How much deep drainage actually occurs in Vertosols under fallows and lucerne?

Summary
Grazing management of lucerne on a Vertosol soil had few differential effects on persistence, biomass yield or water use. After good rain, five weeks rest - one week grazing produced greater water use efficiency (WUE) of forage production than set stocking. All systems were prone to surface run-off and sediment loss, particularly when volunteer grasses were absent. To directly measure deep drainage on the Breeza Plain, three lysimeter access wells were installed to depths of two, five and six metres. To create drainage events, sub-surface drip irrigation was laid over 3.6ha around the wells. Tension lysimeters were constructed. Design and safety issues slowed progress. No deep drainage measurements have been made.

Report Disclaimer
This document has been prepared in good faith on the basis of information available at the date of publication without any independent verification. Grains Research & Development Corporation (GRDC) does not guarantee or warrant the accuracy, reliability, completeness or currency of the information in this publication nor its usefulness in achieving any purpose. Readers are responsible for assessing the relevance and accuracy of the content of this publication. GRDC will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying on information in this publication. Products may be identified by proprietary or trade names to help readers identify particular types of products but this is not, and is not intended to be, an endorsement or recommendation of any product or manufacturer referred to.
Other products may perform as well or better than those specifically referred to. Check www.apvma.gov.au and select product registrations listed in PUBCRIS for current information relating to product registration.

**Copyright**

Grains Research and Development Corporation. This publication is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced in any form without written permission from the GRDC.

**Old or Archival Reports (Projects that concluded in 2007 or earlier)**

The information contained in these older reports is now several years old, and may have been wholly or partially superseded or built upon in subsequent work funded by GRDC or others. Readers should be aware that more recent research may be more useful for their needs. Findings related to agricultural chemical use are also potentially out of date and are not to be taken as a recommendation for their use.

**Conclusions**

Lucerne grazing management
This study suggests that strict rotational grazing is not necessary for hydraulic stability provided that lucerne density does not fall below several plants/m² and that grasses are not discouraged. Although the actual density is not obvious from this work, observations from earlier work (project DAN347) indicated that historic deep drainage in Vertosols is small under 15 year old lucerne with density of 0.5-1 plants/m². Under average rainfall or wetter in this environment, optimum management would have yielded more forage with greater water use efficiency (WUE) and presumably accumulated more root carbohydrate reserves than management with shorter rest periods. With larger root reserves, optimum management might have led to enhanced persistence. If pests and disease had been more prevalent, there might have been an interaction with grazing such that plant survival rates were reduced if management had allowed crowns to be repeatedly damaged by close grazing. There is, of course, already sufficient evidence for the persistence benefits to lucerne stands of periodic resting for five weeks or more (Lodge 1991 Aust J Exp Agric 31, 713-24).

For short pasture phases, deep drainage will mostly remain small even under low lucerne densities. However, the risk of surface run-off and soil loss will increase with decreasing density, particularly if sown or volunteer grasses are not present. In addition, this work indicated that other major contributors to short stand life are
- Too high stocking rates.
- Too frequent late removal of sheep after crowns have been damaged.
- Inadequate plant nutrition.

Wetting of cracking clay profiles after lucerne
The slow recharge of Vertosols dried by lucerne contrasts with the rapid discharge of soil water by healthy young lucerne sown into a full profile. This marked hysteresis appears to be partially mitigated when a perennial grass is present. Although there might be little lucerne surviving at the end of a long (= 5 year) pasture phase, other benefits may well justify the extra cost of establishing a mixed lucerne and perennial grass pasture. For shorter pasture phases in rotation with crops, hysteresis may not be as great if the lucerne is fallowed after just 12 months. Alternatively, after 2-3 years of lucerne, a fallow period of 6-18 months may be needed for sufficient recharge.

Direct measurement of deep drainage using tension lysimetry
The slow progress has been due to unforeseen issues that have had to be dealt with in an appropriate and systematic manner. Issues have centred around the objective that the lysimeter installations should be permanent once installed, the specification, quality and cost of hardware (tubing, fittings, sealants etc); the need to bench test all apparatus and to arrive at a decision as to what level of performance will be adequate in the field; the Occupational Health and Safety (OH&S) documentation process required hazardous substances and procedures. The installation and testing of the subsurface drip irrigation system (SDI) was both relatively expensive and time consuming. However, work is proceeding and should be very useful while the original aims will be met.
**Recommendations**

Lucerne grazing management
Research and development (R&D)
- Continue to provide pest and disease resistant lucerne varieties selected under commercial conditions.
- Encourage an industry that produces drought tolerant, persistent perennial grasses suitable as companion species for lucerne.
- Develop the means and technology for establishing mixed perennial grass and lucerne pastures in areas too dry for phalaris.
- Issues of the establishment and management of lucerne in rotation with crops and as a part of a longer term mixed pastures are more important than issues residual from this work such as the interaction of grazing management with pests and diseases.

Practical
- Before sowing, soil test for nutrient levels and acidity, provide adequate nutrients at sowing. For much of north western New South Wales and especially soils that have been heavily cropped, where grain, forage or hay have been exported, growers should be aware that, as well as phosphorus (P) and sulphur (S), other nutrients such as molybdenum (Mo), zinc (Zn) and potassium (K) may be deficient.
- Use at least recommended seeding rates to suppress weeds and maintain ground cover.
- Graze young lucerne infrequently (several weeks after early bloom) and lightly (not to bare crowns).
- When established, graze for three weeks or less followed by five weeks or more of rest.
- Remove stock when standing biomass is less than 500kg/ha. Have other feed sources available during drought or be prepared to lose the lucerne.
- Avoid having poorly fed and overgrazed plants. They are susceptible to disease and will have exhausted root starch reserves.
- Consider sowing lucerne with or into a mix of cool and warm season perennial grasses.

**Wetting of cracking clay profiles after lucerne**

Research
The slow recharge of Vertosols dried by lucerne contrasts with the rapid discharge of soil water by healthy young lucerne sown into a full profile. This marked hysteresis appears to be partially mitigated when a perennial grass is present. The full nature of this problem will need to be resolved by the lysimeter work.

Practical
If a pasture phase of, say, five or more years is anticipated, it may well be worth the extra effort and cost to establish a mixed lucerne and perennial grass pasture. For a shorter pasture phase in rotation with crops, hysteresis may not be as great if the lucerne is fallowed after just 12 months. Alternatively, after 2-3 years of lucerne, a fallow period of 6-18 months may be needed for complete recharge.

Direct measurement of deep drainage using tension lysimetry
Although progress has been slow due to unforeseen issues, the work is proceeding and will ultimately be very useful. The original aims will be satisfied, justifying the large investment made by the GRDC and NSW Department of Primary Industries (DPI).

The Breeza research will be an important part of a new project looking at the mobilisation and likely fate of the large salt stores under cropping on the cracking clays of north western NSW - or ‘does deep drainage matter under cropping in drier areas?’

**Outcomes**

Through reduced uncertainty in the promotion and adoption of water efficient and hydraulically stable dryland agricultural systems, a reduction in the contribution of dryland agriculture to soil erosion, salt mobilisation and deterioration in stream water quality in north western New South Wales.

Accrual of benefits from the direct measurement of deep drainage part of the project awaits its completion

For the lucerne management work:
Economic
Lucerne grown in rotation with crops need not incur the capital expenditure of subdivision provided that rotations are flexible and that lucerne paddocks can be returned to cropping before deep drainage control and forage production are compromised.
The lucerne grazing management study has shown that lucerne grown on Vertosols will control deep drainage until lucerne density declines to several plants/m$^2$ (not determined due to drought). This suggests that lucerne grown in large paddocks where control of stocking intensity is more difficult than with smaller paddocks can be managed less rigorously provided the paddock can be returned to cropping before hydraulic stability is compromised or the poor water use efficiency (WUE) of forage production becomes costly. Invasion by volunteer grasses will increase as lucerne declines which may have implications for disease control in following cereal crops.

It is a matter of which enterprises are preferred. Where livestock enterprises are dominant, more land will be committed to longer term pastures. Hence lucerne based pastures will need to be rotationally grazed to achieve maximum forage production and persistence; deep drainage will be well controlled. Where cropping is dominant but with lucerne in the rotation, a short rotation of 1.5-3 years would be possible with set stocking and occasional 5-6 week rest periods and would not require major subdivision of paddocks. The length of the rotation would need to be flexible and preferably returned to cropping before plant density declined to the point of leaving bare areas.

Environmental
The lucerne management needed for efficient forage production and persistence appears to be not always required for deep drainage control. Lucerne densities of several plants/m$^2$ together with volunteer grasses will, most of the time, confer drainage control in Vertosols with large plant available water holding capacity (WHC) in summer rainfall environments.

However, the high risk of surface run-off and soil erosion in even dense lucerne stands is a serious issue. This can be partially rectified by including perennial grasses in the pasture mix. For drier areas, there are no persistent, all seasons green or winter growing grasses, commercially available at reasonable cost to complement the summer growth of lucerne.

Social
Successful lucerne management can vary in the capital cost and rigour that is applied. It depends on the nature of the enterprise mix on the farm and the preferences of the farming family.

Achievements/Benefits
Lucerne grazing management

Background
This work was predicated on the reaction to a report to the Murray Darling Basin Commission (MDBC) in the mid 1990s which suggested that to reduce saline base flow to acceptable levels, one third to one half of the Uplands of the Murray Darling Basin must have the minimal recharge associated with treed landscapes. In response to this report, the predictions of increasing stream salinity (Salinity Audit 2000) and the belief that natural ecosystems are inherently more hydraulically stable than agricultural systems, lucerne, and other ‘deep rooted perennials’, have been widely promoted as tools with which to manage agricultural systems such that they might mimic the hydrology of natural systems.

Aims
For best persistence and production, lucerne needs to be rotationally grazed which requires capital expenditure for subdivision of large paddocks. However, small paddocks are not conducive to efficient cropping operations. It was therefore set out to determine how grazing management affects the hydrology and production of lucerne pastures.

Methods
The experiment was conducted on an established lucerne (cv. Siriver) stand, growing on a black Vertosol located near Duri (150 49' 30", 31 14' 00", elevation 460m). Fertiliser applied to the ground surface after soil testing was 37kg P/ha, 48kg S/ha, 80kg Ca/ha, 3.7kg Zn/ha.

The aim was to test stand response to a factorial combination of six rest (5, 3 and 1 weeks) and grazing (1 and 3 weeks) periods. The five weeks rest with one week grazing (5:1) treatment represented a six paddock rotation, the optimum management recommended by departments of agriculture; the 5:3 treatment, the way many growers might manage individual lucerne paddocks not necessarily part of a complete rotation; the 1:1 and 1:3 treatments were to mimic set stocking of large paddocks at a plot scale (i.e. where a mob was moving around a large paddock such that parts of the paddock would receive a periodic spell). The intermediate 3:1 and 3:3 treatments enabled some stand recovery but replenishment of root reserves would be limited.
Each treatment was represented by one phase (plot) of that treatment (and not a complete rotation) replicated three times; the total number of 0.36ha (60m x 60m) plots being 18. Sheep (40-45kg dry Merinos) were drawn from a common mob to implement grazing treatments. Stocking rate (i.e. number of sheep days/24 week cycle) was kept the same for all treatments.

The main findings were:
- Standing biomass under optimum grazing management was greater only under favourable conditions and towards the end of its cycle compared to other regimes.
- Under the conditions of water and/or cold stress prevailing most of the time, grazing management had no effect on production, water use, soil water stores or lucerne plant density.
- Surface run-off and sediment loss were not related to measurable differences between treatments, but to ground cover and surface soil condition. The results clearly showed that when volunteer grasses were present in a lucerne stand, run-off was reduced and sediment loss was negligible.
- Simulation of the 5:1 grazing regime as a fully phased system with the Agricultural Production Systems simulator (APSIM) strongly suggests that the superior biomass production of this treatment was ‘real’ and not due to an artefact arising from the lack of phasing in the experimental design i.e. using just one plot and not a full set of six.

Aspects of site management that may well have contributed to the lack of grazing effects were:
- Adequate plant nutrition after extensive soil testing
- Light or zero stocking whilst the stand was establishing (grazing treatments were imposed on an established stand).
- The lucerne was not overgrazed - sheep were removed once standing biomass became less than 0.5t/ha.

These results are supported by earlier work (DAN347) which found that historic deep drainage under old lucerne pastures, often with about one plant/m², was very small. A more recent study conducted to broaden the scope of this work, using archived DAN347 soil samples, suggests that soil carbon accumulation occurs under lucerne but not to the extent that it might under a grass pasture (Young et al. 2005).

Quantifying water movement through wet and dry Vertosols

Background
Field and modelling research on the Liverpool Plains in northern New South Wales (Ringrose-Voase, Young, Paydar, Huth, Bernardi et al. 2003. Report 3 Agricultural Resource Management Series NSW Agriculture) has shown that deep drainage under opportunity cropping and perennial systems on Vertosols is greatly reduced compared to long fallow systems. Vertosols are the predominant soils farmed in north western NSW and southern Queensland. However, deep drainage was estimated by difference using water balance methods. As deep drainage is usually the smallest term in the water balance and occurs episodically, the actual values may vary considerably from the estimated values. Furthermore, there was some evidence of water draining through the dry subsoil under lucerne (‘bypass flow’). It was found that optimally managed lucerne dried a Vertosol to the extent that the subsoil (>1 m) failed to wet up as expected. This effect was pronounced after the extremely wet winter period of 1998. With low potential evapotranspiration (15% of rainfall) and surface runoff (38% of rainfall), changes in soil water storage (to 6m) were small (12% of rainfall). Water balance calculations produced large apparent deep drainage values (35% of rainfall). Water may have bypassed the soil matrix and moved rapidly down ped surfaces with little wetting of the profile. The observation that lucerne roots at depths of 2-3m are concentrated along major slickenside faces is evidence for water following ped surfaces. That lucerne dries the soil profile considerably more than annual crops has been more widely reported. For example, a long fallow period is required after lucerne for following crops to be successful (Holford and Doyle, 1978 Aust. J. Exp. Agric. An. Husb. 18, 112-17). The extent, and possible partial irreversibility, of drying of a Vertosol by lucerne was shown on a Darling Downs Black Earth (D. Lloyd and K. Coughlan, 1975 ‘Studies on the effects of a ley pasture on animal production and soil chemical and physical characteristics’ Project 113 QDPI). Lloyd and Coughlan (1975) found that water movement to depths beyond 90cm was very slow and incomplete, despite high rainfall, flooding and long fallowing, up to three years after lucerne pastures were ploughed out. It was considered that this drying of the subsoil may be partly irreversible as the water retention of subsoil previously under lucerne was less than that of subsoil previously under wheat and sorghum. The requirement for a long fallow after lucerne may be, in part, to allow the soil profile to recover from extensive drying before it can wet up normally. That is, the process of wetting is not simply the reverse of drying, there is considerable hysteresis. Before the soil recovers from the extremely dry state, water may be lost as by pass flow.

Wetting of cracking clay profiles after lucerne

Aims
To quantify the extent to which a cracking clay profile dried by lucerne will resist wetting

Methods and results

It was not possible to carry out this part of the work on the grazing experiment plots as planned. The property was sold and established lucerne stands generally were in poor condition after the drought.

However, work carried out elsewhere on the Liverpool Plains (Acworth et al. 2005) satisfactorily confirmed the difficulty of wetting a cracking clay after lucerne; despite a combination of herbicide applications and a pass with a chisel plough to roughen the ground to promote infiltration. The fallowing efficiency after 400mm over three months was low (30%) and wet up the surface layers only. The presence of perennial grass appears to mitigate this hydrophobia to some extent; a lucerne and phalaris pasture, fallowed earlier, wet up more efficiently.

The slow recharge of Vertosols dried by lucerne contrasts with the rapid discharge of soil water by healthy young lucerne sown into a full profile. This marked hysteresis appears to be partially mitigated when a perennial grass is present. In a short pasture phase in rotation with crops, hysteresis may not be as great if the lucerne is fallowed after just 12 months.

Direct measurement of deep drainage using tension lysimetry

Aims
To verify model predictions and indirect estimates of deep drainage and to find out whether deep drainage can actually occur below soil dried by lucerne, it was decided to measure deep drainage directly using tension lysimetry and associated instrumentation.

Methods
To measure deep drainage below the root zone of lucerne and most herbaceous plants required access to the subsoil below 3-4m. Liverpool Plains work has shown that 3.5m is about the greatest depth to which lucerne extracts water from a well structured Vertosol.

To access the subsoil at approx. 4.5m, two pump wells were installed to a depth of 6m in a grey Vertosol on the Breeza Plain (NSW DPI Liverpool Plains field station); a third was installed to 2.5m.

The design and specifications of pump wells, access hatches, guard rails around hatches, fall arrest and recovery equipment, ventilation machinery and atmosphere monitoring instruments were guided by the requirements of ‘Safe Working in a Confined Space’ AS 2865 OH&S Act 2000, the need for flood proofing and the strength needed if heavy machinery were to be accidentally driven over the top (the access wells have a low profile to reduce interference with crop microclimate). Draft plans and specifications were compiled and modified after discussions with manufacturers and a consulting engineer. Before construction, final plans were assessed by the consulting engineer. Risk assessments and safe work method statements (SWMS) were approved within NSW DPI.

The prefabricated reinforced concrete well liners were lowered into 2m diameter holes excavated by a Caldwell bucket drill. A subsurface drip irrigation system (SDI) was installed over the 4ha site to create experimental deep drainage events as needed.

Electrical imaging probes were installed at four locations to a 6m depth adjacent to the location of each set of three lysimeter trays to continuously monitor changes in soil water content down the profile.

Tension lysimeters (six stainless steel trays with sintered metal surfaces) and tension control systems have been bench tested. Hardware for installation and support of lysimeters in the subsoil has been constructed and tested.

The slow progress has been due to the unforeseen and often small issues that have needed to be dealt with.
One set of issues centres around the aim that the lysimeter installations should be permanent once installed in a highly corrosive environment where overburden loads will ultimately settle to around 5t/m$^2$. To remove the lysimeter trays once installed is potentially disastrous should the subsoil collapse and effectively destroy the volume of subsoil to which access was gained at great cost. All the same, the lysimeter trays have been designed so that they can be extracted should that be absolutely necessary.

Examples of issues are the specification, quality and cost of tubing, fittings and sealants; the need to bench test all apparatus and to arrive at a decision as to what level of performance will be adequate in the field and the OH&S documentation process required on any potentially hazardous substance.

The installation and testing of the subsurface drip irrigation system (SDI) was both relatively expensive and time consuming.

**Other research**

- Continue work on direct measurement of deep drainage to validate indirect measurements and model predictions.
- Assess whether deep drainage under cropping matters - now, later, or much later - in the cracking clays of north western New South Wales. An immediate benefit is the leaching of salt from the root zone. But what is the capacity of these unconsolidated alluvia to store saline deep drainage before discharge into sensitive water and soil resources?
- The APSIM lucerne module has been successfully validated against these field data collected in dry times suggesting that it is reasonable to use APSIM to predict lucerne water use and productivity in drier areas (DAN00059).

**Additional information**
