The Role of Forages in Sustainable Cropping Systems of Southern Australia

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Abstract

The historical context, recent trends, and possible future role of forages in cropping systems are reviewed. Three recent themes will be developed: 1) The successful exploitation of genetic diversity resulting in commercial development of new legume species as pasture cultivars with specific traits better suited to the needs of current farming systems. 2) Improved understanding of key soil processes under grazed pastures, particularly soil water and soil nitrogen, and how these processes impact on indicators of sustainability like deep drainage and nitrate leaching. 3) An emerging capacity for predicting the effect of pasture-crop sequences on soil processes, crop growth and grain yield.

In response to changing economic pressures and threats to sustainability, new farming systems involving forages are continually evolving. Increasing cropping intensity has placed pressure on pasture-crop systems that rely on self-regeneration of annual legumes following crops. One response has been the emergence of phase cropping systems, where a sequence of pasture years is followed by a sequence of cropping years. Another response has been an expansion in the area of lucerne grown in rotation with crops.

In the future, forages in cropping systems will continue to fulfil the traditional roles of diversifying farm income through livestock production and supporting the cropping enterprise through maintenance of soil fertility. But increasingly, forages will be utilised to maintain the sustainability of agricultural production systems. Examples include competitive forages as a component of integrated weed management and high water use forages for reducing recharge and the associated spread of dryland salinity.

Keywords: legumes, cropping systems, simulation, deep drainage, dryland salinity, sustainability

Introduction

Southern Australia has a unique place in the history of the development of ley farming systems. Subterranean clover and annual medics were first commercially developed here, and ley farming systems, involving the rotation of self-regenerating annual legumes with cereal crops were well developed by the 1960's. The ley farming system had many benefits over the fallow – wheat rotation it replaced.

In recent times, the profitability and sustainability of traditional ley farming systems has been seriously challenged. Market forces, threats to sustainability, and rapid developments in cropping technology have combined to deliver profound change to southern Australian cropping systems. Some of these changes are detailed in the paper.

Pasture species improvement programs have responded to these challenges by redirecting resources away from the traditional species (with the exception of lucerne) and into a diverse array of new, largely non-domesticated species. These changes are outlined in the paper.

The threat of dryland salinity over much of the southern Australian cropping zone has forced a new hydrological imperative to reduce deep drainage from agricultural landscapes. The implications of this new imperative for pasture plant improvement and pasture – crop rotations are discussed.

The complex task of optimising pasture – crop rotations, and assessing the potential of new pasture species, demands a systems approach. Simulation modelling of agricultural production systems has developed to a stage where the impacts of pasture – crop sequences on whole rotation profits and some indicators of sustainability can be predicted. These recent developments are described.

Finally, a positive future role for pastures in cropping systems is predicted. This future will involve new pasture species, new pasture – crop sequences, and new tools for analysing and managing pastures in cropping systems.

Current status of pastures in cropping systems

Pastures remain an important component of cropping systems in many regions of southern Australia. The traditional role for pastures in cropping systems has been reviewed by Puckridge and French (1983) and Robson (1990) and includes; income diversification through livestock products, maintenance of soil fertility, and sustaining crop production by providing options for disease and weed control, and increasing soil nitrogen through biological nitrogen fixation. This traditional role has been challenged in recent years by a number of developments. Firstly, and most significantly, low livestock commodity prices, particularly wool, relative to crop commodities, has encouraged many farmers to intensify cropping at the expense of pastures in order to remain profitable. Secondly, the traditional role of pastures as a cereal root disease break has been questioned, for example, important cereal root diseases (bare patch, *Rhizoctonia solani* and root lesion nematode, *Pratylenchus neglectus*) may actually increase following annual medic (*Medicago* spp.) pastures (Bellotti et al., 2001). These developments have led to a reduction in the area of pastures in some areas. Other developments may lead to the area of pastures in cropping systems increasing. Firstly, the development of herbicide resistant weeds has increased interest in pastures as a component of integrated weed management. Secondly, the need to reduce deep drainage from cropping landscapes has renewed interest in lucerne as a pasture phase between a series of crop years (see section below for more detail).

Given low wool prices during the past decade, the area of pastures in cropping areas could be expected to fall. A recent study (M. Unkovich, pers. comm.) reveals that although the area of total crop has increased in the past fourteen years, the corresponding fall in total pasture area has been surprisingly small (Table 1). Table 1 should be interpreted with caution as the areas are state based and therefore include large non-cropping (permanent pasture) areas. Also, the area of pasture has been derived as the total area of agricultural holdings (excludes forestry, national parks, roads, dams, etc.) minus the total area of crop. As such, the area of 'pasture' in Table 1 includes sown pasture, native grasslands, non-arable country, and fallow. This calculation was necessary, as unfortunately there are no consistent statistics recorded for the area of pastures in Australia. The area of pasture far exceeds the area of crop in all states. In the past fourteen years, South Australia recorded the largest increase in crop area (14.5%) and the largest decrease in pasture area (-3.7%).

Changes in area of crops and pastures for three South Australian cropping regions provide a more detailed picture (Figure 1). The three regions represent contrasting environments and show different trends. The Upper Eyre Peninsula is an area of low rainfall (250 – 350 mm, average annual rainfall, aar) and infertile soils. In this region there has been a decline in total crop area, and pasture area has increased slightly. In the Murray Mallee, rainfall is also low (250 – 350 mm aar) but soil fertility is slightly better than Upper Eyre Peninsula. The area of cropping has risen recently and pasture has slightly declined. The Mid North area receives higher rainfall (400 – 600 mm aar) and the soils are more fertile. The total area of crop has steadily risen and there has been a corresponding decline in the area of pasture. The different trends in area of crops and pasture reflect the availability of alternative break crops that can be substituted for annual pastures in rotation sequences. In the Mid North, available crops include canola, field peas, and faba bean, while in the low rainfall regions, these crops are poorly adapted, and yield and profits are unreliable. Even with available alternative crops, the total area of pasture exceeds the total area of crops in the Mid North region.

Confirmation of the continued importance of pastures in cropping systems comes from a recent survey commissioned by the Grains Research and Development Corporation. The average area (hectares) of crop and pasture on mixed livestock-crops farms was 605 and 1,894 in Western Australia, 365 and 864 in South Australia, 240 and 429 in Victoria, and 337 and 985 in New South Wales (ABARE, 1999). It is clear from the above figures that, despite low wool prices, pastures remain an important component of cropping systems throughout southern Australia.

Despite low wool prices, pastures can still contribute to profitable rotations through their beneficial impact on the grain yield of subsequent cereals. Whole farm profit modelling of the economics of pasture improvement have concluded that every $1/ha spent on pasture can return between $0.87 and $2.67 in whole rotation profit depending on pasture quality and rotation sequence (Krause, 1995). Investment in improved pastures (seed, fertiliser, herbicide) on the Upper Eyre Peninsula of South Australia of up to $57/ha was profitable in some circumstances (Krause, 1997). Despite these findings, actual expenditure on pastures in the cereal-livestock zone is a very low $4.30 - 6.50/ha (ABARE, 1999), reflecting lack of farmer confidence in the profitability of investment in pastures.

Increasing genetic diversity of pasture legumes for ley farming systems

Traditionally, ley pastures in southern Australia have been based on just a few sown species, subterranean clover (*Trifolium subterraneum*), and annual medics (*Medicago truncatula* and *M. littoralis*). The ecology and management of these pastures has been described by Rossiter (1966) and Carter (1987). These species have, in general, been very successful, and continue to provide the basis for the majority of ley pastures in southern Australia. Despite their success, concern over the narrow genetic base of southern Australian pastures has grown. An extreme example is provided by the Upper Eyre Peninsula, where until recently, a single cultivar of strand medic (*Medicago littoralis* cv. Harbinger) was the only pasture cultivar available for an area of over 600,000 ha.

The narrow focus of pasture improvement programs on the traditional species is apparent in the list of new pasture legume cultivars registered since 1990 (Table 2). Sixteen of the twenty-one registered cultivars were either subterranean clover, annual medics, or lucerne. In addition to registered cultivars, a number of new species have recently been commercialised without registration. These include arrowleaf clover (*Trifolium vesiculosum* cv. Cefalu and Zulu), crimson clover (*Trifolium incarnatum* cv. Caprera and Blaza), yellow serradella (*Ornithopus compressus* cv. Charano), French serradella (*Ornithopus sativus* cv. Cadiz), and biserrula (*Biserrula pelecinus* cv. Casbah) (Anon, 1998; Dear and Sandral, 2000).

The past focus of pasture improvement programs is also revealed by the traits incorporated into new cultivars (Table 2). The major focus has been to develop new cultivars with improved tolerance to pests such as aphids (blue green aphid *Acyrthosiphon kondoi*, spotted alfalfa aphid *Therioaphis trifolii*) and diseases such as clover scorch (*Kabatiella caulivora*) and root rots (eg. *Phytophthora clandestina*). A second major focus has been to extend the range of existing commercially available species by selecting earlier and later flowering genotypes. Other traits included harder or softer levels of hardseed, and the general aim of improved persistence and productivity.

In recent years the philosophy of pasture plant breeding in southern Australia has shifted from a focus on continual improvement of the traditional species to a focus on developing new species for problem environments and changed farming systems. This change in philosophy has been based on greatly improved knowledge and understanding of species ecology in the countries of origin (Ehrman and Cocks, 1990; Cocks, 1993) and of species diversity and evolution of naturalised pasture legumes in Australia (Cocks, 1992; Fortune et al., 1995). Driving this change has been the need to address pressing threats to the sustainability of cropping systems such as rising groundwater and intractable weed populations, and the opportunity presented by major changes in the way pastures are rotated with crops. In addition to the largely introduced legume species, some native grasses (eg. *Danthonia* spp., *Microlaena* spp.) and saltbushes (*Atriplex* spp.) have also been recently domesticated and the use of native species in agriculture will increase in importance in the future.

Pastures will continue to fulfil traditional roles such as providing the feed base for livestock enterprises, but their major future role in cropping landscapes will be closely tied to improving the sustainability of these systems (Table 3). Dryland salinity is widely regarded as the most serious threat to the sustainability of cropping systems throughout much of southern Australia (see next section). One of the most promising solutions to this threat is the use of perennial forages to reduce deep drainage below the root zone of annual crops. For this reason, perennial plants with deep roots and summer active growth patterns are needed. Lucerne is currently the preferred species for this role, but other species are needed for areas where lucerne is poorly adapted (eg. acid soils, waterlogged and saline conditions). Of particular importance for plants aimed at reducing deep drainage, is root adaptation to harsh subsoil conditions such as transient soil salinity, sodicity, toxic levels of boron, high soil pH, and high soil strength (Figure 2). Unless plant roots are adapted to these conditions they will not be able to perform the function of de-watering deep subsoil.

Other important roles include the use of pastures in integrated weed management for control of herbicide resistant weeds. Pastures are particularly attractive for this role as they allow the use of non-chemical techniques such as grazing and hay making, as well as non-selective herbicide options such as spray-topping and winter cleaning (Powles and Bowran, 2000). Pastures have traditionally been used to provide a disease break for following cereals, but some pasture legumes (eg. *Medicago* spp.) can allow some cereal root diseases to build up in the pasture phase (Bellotti et al., 2001). It is therefore important for future pasture legumes to have *resistance* to important cereal root diseases so that these diseases are kept at low levels during the pasture phase, as well as *tolerance* so that the pasture species themselves are not effected. Soil organic carbon inputs are usually higher under pasture compared to pulse crops (Crawford et al. 1997) and soil microbial biomass is usually higher following rotations including pastures compared to continuous cropping rotations (Ladd et al., 1994). A possible association between increased microbial biomass and suppression of cereal root diseases has been reported (Roget, 1995). It is therefore important that the performance of new species in terms of total soil carbon input and influence on microbial biomass is not overlooked. Finally, so called 'phase farming', describing several consecutive years of pasture (annual or perennial species), followed by several consecutive years of crops, is seen by many as offering advantages over traditional ley farming systems involving tight rotations of one or two pasture years followed by one or two crop years. Phase farming places different requirements on pasture legume species compared to those required for traditional ley farming systems (Howieson et al., 2000).

Pasture improvement programs in Australia have been quick to respond to the new challenges and opportunities (Table 4). Many of the traditional selection criteria are still in place, but these have been augmented with new objectives. It is interesting to note that the observation by Hutchinson and Clements (1987) that improving pasture nutritive value was not an objective in most Australian pasture improvement programs still applies today. Also apparent is the great increase in species diversity included in current programs. Not all of the species listed will make it through to become commercial cultivars, but there are certain to be several new species added to the list of commercialised species in the near future. In the rush to develop new species it is important that the agronomy, feeding value, and management systems are not overlooked. The Register of Australian Herbage Plants (Oram, 1990) is an interesting compilation of 'new' species that have had little commercial impact.

Reducing deep drainage from cropping landscapes

In many regions of southern Australia, the most serious threat to land and water resources is dryland salinity (Murray Darling Basin Commission, 1999). The cause of dryland salinity is the hydrological imbalance that has followed the replacement of native vegetation communities with shallow rooted annual crops and pastures. The resulting increase in deep drainage below the root zone of annual species has increased recharge to groundwater, causing groundwater levels to rise, eventually reaching the soil surface in low lying areas (Figure 2). An important feature of Figure 2 is the delineation between recharge and discharge zones in the landscape. Secondary salinity occurs when saline groundwater approaches the soil surface causing salinity and waterlogging in the root zone of discharge areas. The cause of rising groundwater is the increase in deep drainage in the recharge zones and it is therefore imperative that deep drainage from these areas is reduced to levels approaching those of the native vegetation communities.

Deep drainage under annual crops and pastures can reach amounts equivalent to 40-50% of the rainfall received, representing a lost opportunity for plant growth as well as contributing to dryland salinity. In addition to contributing to rising groundwater, deep drainage results in nitrate leaching and soil acidification (Ridley et al., 1999). In studies across southern Australia, covering a wide range of soils and climates, lucerne has been effective in reducing deep drainage from the high levels found under annual crops and pastures, to levels approaching those found under the native vegetation (Table 5). Typically, deep drainage under annual crops and pastures is around two orders of magnitude greater than that under the native vegetation. Even in low rainfall (300 – 350 mm average annual rainfall) cropping country, such as around Euston and Balranald, deep drainage has significantly increased under annual crops, causing groundwater to rise, and threatening soil and water quality. Lucerne provides an agronomic solution to deep drainage where soil conditions are favourable for its growth. The profitability of lucerne, relative to alternative options, will largely determine the level of adoption by farmers.

The differences in cumulative evapotranspiration under annual pastures, lucerne, and native vegetation, may result in dramatic differences in the pattern of daily recharge (Figure 3). In this simulation example, recharge under annual pastures occurs from day 100 (early autumn) when annual pastures germinate and young seedlings are unable to utilise stored soil moisture and rainfall. Recharge under annual pastures reaches a peak during winter before reducing in late spring and early summer. In contrast to the annual pasture, there is no recharge under lucerne in autumn and winter, with only a small amount in spring. The key to the success of lucerne for reducing recharge is its ability to dry out deep subsoils (Lolicato, 2000; Pitman et al. 2001). Rotating several years of lucerne followed by several years of annual crop may minimise deep drainage by exploiting the ability of lucerne to de-water subsoils. During the lucerne phase, deep subsoil moisture is utilised by the lucerne, creating a buffer of dry soil for storage of the expected drainage from the next cropping phase. While this rotation holds some promise, simulation studies caution that results are strongly dependent on soil type, rainfall record (particularly episodic high rainfall events), and rooting depth, and conclude that more experimental research and simulation studies are needed (Dunin et al., 1999).

The key to minimising the spread of dryland salinity is greater use of perennial plants with deep root systems that can dry deep subsoils and thus reduce deep drainage. This requirement raises the issue of plant root adaptation to subsoil constraints. Figure 2 highlights surface and subsoil constraints that impair the function of plants growing in recharge areas. Throughout much of southern Australia, subsoil constraints are common. For example, subsoil transient salinity (Figure 2), not to be confused with secondary salinity, occurs in about 30% of wheat growing soils in South Australia (Fitzpatrick et al., 2000). Subsoil transient salinity (ECse > 4 dS/m), along with other common constraints such as high exchangeable sodium percentage (sodicity, ESP >20%), high soil pH (pH > 9.5), toxic levels of boron (B > 15 mg/kg), and high bulk density, may all limit root function in subsoils and thus limit the ability of plants to de-water subsoils. Little is known about the adaptation of lucerne or other potentially useful perennial forage legumes (see Table 4), to these subsoil constraints, and research in this complex area is urgently needed.

Simulation of pasture – crop sequences

The prediction of crop grain yield response to preceding pastures is a function of both soil conditions present at the time of crop sowing and conditions during the crop growing season. A pasture – wheat rotation experiment at Roseworthy, South Australia, illustrates this point. Although inorganic soil nitrogen at crop sowing was higher following legume- compared to grass-dominant pastures, wheat grain yield did not increase in response to the extra nitrogen, as crop growth was limited by low growing season rainfall (Baldock et al., 1997; Yunusa et al., 1998). The complexity of soil water and soil nitrogen dynamics in pasture - crop rotations, and the strong influence of highly variable rainfall on both phases of the rotation, has led some researchers to consider simulation modelling as a tool for both research and management.

The Agricultural Production Systems Simulator (APSIM) was developed to:

1. Predict crop grain yield in response to environmental (soil, climate, management) inputs.
2. Predict trends in soil fertility (soil water, soil nitrogen, soil organic carbon) in response to management, including fertiliser, tillage, residue management, intercropping and rotation sequences.
3. Provide a flexible system for simulating a wide range of applications, an open process for testing and incorporating new modules, and an efficient way to integrate fragmented research efforts (McCown et al., 1996).

A key feature of the APSIM approach is that the soil resource is central to the simulation, responding to climate variability, management, and crop sequence (Figure 4). This feature provides APSIM with the required framework for simulating pasture – crop sequences. Figure 4 depicts the flow of water and nitrogen in a crop – fallow – crop sequence. Beginning at the left, soil water is reduced by crop transpiration. Soil water is also lost by evaporation from the soil surface, but is modified by surface crop residues. Rainfall is stored as soil water during the fallow period, and excess rainfall is lost as runoff. A second crop depletes soil water, but crop water use does not prevent some deep drainage occurring during early crop growth. In this way, the water balance is maintained on a daily basis over the period of interest.

The focus of APSIM has been on soil factors and crop production, although lucerne has been included in the growing list of crops simulated (Robertson et al., 2001). A separate modelling group has developed GrassGro, a system for simulating temperate pasture growth, pasture dry matter digestibility, animal diet selection, animal feed intake, and grazing animal production (Moore et al., 1997). Linking GrassGro into APSIM will allow simulation of pasture – crop sequences and this work is in progress (Bellotti, 2000). The modules required to simulate an annual medic pasture – wheat – barley rotation are listed in Table 6. APSIM provides the overall modelling framework, with individual modules, and the GrassGro model, communicating to each other via the central APSIM 'engine'. Note that APSIM does not currently attempt to model some important growth factors such as root diseases or competition from weed populations.

An example of model performance for a lucerne – wheat rotation experiment located near Toowoomba, Queensland, Australia is given in Figure 5. In this example, lucerne was undersown with wheat in 1988, allowed to grow for four years (1989-1992), removed at the end of 1992, and followed by four consecutive wheat crops (1993-1996). Overall, APSIM predicts the observed lucerne dry matter and wheat grain yield data very well. In addition, data not shown, APSIM accurately predicts the drying out of the soil profile under lucerne and the wetting and drying cycles of soil water under wheat. Soil nitrate is also predicted well, closely matching the observed data showing low amounts of soil nitrate under growing lucerne followed by a large release of nitrate (140 kg/ha nitrate-N) due to mineralisation of organic nitrogen after the lucerne was ploughed out (Probert and McCown, 2000).

Using these simulation tools it is possible to quantify the impact of climate variability within pasture – crop sequences on a wide range of productivity and sustainability variables. For example, the effect of preceding rotation (eg. medic pasture or faba bean crop) on wheat grain yield and protein can be compared over the historical climate record for a range of locations. Another example would be to predict the amount of deep drainage and nitrate leaching occurring over the same scenarios. While these simulation models have important research applications, they are increasingly finding applications as tools for facilitating in depth communication between researchers and farmers about the management of farming systems (McCown et al., 1998).

What is the future role for pastures in cropping systems?

The past 10 to 20 years have witnessed perhaps unprecedented change in southern Australian farming systems. Market forces, such as the fall in wool prices, have driven the trend towards more intensive cropping in some regions. Threats to sustainability, such as dryland salinity and herbicide resistant weeds, are renewing interest in special purpose pastures designed to deliver specific benefits to following crops. Despite the continuing pace of change, and perhaps on the surface somewhat surprisingly, pastures remain an important component of farming systems in many regions.

However, the role of pastures in cropping systems has changed, and will continue to change to suit the requirements of contemporary farming. In the past, the focus for pasture research was on livestock and crop productivity. In the future, whole rotation profits and landscape sustainability will increasingly be the focus of pasture research. Along with this change in role, the characteristics of pasture cultivars used in cropping systems will also need to change. Attributes associated with self-regeneration of annual legumes from soil seed banks, such as high seed numbers and high hard seed percentages, will become less important, or not needed, in rotations involving phases of continuous pasture. On the other hand, attributes associated with sustainability, such as the ability to de-water subsoils, will become more important. Previously wild species will be domesticated as new pasture cultivars to fulfil some of these new roles.

Along with this shift in focus from production alone, to production and sustainability, research into pasture – crop systems has become increasingly complex. On-farm productivity remains essential, but the environmental imperatives of maintaining soil and water quality are assuming equal, if not greater, importance. This increasing complexity is reflected in the requirement for detailed consideration of longer time frames, and larger spatial scales, all against a background of highly variable climate. This is the research scenario in which simulation modelling becomes an essential tool for analysing and interpreting complex interactions and long-term trends.

Increasingly, simulation modelling is becoming accepted as an integral component of research on issues of crop and pasture productivity and hydrologic balance of pasture - crop systems. Recent examples demonstrate the utility of simulation modelling for understanding the dynamics of water and nitrogen in pasture – crop systems. But much more work is needed to expand the geographic coverage of existing models, to include locally relevant crop and pasture modules, and to verify model performance in farmers' fields. In the longer term, inclusion of additional processes such as subsoil constraints will enhance predictive ability.

Pastures will continue to play an important role in the cropping systems of southern Australia. New pasture legume species will be added to the list of traditional species that have served cropping systems so well in the past. New roles for pastures in cropping systems will emerge to complement traditional roles. Simulation modelling will provide new ways of assessing the impact of pastures on whole rotation profitability and environmental sustainability. The next ten years will provide many challenging opportunities for research on pastures in cropping systems.

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Table 1

State	Average for 1983-1984		Average for 1996-1997		%change in crop area	% change in pasture area
	crop	pasture	crop	pasture		
NSW	5,520	49,790	5,070	50,240	-8.1	0.9
Vic	741	3,186	768	3,159	3.7	-0.8
SA	2,223	8,596	2,545	8,274	14.5	-3.7
WA	6,190	19,977	6,662	19,506	7.6	-2.4
Tas	63	1,233	45	1,251	-28.9	1.5
Southern Australia	14,737	82,782	15,089	82,429	2.4	-0.4

*Area of pasture = total area of agricultural holdings – total crop area.
Area of agricultural holdings excludes forestry, national parks, roads, etc.
Area of pasture therefore includes sown pasture, native grasslands, non arable country, fallow, etc.

Table 1 - Change in area (,000 ha) of crop and pasture* from 1983 - 1984 to 1996 - 1997 in southern Australia (data from M. Unkovich, pers. comm.).

Table 2.

Scientific name	Common name	Cultivar name	Agronomic traits	Year registered
Trifolium subterraneum var. *brachycalycinum*	Subterranean clover	Nuba	Replacement for cv. Clare, more productive	1990
Trifolium subterraneum var. *subterraneum*	Subterranean clover	Goulburn	Disease tolerant replacement for cv. Woogenellup	1991
	Subterranean clover	Leura	Disease tolerant replacement for cv. Karridale	1991
	Subterranean clover	York	Productive and persistent replacement for cv. Seaton Park	1995
Trifolium subterraneum var. *yanninicum*	Subterranean clover	Gosse	Disease tolerant replacement for cvs. Larisa and Meteora	1991
	Subterranean clover	Riverina	Productive and persistent replacement for cv. Trikkala	1996
Trifolium michelianum	Balansa clover	Bolta	Later maturing alternative to cv. Paradana	1998
Trifolium resupinatum var. *resupinatum*	Persian clover	Nitro Plus	Early maturing, hard seeded alternative to cv. Kyambro	1998
	Persian clover	Prolific	Early maturing alternative to cv. Kyambro	1998
Trifolium resupinatum var. *majus*	Persian clover	Morbulk	Earlier maturing and more productive replacement for cv. Maral	1999
Medicago truncatula	Barrel medic	Caliph	Aphid resistant replacement for cv. Cyprus	1993
	Barrel medic	Mogul	Aphid resistant replacement for cv. Borung	1993
Medicago littoralis	Strand medic	Herald	Aphid resistant replacement for cvs. Harbinger and Harbinger AR	1997
Medicago tornata	Disc medic	Rivoli	Soft seeded alternative to cv. Tornafield	1990
Ornithopus compressus	Yellow serradella	Paros	Early maturing, hard seeded alternative to cvs. Madiera and	1990

			Eneabba	
Medicago sativa	Lucerne	Quadrella	Disease resistant alternative to cv. Trifecta	1991
	Lucerne	Aquarius	Resistance to phytopthora root rot	1992
	Lucerne	Alfanafa	Salt tolerant alternative to cv. Siriver	1993
	Lucerne	Genesis	Disease and pest resistant alternative to cvs. Aurora and Trifecta	1995
	Lucerne	Sequel HR	Resistance to anthracnose, replacement for cv. Sequel	1998
	Lucerne	Hallmark	Disease resistant alternative to cv. Trifecta	1999

*Australian pasture varieties formally submitted to the "Register of Australian Herbage Plant Cultivars", details published occasionally in the Australian Journal of Experimental Agriculture.

Table 2 - Pasture legume cultivars registered* since 1990 for use in cropping systems.

Table 3.

Potential role	Associated traits	Included in current pasture improvement programs?
1. Reduce recharge	1. Perennial 2. Deep roots 3. Summer growth 4. Plant root adaptation to potential subsoil constraints	Recent awareness of importance. Single species (lucerne) focus. Specific selection criteria not defined.
2. Reduce weed populations prior to crop phase	1. Competitive 2. Herbicide tolerant 3. Component of IWM	Some recent progress. Competitive ability screened, herbicide tolerance screened.
3. Break life cycle of crop diseases	1. Resistance to important crop diseases 2. Tolerance to crop diseases	Recent addition in some programs. Past focus on pasture diseases rather than susceptibility for hosting crop diseases.
4. Biological nitrogen fixation	1. Symbiotic competence 2. N fixation in presence of inorganic N 3. Ability to recover deep inorganic N	Symbiotic competence included in all programs. No detailed screening of N fixing performance.
5. Maintain soil organic carbon	1. Root:shoot ratio 2. C:N ratio of roots	Not currently included.
6. Compatible with current and new farming systems	1. Ease of seed harvesting 2. Relatively soft seeded 3. Ease of removal prior to crop phase	Several programs including these traits

Table 3 - Role of pastures in current and future cropping systems and possible useful traits associated with new pasture legume cultivars.

Table 4.

Trait	Species under evaluation*
Ease of seed harvest, erect flower head, non shattering, readily threshed	*Trifolium resupinatum* *Trifolium michelianum* *Trifolium glanduliferum* *Trigonella balansae*
Resistance to redlegged earth mite	*Biserrula pelecinus* *Trigonella balansae* *Trifolium glanduliferum*
Annual species with deep rooting habit and suitability for dual purpose grazing and forage conservation	*Trifolium vesiculosum* *Trifolium incarnutum* *Trifolium purpureum* *Ononis aleopecuriodes* *Medicago polymorpha*
Tolerance to saline and waterlogged soils	Trifolium tomentosum *Trifolium resupinatum* *Trifolium ornithopodioides* *Melilotus albus*
Acid soil tolerance	*Ornithopus compressus* *Ornithopus sativus* *Biserrula pelecinus*
Adaptation to low rainfall, alkaline, calcareous soils	*Trigonella balansae* *Lotus ornithopodiodies* *Trifolium purpureum* *Astragalus hamosus*
Specific adaptations for persistence under grazing	*Trifolium glomeratum* *Vicia sativa ssp. amphicarpa*
Perennials for subsoil dewatering	*Medicago sativa* *Medicago arborea* *Onobrychis vicifolia* *Hedysarum coronarium* *Dorycnium rectum* *Cytisus proliferus*

* Collated from several sources including; Cooperative Research Centre for Legumes in Mediterranean Agriculture, National Annual Pasture Legume Improvement Program, Grains Research and Development Corporation, and personal communications.

Table 4 - Selection traits currently in use in pasture legume improvement programs and example candidate species under advanced agronomic evaluation.

Table 5.

Location	Deep drainage (mm y^{-1})			Reference
	Annual crops	Lucerne	Native vegetation	
Wagga Wagga (NSW duplex)	101-185	2-25	n.e.*	Dunin, et al., 1999
Wagga Wagga (NSW duplex)	135	3	0	Hatton and Nulsen, 1999
Euston - Balranald (NSW Mallee)	6-23	1	1	Kennet-Smith et al., 1994
Upper South East (SA dune system)	50-70	<5	<1	Walker et al., 1992
Moora (WA sandplain)	141[a]	n.e.	15-85[b]	a. Asseng et al., 1998 b. Smettem, 1998

* not estimated

Table 5 - Comparison of average annual deep drainage (mm y^{-1}) under annual crops, lucerne, and native vegetation (trees and understorey) in southern Australia.

Table 6.

Model / Module name	Processes simulated	Reference
APSIM	Software for simulating agricultural production systems	McCown et al., 1996
SoilWat	Soil water balance, evaporation, infiltration, runoff, redistribution in soil, availability of soil water to plants, drainage	Probert et al., 1998
SoilN	Soil nitrogen dynamics, organic N inputs, microbial biomass, mineralisation, denitrification, nitrate leaching	Probert et al., 1998
Residue	Inputs of above- and below-ground crop or pasture residues, amount, distribution, C:N ratio	Probert et al., 1998
NWheat	Wheat growth, water use and N uptake, biomass accumulation, biomass partitioning, grain yield, and yield components	Probert et al., 1995
Legume	Legume crops and lucerne growth, water and N uptake, biomass accumulation and partitioning, grain yield	Robertson et al., 2001
GrassGro	Pasture growth, pasture quality, diet selection, animal production	Moore et al., 1997

Table 6 - Software available for simulating soil water, soil nitrogen, and crop and pasture growth in pasture – crop rotations.

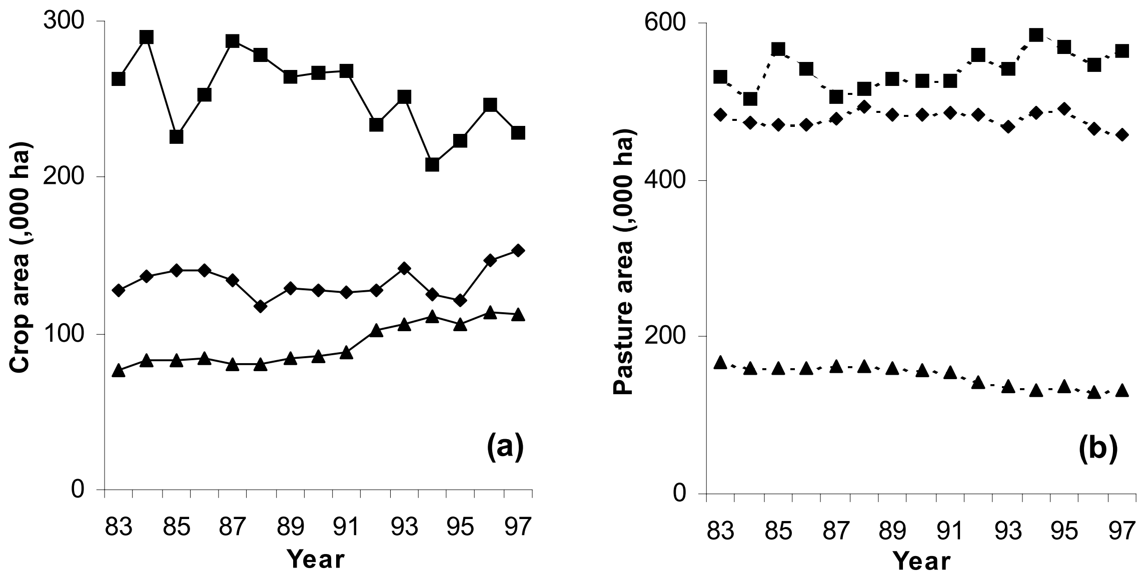

Figure 1 - Changes in area of total crop (a) and total pasture (b) between 1983 and 1997 for selected cropping regions in South Australia. (Upper Eyre Peninsula, Murray Mallee, Mid North).

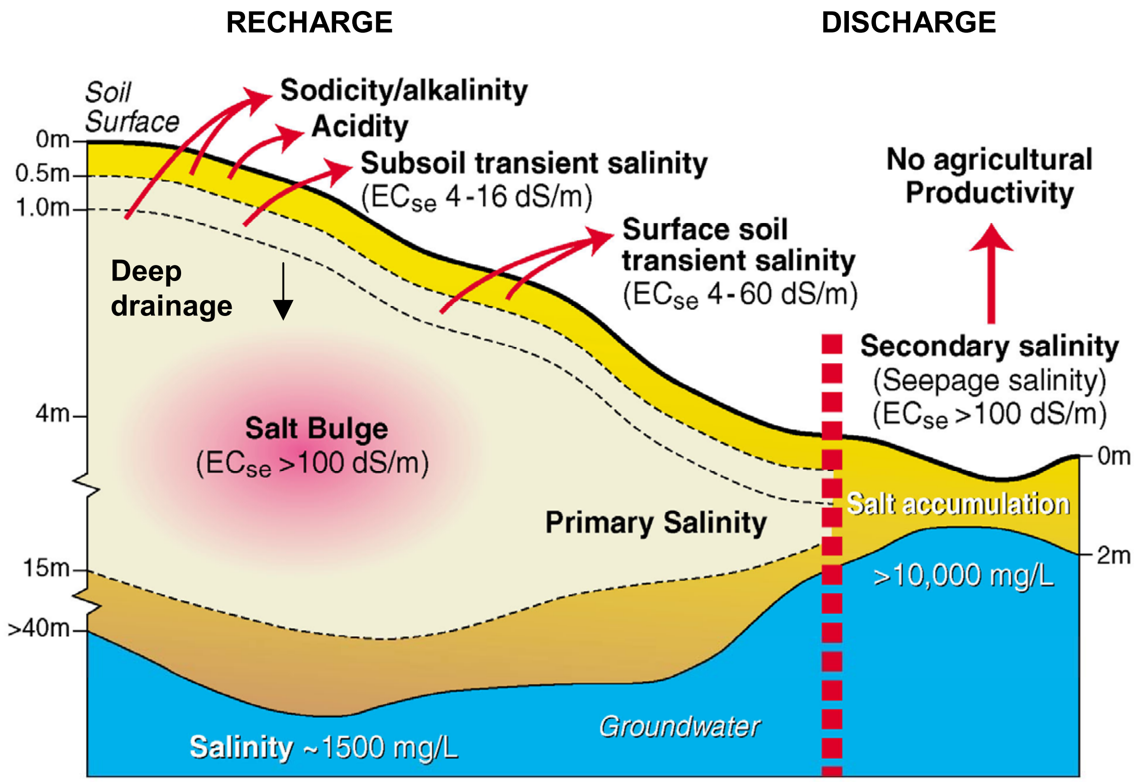

Figure 2 - Schematic diagram of different forms of salinity present in cropping landscapes of southern Australia. Soil salinity is measured as ECse, that is soil saturation extract electrical conductivity measured in deciseimens per metre, dS/m. See text for explanation of terms (Fitzpatrick et al., 2000).

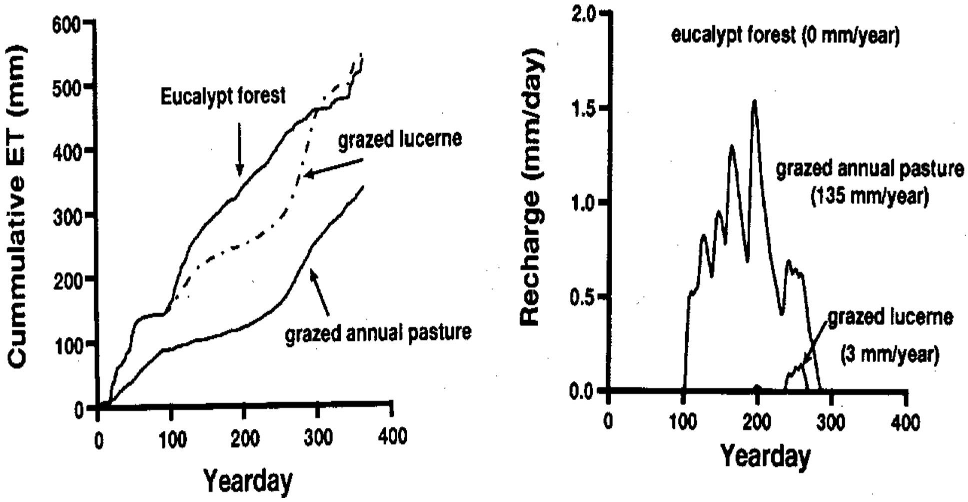

Figure 3 - Simulated cumulative evapotranspiration and daily recharge under annual pasture, lucerne, and native eucalypt forest near Wagga Wagga, New South Wales. (Hatton and Nulsen, 1999).

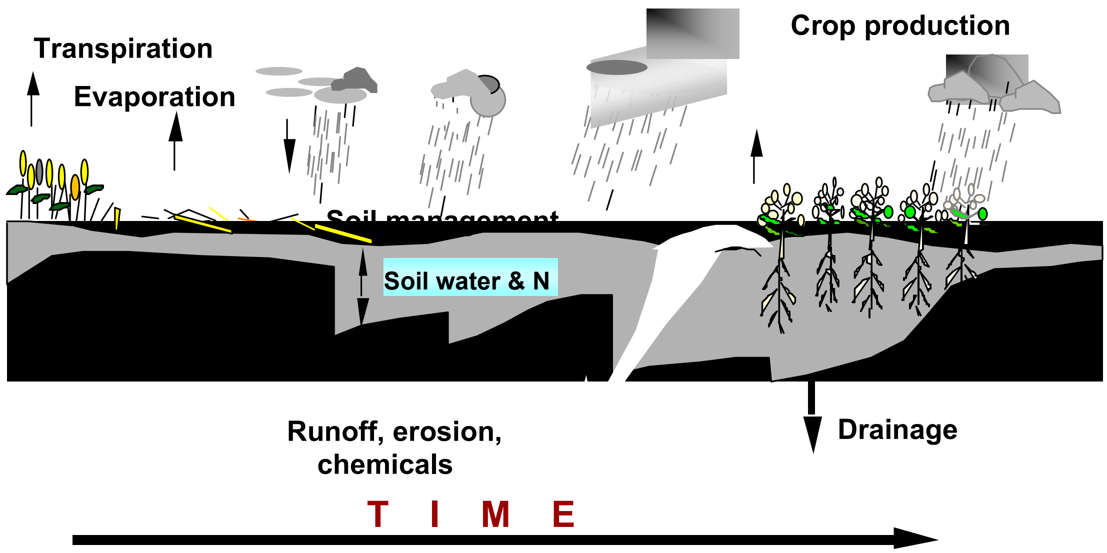

Figure 4 - Schematic diagram of some of the soil and plant processes simulated in the Agricultural Production System SIMulator (APSIM) (Hammer, 2000).

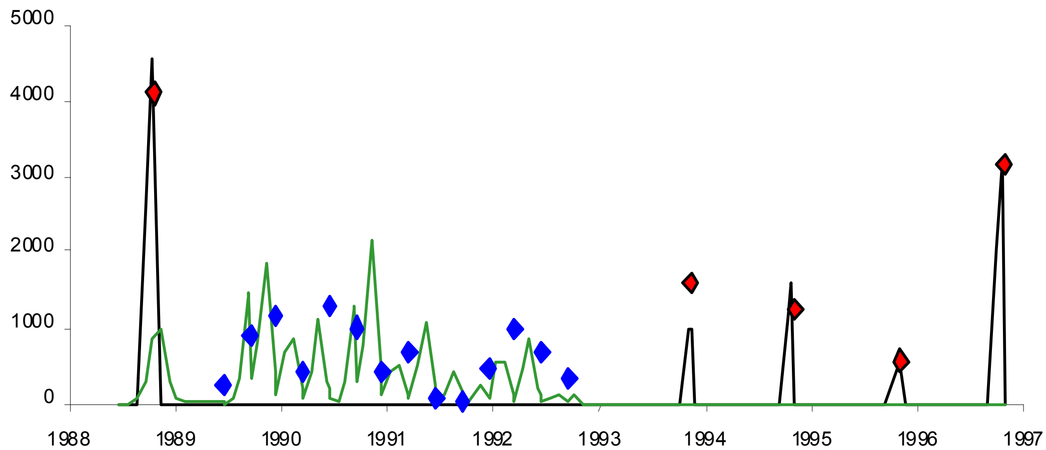

Figure 5 - Simulation of wheat grain yield and lucerne dry matter production in a lucerne (1989-1992) – wheat (1993-1996) sequence. The symbols represent measured data from a rotation experiment near Toowoomba, Queensland, Australia and the lines represent APSIM output. The units for the y-axis are dry matter of lucerne and wheat grain (kg/ha) (Probert and McCown, 2000).