Production and environmental benefits of dewatering cropping subsoils with deep-rooted pasture legumes

Summary
Productivity losses due to waterlogging are a major problem for grain growers in many areas of the Southern Region. In New South Wales (NSW) alone, 1.3 million hectares of croplands are subject to periodic waterlogging, causing estimated losses of $35-$50 M in wet years. Waterlogging occurs as surface ponding or via perched water tables under conditions where underlying soil constraints restrict the rate of infiltration. Waterlogging may also reflect shallow groundwater resulting from changes to the water balance due to the conversion of indigenous ecosystems into agricultural enterprises based on shallow-rooted annual crops and pastures that use less water than the original perennial, deep-rooted native vegetation. In low lying areas and flat landscapes, the unutilised water escaping the roots of annual plant species (on average 30mm-70mm per year in the 500mm-600mm rainfall zone) has increased the incidence of waterlogging, contributed to rising water tables and increased the risk of dryland salinity. A potential solution to these problems may be to reintroduce deep rooted perennial plant species into farming systems to ‘mop up’ excess soil water prior to cropping. Lucerne is one possible candidate that will allow growers to include a perennial in their rotations and still maintain their agricultural productivity. The aim of project CSP243 was to increase the reliability of crop production by delaying or preventing the onset of waterlogging through lucerne’s ability to dry or ‘dewater’ the soil profile before cropping.
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Conclusions
This project explored the feasibility of lucerne-based strategies that growers could employ to enhance the reliability of cropping in wet landscapes prone to periodic waterlogging. The research demonstrated that lucerne uses a greater proportion of the annual rainfall than crops or annual pasture species and has the ability to scavenge water deep in the soil profile. These characteristics proved effective in delaying or preventing the onset of waterlogging in problem soils in the Temora region of southern NSW and resulted in a doubling of wheat yield in the wet 1998 growing season.

The high water use characteristics also greatly reduced the local risk of development of dryland salinity. An on-farm study revealed that lucerne lowered the water table in the immediate area of salt scalds and helped to regenerate salt affected land to such an extent that crops could be grown in areas that had been previously too salty and waterlogged to support plant growth.

While dewatering the soil profile can have benefits in a wet year, this can also result in yield penalties in dry years depending on the timing of lucerne removal prior to cropping, the amount of rainfall prior to sowing, and/or rainfall at critical times during the subsequent growing season. Both experimental data and simulation model predictions indicated that canola was most at risk to yield reductions when grown immediately after lucerne.

Despite the increased risk of yield reductions in the first crop grown after lucerne in dry years, economic analyses of experimental findings and model predictions indicated that phase farming with lucerne still had the potential to increase the productivity and profitability of the cropping phase.

Unfortunately, intercropping was never successfully evaluated under waterlogging conditions. In dry to average years, yield penalties of 20-50% were observed for crops grown in these systems due to reductions in both water and nitrogen (N) supply.

Recommendations
It is recommended that GRDC should continue to support lucerne-based research and development (R&D) and promote the use of lucerne in rotations with crops. Four years of data have demonstrated the production and environmental benefits of phase farming with lucerne.
Crop yields following lucerne were enhanced in a waterlogging year, there were consistent flow-on N benefits for at least 3-4 years after the lucerne phase, and economic analyses suggest that lucerne-crop sequences can increase cropping gross margin (GM) by at least 20% ($86/ha/year) compared to annual pasture-based rotations despite an increased risk of yield reductions in the first crop in a dry year. Experimental data suggest that canola may be more susceptible than wheat to the drier soil profiles following lucerne. Sowing wheat rather than canola as the first crop after lucerne might reduce the risk of yield reductions.

Soil water data collected over the duration of this project indicated that lucerne greatly reduces the risk of deep drainage to ground water. Soil profiles were drier under lucerne than annual pasture or cropping, and the subsoils below the rooting zone of crops can remain relatively dry for several years after lucerne. Sowing lucerne surrounding salt scalds had a rapid localised effect of lowering water tables resulting in the partial reclamation of the saline areas.

However, it should be recognised that there is an inherent risk in focusing solely on lucerne. It is desirable that GRDC also continues to support the evaluation of a range of perennial legumes, dicots and grasses that might be suitable for farming systems in wet landscapes.

**Outcomes**

**Expected Outcome (benefits)**

**Economic Outcomes**

The economic analysis presented in Attachment 3, Appendix C, was prepared in collaboration with local grain growers from the 'Bland'.

In the waterlogging prone regions under study, recent grower surveys indicated that farm area is currently split 50% pasture:50% crop. Appendix C compares GM calculations for cropping enterprises in a three year lucerne - three year cropping sequence with a three year annual pasture - three year cropping rotation.

The calculations assume that only one-third of the cropping program is in canola. Based on long term weather records and data collected from local growers, a severe waterlogging year in the Temora region is likely to occur one year in three. On the basis of experimental results, the calculations in Appendix C assume that waterlogging may cause a yield penalty of 50% (observed for wheat in 1998). For the sake of ease of calculations, it has been assumed that both wheat and canola are equally susceptible to waterlogging, but in reality canola tends to be more sensitive to waterlogging than wheat and yield losses of 75-90% have been recorded for canola in other nearby trials and in local growers' paddocks in 1998 and 2000. Although not susceptible to waterlogging, there is the risk that the first crop after lucerne might suffer from a water deficit in one out of three years (below average rainfall). This yield penalty is assumed to be 20% based on trial results and model predictions. The calculations also assume that the second crop post-lucerne is not likely to be susceptible to either a water deficit (i.e. soil profile in top 1m recharged) or waterlogging (due to root channels improving infiltration into subsoil), but that the third crop post-lucerne is again susceptible to waterlogging just as for the annual pasture rotation.

Despite the risk of yield reductions by the first crop after lucerne in dry years, the economic analysis indicated that the ability to avoid waterlogging may result in at least a 20% increase in overall profit in crop production (equivalent to an additional $86/ha/year in crop production) if growers routinely incorporated lucerne pastures into their farming systems (see Appendix C). This calculation is a very conservative estimate of total economic benefits since the calculations:

1. Do not include the additional value of lucerne to livestock production.
2. Assume that both wheat and canola are equally susceptible to waterlogging, whereas in reality canola would be expected to benefit more from the drier soil profile post-lucerne.
3. Do not account for additional N fertiliser required for second and third crops in the annual pasture-crop sequence to maintain yields at the same levels achieved following lucerne.
4. Assume that the risk of waterlogging is reduced in only the first (due to drier soil profile prior to sowing) and second crop after lucerne (the result of improved water infiltration characteristics of soil due to lucerne root channels). Recent data collected by project CSP343 from the Fergusons Lane trial site suggests that the impact of residual lucerne root channels on water infiltration characteristics persists for at least two years (i.e. into the third crop) following lucerne removal.
5. Do not include agronomic benefits derived from better trafficability and access for timeliness of sowing or spraying with the drier soils after lucerne.
6. Do not include estimates for the environmental benefits (both on-site and off-site) resulting from a reduced risk of soil acidification, deep drainage, rising water tables and dryland salinity.

Similar calculations for case studies undertaken by Graham Trapnell as part of Victorian Department of Natural Resources and Environment (VIC DNRE) project DAV453 suggest that even in the absence of any benefits through the reduced risk of waterlogging, the increased flexibility in crop choice, the longer potential duration of cropping in a rotation, and the 25%-50% greater livestock carrying capacity of lucerne-based systems can result in 30%-35% extra profit per annum after tax compared to annual pasture-crop sequences.

The average additional profit of $86/ha/year in the cropping phase derived in Appendix C is in a similar range to calculations of the average annual benefit from including lucerne in farm rotations from analyses of whole-of-rotation GM ($75 to $105/ha/year) determined for various cropping systems in VIC, southern NSW, and northern NSW/southern Queensland (QLD) that are not subject to waterlogging. To our knowledge, only one analysis has been undertaken to assess the economic benefits from the use of perennial pastures to modify groundwater recharge in areas subject to rising water tables and dryland salinity. In this particular study of the Campaspe Catchment in VIC, annual on-farm benefits of $20/ha were estimated by replacing the existing fallow-cropping-annual pasture sequence with three year cropping-three year perennial pasture rotations.

Environmental Outcomes

Lucerne phase farming systems and lucerne intercropping systems potentially have considerable environmental flow-on benefits. During a lucerne phase, or when lucerne and crops are grown together, it is likely that most of the annual rainfall would be fully used each year. The drier subsoils following lucerne also lower the risk of deep drainage of unutilised rainfall during the first few years of a cropping phase. When re-sown after cropping, the deep root system of lucerne has the ability of mopping up much of the water that may have escaped the crop roots. All these factors contribute to a substantially lower risk of grain production contributing to deep drainage and rising water tables. If the lucerne-based farming strategies were applied on a catchment scale, off-farm benefits would include watertable drawdown and reductions in river salinity. The greater water use characteristics of lucerne combined with the low soil nitrate concentrations maintained during the lucerne phase also has the potential to greatly lower the rate of soil acidification.

Increased soil organic matter resulting from a productive lucerne pasture and more N-fixation will enhance soil carbon and N, improve structure and reduce the risk of soil erosion during the pasture phase compared to annual pasture-based rotations where there is limited ground cover during summer. In addition to benefits, perennial pastures suppress annual weeds so there is also likely to be a reduced requirement for herbicide applications during the cropping phase.

Social Outcomes

As a result of this project, grain growers located in areas on waterlogging prone soils of south-eastern Australia have been provided with a range of lucerne based farming systems which will enable them to maintain cropping land in production which otherwise would become uneconomic due to waterlogging, rising water tables and salinity. Expanding the area of lucerne or other deep-rooted pasture legumes should reduce the suite of environmental problems associated with periodic waterlogging. A phase of perennial pasture will decrease the potential for erosion while the flow-on effects of additional organic matter on improved soil structure, and the impact of inputs of fixed N on subsequent increases in crop yield and grain protein will enhance the long term profitability and sustainability of cropping, and contribute to the long term viability of rural communities in the Southern Region.

Achievements/Benefits

Overview of Project Achievements

Location of trial sites

Grower surveys undertaken at the commencement of the project suggested that a combination of soil problems results in a higher frequency of waterlogging (on average one year in three) and greater risk of crop losses in wet years (up to 90%) in the ‘Bland’ region near Temora than many other areas of southern NSW. The project focused on the ‘Bland’ which covers approximately 766,000ha, but similar soil types and periodic waterlogging also occur over a wide area of southern NSW and north-eastern VIC. These cropping areas are currently under-productive in wet seasons and have been poorly serviced by
Project aims

- To improve management of the hydrological cycle of cropping soils by developing and demonstrating farming systems that can profitably incorporate the tactical and strategic use of deep rooted perennial pasture legumes.
- To provide phase farming options to growers in waterlogging prone regional discharge zones that have the potential to enhance and sustain crop production in the long term.
- To provide grain growers with evidence that it is profitable to include lucerne in rotations to manage the hydrological cycle of soils.

Methodology

A series of on-farm investigations were set up to test the hypothesis that lucerne would improve the productivity of croplands subject to waterlogging and/or salinity. The experiments ranged from paddock-scale studies of water table movement to more intensive investigations comparing the productivity of crops grown after lucerne, subclover or continuous cropping sequences. Details of the major experiments are outlined below:

Evaluating Farming Systems Options for Wet Landscapes

a. Phase farming with lucerne - This system involves growing crops in a rotation with a phase (2-4 years) of lucerne pasture. Once lucerne has sufficiently dried the soil profile, it is removed by herbicides and/or cultivation before a cropping phase. Lucerne is re-established after three to five years of cropping.

b. Intercropping with lucerne - Under a phase farming system there is a degree of uncertainty as to when lucerne should be re-introduced into the rotation, because the soil profile can rewet within a single year of cropping post-lucerne. Furthermore, lucerne has the reputation of being difficult and expensive to establish and hard to remove, so growers are often reluctant to remove a productive lucerne stand for cropping. Intercropping with lucerne is a novel alternative system that involves sowing a crop into an existing lucerne pasture. This ensures that the high water use characteristics of lucerne can be retained during a cropping phase. Intercropping may also allow an easy transition from pasture to cropping and vice versa in response to economic trends.

c. Alternative species to lucerne - Many different perennial and annual pasture legume species were evaluated in the glasshouse and field over the duration of project CSP243 for their potential to be of benefit to growers in wet landscapes. These include species which might be more vigorous, waterlogging or acid tolerant than lucerne, and lucerne genotypes with more prostrate growth habits which might be better suited to intercropping than the current erect, hay-cutting lucerne varieties.

Dealing with Saline 'Hot Spots'

According to the Salinity Audit (Murray Darling Basin Commission 1999) and related documents, the area of salt-affected land in NSW is predicted to increase 60-fold within 50 years. Isolated outbreaks of dryland salinity have begun to occur on farms in localised catchments of southern NSW, and growers are keen to identify and implement strategies that might help prevent the spread of salt scalds. A small saline 'hot spot' (<1ha) was located near Temora, and an on-farm study was initiated in collaboration with local growers and NSW Department of Land and Water Conservation to:

i. Test the impact of salinity on crop and pasture productivity, and
ii. Evaluate the effect of establishing lucerne surrounding the salt-affected area.

Research highlights

1. Phase Farming and Intercropping with Lucerne

1.1 Impact on Soil Water (data presented Attachment 1, Appendix A)

The impact of lucerne on soil water was evaluated at two trial sites (Fergusons Lane near Temora and Corona near Grogan) since 1998. At Fergusons Lane the first crop in 1998 followed two years of lucerne pasture, while at Corona crop yields were compared in paired paddocks following either a six year lucerne pasture, or where the land had been continuously cropped for more than five years.

Prior to sowing, lucerne-based systems were drier in the top 1m (crop rooting zone) than annual pasture-crop sequences or...
under continuous cropping by 15mm-50mm. The largest 'dry soil buffers' were generated when lucerne was removed as late as possible before a cropping phase (in March-April) or when it was not removed at all (intercropping) - Tables 1-3.

The wet growing season of 1998 (130mm greater growing season rainfall than average) provided an excellent example of 'proof of principle' of the residual impact of lucerne reducing the risk of waterlogging. At Corona, crops were sown into a much drier soil profile following lucerne compared with wheat growing in a continuous cropping sequence. The drier soil profile resulted in a marked reduction in waterlogging. Standing water was present for several weeks under continuous cropping, but was never evident in the crop after lucerne (Figure 1- Appendix A).

Year to year differences in plant available water after early vs. late removed lucerne reflected partial recharge of the soil profile as the result of late summer or autumn rainfall. The extent of recharge was characteristic of the particular pattern and amount of pre-growing season rainfall occurring in any one year. In some years, much of the dewatering benefit in the top 1m was lost by heavy rainfall in February-March. However, regardless of the year or timing of removal, the soil remained much drier below 1m than the continuous cropping or annual pasture treatments for at least two to three years after lucerne. The soil profile below 1m was retained as dry as the surrounding lucerne pasture where crops were oversown (intercropped) into lucerne.

While the drier soil profile immediately after lucerne might delay or prevent waterlogging, recent data collected from the Ferguson Lane experimental site as part of project CSP343 suggests that residual lucerne root channels improve water infiltration into the subsoil and reduce the risk of waterlogging in the second and possibly third crop following lucerne.

1.2 Impact on Crop Yield (data presented in Attachment 2, Appendix B)

Rotational treatments had little impact on crop yields at Ferguson Lane in 1998 since this site did not receive sufficient rainfall to induce waterlogging. However, phase farming did increase wheat yield at Corona. The yield of wheat at Corona in 1998 was doubled where sown into a much drier soil profile following lucerne (6t/ha) compared with wheat growing in a continuous cropping sequence (3t/ha) - Table 4. It was assumed that the reduction in waterlogging was the major contributor to this yield improvement (Figure 1), although the effects of disease and reduced N supply cannot be excluded. Unfortunately, waterlogging was not a major constraint to crop production at the main trial sites in subsequent years. Yields of the first crop of wheat (range of 3.6-4.9t/ha) and canola (range of 1.3-2.5t/ha) after lucerne were similar to that observed in neighbouring subclover-crop comparisons between 1999-2001. In any one cropping year, the yields were retained at similar levels up to the fourth crop after lucerne, whereas yields declined in the second and subsequent crops after subclover. The continuous cropping sequence generally required an additional 60kg fertiliser N/ha to achieve comparable yields to the pasture-crop treatments (Tables 4-8). While the drier soil profile prior to cropping could enhance grain yield in a wet year, yields can also be reduced for crops immediately after lucerne in a dry year such as 2001 (e.g. canola - Table 8). Yields of intercropped wheat were similar to unfertilised wheat monocultures in 1999 and 2001. However, competition between the lucerne and intercropped wheat seemed to be exacerbated by extended periods without rain in 2000 and wheat yields were substantially reduced. Yield reductions were observed in every year that canola was intercropped with lucerne.

2. Alternatives to Lucerne

Species of Astragalus, Melilotus, Lotus, Hedysarum, Securigera, and Coronilla were discarded for various reasons including potential weediness and toxicity. Several legume lines were also eliminated from further study as they did not flower in the spring or early summer suggesting poor adaptation to the growth conditions of southern NSW. Some lines of Caucasian clover and Astragalus cicer looked promising in the glasshouse. Both of these are perennial and produce underground stems or rhizomes which might be expected to help plants spread, thus providing good soil cover and protection. Subsequent field testing indicated poor adaptation to the prevailing rainfall conditions or soil types at the main trial sites, and poor persistence or productivity. A group of vigorous annual legumes, Vicia, Trifolium and Biserrula species, were also evaluated for productivity in crop rotations. The forage legume treatments were designed to investigate the potential of ‘nurse crops’ during lucerne establishment which may remain active in waterlogged soils, assist survival of lucerne seedlings, compete with weeds and might be cut for hay to minimise weed seed set. Of the fodder legumes, the greatest biomass was harvested with common vetch, balansa, Persian and crimson clovers. In severe areas of waterlogging, growth was retarded for all species except balansa clover.

Initially, the lucerne variety Jindera was sown as a ‘model prostrate lucerne system’ for intercropping experimentation because it was the only low-growing, winter-dormant variety that was commercially available at the commencement of the
project (marketed by Heritage Seeds). Unfortunately, it was found to be not particularly robust, or competitive in the Temora environment, and although it provided some small ‘dewatering benefit’ over and above the annual pasture or cropping treatments, it did not persist following overcropping with wheat. Evaluation of a range of lines of the Medicago species, M. sativa, M. media and M. varia were undertaken in the glasshouse in 1997 and 1998. Several accessions were found to have potentially valuable characters such as winter dormancy, rhizomes, perenniality and prostrate habit. The most suitable lines trace to wild Spanish germplasm which evolved and persisted in a Mediterranean environment with constant browsing by sheep and goats. These accessions were subsequently bulked up in nursery plots and evaluated in the field in rotation and in mixtures with crops. In general, the prostrate types were not quite as effective in drying the soil profile as the erect varieties such as Aquarius\(^{10}\) (20mm-25mm wetter in top 1m at the time of sowing crop); however, crop yields were similar when intercropping both erect and prostrate types (Table 6-7). The prostrate growth habit was lost to some degree (i.e. shoots became more upright) when grown in competition with a vigorous crop.

3. Dealing with Saline ‘Hot Spots’

In 1999, there was complete crop failure within saline scalds and gradients of growth (depending upon the crop species) away from the edge of the salt (and waterlogged) affected areas. Most of the pasture species (including lucerne) also failed, with the exception being a sparse population of phalaris and tall wheatgrass. Lucerne established in 80ha around the salt scalds lowered the water table by more than 0.5m in less than one year, and rainfall leached surface salt into the subsoil so that in 2000, a wheat crop was established and yielded 1t/ha in areas where there was no plant growth in 1999. It was interesting to note that the water table rose under the scald during the winter of 2000, but not under the surrounding lucerne, indicating that further control of recharge from higher in the catchment was required to reduce discharge in addition to the reduction of the local water table. Lucerne has now been established further upslope from the discharge area and water table monitoring by local growers is continuing.

Other research

Dewatering the soil profile prior to cropping with lucerne should be considered as only one possible approach to reducing the risk of waterlogging and improving the reliability of cropping in the Bland and in similar soil types and environments elsewhere in Australia. Raised beds continue to be promoted in the Southern Region as a ‘panacea’ to waterlogging problems by Southern Farming Systems (SFS), and a range of potential options and combinations of strategies are currently being evaluated by project CSP291. However, there still appear to be opportunities for more co-ordination and better integration of R&D across a range of alternative strategies in the high rainfall zone (HRZ) and in waterlogging prone soil types.

Despite the evaluation of several other potential deep rooted perennial legumes as part of this project, lucerne currently appears to remain the ‘best-bet’ species for the soil types in the Temora region. Project CSP291 is currently comparing rotations involving lucerne with chicory and phalaris in the Bland; however, a much wider assessment of perennial legumes, dicots and grasses seems warranted. Some of this sort of activity will be undertaken by the Salinity Cooperative Research Centre (CRC) project UWA397 that has trial sites planned for waterlogging prone areas of southern NSW, but single row or small plot evaluations may not necessarily be a reliable guide to subsequent performance within crop rotations. Opportunities exist to assess germplasm ultimately selected by project UWA397 (or other related projects) within a farming systems context. This might be possible to a limited degree through another GRDC-funded Salinity CRC project UWA059 that also has nodes of activity in southern NSW and north-eastern and central VIC.

Intercropping (also known as companion cropping and overcropping) has considerable promise as a strategy to prevent waterlogging and control groundwater recharge. Unfortunately, this system was never properly evaluated under waterlogging conditions as part of this project, but it is a system already in use by a number of growers in the wetter regions of VIC and central NSW. Salinity CRC project UWA059 plans to address some of the more pressing agronomic issues associated with intercropping involving choice of crop and/or perennial genotype, and the use of herbicide suppression and fertiliser applications to shift the competitive balance for water and nutrients more in the crop’s favour.

Additional information

Attachments

3. Appendix C - Economics of including lucerne in crop rotations of waterlogging-prone farming regions.
5. Appendix E - Reports of project activities and research results to growers and researchers.