting for similar soils with varying levels of subsoil constraints must be developed if we are to have a capacity to simulate options for management of paddocks (or management zones for Precision Agriculture) in accordance with their levels of subsoil constraints. Prior to this research APSIM did not have a specific capability for simulating the impacts of salinity and sodicity on crop growth. 'Kl' is a function that defines the potential water extraction rate from a soil layer. In this research we used subsoil constraints indices to modify the default value of the water extraction coefficient (kl) of each soil depth layer as a function of subsoil constraints indices. The indices we used included EC, ESP, Na and Cl. Of these, the most effective index for predicting the effects of subsoil constraints on wheat grain yields was Cl. Figure 2 shows the exponential function that was derived for Cl concentration.

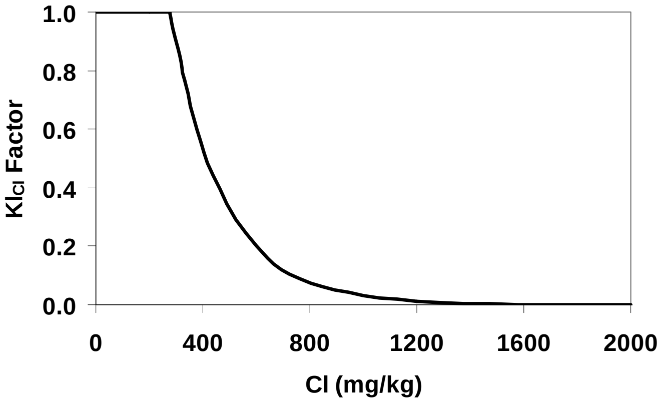


Figure 1.3.2. Optimized factor for reducing root effectiveness in extracting water from a soil layer (kl) as a function of Cl. The equation of the regression line is: (kI = MIN (1.0, $4.0e^{-0.005*Cl}$)

A comparison of simulated and observed wheat yields at 33 sites in the northern grains region showed that the APSIM model accounted for 84% of the observed variability in grain yield with a RMSD of 0.53 t/ha. This result indicates that Cl data provides a useful modifier of kl for improving yield prediction for soils with subsoil constraints.

1.3.3 Predicting the impacts of SSC on crop yields

1.3.3.1 Extrapolating experimental results to different seasons

Given that experimental results will be obtained in a limited sample of specific seasons, it seems desirable to use a cropping systems simulator to investigate the seasonal variability of the impact of subsoil constraints on grain yield. Season variability could be considered to have two sources: (i) difference in the amount of stored soil moisture that can be exploited by the crop, and (ii) difference in effective use of in-crop rainfall. To investigate in-crop rainfall differences we can reset stored soil moisture at the start of each season (e.g. 30th April) and take the past 100 years' weather data for a given location and compare the simulated grain yields of wheat that are calculated with and without the limitations of subsoil constraints on CLL. Figure 1.3.3 illustrates the wheat grain yield differences between a crop growing in Goondiwindi on an unconstrained grey Vertosol and the same crop growing on a soil that has high subsoil constraints. In both cases pre-growing season soil moisture is reset at the start of each season to be 2/3 soil profile full relative to the unconstrained grey Vertosol. As yield differences between treatments vary from less than 200 kg/ha in some years to nearly 3 t/ha in others, we can expect yield responses to be highly variable from year to year.

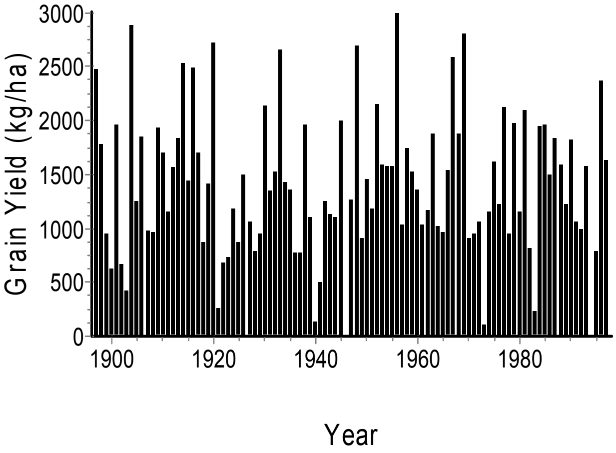
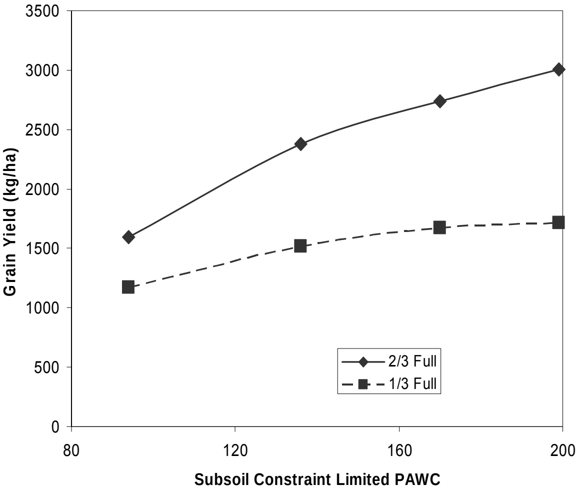


Figure 1.3.3. Differences in annual wheat yields between a grey Vertosol with low subsoil constraints and a soil with high subsoil constraints at Goondiwindi. Each season starts with a 2/3 full soil moisture profile.



Level of subsoil constraints
Very high High Medium Low

Figure 1.3.4. Average wheat yield responses to increasing subsoil constraints at contrasting pre-season soil moisture levels at Goondiwindi.

To investigate the impact of stored soil moisture we contrast the mean results of 4 different levels of subsoil constraints (defined by their effects on PAWC) at two pre-growing season soil moisture profiles, 1/3 full versus 2/3 full. Both scenarios show progressive yield losses in response to severity of subsoil constraints, the effect on wheat grain yield is greater where pre-growing season stored soil moisture, and consequently yield potential, is greater (Figure 1.3.4). We conclude by postulating that both pre-growing crop season (Figure 1.3.4) and in-crop season conditions (Figure 1.3.3) modify the crop's response to SSC.

1.3.3.2 Extrapolating experimental results to different locations

Also of interest is the extent to which these impacts are modified by location. Here we compare four locations: Gunnedah, Goodiwindi, Roma, and Emerald with similar average annual rainfalls (608 mm, 581 mm, 585 mm and 624 mm respectively) but contrasting in degrees of dominance of summer rainfall distributions. Figure 1.3.5 shows that sites with more summer-dominant rainfall had lower yields, although the proportional response to subsoil constraints is similar at all sites. As with yield, the impact of subsoil constraints on drainage is similar for all sites (Figure 1.3.6). Both average annual rainfall and summer dominance influence the overall drainage trend: drainage at Emerald > Goondiwindi > Roma is consistent with higher average annual rainfall leading to higher drainage at these sites. However, Gunnedah with the lowest average annual rainfall has a similar drainage trend as Goodiwindi. Here the average annual rainfall trend is moderated by a trend for lower overall drainage in the more summer-dominant rainfall. This trend may be explained by: (i) more of the annual rainfall is received in the high evaporation potential season, and (ii) summer rainfall is distributed in fewer and larger events than winter rainfall (thus excess water is more likely to be expressed in runoff). Site differences in runoff (not shown) are consistent with summer dominance (and tendency for more concentrated rainfall events). Response to reduced PAWC is relatively flat, indicating that runoff is less responsive to subsoil conditions.

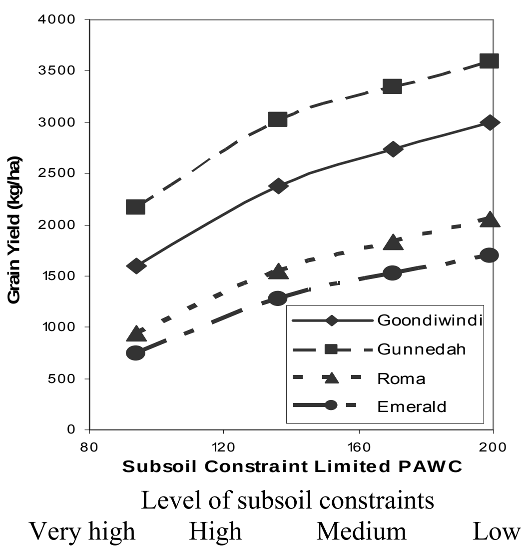


Figure 1.3.5. Wheat yield response to SSCs and location (summer rain dominance) Pre-season Soil Moisture = 2/3 Full.

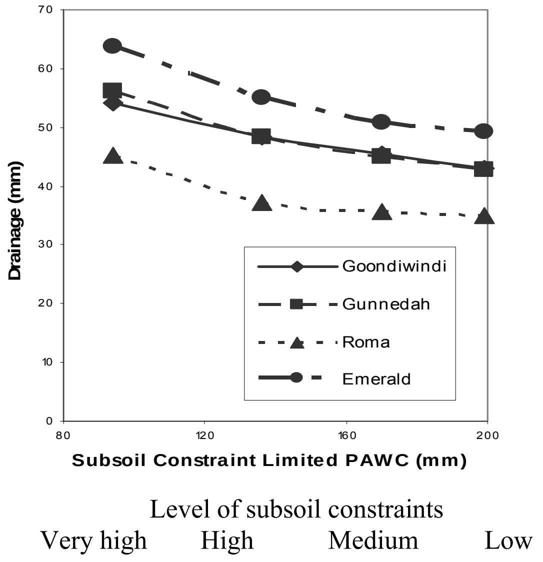


Figure 1.3.6. Pre Drainage response to SSCs and Location (summer rain dominance) Pre-season Soil Moisture = 2/3 Full.

1.3.4 Investigating management options

Because of the nature of the subsoil constraints problem the main approach in the project has been to investigate ways of adapting to the situation, rather than trying to change or ease the subsoil constraints. New crops and varieties have been tested for suitability to local conditions. The results of these trials are still being finalised; in the meantime we present results of a bio-economic analysis of potential savings to growers from reduced fertiliser inputs in response to reduced yield potential due to subsoil constraints.

At the commencement of the project a survey was undertaken to benchmark then-current knowledge, attitudes, skills and aspirations and practices (Buck *et al.* 2006). A significant number of growers (39%) manage soil with subsoil constraints differently, and of those 13% indicated that they used a different fertiliser program. More generally 84% of growers surveyed indicated that they would change their fertiliser program if this was economically viable. Given that the project has identified that subsoil constraints limit the yield potential of wheat crops then growers could adapt their management, either at a paddock or sub-paddock level by reducing fertiliser inputs to soils according to their levels of subsoil constraints if this could be shown to be economically viable.

We defined levels of subsoil constraints according to the mapping criteria used for dryland cropping in Queensland which is based on the concentration of Cl in the top 1 m soil depth: Cl > 1000 mg/kg = Very high SSC; Cl 600-1000 mg/kg = High SSC; Cl 400-600 mg/kg = Mid SSC; Cl < 400 mg/kg = Low SSC. The APSIM model (modified to allow for effects of Cl; Hochman *et al.* 2007) was used to predict wheat response to N in the presence of subsoil constraints for sites at the southern (Goondiwindi) and northern (Emerald) portions of the Queensland grains region. Each site had a grey Vertosol soil which was tested with different levels of subsoil constraints for wheat yield and protein response to total nitrate N. The simulations were run over 45 years, from 1957 to 2002. A continuous wheat cropping system was assumed, with clean fallows and zero tillage. A crop was sown on the first opportunity after 1 May (15 mm rain in a 3-day period). Rates of N were determined at sowing to provide for 30, 60, 90, 120 and 150 kg N/ha in the top 50 cm of the soil profile.

The predicted yield responses to total nitrate N at Goondiwindi and Emerald are shown in Figure 1.3.7. It is at very high levels of SSC that the crop response to N is severely affected. Protein responses (not shown) were also estimated. Using current prices and investment criterion the optimal total N input levels were determined as shown in Table 1.3.1. The actual level of N applied to reach the target is less due to the contribution from mineralisation of soil N and because the entire amount of available N is not necessarily used in any given season. A 'net revenue' figure for the best N strategy on each soil type is shown. At each location the optimal level of N is lowest for the very high subsoil constraints condition. In Table 1 the losses avoided (on a very high SSC soil when fertilising for a mid- subsoil constraints) are $13/ha and $27/ha for Goondiwindi and Emerald respectively. These results are calculated by adjusting for N around the very high subsoil constraints yield responses, rather than comparing between the yield responses.

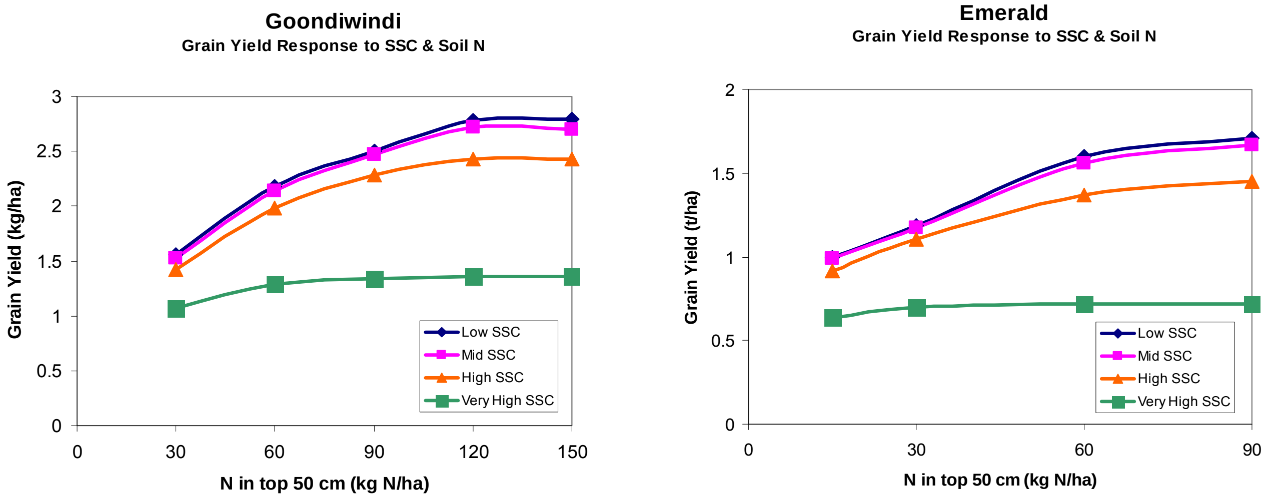


Figure 1.3.7. APSIM predicted yield responses to nitrate N and SSC.

In terms of production responses to N fertiliser the main result is that income can be improved by avoiding over-fertilization of paddocks or zones within paddocks where subsoil constraints are very high (Cl > 1000 mg/kg). The main area of priority for further research and extension to help farmers adapt their on-farm management to subsoil constraints appears to be soils where Cl at 1 m soil depth is greater than 1000 mg/kg.

Table 1.3.1. Optimum N input levels and financial differences between SSC levels.

Location and SSC level	Optimal total N (kg/ha)	N applied (kg/ha)	Gross wheat income - N cost at optimum ($/ha)	Profits by adjusting N rate from Cl levels ($/ha)[a]
Goondiwindi				
Low SSC	120	87	379	
Mid SSC	120	85	371	
High SSC	120	79	328	
Very High SSC	60	37	180	13
Emerald				
Low SSC	90	59	222	
Mid SSC	90	58	216	
High SSC	60	41	181	
Very High SSC	30	17	100	27

[a] For a very high SSC soil compared to being fertilised for a mid-level SSC response

1.3.5 Economic impacts of SSCs

Although a naturally-occurring constraint to production means that crop income is reduced below what it would be without the constraint, there is not necessarily an economic cost to the industry if growers are making their best decisions in the presence of the subsoil constraint. Comparisons with non-constrained regions are not valid if there is nothing that can be done about the subsoil constraints. If R&D leads to the adoption of new management practices in response to the constraint and this leads to increased crop profits, then this can be counted as an economic improvement due to the R&D.

In section 1.3.4 we examined management options in response to the subsoil constraints. If subsoil constraints limit the yield potential of crops then it should follow that wheat growers can respond by adjusting N inputs on constrained soils. If growers have not adjusted their fertiliser strategies, then there is potentially an immediate gain from improved information about better fertiliser management. The information in Table 1 shows the economic optimum level of N input, on average, for each level of SSC at

Goondiwindi and Emerald using a 75% return on investment criterion (CIMMYT 1988). For the very high subsoil constraints cases, growers fertilising for mid-level SSC could adjust their N levels and improve profit by $13/ha in Goondiwindi and $27/ha in Emerald.

Although we don't know the actual levels of fertiliser applications for these soils and regions (Buck *et al*. 2006), by using the $13/ha and $27/ha figures plus the areas of very high SSC soils types above, the annual losses saved could be in the order of $6.6 million and $2 million per annum for Goondiwindi and Emerald respectively. These are substantial amounts of funds which could provide the justification for further data collection and economic analysis.

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2.
Management options

2.1 Winter crops

Graeme Schwenke

Key messages:

- Grain yield of most crop species declined with increasing subsoil Cl.
- Crops showed some differences in sensitivity to increasing subsoil Cl.
- Barley and triticale yielded better than bread wheat at sites high in subsoil Cl.
- Durum wheat yields were more affected by low in-crop rainfall and high levels of subsoil Cl than bread wheat.
- Chickpea and field pea showed a clear decrease in yield with increasing Cl, which was only slightly improved by good in-crop rainfall. Field pea was less sensitive to subsoil Cl than chickpea.
- When sown on time, faba bean out-yielded chickpea, particularly at high subsoil Cl sites.
- Oilseed crops were less affected than wheat by increasing levels of subsoil Cl.
- Among oilseed crops, safflower yielded better than canola or mustard.

In this project we focused on soils where the topsoil properties were non-limiting to crop establishment and growth but the subsoil properties potentially were. Topsoil nutrient deficiencies were deliberately addressed with the use of fertiliser applied at or before sowing. In many cases the subsoil limited root exploration and therefore plant access to stored soil water. Since the in-crop rainfall was generally average to below-average at most trial sites, all the crops grown in our trials relied heavily on access to subsoil water.

Forty-eight separate field experiments were conducted over 4 years from 2003-2006 (Appendix 1), and covered a 1000 km north-south transect across the northern grains region. Twenty-two of these sites were paired-site trials where the same treatments and design were repeated in close proximity (<2 km apart) on soils with contrasting subsoil properties - one of the paired sites had a more serious constraint than the other. The other 26 sites were single-site trials located on soils ranging from unconstrained to severely constraint. There were between 1 and 11 commercial or pre-commercial varieties of each species at each trial. In-crop rainfall ranged from 25-345 mm (mean = 137 mm). Most trials were on cracking clay soils (Vertosols). Four of the 48 trials are not reported here due to drought or disease.

Winter crops growing on moderate subsoil constraints in NSW

The distribution of subsoil chloride (Cl) and sodicity (ESP) levels across the trial sites was skewed. Only a few trial sites were located on subsoils with very high Cl. Most sites had subsoils with low to moderate Cl levels (Figure 2.1.1a). Subsoil sodicity at most trial sites was moderate, with few sites having either very high or low ESP levels (Figure 2.1.1b). Subsoil ESP was not found to be a constraint to grain yield, except at extremely high levels, so is not used in this summary of subsoil constraint impacts on grain yields.

All 44 sites were allocated into categories based on their in-crop rainfall and subsoil (90-110 cm depth) Cl concentration (Table 2.1.1). Low and mid Cl categories were based on the threshold levels of 400 mg Cl/kg for 10% yield reduction in Jimbour chickpea and 800 mg Cl/kg for Baxter wheat (Dang *et al.* 2007). These classes represent the impacts of both salinity and chloride toxicity. In-crop rainfall was normally distributed across the project trials – only a few sites had either very low or very high in-crop rainfall. Table 2.1.1 gives the average rainfall figure for sites within each category of Cl and in-crop rain.

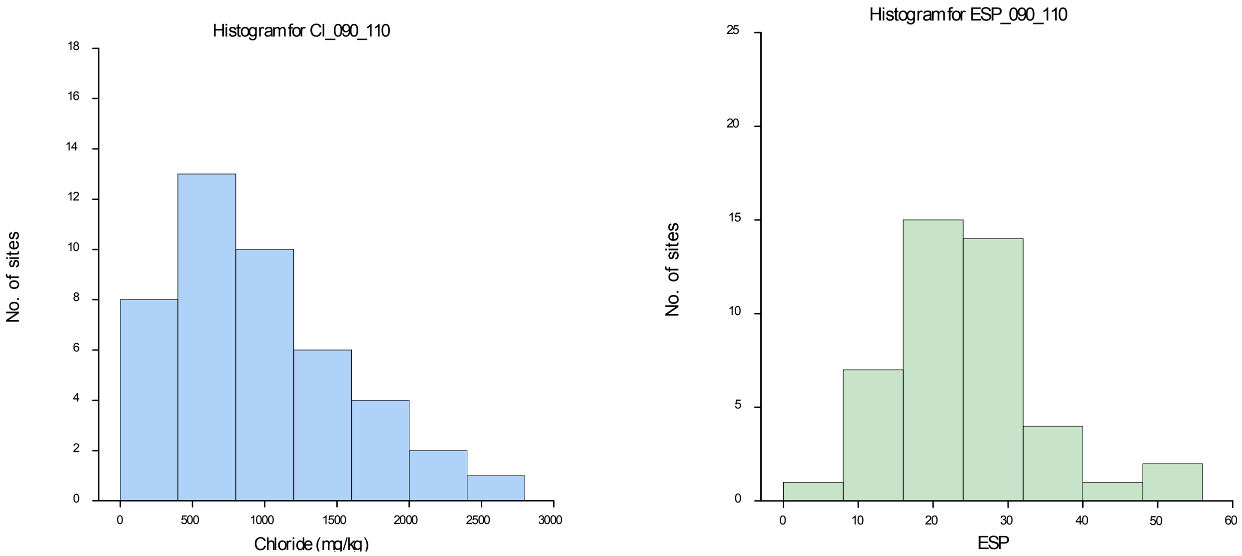


Figure 2.1.1. Frequency distribution of trial sites with regard to subsoil (90-110 cm depth) levels of (a) chloride concentration, and (b) ESP (exchangeable sodium percentage).

Table 2.1.1. Allocation of trial sites into categories determined by in-crop rainfall and the Cl concentration at a depth of 90-110 cm. Codes refer to regional location. Below the code is the average in-crop rainfall (± standard error) for all sites in each category.

	Poor in-crop rainfall (<100 mm)	**Moderate in-crop rainfall** (100-150 mm)	**Good in-crop rainfall** (>150 mm)
Low Cl (<400 mg/kg)	**1 CQ** *(25 mm)*	**2 SWQ, 1 NWs** *(130 ± 7 mm)*	**1 CQ, 1 NWs, 1 NWp** *(203 ± 20 mm)*
Mid Cl (400-800 mg/kg)	**3 CQ, 1 SWQ** *(88 ± 3 mm)*	**1 CQ, 2 SWQ, 2 NWp** *(127 ± 6 mm)*	**3 NWs, 1 CWNSW,** *(217 ± 37 mm)*
High Cl (800-1600 mg/kg)	**2 SWQ, 2 CWNSW** *(71 ± 5 mm)*	**3 SWQ, 2 NWs, 4 NWp** *(131 ± 4 mm)*	**2 SWQ, 1 NWp** *(168 ± 6 mm)*
Very High Cl (>1600 mg/kg)	**2 SWQ** *(60 ± 18 mm)*	**1 NWs** *(127 mm)*	**2 SWQ, 2 NWs** *(186 ± 4 mm)*

NWs = northwest slopes NSW, NWp = northwest plains NSW, SWQ = southwest Qld, CQ = central Qld, CWNSW = central west NSW

The following section presents the grain yield for each species, with results from all trials in each Cl-in-crop rainfall category averaged. All varieties of a species were grouped together. Not every species was grown at each site, so the number of sites making up each mean value is given. The yield of each species at each trial site was also compared to the yield of Baxter wheat (100%), which was grown at all sites. Using relative yields helps to account for site differences in soil and climate. It also addresses the question "as subsoil constraint levels increase, are all crop species affected to the same degree as bread wheat?"

The following series of graphs show grain yields for all sites grouped by subsoil (90-110 cm) Cl level and in-crop rainfall. There are two graphs for each crop species; the graph on the left of each pair shows average grain yields (± standard error) for each category. The number of sites used in calculating the mean for each category is printed on the bars. The right-hand graph shows the average (± standard error) grain yield at each site as a proportion of the grain yield of Baxter wheat (100%) at that site.

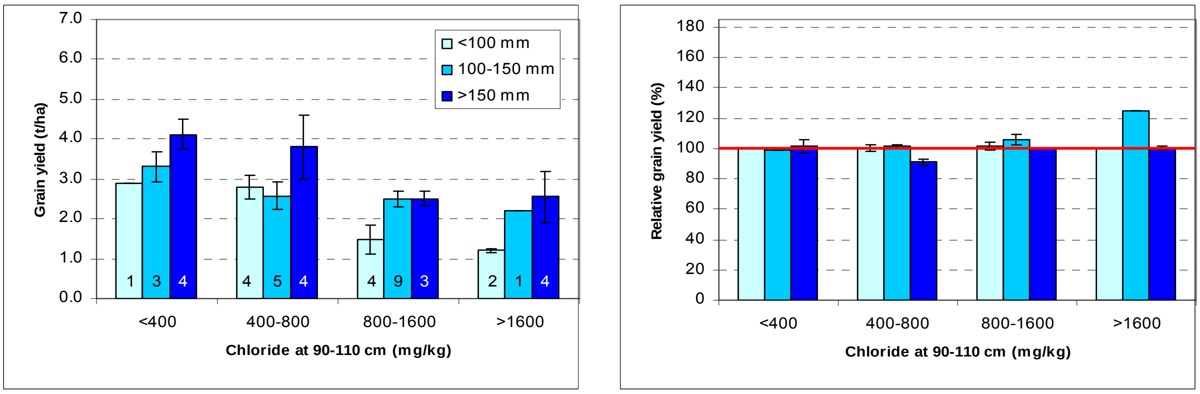


Figure 2.1.2. Bread wheat

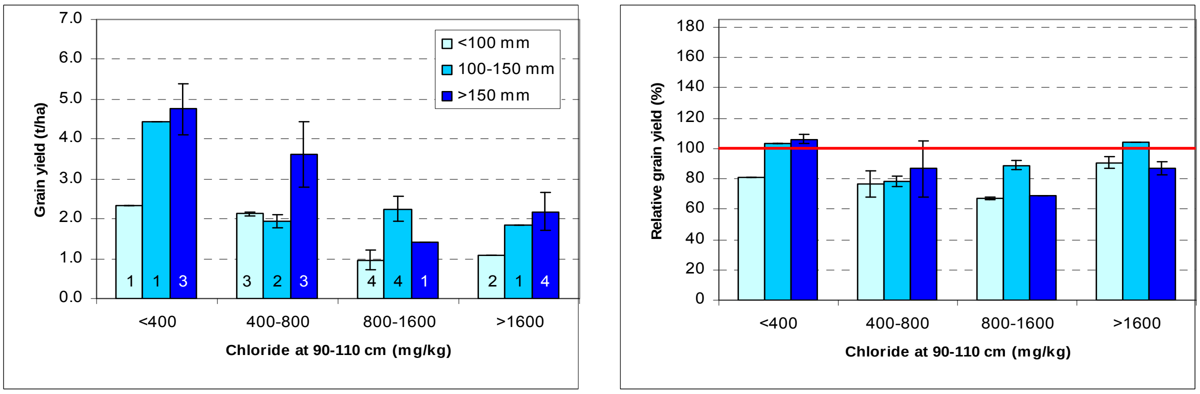


Figure 2.1.3. Durum wheat

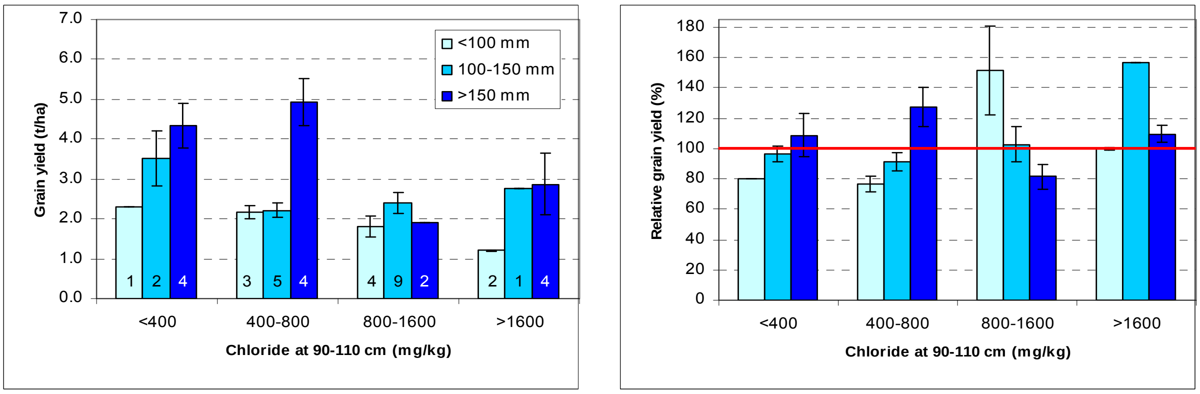


Figure 2.1.4. Barley

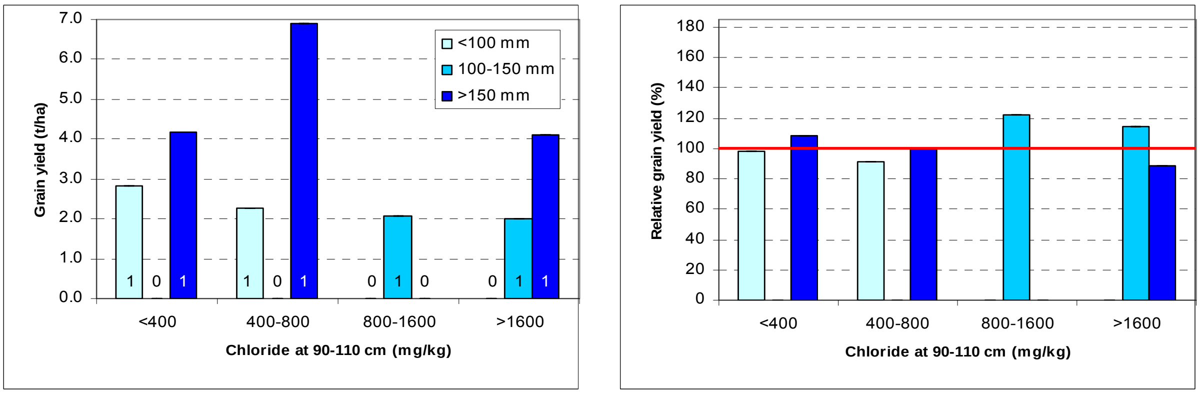


Figure 2.1.5. Triticale

Bread wheat

- Compared to unconstrained sites with good rainfall, those sites with very high subsoil Cl levels had 38% less yield with good rainfall and up to 73% less with poor rainfall.
- Sites with more than 800 mg/kg Cl did not yield more as rainfall increased from moderate to good (Table 2.1.1).
- Sites with mid Cl levels and good rainfall favoured Baxter more than other bread wheat varieties as the relative yield of all bread wheats was around 90% of Baxter.
- At very high Cl levels with moderate rainfall, Baxter yielded less than all other varieties; however this needs to be viewed with caution as this was only at one site.

Durum wheat

- Compared to unconstrained sites with good rainfall, those sites with very high subsoil Cl levels had 55% less yield with good rainfall and up to 77% less with poor rainfall.
- At unconstrained sites durum yields were comparable with bread wheat, provided rainfall was moderate to good
- At most constrained sites durum yielded up to 30% less than Baxter wheat, suggesting a greater sensitivity to subsoil Cl than bread wheat
- Durum grain yields were more affected by poor in-crop rainfall and high levels of subsoil Cl than bread wheat

Barley

- Compared to unconstrained sites with good rainfall, those sites with very high subsoil Cl levels had 33% less yield with good rainfall and up to 72% less with poor rainfall.
- Low to mid levels of Cl sites were particularly affected by poor to moderate rainfall.
- At low to moderate subsoil Cl levels, barley outperformed wheat in good rainfall seasons but underperformed wheat in poor to moderate rainfall.
- At high subsoil Cl levels, barley tended to outperform wheat.

Triticale

- There were not enough sites with triticale for a consistent overall message (7 sites).
- Paired sites at Spring Ridge in 2006 showed a 40% yield decline from a mid level of Cl site to a very high level of Cl site (both with good rainfall).
- There was no yield difference between high Cl and very high Cl paired sites at Garah in 2006 although the relative yield compared to Baxter wheat did decrease from 122% to 114% (both had moderate rainfall).
- In good seasons, triticale yields should equal or exceed those of wheat, but in dry springs, yield is lower than wheat as triticale has a longer grain filling period
- In CQ, triticale yields were similar to bread wheat; however, these sites were either in the low or mid subsoil Cl categories.

Oats

- Only 1 trial site (Wongarbon 2005; which was classed as mid Cl level-good rainfall)
- Yield was 1.2 t/ha which was 36% of Baxter wheat at that site in that year.

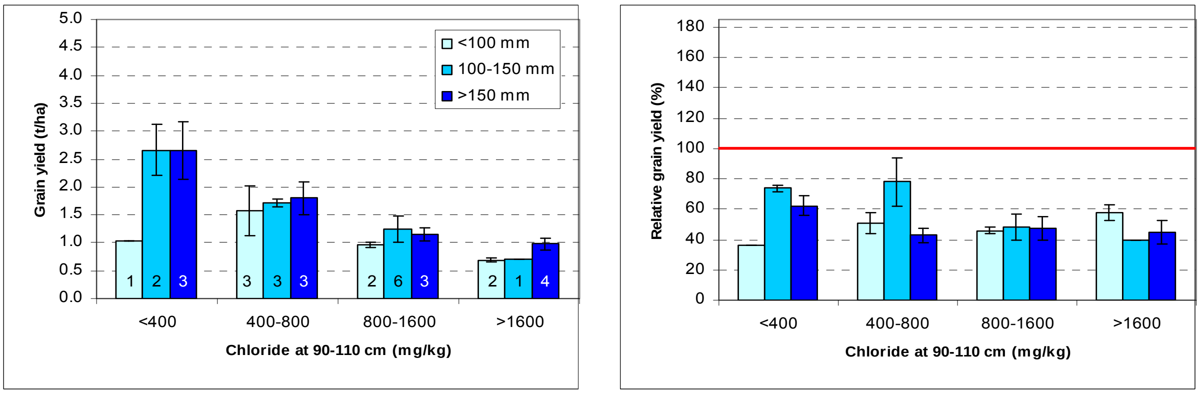


Figure 2.1.6. Chickpea

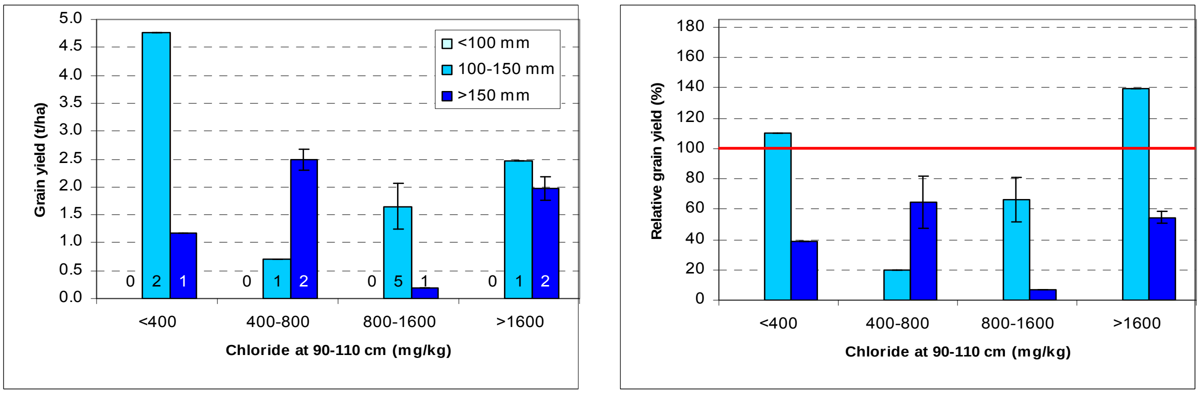


Figure 2.1.7. Faba bean

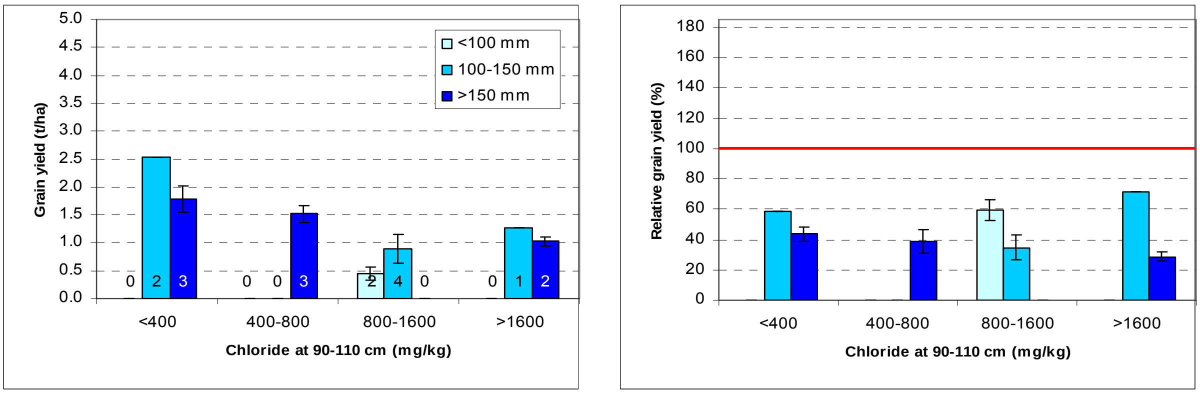


Figure 2.1.8. Field pea

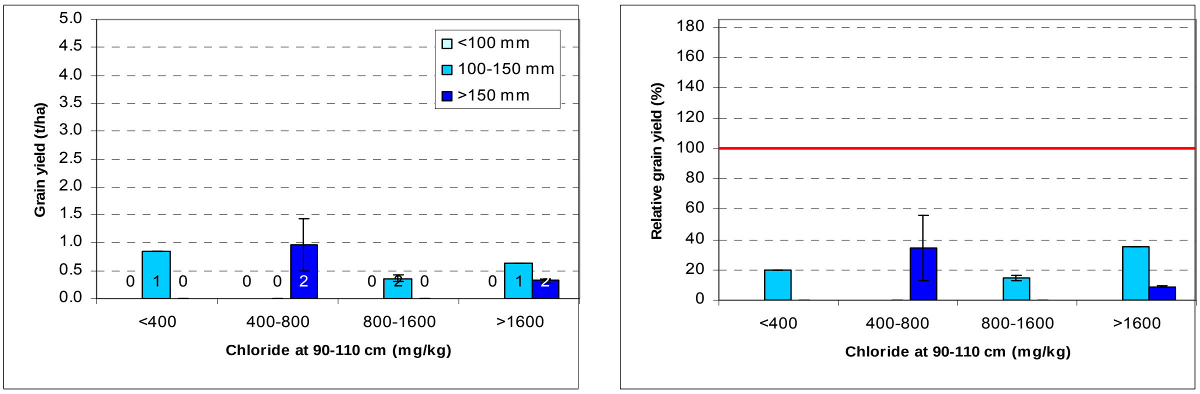


Figure 2.1.9. Lentil

Chickpea

- Compared to unconstrained sites with good rainfall, those sites with very high levels of subsoil Cl had 62% less yield with good rainfall and up to 75% less with poor rainfall.
- Except for a single site with no effective in-crop rainfall, chickpea showed a clear decrease in both actual yield and relative yield with increasing levels of Cl regardless of in-crop rainfall.
- Unconstrained site yields were 60-70% of Baxter wheat but dropped to 45-55% at highly constrained sites. These results indicate that chickpea was more affected by subsoil Cl than wheat.

Faba bean

- Compared to unconstrained sites with moderate rainfall, those sites with very high level of subsoil Cl had 58% less yield with good rainfall and up to 48% less with moderate rainfall.
- Yields at unconstrained sites varied enormously, but the single site with good rainfall was sown late with all the other species at that trial
- When sown on time, faba beans are better yielding than chickpeas at high levels of Cl from comparisons at paired sites
- Lower yielding sites were often associated with uneven establishment, especially where we attempted to moisture-seek but did not get all seeds onto moisture.
- Relative yields were variable with most lower but a few greater than Baxter

Field pea

- Compared to unconstrained sites with moderate rainfall, those sites with very high levels of subsoil Cl had 61% less yield with good rainfall and 51% less with moderate rainfall.
- Yield declined with increasing levels of Cl but there was no consistent impact on relative yield; thus, field pea was affected by chloride similar to wheat.
- Field pea was less sensitive to subsoil Cl than chickpea

Lentil

- Not enough trial data for drawing general conclusions (8 sites had lentils)
- Large declines in average yields (49-84%) from good to bad paired sites in 2005 were not repeated in 2006 paired sites for reasons of high in-crop rainfall at Spring Ridge and different starting soil water at Garah.

Lupins

- Only 1 trial site (Wongarbon 2005; which was classed as mid Cl levels-good rainfall)
- Broadleaf lupin yield was 1.1 t/ha which was 35% of the yield of Baxter wheat at that site in that year.
- Narrowleaf lupin yield was 2.0 t/ha which was 63% of the yield of Baxter wheat.
- In regular variety trials on unconstrained soils, broadleaf lupins usually yield 10-15% better than narrowleaf lupins.

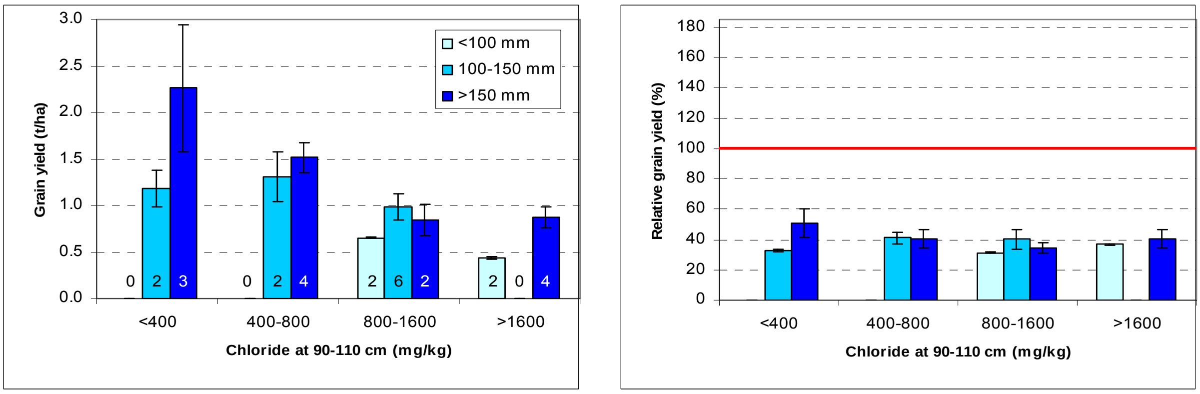


Figure 2.1.10. Canola

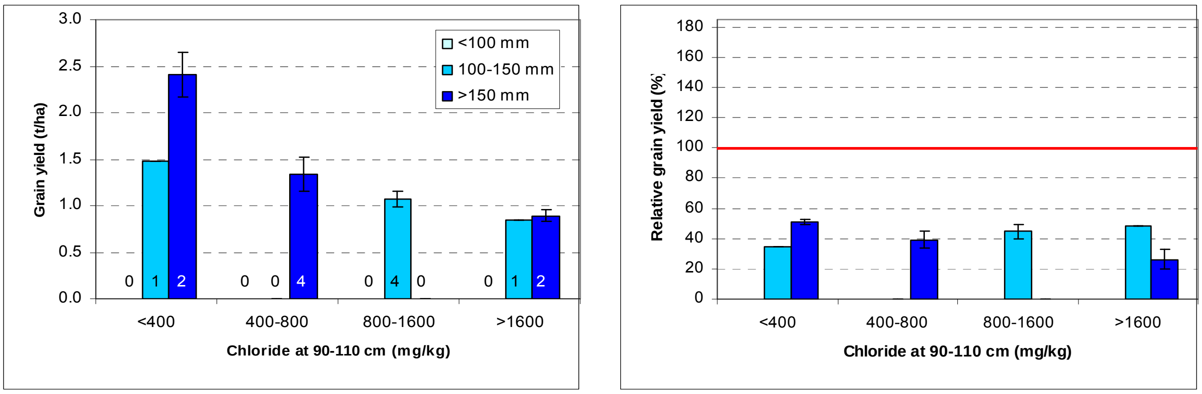


Figure 2.1.11. Mustard

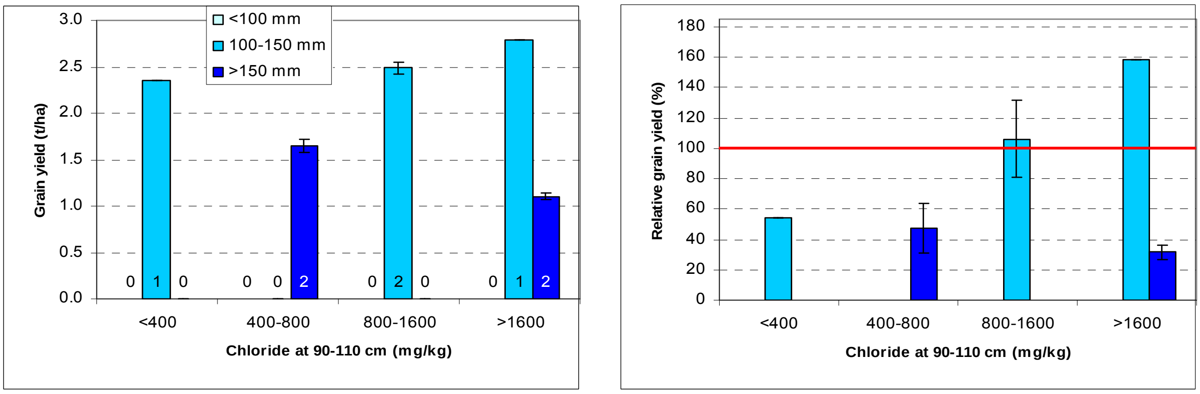


Figure 2.1.12. Safflower

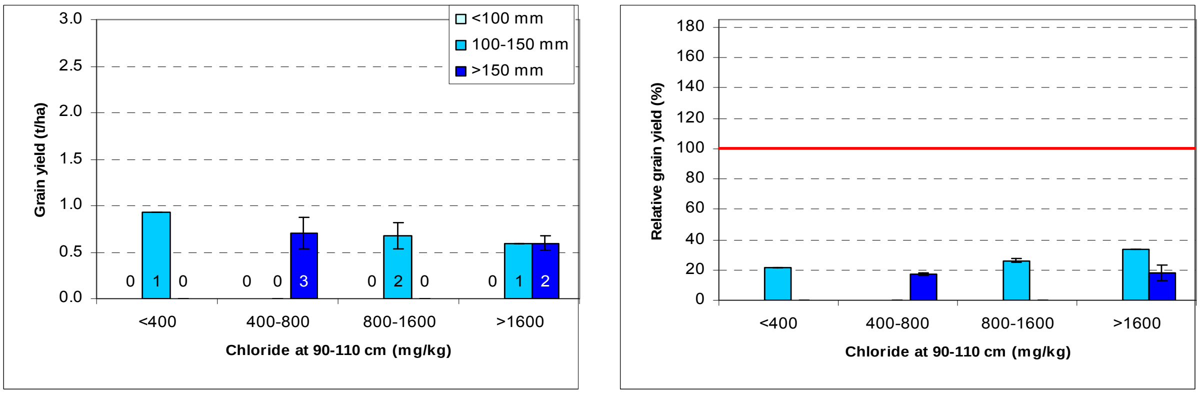


Figure 2.1.13. Linseed

Canola

- Compared to unconstrained sites with good rainfall, those sites with very high subsoil Cl levels had 64% less yield with good rainfall and 80% less with moderate rainfall.
- Subsoil Cl appeared to impact yield more at good than moderate rainfall
- Relative yield in the unconstrained sites averaged 51% of Baxter wheat, but was around 40% in more constrained sites, except for 1 site with very high Cl levels and moderate rainfall where relative yield was 69%.
- Canola results may be affected by pre-harvest shattering losses at some sites

Mustard

- Mustard results were similar to those for canola
- Subsoil Cl appeared to impact yield more at good than moderate rainfall
- Compared to unconstrained sites with good rainfall, those sites with very high subsoil Cl had 63% less yield with good rainfall and 60% less with moderate rainfall.
- Relative yield in the unconstrained sites averaged 51% of Baxter wheat, but was around 40% in more constrained sites, except for 1 site with very high Cl level and moderate rainfall where relative yield was 55%.

Safflower

- Not enough site data for drawing general conclusions (8 sites)
- Safflower was sown later and harvested later than all other crops.
- Harvesting more than a month after all others meant that safflower crops benefited from early summer rainfalls received after other crops had matured or been harvested
- Of the 4 paired site comparisons the “good” site out-yielded the “bad” site by 25% and 40% at two locations with good rainfall, but was no different at two other paired site locations with moderate rainfall.

Linseed

- Not enough site data for drawing general conclusions (9 sites)
- Generally a lower yielding crop than all other crops in the field trials
- Lowest yields were on highest levels of Cl in subsoils, but relative yields were not affected by Cl.
- Of the 4 paired site comparisons the “good” site out-yielded the “bad” site by 6% and 57% at two locations, was no different at another paired site, and was 33% less than the “bad” site at the other paired site location.

General comments

- In-crop rainfall, subsoil Cl levels, and subsoil ESP together explained only 34% of the variation in wheat yield across all 44 sites. Differences in profile moisture at sowing between sites would account for more of the yield variation.
- This summary is purely based on yields. Quality parameters such as protein, oil content, screenings etc also need to be considered in selecting crops for subsoil constrained sites.
- This simple analysis also does not include consideration of the added benefits some rotation crops can have on following cereal crops, such as;
    - The disease break effects of oilseeds or legumes grown in rotation with wheat
    - Added nitrogen benefits from legume rotations
    - Less water demand from shallow rooted legumes such as lentils, allowing shorter fallow periods to refill the soil profile with moisture for the next crop.

Appendices

Appendix 1. Multi-species trials connected with SIP08 northern-grains region project. Only replicated and randomised trials are reported

Region / Research Group	Year	Site / town	Trial setup	Likely subsoil constraints	Species tested (No. of cultivars)	Comments (In-crop rainfall in parenthesis)
Northwest plains, NSW University of Western Sydney	2003	Coonamble	Paired trials (grey vs sodic), small-plot,	Grey = Low Cl, mid ESP. Sodic = mid Cl, mid ESP	Barley (1), canola (1), chickpea (1), faba bean (1), bread wheat (5)	Multi species only on the sodic site, wheat only on grey site. Faba beans and canola sown late. V. high pod shattering losses in canola. A second very late wheat experiment benefited from good rain in October. (154 mm)
	2003	Walgett	Paired trials (grey vs sodic), small-plot,	Grey = low Cl, mid ESP. Sodic = mid Cl, mid ESP	Barley (1), canola (1), chickpea (1), faba bean (1), bread wheat (5)	Grey and sodic sites in same paddock. Faba beans and canola sown late. A second very late chickpea experiment benefited from good rain in October. (148 mm)
	2004	Coonamble	Paired trials (grey vs sodic), small-plot,	Grey = Mid Cl, mid ESP. Sodic = high Cl, mid ESP	Barley (1), canola (1), chickpea (1), faba bean (1), field pea (1), mustard (1), bread wheat (8), durum(1)	Grey and sodic sites in same paddock. Faba beans and canola sown late. Chickpeas on unconstrained site damaged by hares. Very high pod shattering in canola. (135 mm)
	2004	Rowena	Single site, small-plot,	Low Cl, mid ESP	Barley (1), canola (1), chickpea (1), faba bean (1), field pea (1), bread wheat (8), durum(1)	Paired with Cry on site (176 mm)
	2004	Cryon	Single site, small-plot,	Mid Cl, mid ESP	Canola (1), chickpea (1), faba bean (1), field pea (1)	No cereals in this trial, otherwise paired with Rowena site (176 mm)
	2004	Walgett	Paired trials (grey vs sodic), small-plot	Grey = Low Cl, mid ESP. Sodic = mid Cl, mid ESP	Barley (1), wheat (11)	(132 mm)
Northwest slopes, NSW	2004	Spring Ridge	Single site, small plot	low Cl, mid ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (2), fieldpea (2)	Durum best yield. Good stored soil profile water and in-crop rainfall meant SSC not very influential (246 mm)
	2004	Bellata	Paired trials (good vs bad), small-plot	Good = low Cl, low ESP, Bad = low Cl, high ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (2), fieldpea (2)	Frost damage on 1 durum var. Good in-crop rainfall gave high yields (172 mm)
	2005	Bellata	Paired trials (good vs bad), small-plot	Good = low Cl, mid ESP, Bad = mid Cl, v. high ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (3), field pea (2), faba bean (2), lentil (2), linseed (1), safflower (2)	Poor establishment of early species (dry) meant resowing later, followed by heavy rainfall and good in-crop rainfall for main sowing. (206-356 mm)
	2005	Garah	Paired trials (good vs bad), small-plot	Good = low Cl, mid ESP, Bad = high Cl, mid ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (3), faba bean (2), field pea (2), lentil (2), linseed (1), safflower (2)	Emus grazed some wheat, canola, chickpea vars. Very dry finish to season. Lentils showed biggest yield decrease. Bad site matured earlier, crown rot (200-270mm)

Region / Research Group	Year	Site / town	Trial setup	Likely subsoil constraints	Species tested (No. of cultivars)	Comments (In-crop rainfall in parenthesis)
	2006	Garah	Paired trials (good vs bad), small-plot	Good = mid Cl, mid ESP, Bad = high Cl, mid ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (3), field pea (2), lentil (2), linseed (1), safflower (2), triticale (2)	Poor fallow rain did not refill profile at good site, so bad site out-yielded good in many spp. Very dry at sowing (deep), emus grazed some canola, chickpea (127 mm)
	2006	Spring Ridge	Paired trials (good vs bad), small-plot	Good = low Cl, high ESP, Bad = high Cl, high ESP	Bread wheat (5), barley (5), durum wheat (2), canola (2), mustard (2), chickpea (3), field pea (2), lentil (2), linseed (1), safflower (2), triticale (2)	Wind storm 3 days pre-harvest shattered some wheat, barley and canola vars. Losses estimated. Safflower sucked soil driest but lived longest (215-260 mm)
Central west plains, NSW DPI – Trangie	2005	Narromine	Single site, small plot	High Cl, mid ESP (likely)	Bread wheat (6), barley (2), mustard (2), chickpea (2), field pea (2), broad-leaf lupin (1), narrow-leaf lupin (1), safflower (1), linseed (1), oats (1)	Difficult season; drought prevented timely and effective sowing, subsequent flooding rains made weed control very difficult. Only wheat harvested. (? mm)
	2005	Wongarbon	Single site, small plot	Low Cl, mid ESP (likely)	Bread wheat (6), barley (2), mustard (2), chickpea (2), field pea (2), broadleaf lupin (1), narrow-leaf lupin (1), safflower (1), linseed (1), oats (1)	Difficult season; drought prevented timely and effective sowing, subsequent flooding rains made weed control very difficult. (345 mm)
	2006	Narromine	Paired trials (good vs bad), small-plot	Good = Mid Cl, Mid ESP, Bad = High Cl, Mid ESP	Bread wheat (8), barley (5), durum wheat (1), canola (2), mustard (2), faba bean (2), chickpea (3), field pea (3), albus lupin (2)	Sown dry, canola/mustard did not establish, chickpea/faba bean herbicide damaged, very dry season (80 mm)
Central Qld, QDPI	2003	Baralaba	Single trial, large plots, sorghum after	low Cl, low ESP, high EC (gypsum)	Bread wheat (1), barley (1), chickpea (1)	Chickpea hit by frost then regrew using more subsoil water, leaving less for the following sorghum crop (110 mm)
	2003	Bauhinia	Single trial, small plots	low Cl, low ESP	Bread wheat (3), barley (3), durum wheat (2), triticale (2),	A dry season, especially at the finish. triticale = wheat > barley > durum (93 mm)
	2004	Biloela	Single trial, small plots	v. low Cl, low ESP	Bread wheat (1), barley (1), triticale (1), durum wheat (1), chickpea (2)	No effective in-crop rainfall. Triticale = wheat > durum > chickpea. (25 mm)
	2005	Theodore	Single trial, small plots	low Cl, low ESP high EC (gypsum)	Bread wheat (2), barley (1), triticale (1), durum wheat (1)	Good sowing and in-crop rainfall. Most of this fell in the first 6 weeks (up to flowering) and so the grain filling time was hot and dry. Soil gypsum proved to be no constraint (129 mm)
	2006	Baralaba	Paired trials, good vs bad, small plots	low Cl, low ESP (bad = mid Cl, mid ESP)	Bread wheat (4), chickpea (2), durum wheat (2), barley (2)	Bad site abandoned poor establishment then hare and bird damage. Chickpea was poor at good site. Most in-crop rain was in small falls (max 24mm, late incrop) so quite a dry season. Crops survived on subsoil moisture, soil moisture at harvest would be LL. (81 mm)

Region / Research Group	**Year**	**Site / town**	**Trial setup**	**Likely subsoil constraints**	**Species tested (No. of cultivars)**	**Comments (In-crop rainfall in parenthesis)**
	2006	Moura	Single trial, small plots	Low Cl, low ESP?	Bread wheat (4), chickpea (2), durum wheat (2), barley (2)	Good sowing and in-crop rainfall till flowering then hot, dry finish, some threshing losses of barley (87 mm)
Southwest Qld, QDPI / QNRM	2003	Wallumbilla	Single trial, large plots	mid Cl, mid ESP	Bread wheat (1), chickpea (1)	(169 mm)
	2003	Roma	Single trial, large plots	low Cl, low ESP	Bread wheat (1), chickpea (1)	(93 mm)
	2003	Goondiwindi	Single trial, large plots	mid Cl, mid ESP	Bread wheat (1), barley (1), durum wheat (1)	(127 mm)
	2003	Goondiwindi	Single trial, large plots	low Cl, mid ESP	Bread wheat (1), barley (1), durum wheat (1)	(127 mm)
	2004	Goondiwindi	Single trial, large plots	high Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(85 mm)
	2004	Wallumbilla	Single trial, large plots	mid Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(61 mm)
	2004	Wallumbilla	Single trial, large plots	mid Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(61 mm)
	2004	Goondiwindi	Single trial, large plots	mid Cl, high ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(130 mm)
	2004	Goondiwindi	Single trial, large plots	low Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(117 mm)
	2004	Goondiwindi	Single trial, large plots	low Cl, high ESP	Bread wheat (1), barley (1), canola (1)	(122 mm)
	2004	Goondiwindi	Single trial, large plots	low Cl, high ESP	Bread wheat (1), chickpea (1)	(122 mm)
	2004	Muckadilla	Single trial, large plots	high Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(34 mm)
	2004	Bungunya	Single trial, large plots	high Cl, mid ESP	Bread wheat (1), barley (1)	(100 mm)
	2005	Goondiwindi	Single trial, large plots	high Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	White heads (crown rot) observed in wheat plots (186 mm)
	2005	Wallumbilla	Single trial, large plots	mid Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	(181 mm)
	2005	Muckadilla	Single trial, large plots	high Cl, mid ESP	Bread wheat (1), chickpea (1), barley (1), canola (1), durum wheat (1)	White heads (crown rot) observed in wheat plots (200 mm)

Appendix 2. General conclusions and comments from each research group based on their field trial experiences and results.

Research Group	General comments	Winners and Losers
University of Western Sydney	Differences between species trialed were mostly seen at moderately constrained sites, not highly constrained sites – despite some apparent species differences in early season growth. The length of growing season was an important determinant of lower limit of extraction. In the 2003 experiments, canola was able to extract more water than the other species from low Cl subsoil. In the 2004 experiments, wheat and barley generally dried the subsoil more than the Brassica. Notably, there was no difference in the lower limit of extraction between canola and the cereals in the 'Denham' subsoil.	Bread wheats Sunco and Baxter generally performed well on SSC, chickpea poorly
NSW DPI – Tamworth	Sites at Bellata and Spring Ridge were extremely sodic (ESP >50%) and this is likely to be a factor in the constraints to crop growth. Sodicity constraint likely to be a mixture of physical and chemical impacts on plant growth and water infiltration. Getting a good "paired" site for these species trials was difficult as the nature of reduced plant water use in poor areas means that the poor areas generally have greater stored water at sowing than the good sites where the previous crops have grown well. Paired field trials make an excellent visual tool for farmer field days and workshops.	In general, cereals > or = oilseeds > pulses, but plenty of variation occurred between sites. Faba bean was a clear winner for the pulses. The order of cereals changed between sites (and probably constraints).
NSW DPI – Central West	Some really tough seasons in 2005 and 2006 made field trial work very difficult.	It's hard to give a fair comparison of the species used owing to establishment problems in both years and herbicide damage to some in 2006. However, field peas appear to be a useful alternative to cereals.
QDPI – Central Qld	Most sites where trials were run were not particularly constrained according to the soil characterisation properties. Lack of in-season rainfall has been the biggest constraint faced during these trial years. Fallows that only refill the moisture profile to the depth of the constraint maximise cropping frequency and water use efficiency. Hence when present, short fallows are used as a technique to manage around subsoil constraints.	Triticale = bread wheat > barley > durum > chickpea. Chickpeas were below expectations for the region.
QDPI / QNRMW – Southwest Qld	Subsoil salinity primarily due to Cl salts. Barley did not show greater tolerance to salts than wheat or canola, but all three performed better than chickpea and durum wheat.	

2.2 Winter crops cultivars

Graeme Schwenke

Key results for cultivars choice on subsoil constrained sites:

- Bread wheat: Variation across sites was high so most varieties were no different to Baxter; Sunco and Rees tended to yield less than others on average.
- Durum wheat: no variety difference between Wollaroi and Bellaroi
- Barley: Binalong, Fitzroy, and Grout tended to yield better on high to very high subsoil Cl than Gairdner and Mackay.
- Triticale: in northwest NSW, Kosciuszko yielded equal or better than Everest; in CQ Treat yielded equal or better than Speedee (only 1 year data)
- Chickpea: in northwest NSW, Howzat outyielded Jimbour which was equal or better than Flipper and Genesis836; in CQ, Jimbour outyielded Moti
- Faba bean: Fiord outyielded Cairo at Garah and Bellata; but yielded less than Cairo at Spring Ridge
- Field pea: Yarrum outyielded Boreen at 9 of 11 trial sites in northwest NSW
- Lentil: CIPAL414 outyielded Digger at Bellata and Spring Ridge, but yielded less than Digger at Garah
- Canola: Ripper outyielded Rivette at Spring Ridge, but yielded less than Rivette at Bellata
- Mustard: Micky outyielded Kaye at 3 sites but was no different at another 6 sites
- Safflower: No difference between Gila and 555 in northwest

In many of the multi-species trials described in the previous section, the various research teams grew more than one variety of each species, particularly wheat – which was also the subject of several separate variety trials. The following sections focus solely on grain yield comparisons. When reading these results remember that varietal selection at the local level depends on many factors such as season length, geographic location, desired quality, disease resistance, and price.

2.2.1 Bread wheat varieties

A total of 20 commercial bread wheat varieties were compared in 32 separate field trials from central Qld to central west NSW during 2003-2006. Each individual trial had between 2 and 10 varieties. Table 2.2.1 lists the yields of all varieties grown in these trials plus data from another 6 trials that had 1 variety of bread wheat and 1 of durum wheat. Twenty-six of these trials were paired-site comparisons where there were two or more trials in close proximity to each other but located on contrasting soils ("good" vs. "bad" in terms of subsoil chloride (Cl) concentration). Figure 2.2.1 shows the relative yield of all wheat varieties grown at more than 1 pair of "good" (average 600 mg Cl/kg at 90-110 cm) and "bad" (average 1436 mg Cl/kg) sites. Yields are relative to the yield of Baxter at the "good" site in each paired comparison.

Wheat cultivars growing on a high constraints soil in northern NSW.

The grain yields of Sunvale, Strzelecki and Wollaroi compared favourably against Baxter at our unconstrained sites, while those of Lang, Sunlin, and Sunco were generally lower. At constrained sites, Strzelecki clearly produced higher yields than Baxter, while that of Sunco was lower. All other varieties produced yields similar to Baxter.

The data in Figure 2.2.1 compares paired sites based on what constituted a “good” or a “bad” soil. Figures 2.2.2-2.2.7 show the interaction of subsoil Cl levels and in-crop rainfall on yields of the 6 most commonly trialled bread wheat varieties in our project. The number of trials making up each mean value is indicated on each bar. Error bars represent the standard error of each mean. Some of this data is from non-paired sites, single variety sites (Baxter only), or from sites without Baxter, and so not all of it contributed to the relative yields shown in Figure 2.2.1.

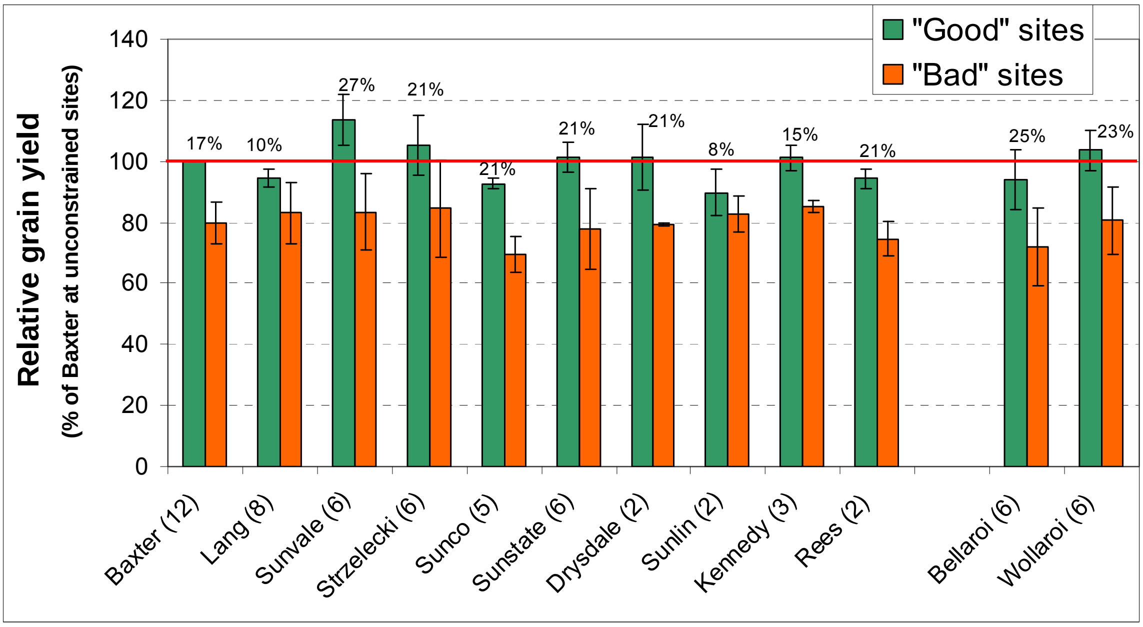


Figure 2.2.1. Mean (± standard error) wheat grain yield relative to Baxter at the “good” site of each paired site comparison. Number in brackets after variety name is the number of paired-site comparisons that included that variety and Baxter. The percentage above each variety’s bar indicates the average decrease in relative yield from each “good” to “bad” sites.

Baxter was clearly constrained by both poor in-crop rainfall and high subsoil Cl levels (>800 mg/kg). But, with good rainfall, there was no further decline in yield from high to very high subsoil Cl levels. Poor to moderate rainfall had a greater impact on yield at very high subsoil Cl levels. Provided rainfall was good, Lang’s yield on soil with at very high subsoil Cl was similar to that at low Cl and was the best of these 6 varieties at the highest constraint level.

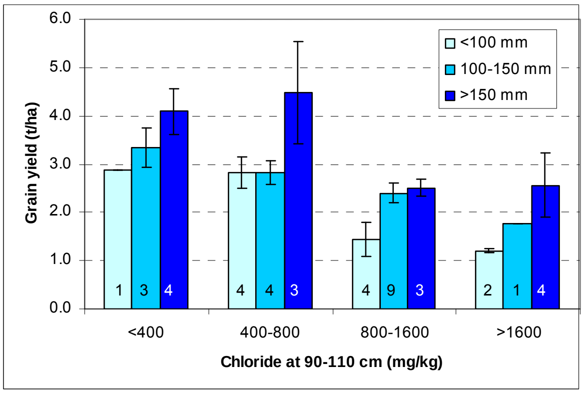


Figure 2.2.2. Baxter (incl. 15 single variety sites)

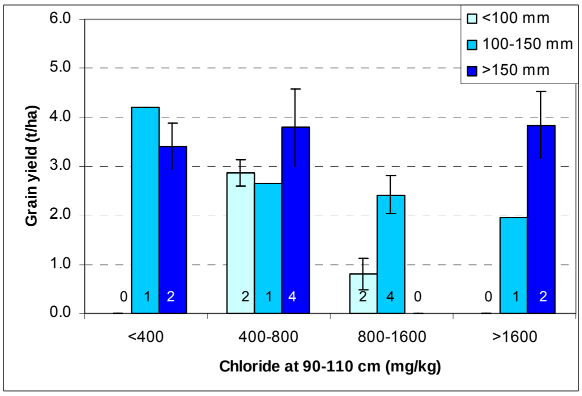


Figure 2.2.3. Lang

Table 2.2.1. Bread and durum wheat cultivars from replicated trial sites (2003-2006). Paired sites are shaded together. Trials where statistical analysis was done have yields followed by letters – yields with same letter were not significantly different; ns = no differences.

Year	*Nearest town*	*In-crop rain (mm)*	*Cl (mg/kg) 90-110 cm*	*Paired site?*	*Baxter*	*Lang*	*Sunvale*	*Strzelecki*	*Sunco*	*Sunstate*	*Drysdale*	*Sunlin*	*Kennedy*	*Rees*	*H45*	*Giles*	*Gregory*	*Ellison*	*Ventura*	*Mulgara*	*Hume*	*Mercury*	*Wegetail*	*Babbler*	*Bellaroi*	*Wallaroi*	*Kamilaroi*	*Yallaroi*
2003	Bauhinia	93	793	no	2.5 a								2.2 a								2.5 a					1.9 b	1.9 b	
2003	Goondiwindi	127	759	Good	2.3 a								2.2 a															1.7 b
2003	Goondiwindi	127	1296	Bad	2.1 a								2.1 a															1.9 b
2003	Walgett	148	750	Good			3.5		3.2		3.1	3.3			2.5													
2003	Walgett	148	1150	Bad			2.7		2.4		2.1	2.3			1.9													
2003	Coonamble	154	430	Good			3.8		3.4		3.1	3.4			2.9													
2003	Coonamble	154	1100	Bad			3.2		2.8		2.3	2.7			2.2													
2004	Biloela	25	21	no	2.9 a																							2.3 b
2004	Goondiwindi	85	1750	no	1.3 a																							1.1 b
2004	Wallumbilla	61	1200	no	2.1 a																							1.4 b
2004	Goondiwindi	130	1340	no	2.7 a																							2.2 b
2004	Goondiwindi	117	759	no	2.6 a																							2.2 b
2004	Muckadilla	35	1613	no	1.2 a																							1.1 b
2004	Rowena	176	81	no	3.0 abc	2.8 bc	3.3 a		2.9 bc		3.0 abc	2.6 cd	3.1 ab	2.7 cd												2.3 d		
2004	Walgett	132	420	Good	2.8 ab	2.7 abc	2.4 cd		2.7 abc		2.5 bc	2.3 d	3.0 a	2.6 bc												2.7 abc		
2004	Walgett	132	940	Bad (ns)	2.5	2.4	2.0		2.1		2.2	2.2	2.4	2.2						2.1				2.1		2.0		
2004	Coonamble	135	880	Good	2.7 bc	2.6 bc	2.6 bc		2.4 c		3.1 a	2.7 bc	2.8 ab	2.7 bc												2.8 ab		
2004	Coonamble	135	1500	Bad	2.0 bc	2.0 bc	1.9 bc		2.2 abc		2.1 abc	2.4 ab	2.2 abc	1.9 c						2.2 abc						1.8 c		
2004	Bellata	160	112	Good	3.8 b	4.1 ab	5.3 a	4.9 ab		4.0 ab															4.1 ab			
2004	Bellata	160	497	Bad	4.0 ab	3.6 bc	4.5 a	4.3 ab		3.3 cd															2.7 d	1.5 e		
2004	Spring Ridge	262	136	no	5.6 abc		4.3 d	5.9 abc												5.1 bcd		4.6 cd			6.4 a	6.2 ab		
2005	Theodore	215	128	no (ns)	3.9																					3.9		3.8
2005	Goondiwindi	97	328	Good (ns)	2.5				2.3																			
2005	Goondiwindi	186	1750	Bad	1.4 a				1.3 a																			1.1 b
2005	Wallumbilla	181	1137	Bad	2.1 a				2.0 a																			1.4 b
2005	Muckadilla	200	1613	Bad	1.5 a				1.4 a																			1.3 b
2005	Garah	180	679	Good (ns)	2.5	2.0	3.3	3.4		2.3															3.2	3.3		
2005	Garah	180	2010	Bad (ns)	2.8	2.9	3.0	2.9		2.8															2.5	2.9		
2005	Bellata	146	315	Good	4.3 a	4.2 a	4.7 a	3.3 b		4.7 a															4.5 a	4.4 a		
2005	Bellata	141	877	Bad (ns)	3.6	3.6	3.6	3.6		3.3															3.6	3.0		
2005	Wongarbon	345	684	no		3.2 a	2.4 ab	3.1 ab															2.1 b					
2006	Moura	87	650	no	3.9 ab	3.2 b							4.4 a															2.3 c
2006	Baralaba	80	552	no (ns)	2.3	2.5								2.6														2.1
2006	Garah	127	1062	Good	1.7 ab	1.5 b		1.8 a		1.5 b															1.4 b	1.8 a		
2006	Garah	127	2117	Bad (ns)	1.8	2.0		2.0		1.8															1.8	1.9		
2006	Spring Ridge	182	482	Good	6.9 a	6.4 b		6.3 b		6.1 bc						6.2 bc									5.1 d	5.9 c		
2006	Spring Ridge	178	2797	Bad	4.6 a	4.8 a		3.7 b		4.5 a						4.2 a									3.5 b	3.5 b		
2006	Narromine	80	990	Good (ns)	1.2	1.3	1.5	1.1		1.4							1.7	1.3	1.5						0.8			
2006	Narromine	81	1317	Bad (ns)	0.4	0.4	0.5	0.3		0.3							0.2	0.3	0.8						0.3			

Sunvale yields decreased with increasing subsoil Cl levels but data was limited from high and very high levels of Cl sites. As with all the other 5 varieties featured in more detail here, sites with poor rainfall yielded poorly where subsoil Cl level was high, but reasonably well where subsoil Cl level was below 800 mg/kg. Strzelecki yields also declined with increasing subsoil Cl levels, but were the highest of this group of 6 varieties in the low and mid Cl levels categories.

Of these 6 graphed varieties, Sunco yield performance was worst in the low and very high subsoil Cl level groups but similar in the other categories. Sunstate, on the other hand, showed no effect of increasing subsoil Cl levels on grain yields provided in-crop rainfall was good; decreasing yields were seen where sites had moderate to low rainfall.

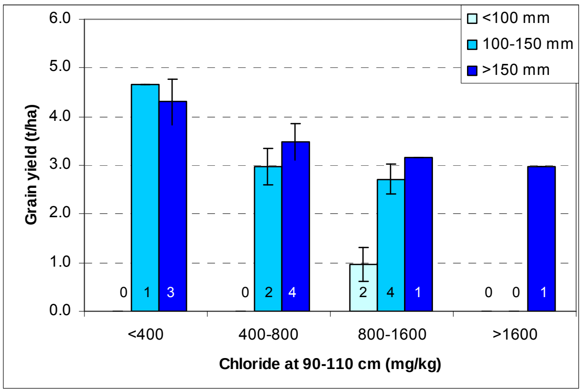


Figure 2.2.4. Sunvale

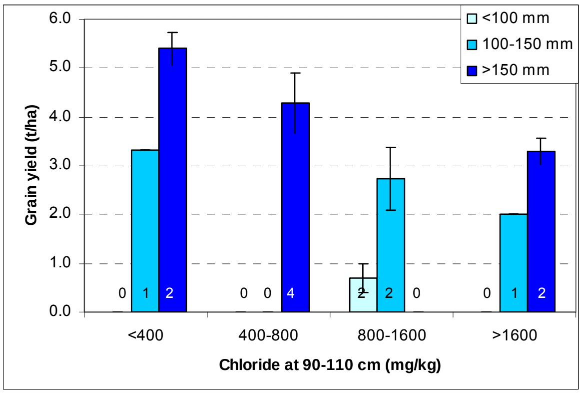


Figure 2.2.5. Strzelecki

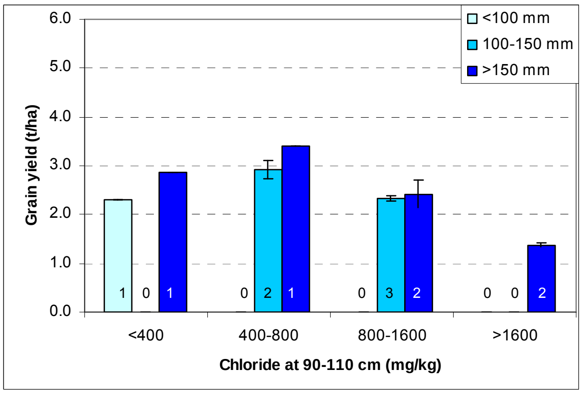


Figure 2.2.6. Sunco

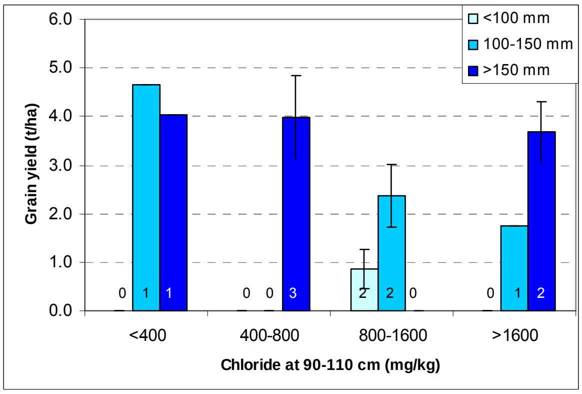


Figure 2.2.7. Sunstate

Highlights from the other varieties were: Drysdale and Sunlin both yielded 110% of Baxter in the high Cl level-moderate rainfall category while Kennedy was similar to Baxter (none of these 3 varieties were grown on very high Cl soils); Rees and Giles performed as shown in Figure 1 in comparison to Baxter; H45 was grown at 2 pairs of sites in northwest NSW that did not have Baxter – in all four trial sites, the H45 produced lower than Sunvale, Sunco, Drysdale and Sunlin; the others varieties either failed or were only grown at 1-2 sites.

2.2.2 Durum wheat varieties

Experimental trials that included more than one durum wheat variety were conducted in central Qld (2 sites; Wollaroi, Yallaroi and Kamilaroi) and northwest NSW slopes (10 sites [8 paired]; Wollaroi and Bellaroi) (Table 2.2.1). The relative yields of Bellaroi and Wollaroi compared to Baxter at the 6 paired sites are shown in Figure 2.2.1. Since standard error of the durum mean grain yields were large, as shown in Figure 2.2.1, it is not possible to state that either variety was better or worse than Baxter. The interaction of constraint and climate on yields is shown in Figs 8 and 9.

Both Wollaroi and Bellaroi showed decreasing yield with increasing subsoil Cl levels, but yields in the very high levels of Cl category were comparable with bread wheats grown at the same sites when rainfall was good. Relative yields compared to Baxter grown at the same paired sites were 90% (good rainfall) or 108% with moderate rainfall (Wollaroi, 1 site; Bellaroi 100%, 1 site). In central Qld, Wollaroi produced yield similar to Kamilaroi in 2003 (1 site, both were 19% lower yielding than Baxter), and equal to Yallaroi in 2006 (1 site, no Baxter).

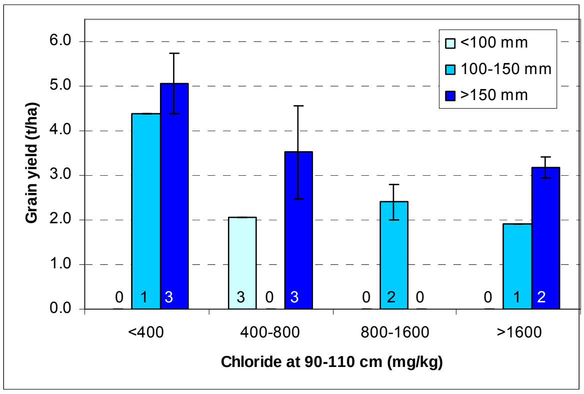


Figure 2.2.8. Wollaroi

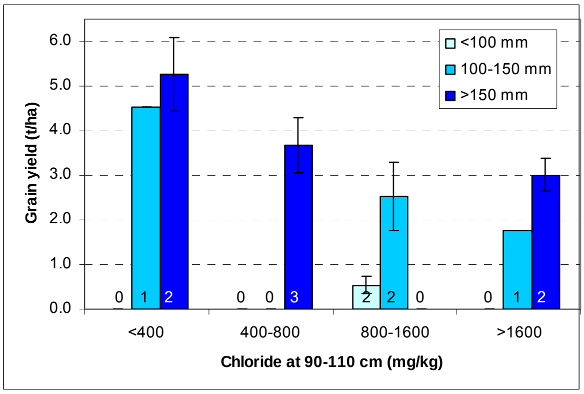
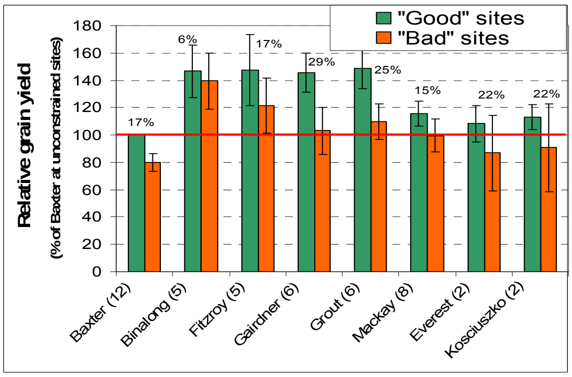


Figure 2.2.9. Bellaroi 2 single variety sites)

2.2.3 Barley varieties

Multiple varieties of barley were compared at 2 trials in central Qld (2003, 2006), 2 in central west NSW (2006 – 1 pair), and 11 in the NSW northwest slopes and plains (2004 – 1 pair, 2005 – 2 pairs, 2006 – 2 pairs) (see Table 2 for all site data). Figure 2.2.10 shows the relative yield of all barley and triticale varieties grown at more than 1 pair of "good" and "bad" sites. Yields are relative to Baxter yield at the "good" site in each pair. At unconstrained sites, most varieties of barley tended to yield higher than Baxter wheat. While there was a yield decline going from the "good" to the "bad" site in most pairs, yields at the constrained sites were often still above those of Baxter wheat. Binalong was the best performer with 3 pairs out of 5 showing no yield decline. Figures 2.2.11-2.2.15 show the interaction of yields with subsoil Cl levels and in-crop rainfall for the 5 most commonly trialled barley varieties.

Barley cultivars growing on a high constraints soil in northern NSW.



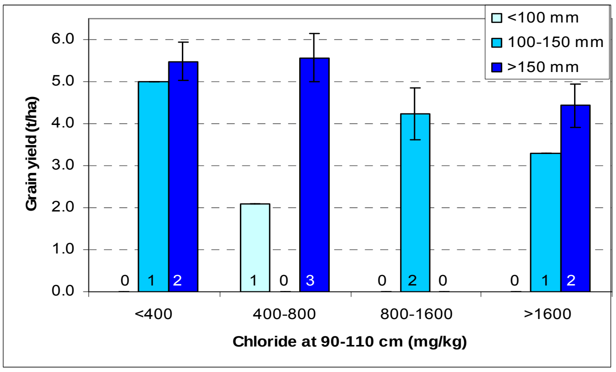


Figure 2.2.10. Barley & triticale vars. at paired sites. **Figure 2.2.11.** Binalong

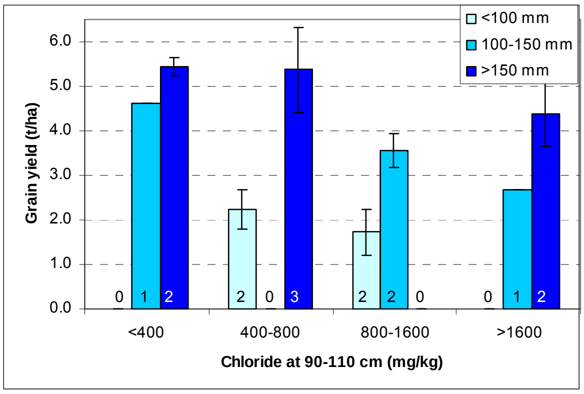


Figure 2.2.12. Grout

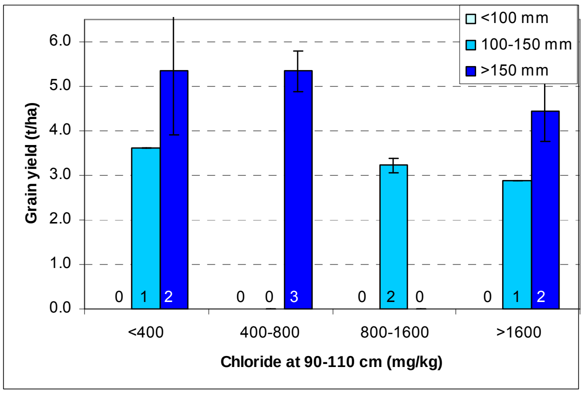


Figure 2.2.13. Fitzroy

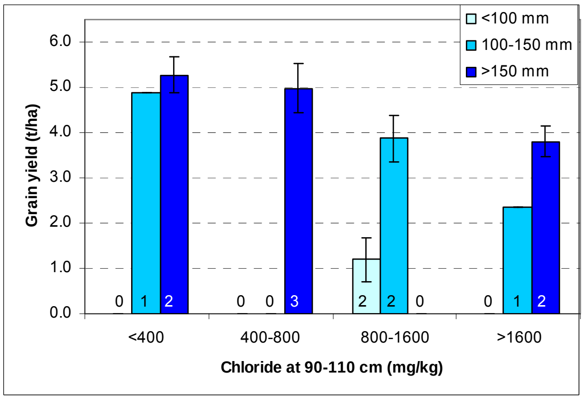


Figure 2.2.14. Gairdner

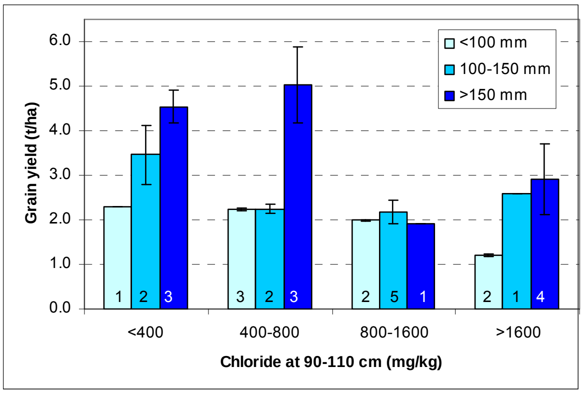


Figure 2.2.15. Mackay (incl. 20 single var. sites)

Binalong, Fitzroy and Grout all showed similar responses to increasing subsoil Cl concentration and in-crop rainfall (Figs 2.2.11-2.2.13) with only slight yield decline at very high Cl levels with good rainfall. Grout and Fitzroy yields were more modest at high Cl levels with moderate rainfall but Binalong still averaged above 4 t/ha. Gairdner and Mackay yields were below the first 3 varieties and closer to Baxter wheat at higher Cl levels.

2.2.4 Triticale

Four varieties of triticale were grown in subsoil constrainted field trials (see Table 2.2.2). At Bauhinia (CQ) Treat out yielded Speedee on a mid Cl levels site with poor in-crop rainfall. Figure 10 shows the relative yields of two varieties grown at 2 paired sites in northwest NSW in 2006, but the variation is very high owing to the averaging of only 2 quite different locations. There was no yield difference between varieties at Garah and no effect of subsoil Cl levels, owing to the "good" site having less available water at sowing. There was a strong effect of subsoil Cl levels on yields at the Spring Ridge 2006 trials. Kosciuszko out yielded Everest by 8% at the unconstrained site, but was no different at the constrained site.

2.2.5 Chickpea

Although chickpeas were grown in 32 separate trials, only 14 of these had between 2 and 3 varieties (Table 2.2.2). Only 3 varieties, Jimbour, Flipper and Genesis 836, were featured at more than one pair of un-constrained and constrained sites (Figure 2.2.16). Of the 11 trials run in northwest NSW, 5 had significant yield differences between varieties as indicated by underlining of the highest yielding variety in Table 2.2.2. In 2004, Howzat yielded more than Jimbour at the Bellata "good" site but not at the "bad" site. In 2005, Howzat was dropped and Flipper and Genesis836 added. Jimbour out yielded these at Bellata "good" site but not at the paired "bad" site. However, Jimbour out yielded Flipper and Genesis836 at Garah "bad" site in 2005 and Spring Ridge "bad" site in 2006, but not at the corresponding "good" sites. Genesis836 was best at Garah "bad" site in 2006. There were yield differences between unconstrained and constrained sites (Figure 2.2.16) for all paired sites although Garah "good" site was worse than "bad" site in 2006 owing to poor stored soil water at the former site. In CQ, Jimbour produced higher yield than Moti at Moura, but had similar yields at Baralaba.

2.2.6 Faba bean

Faba beans were grown in 14 separate trials, of which 8 trials in northwest NSW had 2 varieties; Fiord and Cairo (Table 2.2.3). At half of these 8 trials, Fiord out yielded Cairo by an average of 20% (3 "good" sites, 1 "bad" site) but it was no different at 3 other sites. However, at the Spring Ridge 2006 "good" site, Cairo yields were higher than Fiord by 27%.

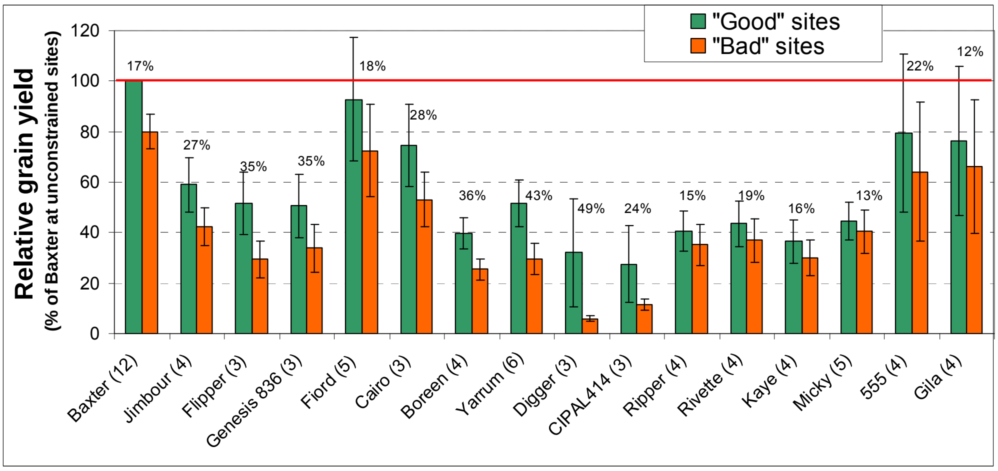


Figure 2.2.16. Chickpea, faba bean, field pea, lentil, canola, mustard and safflower grain yields relative to Baxter at paired-site comparisons that included that variety and Baxter.

2.2.7 Field pea

Four varieties of field peas were grown in NSW field trials. Twelve of the 16 trials with variety Yarrum (Figure 2.2.19) also had another variety or two for comparison (Table 2.2.3). For those 11 sites that had both Boreen and Yarrum. Yarrum produced yields an average of 34% higher than Boreen overall, regardless of whether the site was "good" or "bad". At paired sites, yields for both varieties were an average of 31% lower on "bad" sites than on corresponding "good" sites. The other 2 varieties, Kaspa and Morgan, were only grown at 1 pair of sites in Central West NSW in 2006 and were no different in yield to Yarrum at either site (Table 2.2.3).

2.2.8 Lentil

Two varieties of lentils were compared at 4 pairs of trial sites in northwest NSW in 2005-6 (Table 2.2.3). They were Digger and CIPAL414, an experimental line from Victoria DPI at Horsham. Apart from the "good" site at Garah in 2005, yields were mostly low. Variety differences were not consistent, with CIPAL414 yielding higher at 2 of the 4 "bad" sites, digger higher at 1 site and no yield difference at the other "bad" site. At the "good" sites, CIPAL414 was higher at 1 site, digger at 1 site and no difference at the other 2 sites. The largest yield decline at a paired site location was at Garah in 2005 where mean yields dropped from 1.6t/ha at the good site to 0.3t/ha at the bad site. Yields also declined at Bellata in the same year but in 2006, poor starting moisture at Garah led to higher yields at the "bad" site.

Table 2.2.2. Barley, triticale, and chickpea varieties grain yields (t/ha) from replicated trials in 2003-2006. Paired sites are shaded together. Statistical differences between varieties of a species are indicated – yields with same letter were not significantly different; ns = no differences.

Year	Nearest town	In-crop rain (mm)	Cl (mg/kg) 90-110 cm	Paired site?	Baxter	Binalong	Fitzroy	Gairdner	Grout	Mackay	Kaputar	Skiff	Schooner	Tantangara	Tulla	Treat	Speedee	Everest	Kosciuszko	Howzat	Jimbour	ICCV 98904	Flipper	Genesis 836	Moti
2003	Bauhinia	93	793	no	2.5	2.0 ab				2.1 a	1.8 b					2.5 a	2.0 b								
2003	Goondiwindi	127	759	Good	2.3					2.1															
2003	Goondiwindi	127	1296	Bad	2.1					2.2															
2003	Wallumbilla	169	1221	no	2.7																1.2				
2003	Roma	93	486	no	2.5																1.1				
2003	Walgett	148	750	Good								2.5									1.8				
2003	Walgett	148	1150	Bad								1.7									0.5				
2003	Coonamble	154	1100	no								1.9									0.9				
2004	Biloela	25	21	no	2.9					2.3						2.8					ns 1.1	1.0			
2004	Goondiwindi	85	1750	no	1.3					1.2											0.6				
2003	Wallumbilla	61	1137	no	2.1					2.0											0.9				
2004	Wallumbilla	61.2	1200	no	2.1					2.0											1.0				
2004	Goondiwindi	130	1340	no	2.7					2.4											1.5				
2004	Goondiwindi	117	759	no	2.6					2.4											1.8				
2004	Goondiwindi	122	290	no	2.9																2.0				
2004	Muckadilla	34.6	1613	no	1.1					1.2											0.7				
2004	Goondiwindi	122	366	no	2.8					2.5															
2004	Bungunya	100	1540	no	1.5					1.1															
2004	Rowena	176	81	no	3.0					2.9											1.4				
2004	Walgett	132	420	Good	2.8					2.5															
2004	Walgett	132	940	Bad	2.5					1.6															
2004	Coonamble	135	880	Good	2.7					2.9											1.4				
2004	Coonamble	135	1500	Bad	2.0					2.7											1.7				
2004	Bellata	160	112	Good	3.8	6.1 ab	6.6 a	5.8 abc	5.1 c	5.4 bc										3.1 a	2.7 b				
2004	Bellata	160	497	Bad	4.0	6.2 a	5.7 ab	5.2 bc	4.3 cd	4.0 d										ns 2.0	2.2				
2004	Spring Ridge	262	136	no	5.6	4.8 ab	3.3 c	4.7 ab	5.7 a	4.3 bc										3.9 a	3.3 b				
2005	Theodore	215	128	no	3.9					3.9						4.2									
2005	Goondiwindi	96.5	328	Good	2.5																				
2005	Goondiwindi	186	1750	Bad	1.4					1.3											0.8				
2005	Wallumbilla	181	1137	Bad	2.1					1.9											1.3				
2005	Muckadilla	200	1613	Bad	1.5					1.6											0.9				
2005	Garah	180	679	Good	2.5	ns 4.2	4.2	4.3	4.1	4.0											ns 1.3		1.2	1.1	
2005	Garah	180	2010	Bad	2.8	ns 3.7	3.5	3.3	3.4	3.6											1.1 a		0.6 b	0.9 ab	
2005	Bellata	146	315	Good	4.3	5.0 a	3.6 d	4.9 ab	4.6 bc	4.4 c											3.5 a		3.2 b	3.2 b	
2005	Bellata	141	877	Bad	3.6	5.1 a	3.0 c	4.6 ab	4.1 b	2.9 c											ns 2.0		1.9	2.1	
2006	Moura	87	650	no	4.0				2.8	2.3											ns 3.0				2.4
2006	Baralaba	80	552	no	2.3				1.6	2.3											ns 0.8				1.1
2006	Garah	127	1062	Good	1.7	3.4 a	3.5 a	3.1 a	3.0 ab	2.2 b								ns 2.1	2.1		ns 0.4		0.3	0.5	
2006	Garah	127	2117	Bad	1.8	ns 3.3	2.9	2.3	2.7	2.6								ns 1.9	2.1		0.7 ab		0.6 b	0.8 a	
2006	Spring Ridge	182	482	Good	6.9	ns 6.3	6.1	6.6	7.7	7.1								6.6 b	7.2 a		ns 2.2		2.2	2.3	
2006	Spring Ridge	178	2797	Bad	4.6	5.2 a	5.4 a	4.3 b	5.4 a	5.2 a								ns 4.1	4.1		1.5 a		1.3 ab	1.2 b	
2006	Narromine	80	990	Good	1.2			ns 1.9	2.5				2.3	2.8	2.1										
2006	Narromine	81	1317	Bad	0.4			0.5 c	1.0 ab				1.1 a	1.2 a	0.7 bc										

2.2.9 Canola

Although 4 varieties of canola were grown at trials throughout the project (Table 3), only 10 trials in northwest NSW had more than one variety. There was no overall yield difference between Ripper and Rivette, but Ripper out yielded Rivette at both “good” and “bad” sites near Spring Ridge, while the opposite was the case at Bellata in 2005. There was no yield difference at other sites and years. Despite the average yield declines apparent in Figure 16 for both varieties, only the Spring Ridge pair of sites in 2006 showed a significant yield reduction averaging 31% from the “good” site to the “bad” site, other paired sites showed no effect on yields.

2.2.10 Mustard

Two varieties of mustard, Kaye and Micky, were grown in 9 trials (including 4 pairs) in northwest NSW from 2004-2006 (Table 2.2.3). Both were also grown at another pair of trials at Garah in 2006 but Kaye failed. There was no overall yield difference between the two varieties. However, Micky out yielded Kaye by an average of 29% at 3 sites (2 “good” sites and 1 “bad”). There was no yield difference between the 2 varieties at the other 6 sites. Of the 4 paired sites, there was only a significant yield decline from the “good” site to the “bad” site at 2 locations, Bellata 2005 (10% decline) and Spring Ridge 2006 (36% decline).

2.2.11 Safflower

The varieties Gila and 555 were grown at 4 pairs of trials in northwest NSW from 2005-6. Gila out yielded 555 at one trial (Spring Ridge 2006 “bad”), but there was no variety difference at any of the other 7 trials. There was a significant yield decrease from “good” to “bad” trials at 3 of the 4 paired site locations (average 24% decline).

2.2.12 Linseed

Only one variety of linseed, Glenelg, was grown in the field trials so no variety comparisons are possible.

Table 2.2.3. Faba bean, field pea, lentil, canola, mustard and safflower varieties grain yields (t/ha) from replicated trials in 2003-2006. Statistical differences between varieties of a species are indicated – yields with same letter were not significantly different; ns = no variety differences.

Year	*Nearest town*	*In-crop rain (mm)*	*Cl (mg/kg) 90-110 cm*	*Paired site?*	*Baxter*	*Fiord*	*Cairo*	*Boreen*	*Yarrum*	*Kaspa*	*Morgan*	*Digger*	*CIPAL*	*Emblem*	*Ripper*	*Rivette*	*Hyola 43*	*Kaye*	*Micky*	*555*	*Gila*
2003	Walgett	148	750	Good		0.7								1.7							
2003	Walgett	148	1150	Bad		0.8								1.3							
2003	Coonamble	154	1100	no		0.2								1.1							
2004	Goondiwindi	85	1750	no	1.3												0.5				
2003	Wallumbilla	61	1137	no	2.1												0.6				
2004	Wallumbilla	61.2	1200	no	2.1												0.7				
2004	Goondiwindi	130	1340	no	2.7												0.9				
2004	Goondiwindi	117	759	no	2.6												0.9				
2004	Muckadilla	34.6	1613	no	1.1												0.4				
2004	Goondiwindi	122	366	no	2.8												0.9				
2004	Rowena	176	81	no	3.0	1.2			1.2								0.8				
2004	Coonamble	135	880	Good	2.7	1.2			0.6								0.9				
2004	Coonamble	135	1500	Bad	2.0	1.0			0.3								0.3				
2004	Bellata	160	112	Good	3.8			1.5 b	2.6 a						ns 2.2	2.3		ns 1.9	2.2		
2004	Bellata	160	497	Bad	4.0			0.9 b	1.6 a						ns 2.1	1.9		ns 1.8	2.1		
2004	Spring Ridge	262	136	no	5.6			1.1 b	3.0 a						4.2 a	3.2 b		2.8 b	3.1 a		
2005	Goondiwindi	96.5	328	Good	2.5																
2005	Goondiwindi	186	1750	Bad	1.4												0.8				
2005	Wallumbilla	181	1137	Bad	2.1												0.6				
2005	Muckadilla	200	1613	Bad	1.5												0.5				
2005	Garah	180	679	Good	2.5	2.6 a	1.9 b	0.9 b	1.9 a			1.8 a	1.4 b		ns 1.3	1.3		ns 1.3	1.1	ns 1.7	1.8
2005	Garah	180	2010	Bad	2.8	ns 1.8	1.6	0.8 b	1.1 a			ns 0.2	0.3		ns 1.0	1.2		0.8 b	1.2 a	ns 1.0	1.1
2005	Bellata	146	315	Good	4.3	5.1 a	4.4 b	ns 2.4	2.7			ns 0.8	0.9		1.1 b	1.8 a		1.1 b	1.8 a	ns 2.4	2.3
2005	Bellata	141	877	Bad	3.6	ns 3.8	2.8	1.4 b	1.9 a			0.3 b	0.6 a		1.1 b	1.6 a		ns 1.3	1.4	ns 2.5	2.7
2005	Wongarbon	345	684	no														ns 1.1	0.8		
2006	Garah	127	1062	Good	1.7	2.8 a	1.2 b	0.9 b	1.0 a			ns 0.3	0.3			1.2			1.0	ns 2.9	2.7
2006	Garah	127	2117	Bad	1.8	ns 2.3	2.6	1.2 b	1.4 a			0.9 a	0.4 b		ns 1.2	1.2			1.0	ns 2.4	2.4
2006	Spring Ridge	182	482	Good	6.9	2.3 b	3.2 a	ns 1.8	1.9			0.2 b	0.4 a		1.9 a	1.3 b		ns 1.3	1.3	ns 1.6	1.5
2006	Spring Ridge	178	2797	Bad	4.6	ns 2.4	2.2	1.0 b	1.3 a			0.3 b	0.5 a		1.2 a	0.8 b		ns 0.8	0.8	1.0 b	1.3 a
2006	Narromine	80	990	Good	1.2				ns 0.7	0.5	0.6										
2006	Narromine	81	1317	Bad	0.4				ns 0.2	0.2	0.4										

2.3 Summer crops

Stuart Buck and Ian Daniels

Key messages:

- Grain yields of summer crops did not show significant relationship with levels of subsoil constraints. We conclude that the range of constraints at each of our sites was insufficient to demonstrate a response, and differences between sites included other variables such as sowing date and rainfall
- In general, the water extraction potential of millet, mung bean and sesame appear to be more sensitive to subsoil constraints as compared to sorghum and maize.

Grain yield of summer crops was not related to the levels of subsoil chloride as in case of winter crops (Figure 2.3.1), with the limited set of data available. Therefore, in this Result Book we have compared the results for each region separately.

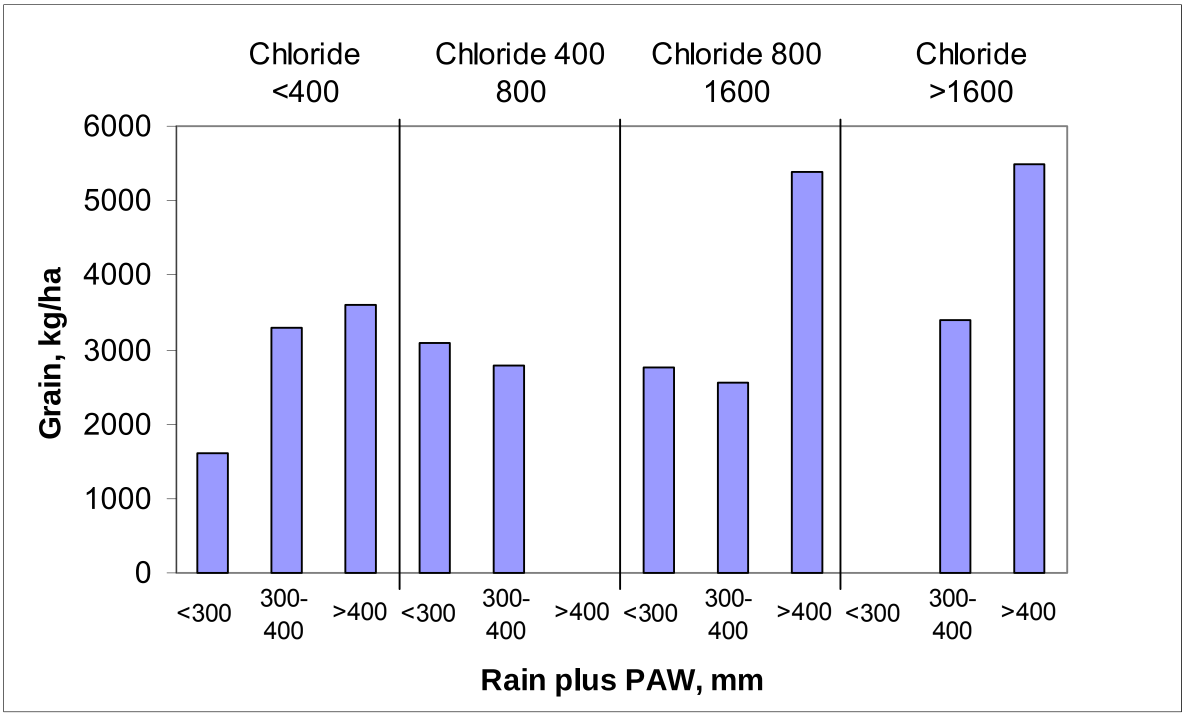


Figure 2.3.1. Grain yield of sorghum grown in northern grains region in relation levels of subsoil Cl concentration.

Southern Queensland

Two trials conducted in south west Queensland on similar soil types located within < 1 km distance, with moderate-high subsoil constraints (800 mg Cl/kg in 1 m soil depth, ESP 5% in 0-10 cm) and very high subsoil constraints (1500 mg Cl/kg in 1 m soil depth, ESP 12% in 0-10 cm). Increasing subsoil constraints significantly decreased the amount of soil moisture extracted by 5 summer crops (Fig. 2.3.2). Summer crops grown on relatively moderate to high subsoil constrained sites extracted almost similar amount of subsoil moisture. However, on high sub soil constrained sites, millet, sesame and mung bean extracted significantly less subsoil water as compared to maize and sorghum.

Summer crops growing on moderate subsoil constraints in southwest

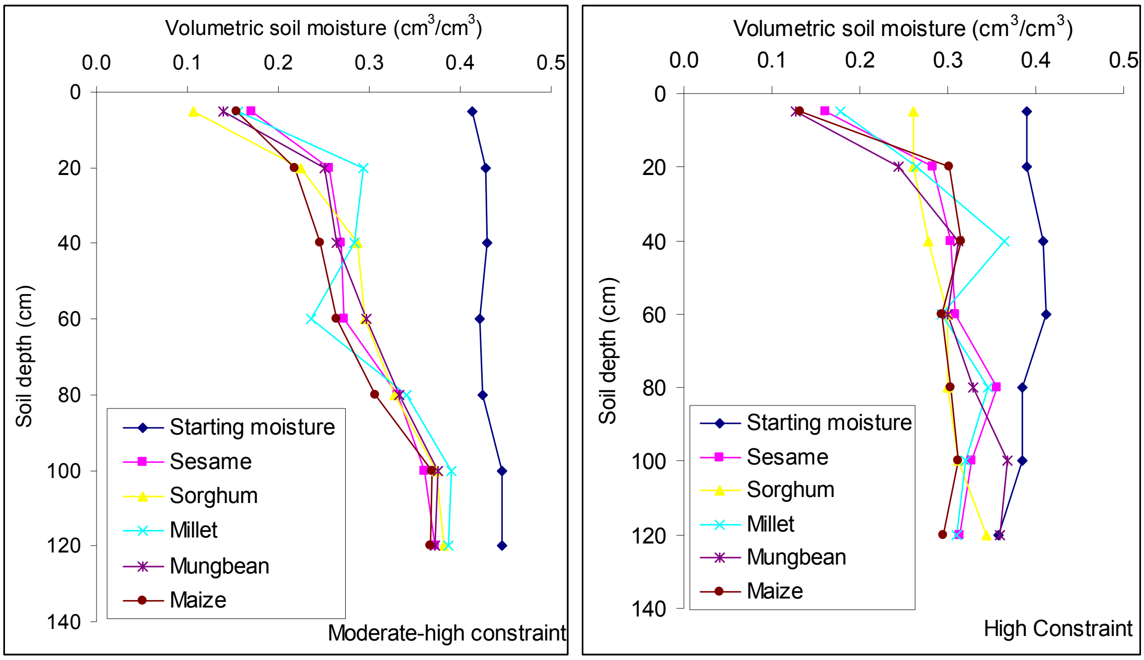


Figure 2.3.2. Pattern of soil water extraction by 5 summer crops grown on moderate and high subsoil constrained sites in southwest Queensland.

Central Qld

In the trials conducted in central Queensland the levels of subsoil constraints were in the low to moderate categories.

During summer 2005/06, two trials were conducted; one at Jambin and the other at Moura with low constraints (< 500 in 1 m soil depth). At the Jambin site, cotton extracted the highest amount of water and to the greatest depth (Figure 2.3.3). This would most likely be due to it actively growing for a longer time than the other crops. Conversely, French white millet used the least water, and extracted to the shallowest depth. The other crops were similar, with sorghum extracting slightly more water than corn and pearl millet. At the Moura site, dry planting conditions resulted in no millet seed germinating and again, cotton used the most water, but extracted to a similar depth compared to the other crops (Figure 2.3.3). Mung beans have used similar amounts of water compared to corn at both sites.

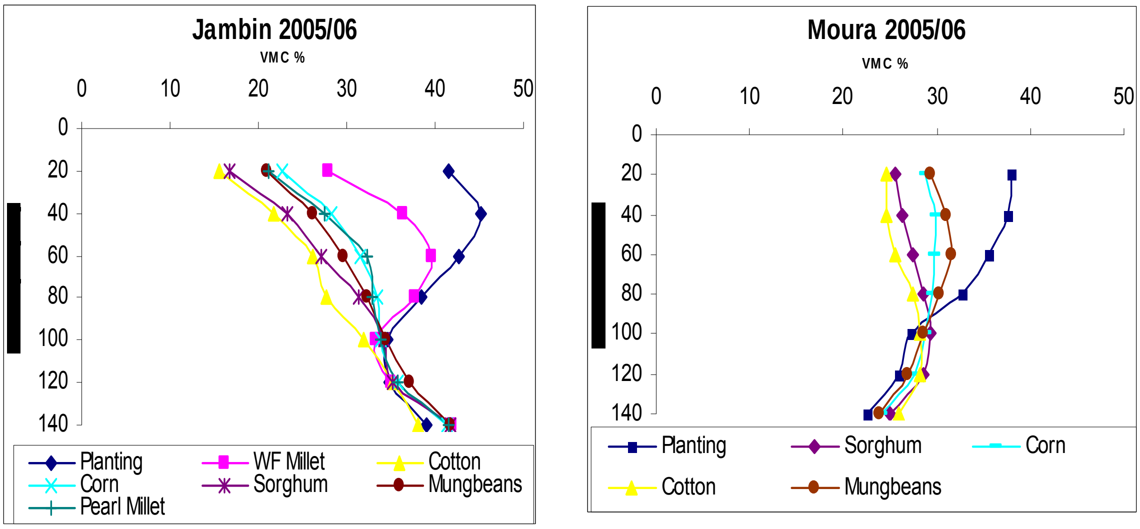


Figure 2.3.3. Water extraction patterns of 6 summer crops at Jambin and Moura with low subsoil constraints in central Queensland.

In comparison, at a highly constrained site (944 mg/kg in 1 m soil depth, ESP was 6.6% in the top 0-10 cm soil) at Baralaba, mung bean roots were limited to 80 cm, whereas French white millet and corn extracted water from 100 cm, and sorghum greater than 100 cm depth (Figure 2.3.4).

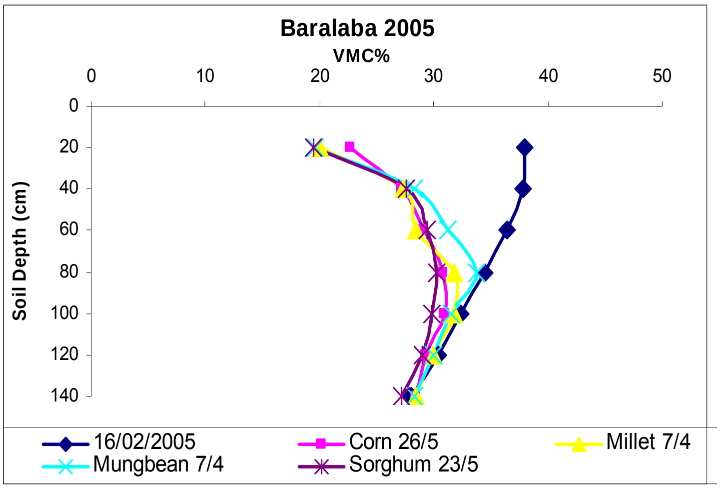


Figure 2.3.4. Water extraction patterns of 4 summer crops at Baralaba in central Queensland.

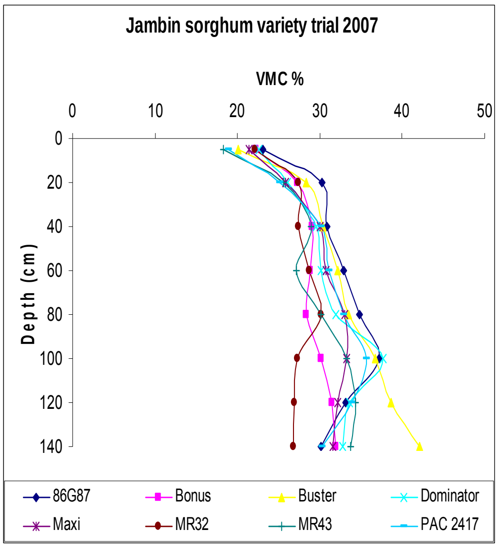
Except for Baralaba, due to the low levels of constraints at these sites, water use has been determined by the length of growing time, with longer season crops (eg cotton) extracting more water than shorter season crops (eg French white millet). This has obvious re-cropping implications, with less rainfall needed after French white millet to refill the profile compared to cotton. Besides cotton, sorghum has the ability to use more water than other crops and this is reflected in higher yields (Table 2.3.1). The water use of mung beans was most affected by higher levels of SSC, whereas corn and millet showed higher tolerance to SSC than mung beans.

Table 2.3.1. In crop rainfall and yields of summer crops in central Queensland

Site	*Incrop rain (mm)*	*Sorghum (t/ha)*	*Corn (t/ha)*	*Mung bean (t/ha)*	*Cotton (Bales/ha)*	*WF millet (t/ha)*	*Pearl millet (t/ha)*
Jambin 2005/06	<170	2.1*	0.7*	1.0	2.6	0.6	1.5
Moura 2005/06	134	3.9	3.7	1.5	3.1	NA	NA
Baralaba 2004/05	<130	3.2	1.9	0.7	NA	0.8	NA

* Bird damaged. Sorghum loss about 30%. Corn loss about 80%.

With regard to sorghum varieties, two Pacific seeds sorghum variety trials (Jambin and Biloela) were monitored to investigate whether a selection of the commercially available sorghum varieties possess differences with soil water extraction. The same varieties were monitored in each trial; MR Buster, MR Maxi, MR 32, MR 43, PAC 2417, Dominator, 86G87 and Bonus and soil water remaining post harvest was the primary measurement. Even though the soil types at both sites were different (Jambin: alluvial black Vertosol; Biloela: brigalow brown Vertosol), both trial recorded subsoil chloride levels between 950 – 970 mg/kg at 100cm. Due to the similarity in subsoil constraint level, the results have been statistically analysed using sites as replicates (as no interaction of treatments and site). There was no difference ($P > 0.10$) of profiles taken to and average depth of 80, 100, 120cm (Table 2.3.2) for any variety. At an average depth of 140cm there is a difference at $P = 0.095$. Overall there is a trend that Buster had extracted the least water, whereas MR32 and Bonus had extracted the most water (table 2.3.2), indicating that more research is needed to fully verify potential water extraction differences in varieties of sorghum.



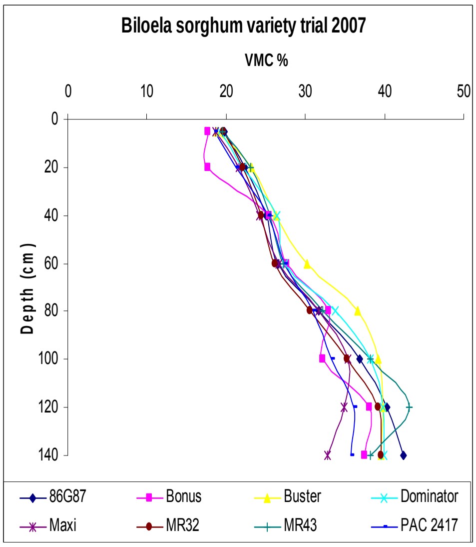


Table 2.3.2. Total soil moisture (mm) present post harvest to an average of 80cm, 100cm, 120cm and 140cm of soil depth for each sorghum variety.

Variety	**Soil moisture (mm) to an average of….**			
	80 cm	**100 cm**	**120 cm**	**140 cm**
	ns	*ns*	*ns*	*P=0.095*
Bonus	237	300	369	439
MR43	239	310	388	460
Buster	260	336	414	496
Dominator	248	324	397	470
Maxi	246	314	382	448
PAC 2417	243	312	382	448
86G87	256	330	403	476
MR32	238	300	367	433
lsd	22	29	35	42

NSW

In the trials conducted in NSW, there were no consistent relationships between levels of subsoil constraints and yields; however, among summer crops, corn yielded best, followed by White French millet and mung beans (Figure 2.3.5).

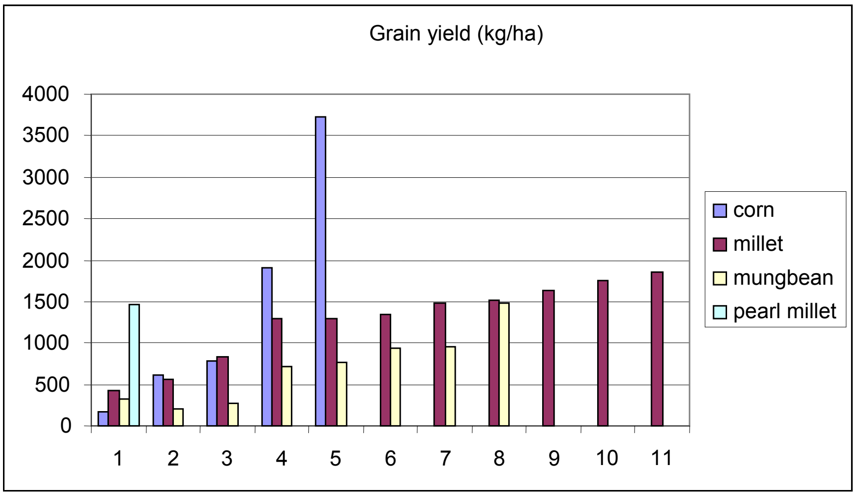


Figure 2.3.5. Grain yield of summer crops grown in NSW.

2.4 Agronomy

Stuart Buck

Key messages:

- Wide row spacings do not overcome the impact of subsoil constraints.
- In subsoil constrained soils, increasing fallow length does not increase water extraction by different crop species.
- Zero tillage increases water capture that can lead to higher deep drainage and chloride movement if opportunity cropping is not practised.
- Drainage is generally higher under cropping than pastures.

2.4.1 Row spacing

Wheat – Southern QLD

Three trials were conducted on soils with moderate to high subsoil constraints in the Roma district. Each trial consisted of 2 row spacings (Table 2.4.1). In the higher yielding trials (Sites 2 and 3), grain yield was significantly reduced at wide row spacings, by more than 10%. In the lower yielding trial (Site 1) there was no significant reduction in grain yield. At the low yielding site, where relatively high levels of screenings were experienced reflecting a greater water stress, screenings were lower at the wide row spacing. There were no differences in screenings at the other sites. Soil water measurements (not shown) indicated no differences in soil water use due to any of the treatments and consequently, trends in water use efficiency were similar to those in yield.

Table 2.4.1. Effect of row spacing on wheat cv. Baxter in the Roma district.

Site	**Row Spacing** *cm*	**Grain Yield** *kg/ha*	**Screenings** *%*	**Plant population** *plants/m²*	**Fertile Tillers** *heads/m²*	**WUE** *kg/ha/mm*
1	33	1134*a*	9.2*a*	84.1*a*	260*a*	5.4*a*
	66	1032*a*	6.9*b*	60.0*b*	202*b*	4.9*a*
	Lsd P<0.05	*129*	*0.4*	*12.7*	*36*	*na*
2	30	2671*a*	3.8*a*	69.0*a*	304*a*	12.3*a*
	60	2282*b*	3.8*a*	63.8*b*	249*b*	10.5*b*
	Lsd P<0.05	*353*	*na*	*5.05*	*49*	*1.6*
3	37.5	1421*a*	3.4*a*	*na*	*na*	10.3*a*
	75	1260*b*	3.3*a*	*na*	*na*	8.3*b*
	Lsd P<0.05	*84.3*	*na*	*na*	*na*	*1.8*

Wheat – Central QLD

One wheat row spacing trial was conducted in central Queensland and used two row spacings; narrow (25 cm) and wide (50 cm). This experiment was sown with the variety Kennedy at the same sowing rate for both spacings, on a soil with moderate levels of constraints (Cl 600mg/kg at 50-70cm). Even with only 70mm of in-crop rainfall recorded, by harvest there were no significant differences in water use between the two row spacings (Figure 2.4.1). However significant yield differences were recorded due to higher numbers of plants established and heads/ha produced in the narrow row spacing (Table 2.4.2).

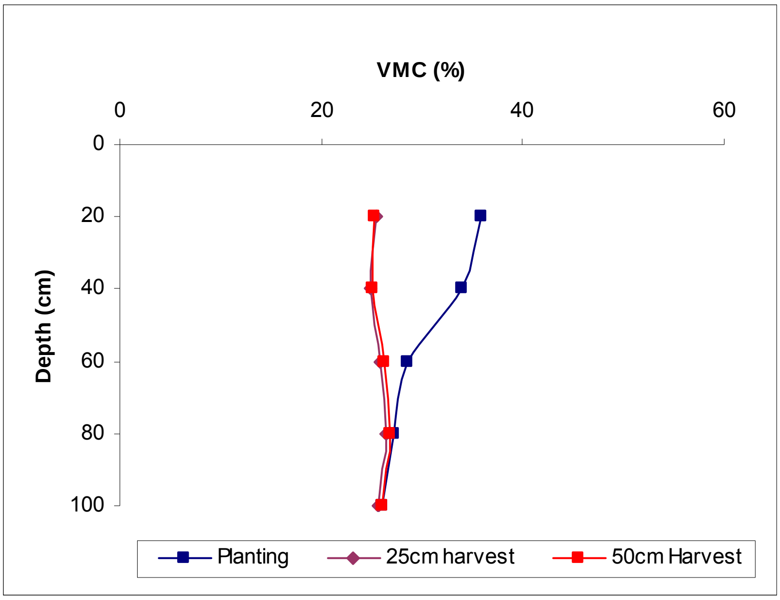


Figure 2.4.1. Wheat grown in 25 and 50cm rows.

Table 2.4.2: Yield, screenings and tillers/ha for CQ wheat grown in 25 and 50cm rows.

Treatment	Yield (t/ha)	Screenings (%)	Plant population (plants/ha)	Tillers (tillers/ha)
25cm	2.60a	0.6ns	1,195,300a	1,610,000a
50cm	2.49b	0.7ns	906,250b	1,360,000b

P = (0.05)

Chickpea

One chickpea row spacing experiment was conducted in Southern QLD, using spacings of 37.5cm and 112.5cm. This trial was primarily grown on subsoil moisture, as one fall of 18mm was recorded after pod filling. Grain yields were therefore significantly impacted, with the narrow spacing recording a yield of 430kg/ha, and 374kg/ha for the wide spacing. Despite no effective in-crop rain, no significant differences in soil water extraction were found (Figure 2.4.2).

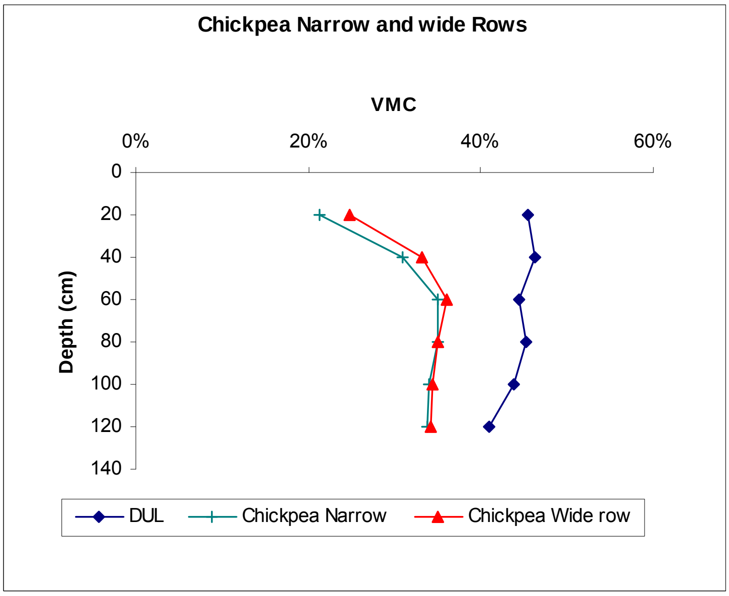


Figure 2.4.2. Effect of row spacing on soil water extraction by chickpea in Southern QLD.

Sorghum

Two trials were conducted in central Queensland to investigate if wider row spacing improved sorghum grain yield in the presence of subsoil constraints.

Trial 1

The first trial was sown to MR Maxi sorghum and used six row spacings; 0.5m solid, 1m solid, 1.5m solid, 2m solid, 1m single skip and 1m double skip. A total of 177mm of in-crop rainfall was received, of which more than 80% occurred in the first 4 weeks. The subsoil constraints levels were low-moderate with chloride levels reaching 500 mg/kg at 90-120cm. Before the trial was sown, the whole site was soil sampled for soil water and subsoil constraints, then after harvest each plot was sampled separately.

Grain yield and water use efficiency (WUE) was significantly lower for the 0.5m solid treatment (Table 2.4.3 & 2.4.4). Screenings were not impacted by row spacing (Table 2.4.4). Overall, widening row spacing past 1.0m solid did not improve grain yield.

Table 2.4.3. Soil water at planting and post harvest, water used and WUE of sorghum grown in 2001/02 in CQ (P= 0.05)

Treatment	**PAW at planting**	**PAW at harvest**	**Water used by crop**	**WUE**
	(mm)	**(mm)**	**(mm)**	**(kg/ha/mm)**
0.5m Solid	73.0	10 c	240 a	9.2 b
1.0m Solid	73.0	18 abc	232 abc	12.0 a
1.5m Solid	73.0	17 bc	233 ab	12.1 a
2.0m Solid	73.0	24 ab	226 bc	12.0 a
1m Single	73.0	19 abc	231 abc	12.4 a
1m Double	73.0	26 a	224 c	13.6 a

Table 2.4.4. Yield, screenings and plant population of sorghum grown 2001/02 in CQ.

Treatment	**Yield (t/ha)**	**Screenings (%)**	**Plant population (plants/ha)**
0.5m	2.18b	7.3ns	60333a
1.0m	2.75a	7.7ns	57833ab
1.5m	2.78a	7.1ns	42111d
2.0m	2.65a	8.2ns	50417c
1m single skip	2.84a	8.6ns	51741bc
1m double skip	2.98a	7.8ns	50028c

Trial 2.

The second trial had three row spacings; 1 m solid, 1 m single skip and 1 m double skip. The trial was sown to MR Buster sorghum into a paddock with low levels of subsoil constraints (Cl, 400 mg/kg at 70-110cm). The crop received 205mm of in-crop rainfall that fell before flowering, therefore it needed to utilise subsoil moisture to maximise yield potential.

The single skip spacing yielded similar to the solid configuration, but was higher than the double skip (Table 2.4.4). Screenings were significantly higher (over double) in the solid configuration, indicating this treatment might have not had as much moisture to fill grain due to higher soil moisture usage earlier in the season. Overall water used and hence water use efficiency was the same for all spacings.

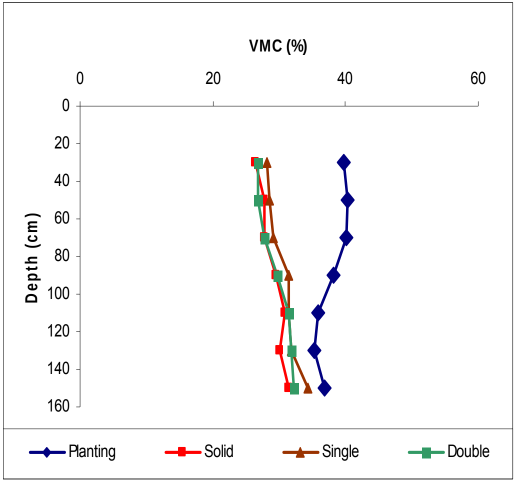


Figure 2.4.3. Soil water at planting and harvest for solid, single and double skip configuration

Table 2.4.5. Yield, screenings and WUE of sorghum grown 2003/04 in CQ

Treatment	Yield (t/ha)	Screenings (%)	WUE (kg/mm/ha)	Plant population (plants/ha)
1.0m	3.85ab	7.9a	15.7ns	57,500ns
1m single skip	4.08a	3.5b	16.5ns	54,178ns
1m double skip	3.64b	3.1b	14.7ns	52,088ns

P= (0.05)

Sorghum planted with 1.0 m, 1 m single skip and 1 m double skip configuration in central Queensland

2.4.2 Fallow period

An experiment was conducted in the Roma district (southern QLD) on a soil with moderate subsoil constraint level to investigate the impact of fallow length on crop water extraction. In the presence of subsoil constraints, increasing fallow length from 6 months to 18 months did not significantly increase water extraction by different crop species (Figures 2.4.6). There were no significant effects of changing fallow length on the crop yield. The results suggested that in the presence of subsoil constraints it is best to keep the fallow period short.

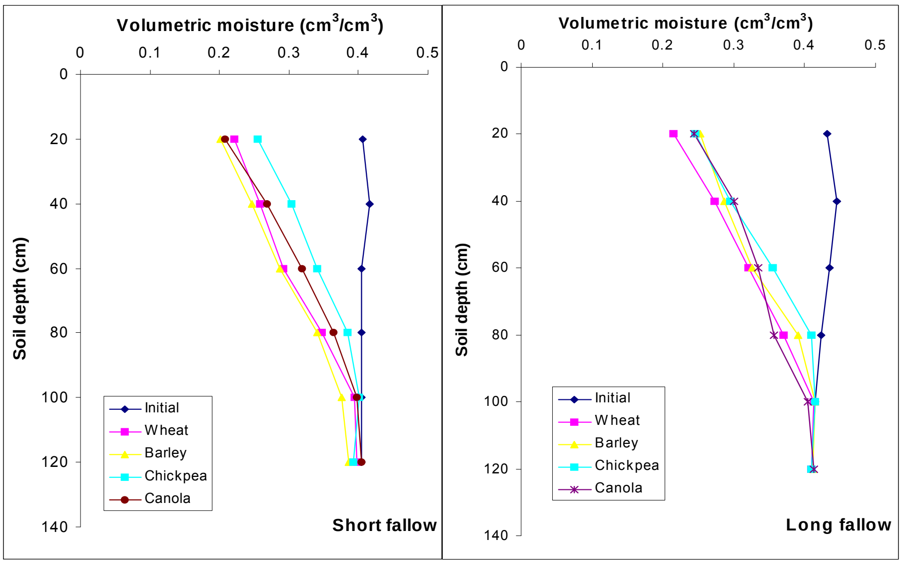


Figure 2.4.6. Effect of fallow length on the pattern of water extraction by various winter crops.

2.4.3 Effects of tillage practices on deep drainage and chloride movement

Tillage management such as zero tillage with stubble retention combined with better soil fertility management to ensure optimum production may provide a long-term solution to arrest or reverse soil sodicity and/or soil salinity.

Central Queensland

The impact of tillage practice on subsoil constraints was not investigated by this project; however a long term experiment was conducted at the Biloela Research Station that investigated the tillage impacts on chloride movement.

The experiment was established in 1983 and incorporated 4 tillage treatments:

1. Traditional tillage (TT) - disc plough, scarifier and cultivator
2. Stubble mulch tillage (SM) - chisel plough, blade plough and rod weeder
3. Reduced tillage (RT) - stubble mulching implements and strategic spraying with herbicides
4. Zero tillage (ZT) - no tillage other than the tines at sowing (all weeds controlled with herbicides)

The Cl levels for TT and ZT treatments were very similar a year after the trial began (Figure 2.4.7). However 9 years later (1993) the Cl profiles indicate large differences between treatments, and this difference was attributable to a 7-fold increase of drainage in ZT (43.9mm/yr) compared to TT (6.0mm/yr for TT). This was consistent with known greater water storage of ZT at this site (Radford *et al.* 1995; McGarry *et al.* 2000), and due to increases in infiltration and hydraulic conductivity due to earthworm and termite activity under ZT (McGarry *et al.* 2000).

Chloride profiles for the 2003 sampling showed upward movement of Cl for both treatments, suggesting no drainage during the 1993-2003 period. This is attributable to the increased frequency of summer cropping, resulting in a drier soil profile. Over the entire cultivation period of 20 years, ZT lost 33% more Cl than the TT treatment.

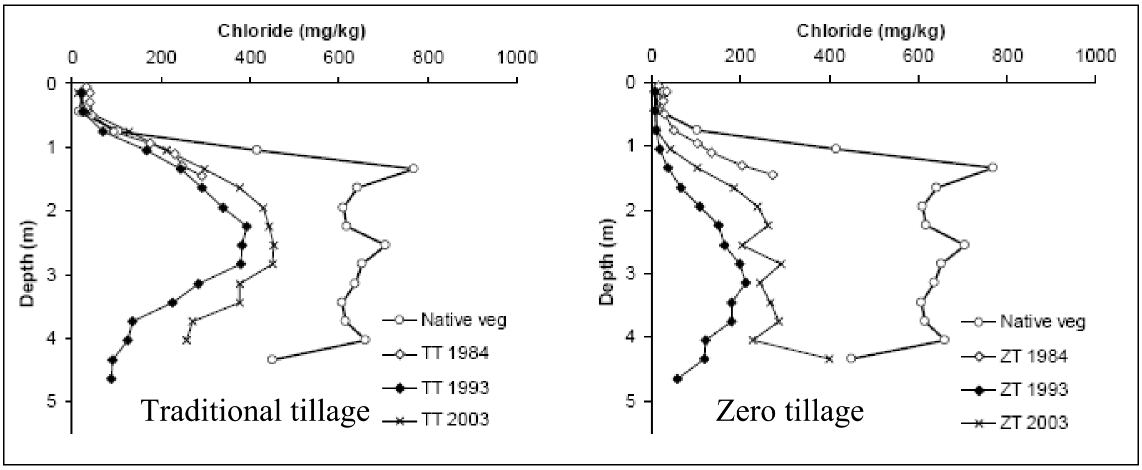


Figure 2.4.7. Effect of tillage practices on chloride movement in subsoil.

Southern Queensland

Dalal (1989) showed that stubble retention and no-tillage reduced both ESP and salt levels in a black Vertosol (Table 2.4.6). Similar effects of these practices have been observed on a red-brown earth soil (red Chromosol) in southern Queensland (Thomas *et al.* 1995) and in long-term zero-tillage trials on grey and black Vertosols of northwest NSW (W. Felton, NSW Agriculture *personnel communication*).

Stubble retention and no-tillage help to maintain soil structural stability and reduce both ESP and salt levels through improved infiltration and increased drainage. Stubble cover would have both chemical and mechanical effects on the soil by increasing organic matter and reducing raindrop impact, thereby assisting in soil stabilization by decreasing clay dispersion. Further, no-till managed soil produces more biopores due to increased earthworm activity, thereby improving soil structure and movement of water (Valzano *et al.* 2001).

Table 2.4.6. ESP and salt concentrations in the Hermitage trial after 13 years of stubble management and tillage in southern Queensland (Dalal 1989).

Stubble management	ESP (0-4 cm)[A]		Salt (t/ha) (0-120 cm)[C]	
	Till	Zero till	Till	Zero till
Burned	2.8^{a}	2.0^{b}	7.3^{a}	3.2^{bc}
Retained	3.1^{a}	1.3^{c}	4.9^{ab}	0.8^{c}

Means followed by same letter in common do not differ significantly at P<0.05

NSW

Results of Cl analysis done at the completion of two long-term (1981-1999) tillage vs cultivation trials in northern NSW are shown in figure 2.4.7. No-tillage with stubble retention led to greater water infiltration into the soil than cultivated treatments both with and without retention of stubble. Over the 18 years of the trials, greater cumulative water movement through the root zone under no-till moved existing Cl salts downwards with it (unpublished data: W. Felton, H. Marcellos (dec), D. Herridge, G. Schwenke, B. Haigh). These were fixed rotation trials; opportunity cropping coupled with no-tillage may not have resulted in as much unused water draining slowly through the profile of these heavy clay soils.

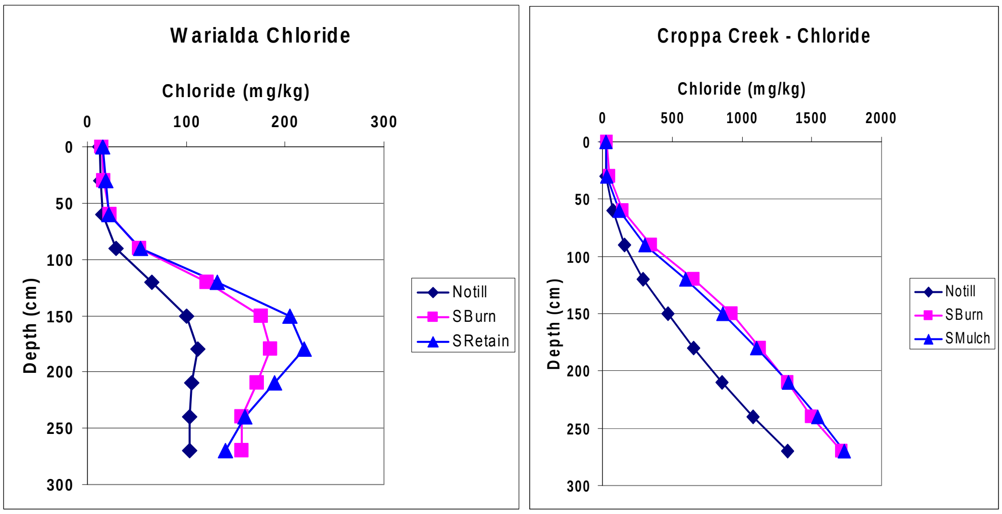


Figure 2.4.7. Chloride levels with depth in two field trials in northern NSW that had 18 years of continuous fallow management treatments.

2.4.5 Land use impacts on chloride movement.

In the Brigalow Catchment Study, conducted at the Brigalow Research Station (near Theodore, central Queensland), the impact of 3 different land uses (remnant brigalow scrub; cropping; pasture) on chloride movement was studied. In this experiment, soil profile Cl was measured after tree clearing and immediately before the cropping and pasture catchments and on 6 subsequent occasions in the following 16 years.

Significant declines in soil Cl occurred immediately after clearing (Figure 2.4.8). Under cropping, there were further changes in Cl distribution over time where soil water storage capacity was exceeded due to limited crop transpiration potential. In contrast, under pasture there was little or no change in soil Cl at any depth after the initial post-clearing pulse. An important point to note is clearing has increased deep drainage, and by flushing Cl salt with it has increased the plant available water capacity. However, there is an important landscape risk as this Cl could move either down slope into neighbouring areas, increasing the risk of salinity outbreaks.

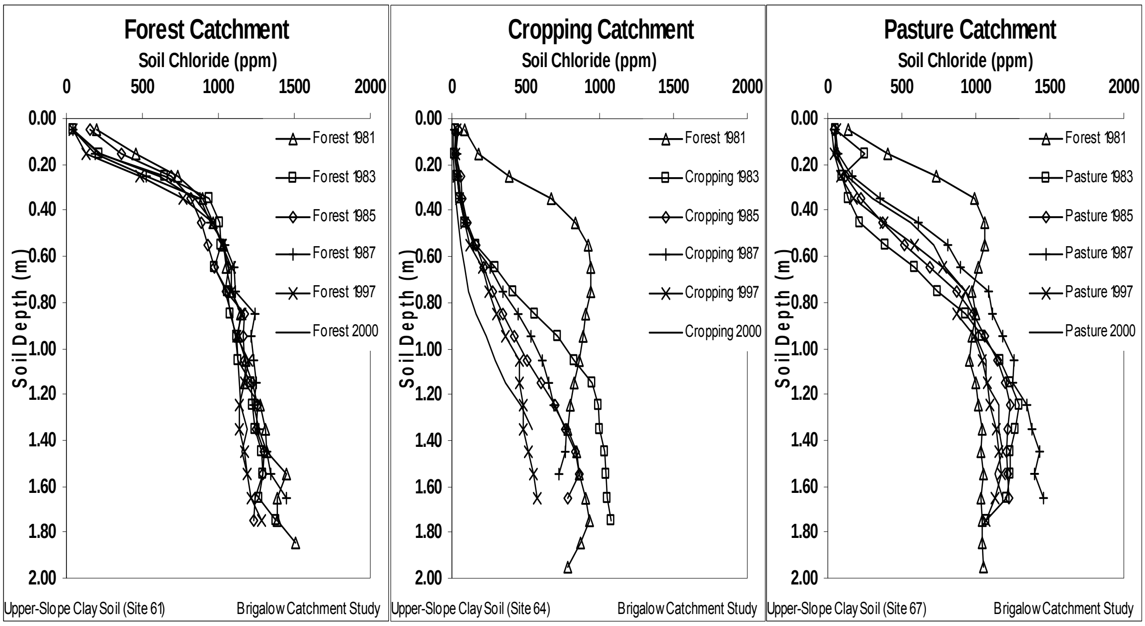


Figure 2.4.8. Chloride movement in an association of uniform fine textured dark cracking clay soils (Black and Grey Vertosols), located in the upper slope position of each of the three catchments of the Brigalow Catchment Study.

References:

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Radford, B.J., Key, A.J., Robertson, L.N. and Thomas, G.A. (1995). Conservation tillage increases soil water storage, soil animal populations, grain yield, and response to fertiliser in the semi-arid subtropics. *Australian Journal of Experimental Agriculture* 35, 223-232.

Thomas GA, Gibson G, Nielsen RGH, Martin WD, Radford BJ (1995) Effects of tillage, stubble, gypsum, and nitrogen fertiliser on cereal cropping on a red-brown earth in south-west Queensland. *Australian Journal of Experimental Agriculture* **35**, 997-1008.

Valzano FP, Greene RSB, Murphy BW, Rengasamy P, Jarwal SD (2001) Effects of gypsum and stubble retention on chemical and physical properties of a sodic grey Vertosol in western Victoria. *Australian Journal of Soil Research* **39**, 1333-1347.

2.5 Plant nutrients

Jai Singh

Key messages:

- An adequate supply of phosphorus and zinc improves the grain yield for wheat, chickpea, barley, canola and faba bean grown on subsoil constrained soils.
- Potassium is likely to increase the shoot growth, but not necessarily the grain yield for wheat.

Increased supplies of plant nutrients such as P, K and Zn, have been reported in the literature to increase the tolerance of various plant species to salt concentrations. We conducted glasshouse and field experiments to evaluate the effect of improved plant nutrition on the tolerance of wheat and chickpea plants to salt and/or sodicity constraints.

Two trials conducted on grey Vertosols in Coonamble (central NSW) on soils with low subsoil constraints (430 mg Cl/kg in top 1 m soil depth) and a high constraints (1100 mg Cl/kg in top 1 m soil depth) to determine the effect of application of phosphorus (P) and zinc (Zn) in alleviating the negative impact of subsoil constraints. Application of both P and Zn, in generally resulted in increased grain yield for various crop species including wheat, chickpea, barley, canola and faba bean in both low and high subsoil constrained soils (Table 2.5.1 and Table 2.5.2) However, percent increase in grain yields of various crops to applied P + Zn on a highly constrained soil was higher as compared to that on a low constrained soil. This indicates that better nutrition helps to alleviate the negative impact of subsoil constraints.

Table 2.5.1. Effect of P and Zn nutrition on a low constraint (430 mg Cl/kg in top 1 m soil depth) grey Vertosol in Coonamble (NSW)

Crop species	Control grain yield (kg/ha)	Percent increase		
		P @ 10 kg/ha	Zn @ 2.5 kg/ha	P + Zn
Barley	2445	9	-7	14
Canola	1505	16	11	22
Chickpea	1424	33	24	41
Faba bean	632	35	-14	24
Wheat	3117	23	8	35

Table 2.5.2. Effect of P and Zn nutrition on a high constraint (1100 mg Cl/kg in top 1 m soil depth) grey Vertosol in Coonamble (NSW)

Crop species	Control grain yield (kg/ha)	Percent increase		
		P	Zn	P + Zn
Barley	1585	38	8	39
Canola	858	16	37	52
Chickpea	812	9	-1	16
Faba bean	135	50	56	74
Wheat	3248	9	-7	8

A trial was conducted in controlled conditions on a low constraint (400 mg Cl/kg in top 1 m soil depth) and a high constraint (2100 mg Cl/kg) soil, to study the effect of applied P and K. There was a greater response to combined use of P and K compared with individual use of P or K (Figure 2.5.2). Further, the response to applied P and K nutrition was greater on soils with high subsoil constraint as compared to low constraint soil.

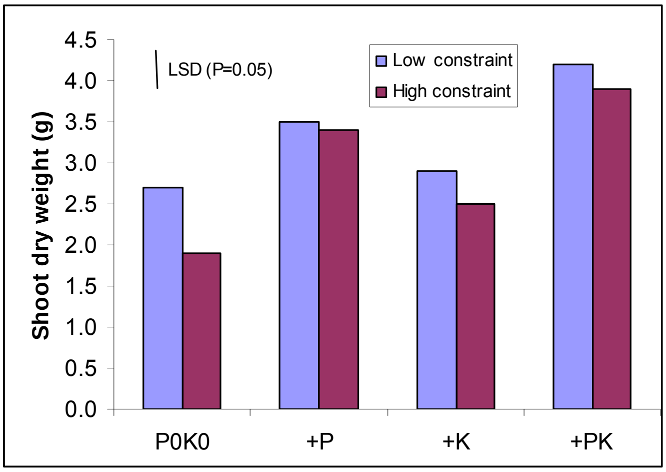


Figure. 2.5.2. Effect of applied P and K nutrition on wheat grown on a low constraint and a high constraint Vertosol.

Another trial was conducted in controlled conditions to study the effect of P and K on wheat varieties subjected to various NaCl concentrations in a glasshouse trial at Roma with brigalow/belah soil. Increased P supply increased the wheat grain yield across varieties at higher NaCl concentration (Figure 2.5.3 a), whereas increased K decreased the yield slightly for Sunco wheat variety, and had no effect on Baxter in the same glasshouse experiment. Increased supply of potassium (K) resulted in improved shoot dry matter yield (data not shown) but not grain yield in chickpea and wheat (Figure 2.5.3 b).

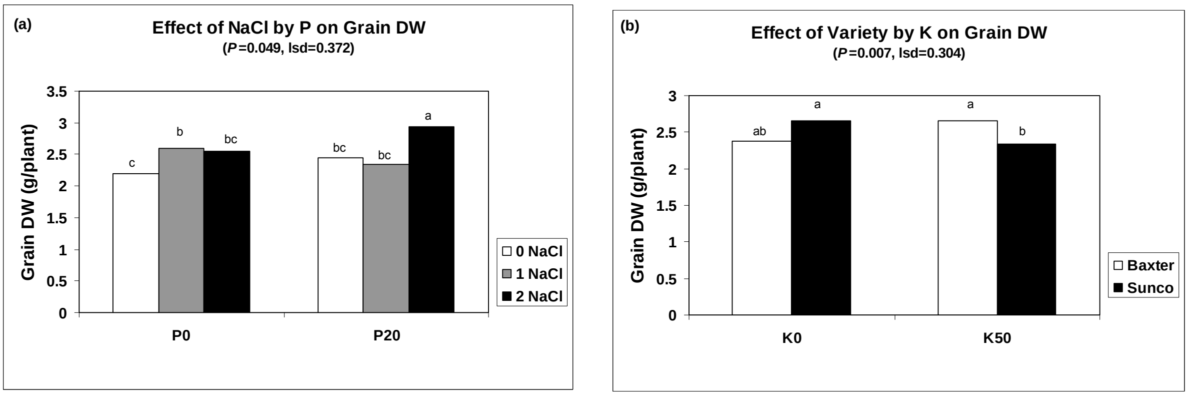


Figure 2.5.3. Effect of phosphorus and potassium applied in the subsoil (below 20cm depth) with added salts on grain yield of wheat cvs. Baxter and Sunco in a glasshouse trial.

Overall, the limited research in this area suggests that increasing supplies of plant nutrients such as P and Zn can improve grain yield of a number of crops when subjected to subsoil salinity. Even thought K uptake is impeded when excess Na is present, the application of K didn't increase grain yield in a number of crops, only an increase in dry matter yield was recorded.

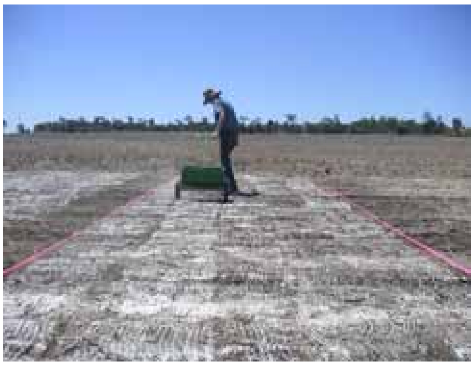
2.6 Ameliorants

Yash Dang

Key messages:

- Surface application of gypsum to topsoil (0-10 cm) with moderate to high ESP significantly increased wheat grain yield.
- Deep placement (20-30 cm) of gypsum did not affect grain yield in the first year; however, there appears to be some effect in the second year after application.

Results from previous field experiments conducted in marginal cropping areas of southern Queensland (Dalal *et al.* 2002) reported a 6% decrease in relative wheat grain yield with every unit increase in ESP above 4 in marginal cropping areas. In the present project we estimated critical levels for ESP in the surface soil for 10% reduction in grain yield. These critical ESP levels were 4.9 for durum wheat, 6.6 for chickpea, 8.6 for canola and 9.1 for bread wheat.



Surface application of gypsum in southwest Queensland

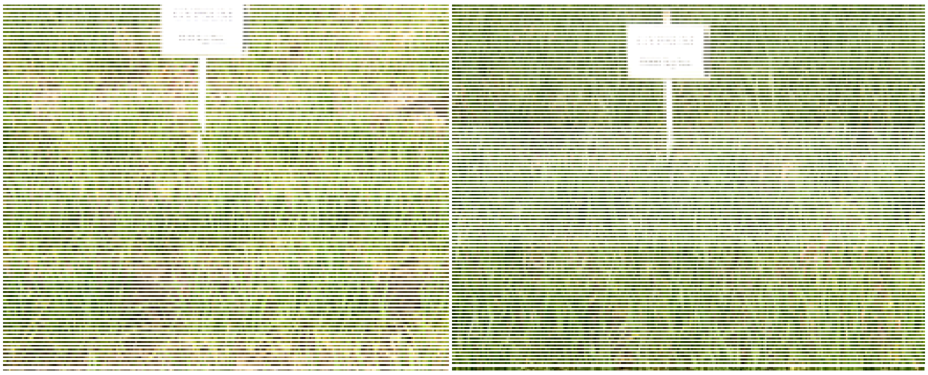
Gypsum

Surface application of gypsum at 2.5–5.0 t/ha significantly improved wheat grain yield in soils with moderate to high ESP in the top soil (Table 2.6.1). Gypsum application improves surface sodicity by flocculating soil, leading to better infiltration and the exchange of calcium for sodium.

Table 2.6.1. Effect of surface applied gypsum on grain yield of wheat cv. Baxter

	ESP (0-10 cm)	No gypsum	Gypsum 2.5 t/ha	Gypsum 5.0 t/ha	% response
SWQ 1	12.5	1447 a		1736 b	20.0
SWQ 2	8.9	1575 a	1728 b	1730 b	9.8
SWQ 3	5.6	2073 a	2109 a		1.7
SWQ 4	4.6	1681 a	1752 a	1648 a	4.2
SWQ 5	3.2	2082 a	2105 a	2073 a	1.1
NSW 1	0.8	2200 a	2200 a		0.0
NSW 2	4.1	3330 a	3310 a		0.0
CQ 1	3.0	880 a	902 a		3.0
CQ2	3.0	1400 a	1613 b		15.0

Values within a row followed by same letter are not significantly different (P=0.05)



Response to surface applied gypsum @ 2.5 t/ha in southwest Queensland

Subsurface application of gypsum did not affect the wheat grain yield in the first year of application. However, there was a significant effect in the second year after gypsum application at one site in central Queensland (Table 2.6.3). The trial is continuing. For correcting subsoil sodicity, high application rates of gypsum, sufficient rainfall and time are required. Improved subsoil drainage may also help salts to leach from the upper layers.

Deep placement of gypsum in southwest Queensland

Table 2.6.3. Effect of gypsum and deep ripping on wheat grain yield

	Wheat grain yield (kg/ha)			
	SWQ	CQ-05	CQ-06	NSW
Control	2192^a	880^a	1400^a	3330^a
Gypsum 2.5 t/ha (surface)	2208^a	902^a	1613^b	3170^a
Ripping (20-30 cm)	2352^a	1178^a	1494^{ab}	3550^a
Ripping + Gypsum 2.5 t/ha	2459^a	1107^a	1650^b	3340^a
l.s.d 5%	NS	NS	162	195

Values within a column followed by same letter are not significantly different (*P*=0.05)

Lime

Lime is another source of calcium, and the impact on grain yield was compared beside gypsum. Results show grain yield was not significantly improved in the first year with the application of 5t/ha lime, and this is most likely due to the high pH of these soils limiting solubility (Table 2.6.2).

Table 2.6.2. Effect of gypsum and lime on the grain yield of wheat

	Wheat grain yield (kg/ha)	
	SWQ	NSW
Control	1448^a	2200^a
Gypsum 5 t/ha	1737^b	2300^a
Gypsum + Lime	1633^{ab}	
Lime 5 t/ha	1579^{ab}	2200^a
l.s.d. 5%	215	NS

Values within a column followed by same letter are not significantly different (*P*=0.05)

References

Dalal RC, Blasi M, So HB (2002) High sodium levels in subsoil limits yields and water use in marginal cropping areas. (Grains Research & Development Corporation project no. DNR 6, final report)

2.7 Alternative land use

Jai Singh, Bodapati Naidu and Anthony Whitbread

Key messages:

- Use of pasture and tolerant forage crops could be one of the most important alternative land use strategies for soils with moderate to high subsoil constraints. Actively growing plants would also reduce deep drainage.
- Mostly drought/salt tolerant grass /pasture and forage species such as lucerne, buffel grass, lablab and forage sorghum are recommended for southwest Queensland.
- Shallow cropping soils (only 60-70 cm deep) with moderate ESP and Cl concentrations are generally not suitable for perennial grass/legume pastures such as bambatsi, and lucerne. Annual pasture and forage crops (medics, lablab, forage sorghum, oats) may be better suited to these soils in southwest Queensland.
- A potential alternative land use to cropping on highly constrained subsoils is commercial agroforestry using an Australian native species such as *Kalpa* (*Millettia* species).

2.7.1 Pastures

Compared with grain cropping, salt tolerant pasture, forage and fodder crops may be more successful in increasing ground cover, soil water use, and overall productivity in highly constrained subsoil areas of southwest Qld. Results from a trial conducted on a high subsoil constrained (1100 mg Cl/kg in top 1 m soil depth) Vertosol in the Roma district showed that burgundy bean and lucerne were more effective in extracting soil moisture from deeper subsoil as compared to perennial lablab, butterfly pea and *vigna* sp. Two years of Lucerne extracted almost twice the amount of moisture in the subsoil as compared to 2 years of wheat cropping (Figure 2.7.1).

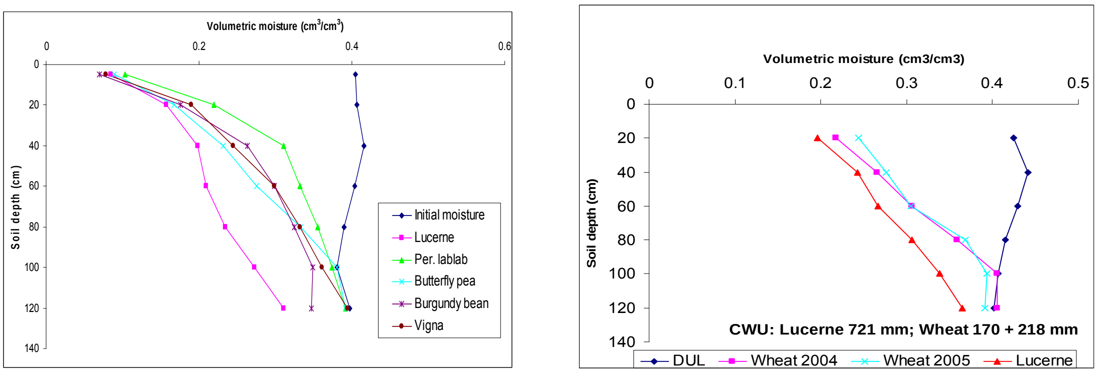


Fig. 2.7.1. Volumetric moisture extracted by various pasture species grown on a soil with moderate to high constraint subsoil in southwest Queensland.

In another trial conducted on a soil with low to medium levels of subsoil constraint, burgundy bean, butterfly pea and lablab all produced typical amounts of biomass indicating this level of subsoil constraint had limited impact on overall production. However the cumulative dry matter yield produced from lablab was significantly higher as compared to the other legumes, primarily due to quicker and sustained biomass production (Fig. 2.7.2).

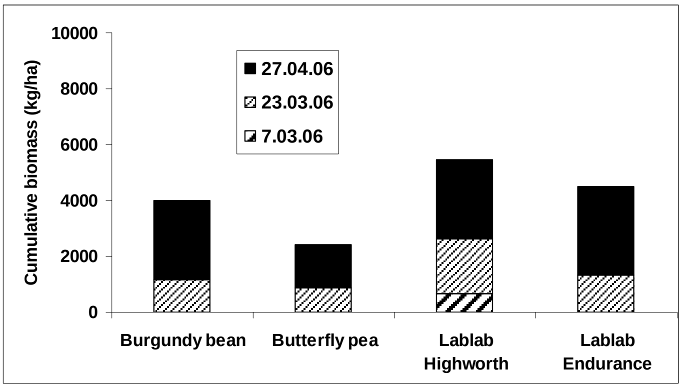


Figure 2.7.2. Cumulative dry matter yield of various pasture species grown on a soil with low to medium subsoil constraint.

Pasture species grown on moderate subsoil constrained paddock in southwest Queensland (Picture curtsey: Ms Cristine Hall)

Inclusion of annual pastures and perennial pastures were most effective in reducing the deep drainage as compared to wheat-fallow cropping rotations (Fig. 2.7.3).

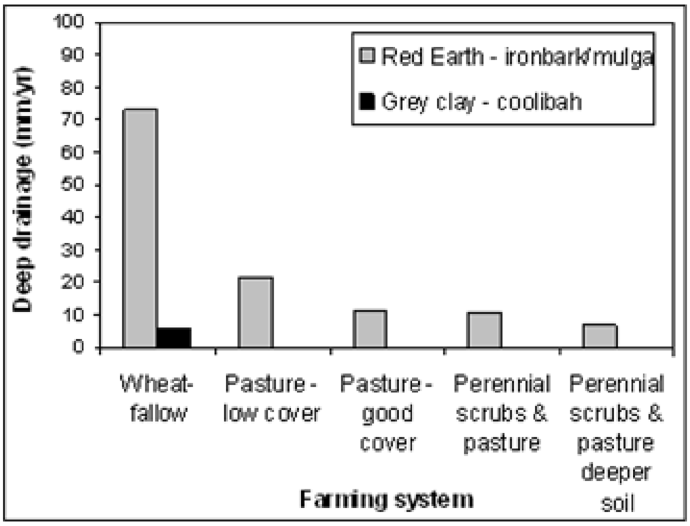


Fig. 2.7.3. The effect of land use on deep drainage near Roma, southwest Qld.

Another field experiment was conducted on a soil with high levels of sodicity in the subsoil. The results of a field experiment near Roma showed that forage silk sorghum, purple pigeon grass and Highworth lablab had greater dry matter production than other grasses and legume species. Among the most successful grass and forage crops were buffel grass, and forage sorghum, oat and lablab (Fig. 2.7.4).

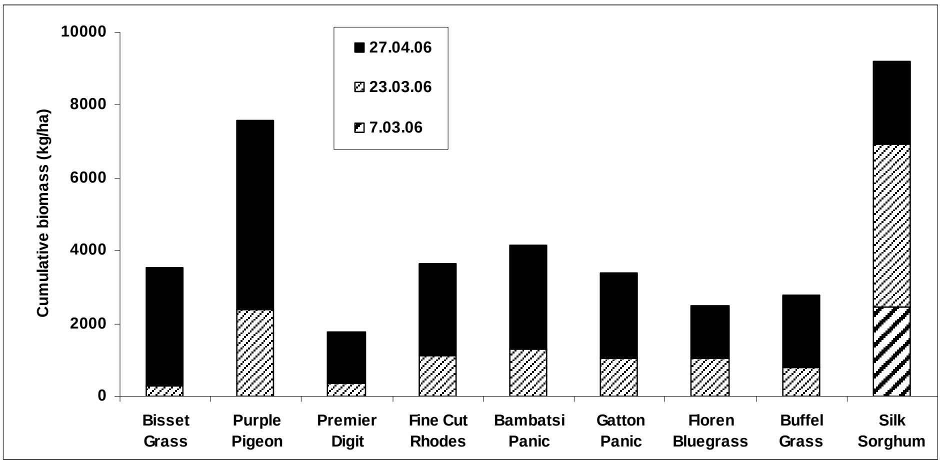


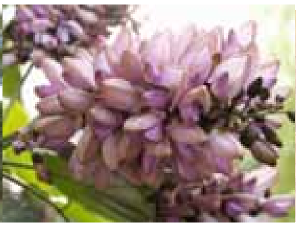
Fig. 2.7.4. Growth of various grass species and forage sorghum (Silk Sorghum), and (b) forage legumes grown on sodic subsoil near Roma.

2.7.2 Agro-forestry

A potential alternative land use to cropping on highly constrained subsoils is commercial agroforestry using an Australian native species known as *Kalpa* (*Millettia* species). Kalpa is a deep-rooted, perennial, salt-tolerant, and nitrogen-fixing tree legume. Kalpa also has some potential to sequester carbon, and produce biodiesel. Laboratory trials have been conducted to examine salt tolerance and oil production, and have proceeded into field trials of Kalpa and *Eucalyptus argophloia* as a control. These field trials commenced in April 2006 at Roma, Theodore, and Charters Towers with 3 replications in Randomised Block Design. Results have shown that:

- Young Kalpa trees are saline tolerant to about 30 dS/m (50% sea water).
- Young Kalpa trees have good frost tolerance (survived -5 °C frost at Roma).
- Kalpa also appears to be drought tolerant as the species is growing with only a few life-saving waterings. *Pongamia* tolerates water logging for several months and Australian *Millettia* might also have a similar tolerance.
- 20 to 50 kg of seed/tree has been harvested from 10-12 year old avenue-trees planted in the Brisbane City Council area. Seed oil and protein content was 29% and 35%, respectively. Assuming about 400 trees/ha (10 x 2.5m spacing) and a conservative seed yield of about 20 kg/tree/year and oil content of 25%, a plantation of Kalpa trees can produce 2000 kg (2,200 liters) oil/ha; 5-7 years after planting. 1 kg pods=0.5 kg seed (+ 0.5 kg shell)=0.125 kg oil for biodiesel + 0.375 kg oil seed cake.
- Oil seed cake contains >30% protein, which can be used as an organic manure or as animal feed.
- Kalpa trees are fast growing. A 10-year old Kalpa tree plantation is estimated to produce about 5 tonnes of wood or 10 tonnes CO_2 sequestered /ha/year.
- An assessment of energy output/input ratio of Kalpa tree is 3.01 (Energy in Biodiesel/input energy); 5.91 (Energy in Biodiesel + by-products/input energy), compared to typical ratios.

Kalpa Tree



Flower Bunches

Pods & Seed

Field Trial (Roma, Nov ’06)

3.

Dissemination of project outcomes

3.1 Training activities

Stuart Buck

The project team coordinated and delivered multiple learning activities for growers and advisers across the northern grains region. Each activity was designed to disseminate practical information to (a) raise awareness and knowledge of subsoil constraints, (b) assist growers to evaluate whether subsoil constraints are an issue on their farm, and (c) determine what can be done to manage around these issues. More than 30 action learning workshops were conducted and more than 100 presentations or discussions delivered at grower group meetings in QLD and NSW. Research data from this project has also been disseminated through the soil water and the crop sequencing ALM's presented to advisers and growers throughout the northern grains region.

This project had strong linkages with farming systems projects (EFS-NSW, WFS-Qld, WFS-NSW, CQSFS) and other groups including CFI, Namoi CMA, Border Rivers Gwydir CMA, Healthy Soils for Sustainable Farming, and Landcare groups.

3.1.1 Workshops

During 2003 and 2004, a series of action learning modules (ALM) were delivered to advisers and growers across the northern grains region. These ALM workshops were designed to increase awareness and knowledge of subsoil constraints, and assist participants to learn about several field tools that could be used easily and cheaply on-farm. Each workshop was held for a full day, and utilised action learning principles to tailor discussion items to local issues and encourage hands-on participation. Participant feedback was positive, with many indicating the workshop provided practical information in an interactive framework.

'Fabulous. Lots of information & learning, hands on. Hardest part was case studies but that was where I learn the most'

'It was very informative, gave clear and very useful information, the practical was good in demonstrating soil properties'

'Very practical and theory based, interactive, interesting'

There was however, some feedback that indicated more information is needed on management options and threshold levels (the thresholds at which different subsoil constraints reduce crop yields). Some participants were keen to also hear more about project activities and results from trial work. This feedback assisted the project team to better direct project activities, namely investigating a wider range of management options.

'Confirmed some of my thoughts and learned some new concepts, would like to have heard new/novel ways of dealing with the issue & more accurate thresholds'

'Quite good @ presentations and Prac. Not as good @ management options part'

'Some good practical information. Looking for more new information that will come out of the present trial work'

3.1.2 Field days/soil pit days

To further extend learnings that the project generated, field days were conducted and promoted amongst local networks of grower groups and agronomists. These field days usually incorporated soil pits, soil cores and demonstrations of EM technology, SSC tool kit, and equipment for measuring PAWC in the field.

3.1.3 Grower group meetings

Linking in with local grower groups was integral to the development of field sites and extension of information. The GRDC-funded farming systems projects in QLD and NSW have provided a platform to reach significant number of growers, leading to a number of presentations by the project team to these groups.

3.1.4 Presentations.

Project staff have extended research findings at other venues, particularly the GRDC update forums. Other venues include QDPI&F research station open days, and Ag Show (Toowoomba) and Namoi cotton growers bus trip. Training activities delivered by staff in the Subsoil Constraints project are listed in Table 3.1.1.

Table 3.1.1. Details of training activities delivered by staff in the Combating Subsoil Constraints project.

What	Audience	Details	State	Region	Location	Number	When
Workshops	Advisors	SSC ALM	QLD	CQ	Moura	1	2003
					Emerald	2	2004
					Biloela	1	2004
			QLD	SWQLD	Goondiwindi	1	2003
					Goondiwindi	2	2004
					Dalby	1	2004
					St George	1	2004
	Advisors	SSC ALM	QLD	SQLD	Toowoomba	1	2006
	Growers	Soil water	QLD	SQLD	Qld	5	2004-2007
					NSW	7	
	Growers	SSC ALM	QLD	CQ	Mackay	4	2005
				SWQLD	Goondiwindi	1	2006
					Wallumbilla	1	2006
				NNSW	Rowena	1	2006
					Pine Ridge	1	2006
					Garah	1	2006
	Growers and advisors	SSC ALM	QLD	SQLD	Goondiwindi	1	2006
					Dalby	1	2006
					Mutdapilly	1	2006
	Growers	Field workshop	QLD	SW QLD	Roma	1	2004
					Goondiwindi	1	2004
	Growers	Workshop	QLD	SWQLD	St George	1	2004
	GRDC	w/s & field day	QLD	SWQLD	Roma	1	2004
	Growers	Landcare groups	QLD	SQLD	Dalby	1	2004
					Brigalow	1	2004
	Growers	Farmlink	NSW	SNSW		4	2005
Field day	Growers and advisors	WFS and CQ SFS	QLD	CQ	Mulga View	1	2003
				SWQLD	Goondiwindi	1	2004
					Roma	1	2004
					Theodore	1	2005
					Goondiwindi	1	2005
					Roma	1	2005
	Growers and advisors	NSW growers	NSW	WNSW	Walgett	1	2003
					Armatree	1	2003
				NNSW	Garah	1	2005
					Bellata	1	2005
	Growers and advisors	NSW growers	NSW	WNSW	Walgett	4	2003-2005
					Coonamble	4	
	Growers and advisors	NSW growers	NSW	NNSW	Garah	1	2006
					Spring Ridge	1	2006
Soil pit day	Growers and advisors	CQ SFS	QLD	CQ	Jambin	1	2004
					Kilcummin	1	2006
					Capella	1	2006
					Dysart	1	2006
					Gindie	1	2006
					Theodore	1	2006
					Wowan	1	2006

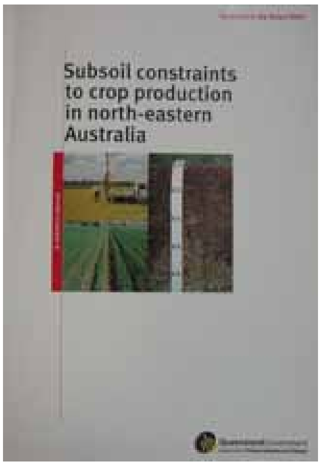
What	**Audience**	**Details**	**State**	**Region**	**Location**	**Number**	**When**
Group meetings	Growers	WFS	QLD	SWQLD	Wallumbilla Muckadilla St George Billa Billa	1 1 1 1	2002 2002 2002 2002
	Growers	CQ SFS	QLD	CQ	Dysart Capella Emerald Gindie Theodore Wowan Baralaba Theodore Theodore Jambin	1 1 1 1 1 1 1 1 1 1	2003 2003 2003 2003 2003 2003 2003 2005 2006 2006
	Growers	WFS	QLD	SWQLD	Rockycrossing Nindigully Et Nindigully W	1 1 1	2003 2003 2003
Presentations	Growers	Ag Show	QLD	SQLD	Toowoomba	1	2003
		RS open day	QLD	SWQLD	Roma	1	2003
		GRDC update	QLD QLD NSW NSW NSW QLD QLD QLD QLD NSW NSW	SWQLD SWQLD NNSW NNSW CNSW SQLD SQLD SQLD SQLD CNSW CNSW	Goondiwindi Westmar Moree Narrabri Nyngan Goondiwindi Goondiwindi Goondiwindi Mungindi Dubbo Dubbo	1 1 1 1 1 1 1 1 1 1 1	2004 2004 2005 2004 2005 2005 2006 2007 2006 2004 2007

3.2 Resource materials produced

Yash Dang

The following resource materials and tool kits were developed by the subsoil constraints project team.

3.2.1 Reference manual: "Subsoil constraints to crop production in north-eastern Australia" (Published by Queensland Department of Primary Industries & Fisheries)



Subsoil constraints
to crop production
in north-eastern
Australia

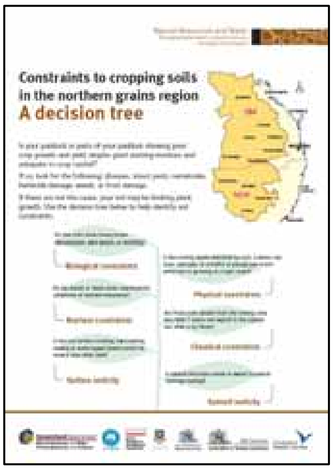
This manual aims to provide a comprehensive summary of our current knowledge about subsoil constraints, in particular:

- the key soil processes involved in the development of subsoil constraints, and that are affected by subsoil constraints
- how subsoil constraints impact on crop productivity
- procedures to identify areas with subsoil constraints
- options to improve management on subsoil constrained sites

This manual accompanied workshops that included topics on:

- gauging the impact of subsoil constraints in the participants' local area
- how subsoil constraints are formed
- physical, chemical and biological processes on which subsoil constraints impact
- a hands-on session reviewing in-field soil testing procedures
- a group review of case studies from subsoil constrained paddocks
- facilitated discussion of management options

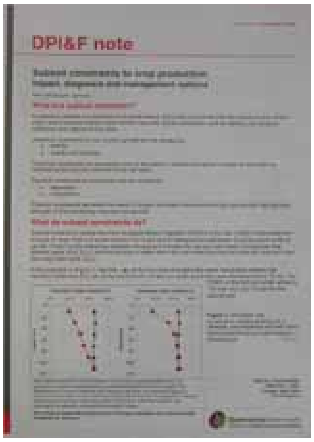
3.2.2 Decision tree: Constraints to cropping soils in the northern grains region: A decision tree. (Published by Queensland Department of Natural Resources & Water and GRDCon-line)



Constraints to cropping soils
in the northern grains region
A decision tree

The 'decision tree' was developed to help northern region grain growers to identify and manage topsoil and subsoil constraints to cropping. It contains useful, easy-to-read information on biological, nutritional, physical and chemical constraints, and enables readers to work through tests for possible constraints to determine which ones may be operating on their property or paddock. The decision tree is available online at (http://www.grdc.com.au/growers/res_summ/dnr00004.pdf).

3.2.3 Crop note: Subsoil constraints to crop production: impact, diagnosis and management options. (Published by Queensland Department of Primary Industries & Fisheries).



DPI&F note

The crop note provides information on the diagnosis of subsoil constraints, and discusses their impacts on crop production. It also provides useful information on selecting good agronomic options to manage subsoil constraints.

3.2.4 Tool kit manual: An instruction booklet for assembling and using a tool kit for identifying subsoil constraints in Australia's northern grains region. (Published by Queensland Department of Natural Resources & Water)

The soil testing tool kit has been designed to enable farmers and advisers to correctly identify the subsoil constraints that affect crop production in many parts of the northern grains region. It can be used in other regions of Australia as well to identify and assess the potential extent of soil constraints.

The tool kit manual describes the contents of the tool kit and how to use them to test for, and in some cases quantify, the presence of subsoil constraints. It also aims to provide sufficient information for interested persons to construct their own test kit using equipment purchased from scientific instrument suppliers.

For more information and to obtain a copy of these publications please contact:
Qld Department of Natural Resources and Water,
Call Centre Ph. 13 13 04 Email enquiries@nrw.qld.gov.au

Qld Department of Primary Industries and Fisheries,
Call Centre Ph. 13 25 23 Email callweb@dpi.qld.gov.au

NSW Department of Primary Industries- Tamworth
Ph. 02 6763 1100

The Manager,
Extension and Grower Programs
Grains Research and Development Corporation
PO Box 5367, Kingston ACT 2604
Phone: +61 2 6272 5525 Fax: +61 2 6271 6430
Web: www.grdc.com.au

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3.3.1. Manuals, booklets and other reports

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4.
Evaluation

4.1 Evaluation of project impact

Stuart Buck

Key messages:

- Large numbers of growers and advisors throughout northern grain region have participated in project activities.
- The project has increased knowledge of identification and impacts of subsoil constraints, with advisors gaining more knowledge than growers.
- In 2003 39% of growers and 68% of advisors indicated they manage soils with subsoil constraints differently to those without. In 2007 these responses have significantly increased to 68% of growers and 90% of advisors.

At the commencement of the project (2003), a survey was undertaken to benchmark growers' and advisors' knowledge, attitudes, skills, aspirations and practices relating to subsoil constraints. A total of 421 growers and 93 advisors in the northern grains region responded to this survey. During the last 6 months of the project (2007) a final project survey was conducted in the same geographic location. A total of 392 growers and 49 advisors responded to this survey. Comparing the 2007 results to the 2003 survey provides information to help determine the impact of the project.

4.1.1 Stakeholder involvement

The project has conducted a number of activities involving stakeholders, namely action learning workshops, field days and presentations (see section 3.1 for details). Stakeholder involvement in these activities over the project term was gauged in the final survey. Compared to growers, a greater proportion (P<0.001) of advisors have 'participated in workshops, field days' and fewer had 'never heard of the project' (Table 4.1.1). This shows that advisors were more likely to have heard about the project, and also be more actively involved in it.

Table 4.1.1. Level (%) of involvement in the project by stakeholders.

Involvement	Total	Growers	Advisors
Never heard of the project	32	36	6
Have heard, but never participated	37	38	29
Participated in w/s, field days	23	19	55
Actively involved	6	6	6
Other	2	1	4
Number of respondents (n)	435	386	49

4.1.2 Awareness of subsoil constraints

In 2003, a greater proportion (P<0.001) of advisors than growers responded that SSCs were 'somewhat of a problem' with fewer responding 'small problem' and 'not a problem' (Table 4.1.2). However, very few growers and no advisors responded that subsoil constraints were 'not a problem', indicating subsoil constraints are thought to be a problem in just about all districts of the northern grains region. Overall, only 15% of each group were unsure of the severity of SSC in their region, indicating there was a high level of awareness of subsoil constraints by both groups at the time of the survey.

Table 4.1.2. Awareness (%) of subsoil constraints in 2003 versus 2007.

	2003		2007	
Problem level	**Growers**	**Advisors**	**Growers**	**Advisors**
Not a problem	7	0	15	0
Small Problem (0-10% of land affected)	26	8	31	11
Somewhat of a problem (10 – 50% of land affected)	32	62	28	79
Major problem (50 – 100% of land affected)	20	15	13	11
Not sure	15	15	14	0
Number of respondents (n)	421	93	385	47

The 2007 survey results show a greater proportion ($P<0.001$) of advisors responding 'somewhat of a problem' compared with growers (Table 4.1.2). This is the same as the 2003 response, indicating that most advisors still believe subsoil constraints affect between 10 – 50% of land in their districts. A larger proportion of growers in 2007 believe less land is affected by SSC than the proportion of advisors (Table 4.1.2) which is also a similar trend to the 2003 responses.

Although there were no other differences in responses between the two survey periods (2003 and 2007), it is worth noting the proportion of advisor respondents indicating ‘not sure’ (from 15% to 0%) during this time (Table 4.1.2). This indicates an increase in awareness of subsoil constraints by this group, as no advisors in 2007 were unsure about whether subsoil constraints were a problem in their area.

4.1.3 Knowledge of subsoil constraints

4.1.3.1 Overall knowledge of subsoil constraints

The end of project survey asked stakeholders to rate how their knowledge of subsoil constraints had changed over the last 5 years. Compared to advisors, a greater proportion ($P<0.05$) of growers had indicated that their knowledge hasn't improved in all areas (Table 4.1.3). A greater proportion of advisors indicated that their knowledge had improved moderately for 'the cause of various SSC', and improved a lot for 'the impact of SSC on crop performance’ (Table 4.1.3). The impact gap between growers and advisors reflects the project strategy of directly targeting advisors through the action learning workshops, with the anticipation that information would then flow to a large number of growers.

Table 4.1.3. Responses (%) to four areas of subsoil constraint knowledge.

Areas:	**Hasn’t**		**Slightly**		**Moderately**		**A lot**	
	Growers	**Advisors**	**Growers**	**Advisors**	**Growers**	**Advisors**	**Growers**	**Advisors**
The cause of SSC	13	2	39	29	28	48	19	21
Which SSC are present	20	2	33	33	26	39	21	26
SSC impact on crop performance	17	0	30	26	35	36	18	34
Ways of managing soils with SSC	17	2	36	36	30	43	18	19

4.1.3.2 Knowledge of the occurrence of subsoil constraints.

In 2003, the response to whether subsoil acidity was a problem was independent ($P<0.10$) of the group. The response to whether subsoil alkalinity, high bulk density, salinity, sodicity and nutrient deficiency were problems was related ($P<0.001$) to the group, with a greater proportion of advisors making a ‘yes’ response compared with farmers (Table 4.1.4). In addition, for nutrient deficiency and sodicity, fewer advisors responded with ‘unsure’ compared with growers (Table 4.1.4).

Table 4.1.4. Responses (%) to whether particular constraints were a problem on their property/district.

Constraints	Yes				No				Unsure			
	Growers		Advisors		Growers		Advisors		Growers		Advisors	
	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007
Salinity	22	28	71	72	49	56	9	19	30	16	20	9
Sodicity	42	46	85	88	26	32	0	8	32	22	15	4
Acidity	10	17	16	24	49	59	39	60	42	24	45	17
Alkalinity	24	25	48	39	32	49	12	36	44	26	40	25
High bulk density	31	46	48	52	21	27	8	17	43	27	44	30
Nutrient toxicity/def	42	62	77	77	18	20	1	11	40	17	22	11

In 2007, a greater proportion of advisors believed that nutrient toxicity/deficiency (P=0.094), salinity (P<0.001) and sodicity (P<0.001) limit crop yields in their district compared to growers. The response to acidity, alkalinity and high bulk density was independent (P>0.10) of group (advisor or grower), indicating no difference between how each group responded for these constraints (Table 4.1.4).

Comparing the 2007 results to 2003, there were no significant differences in the responses from the two surveys, except for acidity, where there was weak evidence (P<0.10) that the proportion of unsure responses had reduced, particularly with advisors (Table 4.1.4). Even though differences between the sampling times (2003 Vs 2007) are not statistically significant, there is an overall indication that both groups are more confident in their knowledge of SSCs. This is evidenced by the lower proportional trend of unsure responses in 2007.

4.1.3.3 Knowledge of the impacts of subsoil constraints.

Responses in 2003 to the question of whether subsoil constraints increase disease risk or can be successfully managed were independent (P>0.10) of the group (grower or advisor) with approximately half agreeing and half unsure (Table 5). Also, responses to whether subsoil constraints reduce profitability was independent (P>0.10) of the group with approximately 85% agreeing (Table 4.1.5). Responses relating to the impact of SSCs on plant available water, rooting depth, sustainability, yield and difficulties in managing were dependent (P<0.05) of the group with a greater proportion of farmers being unsure (and fewer agreeing) compared with advisors (Table 4.1.5).

Table 4.1.5. Responses (%) on the impact of subsoil constraints.

Constraints	Agree				Disagree				Unsure			
	Growers		Advisors		Growers		Advisors		Growers		Advisors	
	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007
Limit plant rooting depth	82	84	98	98	2	4	0	0	16	12	2	2
Reduce PAW	80	83	98	94	3	3	0	4	17	13	2	2
Can be successfully managed	52	66	52	67	3	3	1	6	46	31	47	27
Reduce crop yield	83	91	92	96	2	2	4	0	15	7	3	4
Reduce profitability	85	90	86	83	3	1	5	2	12	8	9	15
Reduce sustainability	53	72	67	45	9	10	14	26	39	18	18	30
Increase disease risk	34	42	33	38	12	19	12	21	54	40	55	42
Make management more difficult	74	82	87	89	6	9	2	4	20	9	11	6

In 2003 a high proportion of both groups agreed that SSCs 'limit plant rooting depth' and 'reduce PAW', and this level of agreement were maintained in 2007 (Table 4.1.5). However more growers in 2007 were unsure whether SSC 'limit rooting depth', 'reduce PAW', and 'can be successfully managed' compared to advisors (table 5). More growers agree that subsoil constraints 'reduce sustainability', whereas more advisors are unsure if subsoil constraints 'reduce sustainability' (Table 4.1.5).

Comparing 2007 results to 2003, a lower proportion of growers in 2007 are unsure if subsoil constraints 'limit plant rooting depth', whereas a lower proportion of both groups are unsure if subsoil constraints 'increase disease risk' and 'make management more difficult' (Table 4.1.5). These results indicate a change in knowledge by both groups, as fewer growers and advisors are unsure about the impacts of subsoil constraints.

4.1.4 Management of subsoil constraints

In 2003, a significantly higher proportion (P>0.001) of advisor respondents (68%) compared to grower respondents (39%) indicated they manage soils with subsoil constraints differently to those without (Table 4.1.6). In 2007 these responses have significantly increased, with 68% of grower and 90% of advisor respondents indicating they manage soils with subsoil constraints differently to those without (table 4.1.6). In comparison to the growers surveyed, the proportion of advisors in 2007 whose clients were managing soils with subsoil constraints differently to those without is still significantly higher (P<0.001) Table 4.1.6).

Table 4.1.6. 2003 and 2007 responses (%) to managing soils differently with subsoil constraints than soils without.

	Growers		Advisors	
	2003	2007	2003	2007
Yes	39	68	68	90
No	49	13	12	0
Don’t have SSC	12	19	1	2
Don’t advise on SSC	na	0	19	8
Number of respondents (n)	421	385	93	49

The 2007 response that 90% of advisors (Table 4.1.6) manage soils with subsoil constraints differently to soils without is in contrast to the results in Table 4.1.5, where 27% of advisors were unsure if subsoil constraints could be successfully managed. Presumably this is because many advisors feel the need to do something about SSC, but some are unsure about the longer term success. The grower response to this issue was somewhat different: in 2007, with 68% of growers managing soils with subsoil constraints differently to those without. This was in agreement with the result in table 4.1.5, where 31% were unsure if subsoil constraints can be successfully managed.

Of the growers who were managing soils with subsoil constraints differently, a range of techniques were used, including selecting tolerant crops/varieties; zero/minimum tillage; different fertiliser programs; deep ripping and replacing cropping with pastures. The range of techniques being advocated by advisors included: crop and variety selection, including crop rotations; adjusting yield predictions and inputs (fertiliser, seeding rate) based on severity of subsoil constraints; quantifying zones where differences occur and managing inputs within them; adjusting enterprise selection (cropping vs pasture vs trees) depending on subsoil constraints severity and crop profitability; and ameliorating sodicity problems with gypsum.

Conclusions

At the commencement of the project, many growers and advisors were already aware of how much land is impacted by subsoil constraints and which constraints occurred in their districts. This level of awareness over the last 5 years is broadly unchanged. A large number of growers and advisors have participated in project activities, however there has been a larger impact on advisors compared to growers. Increases in knowledge of the types of subsoil constraints present and the impacts are apparent.

In 2003, a large number of both groups, particularly advisors were managing soils with subsoil constraints differently to soils without. By 2007, significantly higher number of growers and almost all advisors are managing soils with subsoil constraints differently to those without however, about 30% of both groups are unsure if subsoil constraints can be successfully managed in the long term.

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5.
Grower Case Studies

Russ Boadle and Bernie Reppel

Soil tests key to chloride management

Neville Boland, Goondiwindi, Southwest Queensland

Confronted with patches of severely stressed and unproductive chickpeas where soil cores indicated there was ample moisture under the crop, Neville Boland was looking for answers.

Neville and Penny Boland farm 1215 hectares of their 1487 ha Goondiwindi district property ‘Mandama’ in conjunction with another 1822 ha Moonie district grain property.

Neville Boland believes identifying and measuring patches of subsoil constraints has provided confidence in the future productivity of his grain enterprise.

Neville said he began share farming Mandama in 1999 introducing zero till and Controlled Traffic Farming to mainly target grain sorghum and wheat but leaving the crop rotation window open for other seasonal opportunity crops.

The questionable performance of winter chickpeas on Mandama first became an issue in 2002.

“A portion of one paddock planted to chickpea was never harvested whereas the balance of the crop and adjoining paddocks delivered quite acceptable yields,” Neville said.

“Ensuing investigations revealed a gypsum layer at 50-70 cm depth under the failed crop and the subsoil was quite wet below this level.

“This left us to assume the gypsum layer was creating a subsoil constraint limiting crop root development.

“That assumption proved unfounded as under the successful chickpea crop, the tap roots had gone through the gypsum layer and utilised available soil moisture to a depth of 1.2 m,” Neville said.

A timely subsoil constraints grower meeting was convened by Department of Natural Resources and Water soil scientist Yash Dang on a neighbouring property, which subsequently provided the answer to the poor chickpea performance.

“Soil tests showed that electrical conductivity went off the scale caused mainly by high soil gypsum and high chloride,” Neville said. High chloride levels were found in the areas where chickpeas failed.

“Our next step was to engage a consultant and conduct an EM38 survey across the whole farm to measure and identify the patches of sub surface soil chloride to a depth of 1.5 m. An EM38 is a sled-mounted device used to measure soil electrical conductivity”. The high chloride patches closely matched the areas where chickpeas had failed.

Neville said that where there were high EM38 readings, these sections of the paddock were now restricted to wheat, barley and sorghum crops which can tolerate the chloride and salt which form a subsoil constraint.

Where sodicity is an issue, Neville avoids planting the less tolerant chickpea and mung bean leguminous crops.

To help manage the main subsoil constraint, Neville said he was maintaining the zero till approach which was steadily increasing water penetration and successfully washing the chlorides deeper into the soil profile beyond the root zone.

“Where we have identified subsoil constraints, we still apply starter fertiliser but have reduced the nitrogen (urea) fertiliser application as it was not being fully utilised.

“These paddocks always yield a little less than the unconstrained soils and the impact on productivity is greater during a dry growing season.”

Cropping on Mandama has come a long way since 2002 and with confidence in the future productivity of this grain growing enterprise, Penny and Neville purchased the property in 2004.

Neville said to fully appreciate the actual chloride levels in the subsoil and the depth at which they occurred, comprehensive soil testing has been undertaken to provide an accurate assessment of all components rather than a reliance on conductivity readings alone.

The Boland family have been involved in on-farm trials involving the Department of Primary Industries and Fisheries, NRW and CSIRO and have taken positive action by applying the adage – “If you can’t measure, you can’t manage”.

Inspecting a soil pit for on-farm identification of subsoil constraints at Mandama.

Revise crop options for constrained soils

John Nolan, Wallumbilla (Roma), Southwest Queensland

Low water use efficiency of grain crops was the initial indicator of a potential subsoil constraint on some of John Nolan's heavy clay brigalow-belah farming country.

John and Elizabeth Nolan operate a 3645 hectare Roma district cattle and grain property, Bindaroo, where some 1620 ha has been developed to grow forage crops, hay and grain.

John Nolan believes that association with the subsoil constraints project has led to revising crop options, improved water use efficiency and profitability on his grain and cattle property.

John acknowledges that a degree of salinity in 1 metre deep brigalow soil types throughout the Maranoa region was an accepted and natural component of the overall package.

Some years ago following a wheat crop, John noted there was still considerable moisture and unutilised nutrients left in the soil profile. The realisation that there was a possible subsoil constraint problem on 810 ha of the heavier soil type selected for grain production prompted further investigation.

Further observations showed that chickpea crops grown under a zero till and Controlled Traffic Farming system on Bindaroo were accessing soil moisture to 600 mm deep whereas wheat was extracting moisture to a depth of 800-900 mm.

When regional members of the Top Crop Group were each called on to nominate a problem paddock to undertake on-farm cropping trials, John selected the wheat paddock where the crop water use efficiency was questionable.

Soil testing identified salinity barriers as the main subsoil constraint and trial work was set in motion to gauge the comparative performance of wheat, sorghum, barley, Durum wheat, chickpea, canola and lucerne.

John said he had undertaken extensive soil testing coupled with aerial electromagnetic surveillance to identify and measure the extent of the constrained soils. "It was envisaged the electromagnetic survey could be used as a quick reference to plot the cultivation areas with the higher salinity constraints but it proved difficult to identify the difference between the salts and wet clay," John said.

"It was necessary to soil test to further ground truth these results – a costly and difficult exercise – that ultimately provided the essential information."

"Where we have mapped and measured the high electrical conductivity readings, we have a clear indication of what we can and cannot grow to make a profit and we do not waste money by trying to grow a sensitive crop such as chickpeas."

John said he found a simple but effective way of identifying the extent of the subsoil constraint was to set up neutron probe sites to provide an indication of how deep the crop roots were able to access moisture.

Going back to the Top Crop trial, it was the lucerne that did well relative to the other crops.

Growers and GRDC northern panel members inspecting cropping options at Bindaroo

In a paddock adjacent to the trial area, John planted dryland lucerne as a rotational cropping option to address an on-going wheat crown rot problem, reduce the underlying soil moisture and provide a high protein cattle feed.

For two years, the lucerne was grazed and forage cropped and despite unfavourably dry seasonal conditions, it delivered the most economical return of all the trial crops.

“It is our intention to plant more lucerne for weed control in our grain cropping rotation and because of its nitrogen fixing ability, it will contribute toward improved soil fertility,” John said.

Trial work was still progressing on Bindaroo to improve water use efficiency in the grain growing paddocks but planting wide rows had not been the answer.

Where there are identified subsoil constraints that impact on crop performance, John no longer plants grain.

The Nolan family also farm 800 ha to grow forage sorghum and oats for their cattle breeding and finishing business in conjunction with commercial hay production.

Depending on seasonal conditions and demand, home-bred cattle are sold as weaners or taken through to domestic slaughter weight off oats as two-year-olds or held for the heavyweight Jap ox market. When the opportunity prevails, weaners are also purchased to be crop or pasture finished.

Subsoil constraints knowledge simplifies crop management

Joe Reddy, Wowan Central Queensland

Callide Valley grain grower Joe Reddy has always been aware of differing crop performance on some of his lighter red brigalow soils and now he understands why.

Joe and his wife Rhonda are principals of Dixalea Farming Company and operate a successful 890 hectare mix of irrigated lucerne, dryland grain and a composite beef breeding herd in the Wowan district.

When approached by the project, Joe Reddy didn't hesitate to investigate the crop performance impacts of subsoil constraints on his property.

As an active co-operator member of the Central Queensland Sustainable Farming Systems Project group for more than a decade, Joe has been a willing convert to zero till technology and Controlled Traffic Farming.

When Department of Primary Industries and Fisheries soil management research scientist Stuart Buck sought the Reddy's cooperation to investigate subsoil constraints (SSC) impacting on crop performance, there was no hesitation.

Joe farms 324 ha of dryland cultivation and up to 35 ha of irrigated lucerne.

Test drilling on Dixalea's heavy Callide alluvial soils showed they were more than 2 metres deep with an exceptional water holding capacity ideally suited to both lucerne and grain production. This soil has no physical or chemical constraints to limit the uptake of plant nutrients or restrict the availability of water to the plant root system.

When assessing the lighter red brigalow soil cultivation country, soil tests identified sodicity as a subsoil constraint in clearly identifiable bands across some areas of cultivation.

As sodicity causes clay particles to swell and disperse when wet, they can form a packed layer anywhere in the top 1 m of soil creating a physical barrier to crop root penetration which in turn limits the soil's water holding capacity.

Joe said aerial photographs highlighted the constrained subsoil bands which showed up as a lighter colour.

"I now have a better understanding of SSC so I can now manage the issue with confidence," Joe said.

“For example, if our grain sorghum crop was moisture stressed due to a dry finish, I would start harvesting on the known SSC soils where the crop would be most prone to lodging.”

Joe said another observation regarding the sodic soil bands was that because of the lighter soil texture and shallow depth, both the weed pressure and weed species differed from the other soils.

“The weed population tends to be heavier with a greater percentage of grass weeds that tend to get away quickly.

“Now I know what I am dealing with, I can manage these known SSC areas by spraying earlier to keep weeds in check,” Joe said.

“In the brigalow soil paddocks, the limited areas impacted by SSC have no influence on my crop choice.”

Joe is a committed opportunity farmer – if the subsoil moisture is available, he will plant wheat, chickpeas, sorghum or mung beans in the seasonal planting window.

Provided there was adequate in-crop rain to keep the moisture profile topped up in the SSC affected cultivation, he said there was no discernable difference in growth or grain yield.

Joe surmises that knowing exactly where the SSC soils were within each cultivation paddock could lead to a potential cost-saving spin-off with the future development of computerised variable fertiliser application technology. He believes growers could probably reduce fertiliser and seeding rates on the shallow constrained soils.

Wowan district grain grower Joe Reddy is an opportunity farmer with an understanding of how to manage his limited cultivated areas of sodic soils.

Time and zero till tackles sodicity

Lex Webb, Baralaba, Central Queensland

After just 20 mm of rainfall, Baralaba landholder Lex Webb said some parts of the family's 2200 hectare grazing and grain property, Belvedere, would be covered in pooled water making it appear more like an 80 mm fall.

> ***Lex Webb believes the 110 per cent support offered by staff from the Combating Subsoil Constraints Project was a major influence that has enabled them to identify and successfully manage the limitations imposed by subsoil constraints.***

A follow-up soil probe would clearly show there was minimal soil moisture intake where this pooling occurred on the heavy brigalow clay soils that tended to seal off after rain.

For Lex Webb, that was an initial indication there could be an underlying problem associated with indifferent crop performance in identifiable sections of the affected paddocks.

The Webb brothers Lex and Lester farm 700 ha of the predominantly heavy brigalow clay soil targeting spring/summer crops of grain sorghum and mung beans and winter wheat and chickpeas.

Ten years ago thanks to their project involvement with the local Sustainable Farming Systems Group, soil tests showed there was sodicity at 200 mm down to 600 mm depth.

Lex said it was evident that as the cultivation was worked up, it just exacerbated the surface sealing and the poor water infiltration of the heavy clay soil, hence wasn't allowing crop roots to reach their full potential.

"Even though some country has been cultivated for 35 years, the subsoil constraints are most obvious on previously melon-holed country," Lex said.

The Webb family were immediate converts to zero tillage and Controlled Traffic Farming nine years ago, and this technology has made cropping viable in the face of tough seasonal conditions.

"There is no doubt that zero till is contributing to improved moisture penetration in our sodic soils, helped by the protective stubble cover and a notable increase in plant rooting depth.

"The deeper root systems are ultimately helping to lift the water holding capacity in our problem soils.

"We also embarked on targeted fertiliser programs with nitrogen, phosphate and various blends containing zinc and sulphur but the resultant crop response did not deliver in terms of dollars invested."

Lex said that while basic fertiliser rates were still applied, it was not a top priority.

“Now that there is greater root penetration in the constrained soil, we suspect current crops are actually tapping into a nutrient bulge under the sodic layer.

“It is also apparent that even with a dry seasonal finish, zero till crops on our sodic soils can now access enough soil moisture to set a reasonable yield,” Lex said.

Lex said the farming policy was to opportunity crop when there was available moisture but it was also important to rotate crops to maintain stubble cover and boost organic matter in the long term.

“Our rotational preference is to plant grain sorghum followed by chickpeas and then put the paddock back to mung beans followed by wheat.

“To improve the microbiological balance in our brigalow soils which are continually subjected to herbicide applications under zero till, we are currently setting up a nutrient injection system on our planter to be used this summer.”

Lex was adamant that the 110 per cent support offered by the Department of Primary Industries and Fisheries extension officers was a major influence that had enabled them to identify and successfully manage the limitations imposed by subsoil constraints.

To support Belvedere’s cattle breeding operation which targets the premium return EU market, forage oats are cropped and grazed in conjunction with a grain feeder.

They also plant forage sorghum annually which is ensiled into pits and used to supplement weaners and growing cattle to take seasonal pressure off their pasture.

An email changed practices at Garah

Andrew Crowe, Garah NSW

Andrew Crowe has changed his crop sequence, stopped using long fallows and shortened the interval between crops on 1120 hectare Sunbury, at Garah.

And all because he read an "Australian Grain" magazine article by CSIRO specialist salinity scientist Dr Rana Munns, about her research into improving the salt tolerance of durum wheats.

Andrew Crowe believes that local growers are now able to make better use of PAW and maximise production on their country with subsoil constraints thanks to the EFS/SIP08 projects.

One thing led to another and Sunbury became a major site for Eastern Farming Systems and Subsoil Constraints (SIP08) research into subsoil constraints

"We emailed Dr Munns in response to the article she had written, because we were not getting good results from the farm and weren't sure what the problem was," Andrew said.

"In the end all we had to do was provide the land and work around the trial blocks; the scientists and their teams did all the work."

"They put in a huge amount of work and resources."

"Dr Munns and (NSW DPI durum wheat breeder) Ray Hare did a lot of work with durum wheats and the EFS/SIP08 team looked at lentils, chickpeas, fieldpeas, faba beans, canolas, mustards, linseed, bread and durum wheats, triticale and barley over a couple of hectares."

Andrew and his wife Jodie sharefarm Sunbury, where the EFS/SIP08 subsoil constraints research was carried out. It's heavy, self-mulching black soil, cropped for about 30 years and bought by the current owners in 1999.

Yield variation led Andrew to organise an electro-magnetic survey by George Truman formerly of NSW Department of Infrastructure, Planning and Natural Resources, which more or less pinpointed the areas with salinity/subsoil problems.

From them NSW DPI soils scientist Graeme Schwenke selected sites with and without subsoil constraints for the EFS/SIP08 trials.

“One take home message from all the work on Sunbury is that, because our soils can hold so much water, even if plant accessible water only goes down 50 centimetres, it is still a pretty good bucket,” Andrew says.

“In some areas there is over a metre deep of plant available water (PAW), in those with more subsoil constraints around 50 centimetres. But combined with our annual rainfall they will still grow a good crop”.

“And we know barley will do a better job than wheat – and sorghum for that matter – of extracting water from high chloride soils.”

Andrew says he learned a lot from the EFS/SIP08 trials, and so did other growers in the area, as there have been a number of well-attended field days.

He believes that local growers are now able to make better use of PAW and maximise production on their country with subsoil constraints.

Eight or so years ago there had been a lot of long fallow out of sorghum around Garah, while now there is more double cropping as people make sure they use available moisture.”

On Sunbury itself there are those changes of crop sequence, the end of long fallows and the shortened intervals between crops.

Farming systems and subsoil projects brings changes at Bellata

Drew Penberthy, Bellata NSW

Drew Penberthy was well aware he had subsoil constraints on his 640 hectare Lochearn property, at Bellata, before he made contact with the NSW DPI scientists working on that stream of the Eastern Farming Systems and Subsoil Constraints (SIP08) projects.

That shouldn't be a surprise, because Drew is an agronomist as well as a farmer, operating as Penagcon (Penberthy Agricultural Consultants).

He'd noticed soil problems through his yield maps, with areas of paddocks constantly not performing, despite up to 100 kilograms of nitrogen to the hectare. And he had such non-responsive areas in a number of his paddocks.

Chickpea yields were cut by half, and yields of wheat and barley from 4.5 t/ha to 3 t/ha. Results were worse in seasons dry at flowering time. The big, bulky biomasses produced by the nitrogen did not continue on.

Drew's grandfather Bob bought Lochearn in 1960 and Drew began managing the property in his own right in 2003. His father Bruce has a property next door, and the two men farm a total of 1800 hectares.

Its heavy black soil was mostly treeless, grassy plains. Some 120 hectares of Lochearn are subject to subsoil constraints, with an ESP of 60 about 1.5 metres below the surface.

Most of Lochearn was contoured in the 1960s and 1970s and after that time all those banks are farm-over.

Minimum till was introduced five years ago and controlled traffic (CT) two years after that. CT direction is both across the slope and up and down, dictated by a hill in the middle of the property.

Drew Penberthy says the projects helped him to identify which crop and which variety would deliver the best gross margins on country with subsoil constraints.

Drew says the main benefits of his association with the EFS and SIP08 projects were:

- the added expertise of NSW DPI soil scientists Graeme Schwenke and Bill Manning,
- the extra soil tests they were able to carry out under the projects, and
- the ability to try a wide range of crops and varieties on constrained and unconstrained soils on Lochearn.

"The projects helped us identify which crop and which variety would deliver the best gross margins on country with subsoil constraints, and I can extend that knowledge in two ways, directly to my agronomy clients and more indirectly through the Northern Grower Alliance, of which I am a board member," he says.

"Findings from the project have relevance to much of the northwest Slopes and Plains cropping country where heavy cracking clay soils can have increasing constraints to root exploration with profile depth. Results will guide future crop choices to maximise productivity from these soil types".

“Varieties can make a big difference, as can the type of crop. Durum wheat doesn’t do nearly as well as Sunvale or Baxter bread wheats in a situation of sub-soil constraints, for instance.

“Chickpeas won’t perform at all but faba beans will go a lot better.”

“Overall barley is better than wheat, but more work needs to be done on summer crops, because I grew sorghum last year without any in-crop rain.”

“The effect of the subsoil constraints was obvious, because the sorghum could only try to pull the water out of the non-sodic layers.”

Drew’s preferred rotation on Lochearn is wheat, a legume, wheat again and then fallow through to summer crop, a total of four crops in five years, which he believes is sustainable in the Bellata district.

Legume choice used to be faba beans, as much as for the crop’s fixed nitrogen as anything else, but chickpeas have been preferred in recent years because of the price.

Regular soil tests – between 0 and 30 cm, 30 and 60 cm, 60 and 90 cm and occasionally deeper – are taken with GPS references and carried out to analyse sodium constraints and establish what is happening by increments.

Drew now uses a Raven Monitor to vary Big N fertiliser application rates according to his salinity and yield maps, with the aim of manipulating the crop canopy – fertilising only for an average yield, looking to later applications of nitrogen – possibly liquid – in good years.

Next year he plans variable seeding rate trials and perhaps trials of fertilisers other than nitrogen – phosphorus, zinc and potassium – because he believes his crops in some cases are taking up sodium instead of potassium.

He is also interested in researching the effect of wider rows, “in that you change the bucket. I will do that research – as well as some on plant populations – on my own,” he concludes.

“Hopefully further research can continue on subsoil constraints for summer crops.”