FINAL REPORT

DNR00008

SIP08 (north) Advanced Techniques for Managing Subsoil Constraints

PROJECT DETAILS

PROJECT CODE:	DNR00008
PROJECT TITLE:	SIP08 (NORTH) ADVANCED TECHNIQUES FOR MANAGING SUBSOIL CONSTRAINTS
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Summary

By using data rich spatial information such as yield mapping, remote sensing and electromagnetic induction it was dentified that subsoil constrained (SSC) crop growth. To quantify and map spatial and temporal variability and develop and apply site-specific management, 7 focus sites were used in the Northern grains region. Finally, the soundness of management strategies to meet sustainable goals (economic, environmental and social) were evaluated

Matching fertilizer nutrients to realistic yield potential in the presence of subsoil constraints saved between $19/ha to $45/ha/annum, and site-specific gypsum application resulted in cumulative profit of $143/ha over 3-4 years, with increased Plant available water capacity and Water Use Efficiency.

Conclusions

Major conclusions that emerged during the course of the project are:

1. Substantial spatial subsoil constraint variability occurs within a field or farm;
2. Spatial patterns of subsoil constraint manifest in the spatial pattern of crop growth;
3. Targeted soil sampling and analysis, yield mapping, remote sensing and electromagnetic induction survey especially at lower limit, field spectrometer can be employed to locate areas suspected of subsoil constraints;
4. Remote sensing offers an opportunity to obtain simulated yield mapping;
5. Measuring spatial variability in apparent electrical conductivity at wet and dry profile provided reasonably good agreement with measured spatial variability in plant available water capacity;
6. Matching fertilizer nutrients to realistic yield potential in the presence of subsoil constraints resulted in saving between $19/ha and $45/ha/annum;
7. Ameliorating subsoil constraints with gypsum resulted in cumulative profit of $143/ha and an increase in 10 mm of PAWC within the next 3-4 years of cropping;
8. Wheat genotypes with the desirable root traits of SeriM82 tended to show less yield reduction than some other genotypes;
9. Hyperspectral sensor offers opportunity to differentiate crop performance under subsoil constraints;
10. Chloride concentration in the young mature leaf provides a good measure to identify cultivars tolerant of subsoil constraints;
11. Yield penalty due to high subsoil constraints was seasonally variable, with more in-crop rainfall, resulting in less negative impact;
12. 1High Cl concentration in the subsoil was principal determinant of subsoil water extraction and poor crop yield.

Recommendations

Major recommendations from the project otcomes and outputs are:

1. Identification of spatial and temporal variability in grain yield as a first step;
2. If substantial spatial variability (CV>10%) exists, there is sufficient variation to divide the paddock into different zones;
3. If substantial seasonal variability (CV >25%) exists, then base differential management decisions on multi-year yield maps;
4. In the absence of yield maps, use surrogate simulated yield maps derived from remotely sensed imagery;
5. Identify underlying cause(s) of spatial variability using soil and plant sampling and growers' knowledge and experience;
6. Design and conduct on-farm trial to find optimum management option for the identified constraint;
7. Apply management strategy in consultation with grower;
8. Evaluate soundness of management strategy in terms of economic, environment and social prespective;
9. Use multi-year remote sensing or yield maps to identify suspected areas of subsoil constraints at field/farm/landscape scale;

10. Electromagnetic surveys both at wet profile and dry profile provide reasonable good relationship with attributes of subsoil constraints;
11. EM38 survey at dry profile is better related to subsoil constraint, especially with unused soil moisture after the harvest of crop, especially after dry finish;
12. Wheat genotypes with the desirable root traits of SeriM82 perform better in the presence of subsoil constraints;
13. Chloride levels in the top 1 m soil depth provides a good indicator of severity of subsoil constraints;
14. Yield penalty due to high subsoil constraints was seasonally variable, with more in-crop rainfall, resulting in less negative impact;
15. Depending on season, classify the subsoil constraints as follow: Cl< 400 mg/kg-low (no) constraints; 400-600 mg/kg-Mild subsoil constraints (legumes especially chickpea start to show yield penalties); Cl, 600-1000 mg/kg- High subsoil constraints (cereals e.g. durum wheat, bread wheat show yield penalties); Cl, > 1000 mg/kg- Very high subsoil constraints (low grain yields; oilseed crop show yield penalty; crop production may not be econmic);
16. Consider applying gypsum if ESP>6 but should apply gypsum if ESP>10 in the top 10cm soil, and consider benefits over 3-4 years;
17. Determine realistic yield potential in the presence of subsoil constraint.

Outcomes

The main conclusions drawn from the advanced techniques to manage subsoil constraints were:

Economic outcomes:

- Use of data sources rich in spatial information such as yield mapping, remote sensing and electromagnetic induction survey especially at lower water extraction limit by the crop would provide an opportunity for growers to economically locate areas suspected of SSCs at field or farm scale.
- Surrogate yield data can be obtained by calibrating NDVI derived from remotely sensed imagery to estimate the monetary value of appropriate site-specific management options.
- Measuring spatial variability using EM38, in apparent electrical conductivity at wet and dry profile, would provide economic and reasonably reliable estimates of spatial variability in plant available water capacity.
- Matching fertilizer nutrients to realistic yield potential in the presence of subsoil constraints resulted in a cost saving between $19/ha and $45/ha/annum.
- Ameliorating subsoil constraint with gypsum resulted in cumulative profit of $143/ha within the next 3-4 years of cropping.

Environmental outcomes:

- High unused nitrate-N concentration and unused moisture in the soil profiles of constrained areas at crop harvest results into environmental degradation. Matching fertilizer nutrient inputs and water use would reduce environmental the footprint.
- Gypsum application could potentially increase Plant Available Water Capacity (PAWC) (by reducing lower limit of water extraction by a crop) within the next 3-4 years of cropping, and hence, potentially resulting in reduced runoff.
- Conceptual model to determine realistic potential yield in the presence of subsoil constraints would help in matching input to output. For example, ameliorating subsoil constraint with gypsum resulted in cumulative profit of $143/ha within the next 3-4 years of cropping, and variable N fertilizer rate application saved $19-$45/ha/annum, and potentially reduced greenhouse gas nitrous oxide emissions, and water pollution.

Social outcomes:

- Large number of growers and advisors throughout northern grains region have participated in project activities. A total of 13 action learning workshops and several presentations or discussions were delivered at grower group meetings in Queensland and New South Wales. Research data from the project had also been disseminated through 11 field days, 5 Healthy Soil workshops, and a Healthy Soil Symposium.
- Project has increased knowledge of identification and impacts of subsoil constraints, identified the spatial variability of subsoil constraint, and manage subsoil constraint variability to increase profitability and reduce the environmental footprint by site-specific management.

Achievement/Benefit

In north-eastern Australia, subsoil attributes such as salinity, sodicity, acidity, and phytotoxic concentrations of chloride (Cl) constrain the growth of crops by reducing the ability of roots to obtain water and nutrients. Identification of the spatial variability of these constraints will allow farmers to manage this variation for profitable outcomes, and to minimise environmental degradation. Accurate information on the variability of subsoil constraints across the landscape is difficult to obtain. Soil sampling to identify the distribution of possible subsoil constraints, both spatially across the landscape and within the soil profile, is time-consuming and expensive. As an alternative to intensive soil sampling, we identified subsoil-constrained crop growth through the use of data sources rich in spatial information, such as crop yield mapping, remote sensing and electromagnetic induction. To quantify and map spatial and temporal variability we selected 7 focus sites throughout the northern grains region. The farm sites were located near Biloela (Site 1), Muckadilla (Site 2), Wallumbilla (Site 3), Goondiwindi (Site 4), Garah (Site 5), Bellata (Site 6) and Narrabri (Site 7).

Tools for mapping soil and crop variability

Generally there are three ways to measure soil and crop variability:

- Discretely (e.g. point sampling of soil or plant properties)
- Continuously (e.g. on the go yield monitoring, EC sensor)
- Remotely (e.g. through aerial photographs, satellite image).

In this project we integrated spatial data using yield monitoring, electromagnetic induction, remote sensing, topographic data, and growers' knowledge and experience to partition fields into potential management zones. We used extensive soil testing and local knowledge to identify the cause(s) of field variability. We conducted on-farm trials to develop and apply site-specific management. Finally, we evaluated the soundness of management strategies to meet sustainable goals (economic, environmental and social).

Yield mapping
Site-specific yield data for crops were accessed from growers who collected yield data at harvest using yield-monitoring equipment fitted to the grain harvester, linked to a differentially corrected GPS. Yield monitor data were cleaned to remove spurious observations associated with harvester dynamics, speed changes, cutting overlaps and turns. When all seasons' yield data had been interpolated to a common grid, multivariate k-means clustering analysis was used to define the productivity zones.

Remote Sensing
Surrogate yield data can be obtained by calibrating an archive of limited ground-based measurements of yield to the Normalised Difference Vegetation Index (NDVI), derived from an archive of remotely sensed imagery at flowering. For a 10-year study period on a wheat-growing farm at Goondiwindi, areas where yield consistently failed to reach the 75th percentile in a given year and over several years were regarded as constrained by at least one unknown factor. The predictions showed that 44% of the farm had consistently low yield. Soil samples averaged for the low-yielding area, compared with the high-yielding area, had relatively high concentrations of subsoil chloride and, in the topsoil, relatively high exchangeable sodium percentage, unused nitrate nitrogen and unused volumetric moisture content after the harvest of crop and after dry finish. Therefore, these techniques and methods offer the ability to delineate areas suspected of subsoil constraints, and to estimate the monetary value of appropriate site-specific management options so as to optimise economic returns and minimise environmental damage.

Electromagnetic induction
Soil physical and chemical properties measured in the 0-1.5 m depth in the soil profile showed that EM38 measurements (ECa; apparent electrical conductivity) either at upper limit (fully wet soil profile) or at lower limit (soil moisture at crop physiological maturity) were positively correlated with soil Cl concentration or electrical conductivity of saturated extract (ECse), and soil moisture. Although the spatial patterns of ECa remain temporally similar, ECa at lower limit gave stronger correlation with measured soil properties than ECa at upper limit. In general, ECa provided the best estimates of the deep subsoil properties and especially for soil Cl concentration and ECse. Strong negative correlations between ECa measurements at lower limit and soil moisture at lower limit indicated the presence of subsoil constraints. Cereal yields showed strong negative correlation with ECa measurements both at upper limit and lower limit (although stronger with the latter). Strong correlations between ECa at lower limit, and soil properties associated with subsoil constraints in the region and winter cereal

yields indicate that management zones delineated by ECa at lower limit provides an excellent framework for site-specific management of winter cereal crops in the region.

Estimating soil's plant available water capacity (PAWC)
Measured soil water in 0-1.5 m soil depth at wet and dry profiles had a positive relationship with profile-average ECa. The values of coefficient of determination between measured soil water and profile average ECa were substantially higher in the dry profile than the wet profile. Predicted PAWC showed good agreement with the measured PAWC, with most of the values were near 1:1 line. A comparison of spatial variability of predicted PAWC with measured PAWC showed reasonably good agreement ($R2 = 0.30$).

Managing variability

Potential management zones were delineated based on multi-year grain yield, remote sensing and ECa of paddocks into either two or three zones in the present study. On-farm trials were conducted to find the optimum management strategy for each zone. The strategies were evaluated in terms of economic, environmental and social perspectives.

For all 7 focus sites, we were able to quantify spatial and temporal variability in grain yields and underlying cause(s) of this variability. All selected sites had coefficient of variation in grain yield greater than 10%, suggesting that there was sufficient variation to divide the paddock into different zones. Most notable differences in zones were significantly higher Cl concentration in the subsoil at about 0.6 to 1.1 m soil depths, high exchangeable sodium percent (ESP) and/or high exchangeable magnesium percent (EMgP) at the surface as well as in the subsoil in low yielding areas (1.1 t/ha) as compared to medium (1.6 t/ha) and/or high yielding zones (>2.4 t/ha). In general, low yielding zones as compared to high yielding zones had high concentration of unused nitrate-N throughout the soil profile; however, differences were most pronounced in the subsoil. In both 2008 and 2009 years, winter crops had dry finish and low yielding zone had significantly higher unused soil moisture after the harvest of crops, which indicated presence of subsoil constraints.

Benefits to matching input(s) and/or ameliorating constraint(s) to realistic yield potential were quantified on six sites. For example, on-farm trials conducted on site 1 showed no significant response to applied N in the constrained areas, resulting in a
loss of $45/ha/annum with farmer's uniform rate of N application. On the other hand, the unconstrained area being under-fertilized resulted in a loss in potential production. On site 5, the gross margin with farmer's uniform application of 100 kg N/ha was $31/ha in unconstrained areas, which decreased to -$19/ha in constrained areas. Similarly at site 4, the gross margins at farmer's uniform application of 40 kg MAP/ha were estimated to be A$12/ha for unconstrained and -A$21/ha for constrained areas.

Relatively constrained areas of all sites except at site in Narrabri had high ESP and/or EMgP in the surface soil. Application of gypsum at 2.5t/ha significantly improved grain yield at all the sites. Although gypsum application was uneconomical in the first year of its application, full benefits of gypsum were realised within 3-4 years after gypsum application. For example, gypsum applied once at 2.5 t/ha in 2004 resulted in cumulative profit of $143/ha in 3 years of cropping. Application of gypsum also resulted in an increase in 10 mm of PAWC after 4 years with a deep leaching of 115 tonnes of NaCl equivalent salt from 0-1.5 m depth in the soil profile (below root zone).

Besides matching inputs to realistic yield potential in the presence of soil constraints and ameliorating with gypsum, we also evaluated relative performance of winter and summer crop species for adaptation. In constrained areas, growing chickpea resulted in moderate to severe yield penalty. In these areas, farmers decided to stop growing chickpea and had sown to pasture on Site 2, oats on Site 3 and barley on Site 5.

Cultivar adaptation to subsoil constraints

Wheat genotypes with the desirable root traits of SeriM82 tended to show less yield reduction than some other genotypes. The yield benefit from these traits seems to be expressed not only in unconstrained soils but also in the presence of subsoil constraint. Superior performance in the presence of subsoil constraint appears to be associated with superior performance under water-limited conditions in certain genotypes. There appears to be a scope for growers to optimise productivity in the presence of subsoil constraint by making informed choices among existing cultivars.

All sorghum hybrids showed significant decrease in grain yield grown on constrained sites compared with unconstrained sites. However, the differences within hybrids grown on either constrained or unconstrained sites were not significant.

Discriminating crops under subsoil constraint using hyperspectral sensor

The canopy reflectance data collected using a field spectrometer corresponded to a field view of about 44 cm diameter on the canopy. The partial least square regression analysis of the data showed that it is possible to discriminate the canopy reflectance of crops taken between two sites of different soil attributes. The correlation coefficient between predicted and measured values in a model used to discriminate subsoil constraints using reflectance data of wheat and barley crops was high. The best bands were observed from those bands in the red and near infrared regions. Thus, field spectrometer provides cheaper alternative to remote sensing.

Subsoil constraints threshold

The yield penalty due to high subsoil Cl was seasonally variable, with more in-crop rainfall (ICR) resulting in less negative impact. A conceptual model to determine realistic yield potential in the presence of subsoil Cl was developed from significant positive linear relationship between crop lower limit and subsoil Cl.

Realistic potential yield = [(ICR+PAW) * water use efficiency] - subsoil Cl

In-crop rainfall, available soil water at sowing in the 0.70-0.90 m soil layer and soil Cl in the 0.90-1.10 m soil layer accounted for 80-92% of the variation in grain yields of the 5 winter crops including bread wheat, durum wheat, barley, chickpea and canola. Inclusion of exchangeable sodium percent of the top soil (0-0.1 m soil layer) marginally increased the descriptive capability of the ridge regression model. Subsoil Cl concentration was found to be the principal determinant of subsoil water extraction. We defined the levels of subsoil constraints based on Cl concentration in the top 1 m of soil below:

- 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)

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) identify the spatial variability of subsoil constraint, and (c) manage subsoil constraint variability to increase profitability and reduce the environmental footprint. A total of 13 action learning workshops and several presentations or discussions delivered at grower group meetings in Queensland and New South Wales. Research data from the project had also been disseminated through 11 field days, 5 Healthy Soil workshops, and Healthy Soil Symposium to advisers and growers throughout the northern grains region.

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

- Workshop manual (Managing Paddock Variability Using Precision Agriculture): A guide to managing paddock variability using precision agriculture,
- Workshop workbook (Maximise Gains by Managing Subsoil Constraints: Options and Impacts): A guide to interpret soil test results to optimise management options.

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Intellectual Property Summary

Not applicable

Collaboration Organisations

Not applicable

Collaboration Details

Not applicable