Defining agricultural management strategies that optimise water and nutrient use in Mallee environments of southern Australia

Summary
The project aim was to establish sound crop system modelling capability that would provide strategic direction and risk assessment to existing Mallee Sustainable Farming Inc research (MFSI) in the Mallee.

New methods to model the effect of widespread subsoil chemical constraints on crop yields were developed to improve the predictive ability of models from 40-70%. Coupling these improved models with climatic records and economic parameters indicated that cropping intensification can improve the economic performance of Mallee farms with neutral or beneficial effects on drainage and nitrogen (N) leaching. The modelling approach has allowed the extension of field trial outcomes to a much wider range of environments across the Mallee.

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Conclusions

It was demonstrated that Crop Systems Simulation Model (CropSyst) and Agricultural Production Systems sIMulator (APSIM) models were appropriate tools for application in economic and environmental risk analysis in Mallee-type environments, provided lower limits of plant available water (PAW) used accounted for subsoil chemical constraints. This approach (e.g. adjusted lower limits) was found to be a valuable first step in modelling the effects of subsoil compaction in sandy Mallee soils. Models were used to derive risk profiles for production (yields, profit) and environmental (deep drainage, N leaching) variables. Analysis reinforced the field results, which showed the economic benefits of the intensive farming approach – derived by David Roget and co-workers in the MSF project - and highlighted the term long-term stability of this in terms of neutral or beneficial effects on deep drainage and N leaching. The modelling approach has added a level of confidence to the experimental outcomes from MSF and allowed the evaluation of impacts of farming system change across a wider range of rainfall environments that could be experimentally evaluated.

Crops and pastures in low rainfall Mallee environments are almost invariably growing under some form of stress. The concept of co-limitation of principal stresses and the need to equalise (not eliminate) them, to obtain optimum crop and economic performance, has provided a valuable basis for the development and management of improved Mallee farming systems.

Recommendations

1) Intensification of cropping in the Mallee is technically feasible, and economically and environmentally justified. Extension work is required to help implement more intensive farming approaches in Mallee environments.

2) Cereal yields of 20kg/ha/mm of water used by crops are achievable in the Mallee and crop performance should be assessed against that benchmark. An assessment of the effective lower limit of PAW (particularly as a result of subsoil constraints) is required to properly assess paddock performance. Optimum performance of most Mallee paddocks will not be achieved until the spatial variability of soil type/subsoil constraints and the associated variability in PAW can be adequately quantified and managed. Electromagnetic induction (EMI) techniques (EM38) developed in project CSO216 provide a real possibility to achieve this goal.

3) The risk associated with break crops (canola, pulses) can be reduced by further developing risk management strategies accounting for soil water content and seasonal rainfall outlook. More reliable break crops are critical for the Mallee and low rainfall environments in general.

4) Mallee growers need to be aware that soil compaction can be a significant issue on sandhills and that ripping may provide an economical solution, leading to yield increases of up to 0.6t/ha. There is a strong environmental imperative to improving sandhill performance because compacted sands with an effective shallow rooting depth are highly likely to be contributing a
substantial component of the groundwater recharge below Mallee soils.

Outcomes

This project substantially added to the knowledge of the ongoing MSF1 project and the input it has provided and will continue to contribute for valuable economic and environmental outcomes. The ability for growers to sustainably generate greater farm profitability is likely to lead to favourable social benefits.

Specific outcomes:

1) A risk analysis that indicated cropping intensification in low rainfall Mallee regions provides a platform to improve production and profits, and to reduce seasonal variation with neutral or positive effects on environmentally relevant processes, including deep drainage and N leaching. This modelling approach confirmed the research trial results from MSF and allowed an assessment of impacts across a wider range of Mallee environments. A key outcome from this work was the development of the concept of co-limitation of key crop requirements (water and N). In these low rainfall and high-stress environments, optimum profitability was shown to occur when the stresses from key limitations are equal because there is little opportunity to minimise water stress, in particular. Guides have been written to help growers and advisers implement these cropping strategies.

2) The ‘Mallee Calculator’ was developed, tested and released for use by growers and advisers. It is freely available at the CSIRO website (http://www.clw.csiro.au/products/ncalc/index.html). With the collaboration of Primary Industries and Regions South Australia (PIRSA) staff, this decision support tool reached and influenced the practices of more than 200 growers in SA.

3) A detailed assessment of four years of data from 50 MSF grower focus paddocks has shown that a water use efficiency (WUE) of up to 20kg/ha of grain/mm of water used by the crop is being achieved in commercial paddocks, but there are many limitations to growers achieving this. Chemical subsoil constraints and their variability within and between paddocks were shown to be a principal limitation to improved efficiencies. This project has substantially added to the understanding of the impact of these chemical constraints through the development of relationships between the levels of subsoil constraints and yield impacts, and by demonstrating that their impact is directly related to reduced water use by crops.

4) Field and modelling studies showed economic and environmental benefits of deep ripping in compacted sandy soils. Economically, ripping improved yields, protein content and profit. Based on measured yield responses, treatment costs and commodity prices, it is estimated that for each 1% of Mallee land affected by compaction, ripping could generate a benefit of about $1 million. Environmentally, ripping would contribute to large reductions in the frequency and rate of drainage beyond the crop root zone because compacted sandy soils act like a one-way, downward value for water movement.

Achievements/Benefits

The project’s primary aim was to establish a cropping system modelling capability to provide strategic direction, risk assessment and stimulation of ideas in the unique Mallee environments of southern Australia. It proposed to add value to the existing farming systems work being undertaken in the Mallee, particularly the MFS1 project, which was investigating new farming systems to optimise productivity and profitability. The project achieved all its aims and contracted outputs.

Terminal drought is a trademark of Mallee environments. This stems from seasonal (winter) rainfall, rapidly increasing evaporative demand during the critical stages of grain set and filling in soils with low PAW, associated with dominantly coarse-textured soils in the higher sections of the landscape, and chemical constraints - high boron (B) and sodium (Na), salinity, alkalinity in soils with greater clay content in the flatter parts of the landscape. The main challenge was to find alternative modelling options to account for the effects of subsoil chemical constraints on key processes, including water uptake, crop growth and yield. The problem is particularly difficult because of the confounding effects of chemical constraints, e.g. salinity is correlated with B content and alkalinity.

Models were tested against field data encompassing key aspects of the carbon (C), growth, N and water economies of crops, phenology and grain yields. Data covered all soils and a wide range of management and climatic conditions of New South Wales (NSW) and the Victorian (Vic) Mallee and Wimmera, and selected locations from the Eyre Peninsula (EP) in SA to Junee, NSW.

The identification that yield impact of the widespread subsoil constraints across the Mallee could be directly attributed to
reduced PAW has had a significant impact. It has allowed researchers and many growers (through MSF Red Hot Go paddocks) to assess the effective lower limits of soil water for their paddocks and to derive the real water limited yield potential and more appropriate fertiliser strategies. This relationship between subsoil constraint and PAW has also been a key plank in the successful development of EM38 mapping for the spatial management of subsoil constraints within paddocks (project CSO216).

A benchmarking study of soil, weather, crop and management information from the Mallee Sustainable Farming Project (MSFP) grower focus paddocks was compiled and used to analyse the performance of wheat crops in terms of yield and grain quality. This analysis contributed to the project's understanding of the major constraints for crop productivity in the area, and also provided the field-based background for simulation studies. There was a one-third variation in yields in seasons and locations accounted for by rainfall while the remaining two-thirds could be attributed to the efficiency in the use of rainfall. Late sowing, hostile subsoils and shortage of nutrients were identified as major constraints of crop rainfall use efficiency.

An important conclusion from this analysis is that much of the under-performance of Mallee crop production can be addressed through improved farming systems and improved management. The analysis also highlighted that wheat yield potential of 20kg/ha/mm of water used by the crop is achievable in commercial paddocks with the right management.

The theory of co-limitation was developed to provide an alternative framework to analyse interactions between water and N, which is particularly appropriate for more intensively cropped and higher input farming systems. In contrast to the limiting factor paradigm (that crops are restricted by the most limiting factor), co-limitation proposes that simultaneous constraints are imposed by multiple resources. In the high-stress environment of the Mallee, optimum productivity (and profitability) occurs when water and N stress are equal. A combination of field and modelling studies lend support to this theory, and a decision support tool was developed on that basis. The decision support tool tailored to Mallee environments is a user-friendly model to calculate fertiliser requirements for cereals and canola. In collaboration with PIRSA extension staff, this tool is widely used and has strongly influenced management practices of growers in SA.

A combination of grower field trials and modelling has demonstrated that soil compaction can be a significant issue in Mallee soils. Ripping dramatically reduced soil penetration resistance and resulted in yield improvements ranging from nil to 43%. Yield response to ripping remained for at least two cropping seasons. Increased transpiration and photosynthetically active radiation (PAR) interception fully accounted for the increase in crop growth associated with alleviation of soil compaction. Ripping did not affect transpiration efficiency or radiation-use efficiency. The proportion of evapotranspiration accounted for by soil evaporation (E:ET) declined from 0.58% in controls to 0.36-0.45% in ripped sandhills. Long-term simulations indicated important changes in the fate of water in response to ripping in sandy soils, including a moderate increase in evapotranspiration, a substantial reduction in E:ET and large reductions in the frequency and rate of drainage beyond the crop root zone. The issue of soil compaction was identified by growers through plant available soil water monitoring as part of the MSF Red Hot Go focus paddock program. It is an excellent example of the benefits of joint learning from collaborative farming systems projects.

Besides the contracted outcomes, the project work delivered substantial research products on six additional lines, which expanded and complemented the original project in content and geographical scope.

These included:

1) The analysis of rainfall patterns in a transect from Streaky Bay (SA) to Junee (NSW), and their agronomic consequences in terms of water budget and N mineralisation.


3) Extension and validation of model principles derived to account for subsoil constraints in the Mallee, to higher rainfall, heavier soils typical of the Wimmera.

4) Identification of environmental and management constraints for wheat grain quality.

5) Use of Gini coefficient and Lorenz curves to characterise spatial variation in yield.

6) Approaches to intensification of agricultural systems in the Pampas of Argentina.
The project and related research activities delivered a decision support tool for fertiliser management widely adopted in SA, 21 industry publications and 34 scientific articles.

**Other research**

Development of diagnostic tools is needed to detect subsoil compaction in Mallee soils. With existing prices and costs, and based on field measured responses, it is estimated that deep ripping could improve profits at a rate of $1 million per 1% of affected Mallee land.

A novel method to account for chemical subsoil constraints in crop simulation models has been developed that can be useful to deal with risk analysis in other locations where these constraints are prevalent.

The main source of inefficient water use in Mallee farming systems is soil evaporation. Run-off is unlikely and deep drainage occasional, but not substantial (from a production viewpoint). Improved productivity has to be related with varieties (e.g. high vigour) and management (e.g. fertiliser rates) with the aim of reducing soil evaporation. Importantly, in an international benchmarking study, the project showed that inefficiencies in low rainfall environments of south-eastern Australia are not a local problem, but a widespread feature of low rainfall environments worldwide and the low input farming systems that have developed. The principles and conclusions from this and associated projects are likely to have widespread application across low rainfall areas in Australia and internationally.

**Additional information**

**Scientific papers in refereed journals**


**Scientific papers in conference proceedings**


