Managing the fallow period for optimum water use and nitrogen availability

Summary
This project aimed to evaluate the effect of summer fallow management on soil water storage. A combination of field experimentation and simulation analysis was used to quantify the effects of different management practices and to explore management strategies. Control of weeds had the greatest impact on soil water storage during the fallow (11 mm on average). In autumn and winter residue retention past May 1st was effective in conserving moisture (average 9-25 mm depending on residue levels). The findings have been communicated to growers and advisers. Fallow management strategies have been developed that benefit the crop in drier years and reduce the risk of deep drainage in wetter years.

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**Conclusions**

- Weed management was found to be the most effective means of conserving soil moisture during the summer fallow (average of 11 mm and in 26% of years more than 20mm), whereas residue management such as flattening of stubble (e.g. with a Coolamon harrow) had only limited impact (average of 4 mm, 77% of years an effect of less than 5 mm).
- In autumn and winter, residue cover played a bigger role, reducing soil evaporation quite effectively (averaging 9 to 25 mm for treatment effects from May 1st depending on residue levels).
- Because prolonged dry periods are quite common in summer, the impact of weeds will normally only be significant when rainfall has wet the soil to below the evaporation front (usually 20-30 cm).
- When the aim is to maximise soil water storage, use of herbicide sprays can be minimised by applying them tactically depending on depth of wetting of the soil profile.
- While weed management is effective in controlling soil moisture storage during summer, it is difficult to find a balance between benefiting the crop and reducing the risk of deep drainage without the early availability of seasonal rainfall forecasts.
- Residue retention (>1 t/ha) past sowing currently appears to cause a relatively large increase in the risk of deep drainage (e.g. 19 mm for 4 t/ha, 7 mm for 2 t/ha), with limited benefits to the crop. However, if the negative impacts of retained residue (nitrogen (N) immobilisation, disease, cold temperatures) could be alleviated, the conservation of soil moisture, which is quite effective in autumn/winter, could potentially benefit the crop significantly in dry years.

**Recommendations**

**Grower recommendations**

- Summer fallow management, and in particular weed management can have a large impact on the amount of water that is stored in the soil during the summer fallow. In dry years, controlling weeds can be very beneficial to the subsequent crop, although in wetter years it may contribute to a risk of deep drainage. Maintaining residue cover after sowing does not appear to benefit the crop, but does increase the risk of deep drainage in wetter years. Strategies included in Appendix C (Attachment 1) provide suggestions on how to manage for different aims.

**Researcher and research investor recommendations**

* See “Other Research and Development Opportunities” below

**Industry recommendations**

- This project has demonstrated that summer fallow management can play an important role in regulating soil moisture storage, either to reduce the risk of deep drainage, or to benefit the crop. Increasing farmer awareness further of the consequences of alternative managements of summer fallsows will be important if the current run of dry years continues. Upon a return to wetter climatic conditions, farmers and advisers should also be made aware of the need to modify fallow management in wetter years in order to find a balance between the risk of deep drainage and crop performance.
Outcomes

Expected outcome: Farmers to be more aware of their ability to manipulate soil water through management of summer fallows so they can influence water conservation for increased crop production and risk of deep drainage.

Economic outcomes

The major economic benefits from this project will arise from a better understanding among growers and consultants of the role of fallow management, and in particular summer weed management, in providing the crop with valuable extra soil water in dry years. After the relatively wet 1990s when this was not critical in south eastern Australia, growers and advisers in the Wagga Wagga, Harden, Young, and Junee region welcomed and valued information received (in conjunction with project CSP00049) on how to conserve soil moisture during the fallow. If climate change leads to more prolonged dry periods, increasing farmer awareness of the consequences of alternative managements of summer fallows will have significant benefits to the industry. This study suggests for example, that appropriate summer weed control could result in up to 35 mm (average of 11 mm) of additional stored water which may result in wheat yield benefits of up to 1.3 t/ha of wheat (average 0.3 t/ha for 1960-2006 climate history). In dry years this can sometimes be the difference between harvesting a crop or not. These potential gains need to be considered against the potential increased risk of deep drainage in wetter seasons (> 300 mm growing season rain).

Environmental outcomes

The project has confirmed that fallow management has an important role in regulating soil water storage and hence can be used to reduce the risk of deep drainage losses to groundwater. Important determinants of the amount of water stored under summer fallow have been identified. Upon a return to wetter climatic conditions, they can be applied to increase farmer awareness of the need to modify fallow management in wetter years. Residue retention past May 1st has been identified as a practice that increases the risk of deep drainage quite significantly (average effect 19 mm for 4 t/ha residue cover), especially in years with above average growing season rainfall (GSR). A tactical approach to management decisions that balances between the risk of deep drainage and crop performance would, however, rely quite heavily on early growing season rainfall forecasts, something not yet available.

Achievements/Benefits

Background and aims

Successful control of deep drainage under agricultural systems requires careful management of all factors affecting the water balance in order to maintain an appropriate target soil water storage buffer and maximise the chances of storing water from large rainfall events within the root zone. Soil water monitoring on farms in the vicinity of Wagga Wagga, New South Wales (NSW) (GRDC project CSO197; LWA project CDS20) showed on a few occasions that the way surface residue and weeds were managed during the summer fallow period could have a large effect on the amount of water stored in the profile and the amount of deep drainage during the subsequent growing season.

Sometimes stored soil moisture may, however, constitute a significant proportion of the water needed for crop growth. This is particularly so in drier climates and in the northern wheat-belt with its summer dominated rainfall. Traditionally, less importance has been placed on stored soil water in the wetter climates of south eastern Australia. The series of dry seasons since 2001 has, however, re-focused attention on water conservation due to some dramatic impacts on crop response attributed to management-related differences in stored water.

The aims of this project were, therefore, to (1) quantify the effects of different fallow management practices on soil water storage for a range of different rainfall patterns, and (2) develop fallow management strategies that minimise deep drainage without detrimentally affecting the subsequent crop by limiting water availability.

Achievements

This project has improved the understanding of soil water dynamics during the summer fallow and the impacts of different management through a combination of field experimentation and simulation analysis for a Red Kandsol near Wagga Wagga.

- In particular the project has established that:
weed management is important relative to residue management for fallow moisture storage, and

- residue cover has a surprisingly large impact on water storage in the late autumn/winter months.

The project has shown the interactions of fallow management with rainfall patterns and possible ways that soil water monitoring might be used in decision making. Fallow management principles have been developed but drought conditions prevented adequate validation and were not conducive to promoting techniques to minimise deep drainage. The main project findings are described briefly below. Further details are provided in Appendices A and B (Attachment 1), which include referenced Figures and Tables. Appendix B also provides details of project contributions to the further development and testing of the Agricultural Production Systems simulator (APSIM) model used for the simulations.

(1) Relative importance of weed control and surface residue management during summer

During the very dry summers of 2003-04 and 2004-05 management impacts on soil water storage were negligible. In the 2005-06 trial, weed control (on average 22 mm saved) was more important to water conservation than flattening of stubble (e.g. with a Coolamon harrow - no effect); harvesting of straw caused an average loss of 10 mm moisture (see Table A1 for details).

The limited effect of flattening of the stubble on soil evaporation losses was confirmed by experiments with weighing lysimeters. Treatment differences were generally only observed for a brief period after large rainfall events and reversed after a few days so that the cumulative difference in evaporation just prior to sowing was at most 3-4 mm (see Fig. A1).

Simulations using 46 years of historical climate data (1960-2006) confirmed that strict summer fallow weed control was the most effective way to increase soil water storage with a higher average effect on sowing soil moisture (+11 mm) than flattening of stubble (+4 mm), and a more frequent occurrence of larger effects of >20 mm (26% of years). The effect of controlling weeds could be as large as 35 mm extra soil water storage at sowing, although this would depend on weed density and rooting depth.

Maintaining a stubble cover as opposed to harvesting straw was predicted to increase soil water storage, with the magnitude of the effect rapidly increasing the longer residue reduction (e.g. burn) was delayed (average gain +10 mm if maintained until mid-April, +13 mm until end of April, and +20 mm until sowing (conditional upon rainfall between 1 May and 15 June).

(2) Impact of rainfall distribution

An analysis of the effect of rainfall amount and distribution on the simulated fallow management impacts demonstrated the following:

- If a rainfall event is followed by a dry period, soil evaporation under stubble can catch up to that with less stubble cover, minimising its cumulative effect. Therefore, flattening stubble had a bigger impact on water conservation in years with rainfall distributed over several events (e.g. 1973, 2001) rather than in large single events (e.g. 2002, 2003).
- In years with very high summer rainfall (>300 mm, e.g. 1989, 1994) residue effects were minimised due to full wetting up of the profile.
- Due to the frequent occurrence of prolonged dry spells during summer, weeds generally only have an impact when rainfall events are large enough to wet the soil below the evaporation zone and weed roots reach this depth. Therefore, the biggest effects of weed control were achieved when summer weeds emerged following large rainfall events early in the summer fallow (e.g. 1971). Summers dominated by smaller rainfall events or those with late germinating rain (e.g. 1999) benefited less from weed control.
- In very dry summers (2004, 2005) management impacts on soil water storage were generally negligible.
- The total amount of rainfall between harvest and sowing on its own was, however, not a good predictor of the benefits of weed control because of carry over of late rainfall from previous cropping seasons (e.g. summers of 1967, 1986, 2006).

(3) Impacts on yield and drainage

In 2006 crop growth responded to the small differences in stored soil moisture (around 0.4 t/ha biomass, see Table A1), but unfortunately the crop had to be aborted due to the continuing drought. It could not be determined whether these differences were translated into yield effects. In the simulations the average wheat yield benefit from the extra stored water was 0.3 t/ha, but depended on growing season rainfall and distribution (up to 1.3 t/ha).

The differences in soil moisture storage at sowing due to fallow management could result in drainage effects as large as 40-
50 mm, but the average effect was much lower (around 7 mm for difference created by weed control, 10 mm for difference created by harvesting of straw).

(4) Strategies for summer fallow weed control

Strategies for maximising yield

- To maximise benefits of summer water storage to the subsequent crop, strict weed control should be adopted.
- The number of sprays can be reduced by spraying only when a rainfall event has wet the soil below the evaporation zone (20-30 cm). On the Red Kandosols around Wagga Wagga, about 20 mm of moisture can be conserved from a wetting event to 60 cm.
- The depth of wetting from a rainfall event will depend very much on antecedent soil moisture, rainfall intensity, and soil type. Measurements of soil water status should be taken as these integrate the effects of all these factors. The use of simple soil moisture sensors has been explored elsewhere (Bond 2006a,b). They measure soil water potential and can identify wetting and drying events.

Strategies for minimising deep drainage

- To minimise the risk of summer water storage contributing to deep drainage, spraying of summer weeds should be delayed as long as possible. But spraying should be carried out before setting seed with enough time left for their control prior to sowing of the winter crop.
- Spraying could potentially be carried out on the basis of whether the subsoil (>80 cm) is wet or not (e.g. with soil water potential sensors as above), but the simulations suggest this has limited predictive skill. The biggest factor determining whether the stored moisture leads to deep drainage is the amount of growing season rainfall. Improved seasonal climate forecasts that have predictive skills from summer would be helpful, but are not yet available due to a "predictability barrier" (McIntosh et al. 2007).

(5) Impact of residue retention in autumn and winter (past sowing)

The lysimeter experiments showed that a 4 t/ha residue cover past sowing (early and mid June) could reduce evaporation losses by approximately 10 mm in 2005 (see Fig. A2) and 15 mm in 2006. Simulations suggest that residue retention past May 1st (opening of sowing window) can reduce soil evaporation losses by up to 45 mm, depending on residue levels and rainfall patterns (see Table B2 for details). Residue levels of at least 2 t/ha would be required to conserve amounts of more than 5 mm. At 4 t/ha the average evaporation reduction was predicted to be 25 mm.

While soil moisture is conserved, benefits to yield are predicted to be surprisingly small, and in wetter growing seasons (>300 mm) even negative (e.g. Fig. B1). This appears to be due to decomposition of the residue causing nitrogen immobilisation. These simulation results match experimental findings summarised by Kirkegaard (1995), who listed lowered temperatures and disease problems in residue retained systems as other potential negative impacts on crop vigour.

In years with above average growing season rainfall (>318 mm), simulations suggest that the soil moisture conserved by residue retention is largely lost in deep drainage, except if the soil below 40-50 cm was dry (drier than -200 kPa) at the end of April. The overall average drainage increase was 19 mm for 4 t/ha and 7 mm for 2 t/ha residue cover.

(6) Strategies for residue retention

- To maximise benefits for the crop, residue cover should be maintained as long as possible during autumn, but only retained past sowing if potential negative impacts such as nitrogen immobilisation can be managed. In years with below average growing season rainfall this may increase yield potential.
- To minimise the risk of deep drainage, residue retention should be avoided as much as possible and residue loads reduced to 1 t/ha or less, unless required for other purposes (e.g. erosion control).
- If negative impacts of retained residue on crop vigour can be managed, there may be value in deciding on residue retention past sowing tactically on the basis of seasonal climate forecasts and soil water measurements, e.g. reducing the residue load to 1 t/ha or less when growing season rainfall is predicted to be above average and the soil below 40-50 cm is wetter than -200 kPa. Due to the drought in recent years, this approach has not yet been tested.
- It should also be noted that the confidence with which this tactical approach can be applied, depends very much on the predictive skill of the rainfall forecast.

Benefits to industry
This work has confirmed that fallow management can play an important role in regulating soil moisture storage. It can either be used to benefit the crop or to reduce the risk of deep drainage. The project has contributed to a greater awareness of the key elements of fallow management that can make a difference in soil moisture storage. Presentations on fallow management during drought conditions were conducted at GRDC Adviser Updates (Wagga Wagga Feb 2007) and follow up pre-season grower talks (both in conjunction with project CSP00049).

In south-eastern Australia where soil moisture conservation now appears critical in the drier years, but deep drainage still a risk in wetter years, it will be important to adopt a tactical approach to fallow management. Some strategies have been proposed as part of this project (see above and Appendix C) including the use of soil moisture measurements, e.g. using soil water sensors developed as part of project CSO0004 (Bond 2006a,b), to determine the soil water status of soils and avoid uncertainties of predicting amounts of water infiltration, evaporative losses and weed transpiration.

Further information


Other research

As weed growth was limited in the field experiments due to drought conditions, the simulations assumed generic weeds at a fixed density (15 plants/m2). In discussing project results with farmers their questions often revolved around the type of weeds and densities. It was felt that the model was not sensitive enough to give answers to such questions. Further work would be warranted to determine the relationship of soil moisture storage to type and density of weeds. Strategies sensitive to these issues should be established. These should incorporate knowledge about weed growing cycles, timing of seed setting, ease of removal, and the impact of grazing the weeds. Further work is also needed on the effect of fallow management on nitrogen (N) dynamics. The interaction of surface residue with soil nitrogen dynamics in residue retained systems needs attention as well as quantification of the uptake of N by summer weeds and the dynamics of its release upon decay of its residues. Drought conditions prevented this from happening during the course of this project. Quantification of disease risks from residue retention or keeping a ‘green bridge’ during the summer fallow would also be important.

The project’s concepts and strategies could benefit from further work on incorporating soil water measurements (using simple and cheap sensors) into management decision-making.

Tactical management could be greatly improved if appropriate seasonal climate forecasts were available. For summer fallow management (e.g. spraying of weeds) or residue retention decisions, these forecasts would have to be available in summer or early autumn and extend for six to nine months. Currently seasonal rainfall forecasts have limited predictive skill prior to July.

The current project has provided an understanding of factors that determine water conservation from fallow management, based on analyses for a Red Kandosol in the Wagga Wagga region. The principles underlying the fallow management strategies will hold for other soils and climates, but the relative effects may change. The project results form a good platform for subsequently analysing the opportunities from different fallow management strategies in other grain growing areas, e.g. through application of further simulation analysis.

Additional information

The following are attached:

Attachment 1

Appendices from original CSO232 Final Report
Appendix A: Experimental treatment effects
Appendix B: Model development and simulated effects of fallow management
Appendix C: Towards fallow management strategies

**Attachment 2**

Fallow management affects the risk of deep water loss (paper 4th International Crop Science Congress)

**Attachment 3**

Increasing the options for managing the risk of deep drainage losses (paper GRDC Updates Wagga Wagga Feb 2004)

**Attachment 4**

Fallow management, water storage and wheat yield in southern NSW (paper GRDC Updates Wagga Wagga Feb 2007)

**More recent research is being undertaken in project CSP00111 (The National Water Use Efficiency Initiative); see also:**
(www.csiro.au/science/Water-Use-Efficiency.html)