Farming systems of Southern Australia

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Introduction

Wheat, coarse grains, wool and sheep meats are the major products from approximately 60 million ha of farmland in southern and eastern Australia. Although these farming systems occupy only a small fraction of the continent, and an even smaller proportion of the Australian labour force, they account for approximately 40% of Australian exports and constitute, for many products, a significant proportion of world trade.

Study of these farming systems - man made ecosystems - is as fascinating and vital as the study of any natural ecosystem. Economic necessity dictates continuing, even increasing production from these systems and yet their long-term stability remains uncertain. Indeed the major threats of rising water tables, salinization, soil erosion and acidification are the products of a development ethic that to replace natural, stable ecosystems, disparagingly known as 'scrub' or 'bush', and establish agriculture was inherently good. These attitudes have faded with maturity, but their legacy includes the destruction of entire native ecosystems and the clearing of some areas with scant regard for long term biological or economic sustainability.

The characteristics of southern Australia's farming systems are well known: the intimate association of crops and animal enterprises; low and variable rainfall and in consequence, low average crop yields and large year to year variability; low nutrient status of most soils; and reliance on biological sources of nitrogen from leguminous plants. Of these, the association of cereal crops and animal enterprises based on annual pastures, is the distinguishing characteristic of agriculture in southern Australia. These enterprises complement each other, particularly in the cycling of nitrogen, but are also antagonistic; and managing the technical and economic aspects of this interaction remains a challenge for scientists and farmers alike. Other important farming systems considered here are those using fallow in rotation with cereal crops, and the emerging grain legume-cereal rotation.

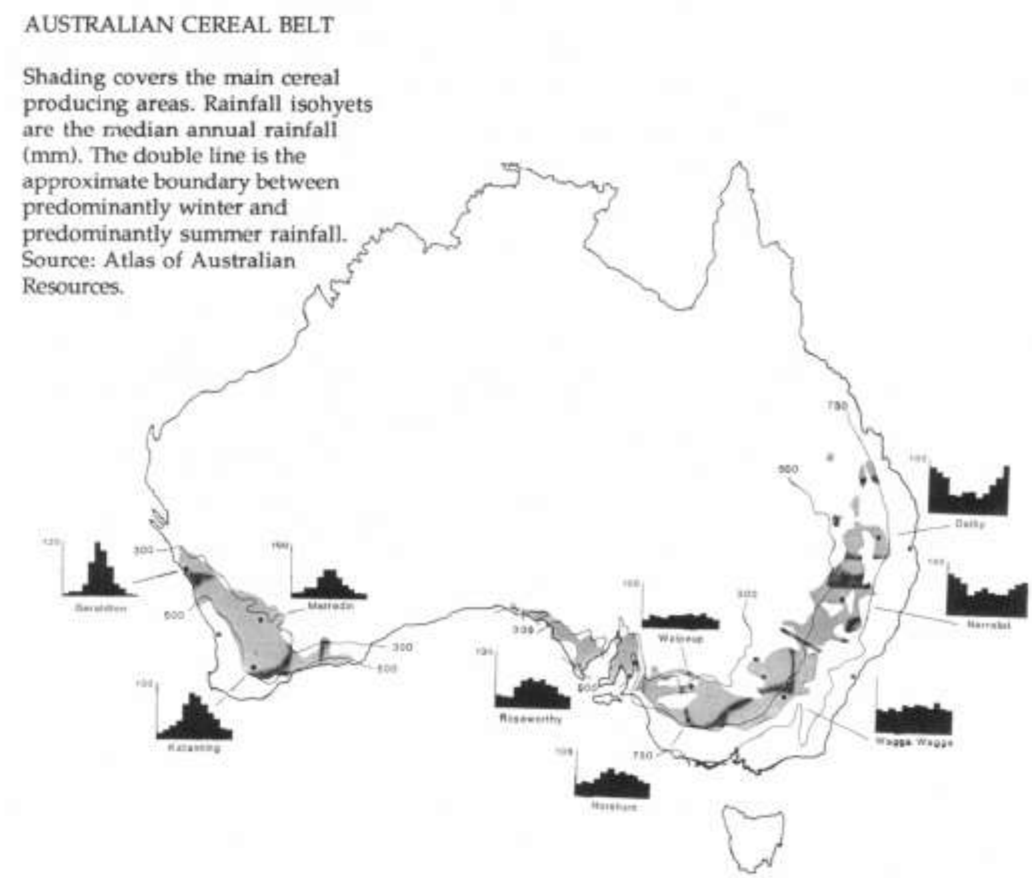
Climate

The agricultural areas of southern Australian occupy the the south-west, south and south-east of the continent. In the southern, winter rainfall region, most cereal and sheep production occurs between the 250 mm and 625 mm annual rainfall isohyets (Fig. 1). The lower limit is imposed by the water supply, but on the higher rainfall edge, dissected landscapes and more profitable alternative enterprises restrict production. In the south-east and east, winter rainfall from southern weather systems is supplemented by summer rainfall from air masses of Pacific origin and rainfall grades from summer dominant in the north to a uniform distribution over central New South Wales. Cereals are grown between the 400 and 650 mm isohyets in the south grading to 600-775 mm in the northern, strongly summer rainfall areas.

Nix (1977) examined the agro-climatic characteristics of the Australian cereal belt using a numerical classification of climatic attributes related to the development pattern of a standard wheat cultivar. This analysis, delineated three regions: a southern winter rainfall region, a northern region of summer dominant rainfall and a south-eastern region of high (> 550 mm) and evenly distributed rainfall. Further division of each regions may be made on the basis of rainfall amount and distribution, temperature and radiation data.

In the southern, winter rainfall region, rainfall is distributed with a peak in the growing season (April-October). This characteristics is most pronounced in the west where Geraldton receives 80-85% of annual rainfall in the growing season. More typically, 60-70% of rainfall is received in the growing season, for example Merredin 66%, Clare 61%, Walpeup 59% and Horsham 58%. Mid-winter temperatures are mild (12-15?C day/5-8?C night) and mid-winter radiation levels low (9-11 MJ/m2.day).

Figure 1. The Australian cerealbelt (shaded). Isohyets are the median annual rainfall. The double line represents the approximately boundary between winter and summer dominant rainfall.



The summer rainfall, north-eastern region extends from central New South Wales to Queensland. Rainfall is higher than in the south and increases in both amount and summer dominance to the north. Dubbo receives 531 mm, with 42% falling in the winter (May-October) growing season, Narrabri receives 662 mm (38%), Dalby 614 mm (29%) and Biloela 705 mm (19%). Mid-winter temperatures are 15-19?C day/8-12?C night, higher than in the southern region except at high elevation. Mid-winter radiation levels are also more favourable for plant growth. The south-eastern, high rainfall region, lies to the south and east of the present cereal belt (Fig. 1), rainfall is high (> 550 mm) with significant amounts in both summer and winter. Midwinter temperatures are cool to cold (10-12?C day/4-6?C night) and radiation levels low (7-9 MJ/m^2.day). This region accounts for less than 5% of cereal production, but is a major producer of animal products.

Soils

Soil properties represent the second environmental determinant of ecosystem productivity. Australian soils reflect the great age of the continent, its low relief and the virtual absence of recent mountain building, volcanism and glaciation, that have been so important **in** forming soils elsewhere. The origin of many Australian soils can be traced to the Tertiary period when the continent was subject to planation to a low relief, deep weathering and the extensive development of lateritic duricrusts. Remnants of these duricrusts still dominate many Australian landscapes and most of the soils are formed on deeply weathered materials exposed by erosion of the Tertiary landscape or on materials derived from erosion of the duricrusts. Because of the extreme weathering of the parent materials, the soils are generally of very low natural fertility and there are widespread deficiencies of phosphorus, nitrogen and of a wide range of trace elements.

Table 1 lists the major soils used for crop production in southern Australia. Broadly, the crop ecosystems of southern Australia are found on four types of soil: sands, earths, clays and duplex profiles (Table 1).

Table 1. Major soils used for cereal production. Adapted from McGarity (1977) and Moore, Isbell and Northcote (1983)

Generalized profile form	Australian soil groups	Soil taxonomy
Coarse-textured soils (sands)	Siliceous sands	Quartzipsamment, Torripsamment
	Earthy sands	Quartzipsamment, Torripsamment
Earths	Solonized brown soils	Calciorthid, Palexeralf
	Red and Yellow earths	Paleustalf, Haplustalf
Clays	Black earths	Pellustert, Chromustert
	Grey, Brown and Red clays	Torrert, Chromustert
Duplex soils	Red-brown earths, Solodized solonetz and Solodic soils	Rhodoxeralf, Haplustalf, Natrustalf, Natrixeralf, Paleustalf

Current cropping systems

Current agricultural systems are technical and economic solutions to the constraints of local climate and soils. Five main systems are identified in Table 2. Within each of these there are a number of identifiable sub-systems which may be broadly grouped as rotations which involve pasture, rotations involving only cereal crops and cultivation ('fallow'), and crop rotations of cereals with grain legumes.

Table 2. Major small grain production systems of Australia subdivided on rainfall and soil texture

Winter low rainfall (E 300 mm)		Winter medium rainfall	Winter high	Summer
coarse textured soils	fine textured soils			
C-(VP...)	F-C	C-(P...)	C-(P...)	SF-C
C-GL	C-C	C-C	C-P-P	F-SC
	F-C-(P...)	C-GL		SF-C-S
	C-GL	C-GL-C-(P...)		-F-SC
		F-C		

Key: C = Cereal crop, GL = Grain legume, SF = Summer fallow, VP = Volunteer pasture, F = Fallow, SC = Summer crop P = Legume pasture.

Ley farming systems

The main pasture ley systems (see Table 2) are found on red-brown earths, solodized solonetz, solonized brown soils and red earths. Their common features are that the pastures are annual and regenerate from seed each year, a legume pasture species is present and the pastures are grazed by sheep. This ley-crop system has reached its greatest development in the medium-high rainfall (350-650 mm annual rainfall) parts of the southern, winter rainfall region, but pasture systems using annual medics extend into the 250-350 mm rainfall region.

Nitrogen flows

The single most important functional interaction in ley farming systems is that concerning the accumulation and subsequent depletion of soil nitrogen in the legume pasture-cereal crop rotation. Cereals remove about 18 kg of nitrogen per tonne of grain or 29 kg for the 'average' 1.6 t/ha Australian wheat crop. All systems using cereal crops incur this cost to soil nitrogen which must be met by mineralizing soil organic matter or application of synthetic sources of nitrogen.

Under leguminous pastures, soil nitrogen increases as the quantity of symbiotically fixed nitrogen exceeds the losses from mineralization of organic nitrogen in the undisturbed pasture. Where crop and pasture phases alternate, soil organic nitrogen will fluctuate. Several long-term rotation experiments (Rowland 1980) have demonstrated this rise and fall in soil nitrogen - the very essence of the ley farming system. In the experiment reported by Rowland (Fig. 2) the subterranean clover pasture

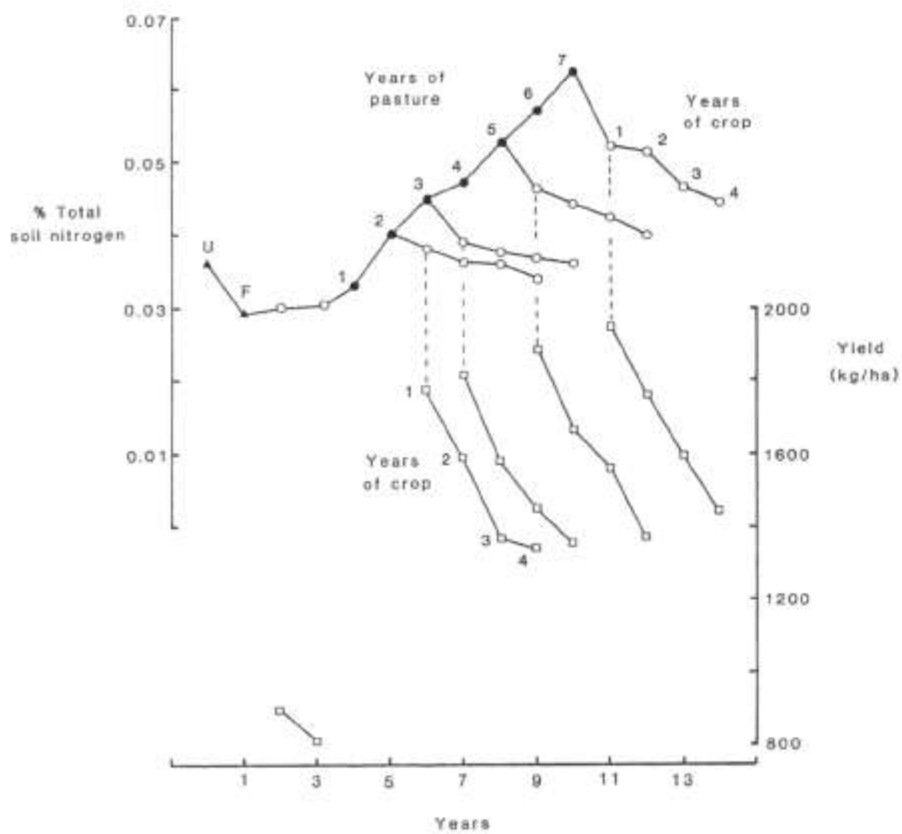


Figure 2. Trends in total soil nitrogen and wheat grain yield in a long term rotation experiment at Wongan Hills, Western Australia. Adapted from Rowland (1980).

increased total soil nitrogen at about 64 kg/ha/year and after seven years had increased total soil nitrogen from about 450 kg/ha under the native heath vegetation to over 800 kg/ha with no sign of a new equilibrium. Sowing the pastures to wheat caused a rapid decrease in total soil nitrogen in the first crop followed by a slow subsequent decline. Wheat yields also increased with increasing length of the pasture phase, but the main effect was seen after the first two years of legume pasture.

Greenland (1971) formalized the balance between accumulation and depletion of soil nitrogen in a simple equation -

$$\frac{dn}{dt} = -kn + a \qquad [1]$$

where k is a decomposition constant for soil organic nitrogen, N the nitrogen content of the topsoil (say 0-10 cm) and 'a' the accumulation of nitrogen per unit time for the same volume of soil.

For a long running fallow-wheat rotation on a red-brown earth Greenland assumed that 4% of soil nitrogen was mineralized each year (k = 0.04) and that nitrogen accumulation was 20 kg/ha/year. These parameters suggest a reduction in soil nitrogen from 3,000 kg/ha (0-10 cm) at the start of the experiment to a value of about 1,000 kg/ha after 50 years and an eventual new equilibrium soil nitrogen level of 500 kg/ha.

Introducing a legume pasture to the rotation changes both 'a' and 'k'. Many studies have estimated the accumulation of soil nitrogen under pasture and these have been summarized by Clarke and Russel (1977) and Rowland (1980). Of 22 estimates of nitrogen accumulation under temperate pasture legumes in southern Australia, the mean annual increment in soil nitrogen was 67 kg/ha/year and the range 35-182 kg/ha/year. Few precise measurement of the decomposition constant under annual pasture, have been made, but Greenland (1971) gives values of 2.9% and 1.3% for two annual pastures - values much lower than for crops where cultivation hastens mineralization. Using k = 0.02 (i.e. 2%) and a = 67 in equation 1 gives an equilibrium soil nitrogen content under permanent pasture of 3350 kg/ha. Rotations of alternating pasture and crop will accumulate and deplete soil nitrogen around values which will depend on the length of the pasture phase.

In the context of nitrogen cycling, what is important is not the actual levels or trends in total soil nitrogen but the level of mineralization that will make nitrogen available to the crop. For various rotations and assuming that for a crop k = 0.04 (4%), the equilibrium soil nitrogen levels and mineralization on breaking up the pasture are:

	Equilibrium Soil N (kg/ha)	Mineralization (kg/ha)
Continuous pasture	3,350	134
2 Crop : 4 pasture	1,125	77
1 Crop : 1 pasture	1,450	58
Continuous crop	500	20

Equation 1 is clearly a gross simplification of the nitrogen flows in a rotation. In reality, soil nitrogen does not exist as a single homogeneous pool; and the values of 'k' and a will change with season, crop and cultural conditions. Even so, it demonstrates the basic nature of the interaction between legume pastures and crops and has been extended by Clarke and Russell (1977) and Russell (1980).

Flows of water

An increase in water supply to the crop following a pasture has seldom been considered, but crops may also benefit from an augmented water supply if they follow a shallow rooted pasture species which cannot extract soil water to the depth of the wetting front. Soil water profiles under wheat and a subterranean clover monoculture were recorded by Perry, Tennant and Hamblin (unpublished data). Wheat grew 9.8 t/ha biomass and extracted water to about 2.4 m depth whilst the dense clover sward grew 4.8 t/ha biomass, matured two weeks earlier and extracted water to only 1.5 m depth. At maturity, the soil profile under clover held an additional 55 mm of water to 3.8 m depth.

Deep rooted lucerne pastures may have the opposite effect, depleting the water supply available to the crop. Holford and Doyle (1978) found that lucerne dried a black earth profile to 200 cm compared to 150 cm for a wheat crop. Yield of the following wheat crop was depressed by 33% compared to continuous wheat.

Soil structural improvement

The physical structure of surface soils as measured by such properties as soil strength, aggregate stability and porosity also change through the phases of a rotation. Soil aggregate stability increases under pastures and decreases under continuous crop (Greacen 1958, Stoneman 1973, White et al. 1978). Changes in aggregate stability accompany changes in soil organic matter or total soil nitrogen (Greenland 1971); for example, changes in percentage water stable aggregates in the rotation trial in Fig. 2 followed an almost identical pattern to that recorded for total soil nitrogen (Stoneman 1973). Of particular note is that although aggregation increased slowly under the pasture, it decreased dramatically in the first year of crop, but then only slowly under subsequent crops.

Surface structural degradation is an important problem on the widespread red-brown earths (Greenland 1971). When cultivated too frequently or when too wet, these soils slake and form crusts which reduce seedling emergence and have very low infiltration rates (5 mm/hr). Ponded water may evaporate or run-off causing a loss of soil water in a system where the water supply determines yield. Thus, on these soils, improvement or maintenance of a porous surface structure is vital for crop production and this implies the accumulation of organic matter in the surface. Periods of pasture are the most biologically effective way of increasing organic matter at the soil surface.Cereal production using reduced or zero cultivation may slow the loss of organic matter and surface structure (Hamblin and Tennant 1980), but probably cannot arrest the decline.

Soil acidity

The increase in soil organic matter under legume pastures so desired for its beneficial effects may also lead to a gradual acidification of the soil which in the long term may decrease productivity (e.g. Williams 1980). The significance of acidification in southern Australia is still difficult to judge, but many Australian soils are already naturally acidic due to their age and parent materials. Approximately 7 x 106 ha in New South Wales, 2 x 106 ha in Victoria, 0.4 x 106 ha in South Australia and 1.5 x 106 ha in Western Australia can already be considered strongly acidic with a pH (measured in a 1:5 water suspension) of less than 5.5 (Coventry 1985). Of equal concern however must be the extensive areas of mildly acidic soils (pH 6.0-6.5) that have been sown to subterranean clover leys since 1950. Decreases of 1 pH unit would bring many soils to a pH of 5.0-5.5 where exchangeable manganese and aluminium could depress growth of rotational species such as barley, rapeseed and, to a lesser extent, wheat which are more sensitive to these toxicities than subterranean clover.

Biotic interactions

Biotic interactions - the effects of a pasture on weeds, insect and disease organisms appearing in the crop and the effects of a crop on the re-establishment and productivity of a pasture - have been widely acknowledged, but little studied. Legume pastures are seldom monocultures but undergo successional changes as non-legume species invade to utilize the increasing soil nitrogen. These changes have been well documented for pastures in southern Australia (Rossiter 1966). Grasses, which may be

important components of the legume pastures, are alternate hosts for the serious root disease 'take-all' Gaeumannomyces graminis and for cereal cyst nematode (Heterodera avenae) both of which may seriously reduce cereal yields. Insect pests of cereals including Agrotis spp. and Desiantha spp. also increase in grassy pastures although they are of little importance compared to the fungal and nematode root diseases.

Fallow farming systems

Systems using fallow are mainly found on soils with high moisture holding capacity such as red-brown earths, solonized brown soils, black earths and grey and red clays. Descriptions of fallow-crop systems have been given for New South Wales (Kohn et al. 1966), South Australia (French 1978a,b), and central Victoria (Cooke et al. 1985). Short fallow (1-3 months) is not incompatible with legume pastures in a cereal-pasture ley system but long fallow systems (9-15 months) support few or no livestock and are characteristic of crop production in many semi-arid environments. The central feature of fallow-crop systems in southern Australia is that the potential production of a full year's crop or pasture is foregone to increase the biological resources available to a following crop. Water and nitrate have commonly been considered as the two most important benefits of fallowing and in most studies (Table 3) there are substantial increases in both of these when a long (12 month) fallow is compared to no fallow at the same date of sowing. Whether water or nitrate accumulation is most significant depends on cropping history, soil type and seasonal conditions. For example Wells (1971) and Cooke et al. (1985) found that yield responses to fallow were better explained by soil nitrate levels after fallow; but Tuohey et al. (1972) found strong evidence that moisture conservation was the cause of the yield resonse to fallow in the Wimmera region. The interaction of water and nitrogen is well illustrated by French (1978a, b) where the value of additional nitrate from fallowing depended on the nitrate levels of non-fallowed soil and only then when crop water use exceeded 230 mm.

Table 3. Increments in soil water and nitrate at sowing from long fallow compared to crops sown without fallow in southern Australia. Modified from Ridge (1986)

Location	Fallow increment[A] Water (mm)	Fallow increment[A] NO_3N (kg/ha)	Non-fallow yield (kg/ha)	Yield increment (kg/ha)	Reference
Minnipa (S.A.)	9	21	1,326	105	French 1978a
Turretfield (S.A.)	23	12	1,657	387	French 1978a
Merredin (W.A.)	33	-	959	420	Tennant 1980
Wagga Wagga (N.S.W.)	15	50	-	-	Kohn et al. 1966
Wimmera (Vic.)	52	50	2,010	1,130	Tuohey et al. 1972
N-central Victoria	29	28	1,254	560	Cooke et al. 1985

[A] All data are averages for various numbers of years and sites. See original references for details.

Effects of fallowing other than those associated with water or nitrogen accumulation have received less attention and are more difficult to quantify. Meagher and Rooney (1966) showed that Cereal Cyst Nematode (Heterodera avenae), a serious pest in Victoria and South Australia, was reduced by fallowing and similar effects would be expected for Take-all (Gaeumannomyces qraminis) and other cereal pathogens. Cooke et al. (1985) also commented that farmers in north-central Victoria fallowed, in part, to control annual ryegrass (Lolium rigidum) although selective herbicides now make this unnecessary. Timeliness of sowing is also a reason why farmers may prefer to have some fallow land especially where large areas are to be sown.

The average grain yield increment that accrues to long fallow is often of the order of 40-50%. Taken at face value, this implies a gross inefficiency in the use of resources for crop production - one year's production is foregone to increase the following year's return by only 40-50%. Averages, however, mask the seasonal variability of response (Table 4). Thus in some years, generally those with a high growing season rainfall, there is no response or even a negative response to fallowing in the preceding year. In other years there is a moderate response, but in years of very low growing season rainfall, a fallow may increase yield by 100-150%.

Table 4. Grain yield increment from long fallow for successive years at two sites Turretfield (S.A.) 1957-1961 (French 1978b), Merredin (W.A.) 1973-1978 (Tennant 1980)

Year	Turretfield				Merredin			
	Non-fallow yield kg/ha	Fallow kg/ha	Increment %	GSR* (mm)	Non-fallow yield kg/ha	Fallow kg/ha	Increment %	GSR (mm)
1	1,185	415	35	249	1,547	245	16	270
2	2,145	-155	-7	417	1,933	-350	-18	307
3	490	800	163	157	637	903	141	245
4	2,750	-220	-8	478	506	537	106	165
5	1,010	665	66	318	323	314	97	154
6	-	-	-	-	1,786	95	5	181

* Growing season (May-October) rainfall.

Long fallow systems thus act to even out fluctuations in grain yield and farm income, but do so a the cost that in some years the fallow may return nothing. Such variability helps explain why Ridge (1986) calculated equal returns but much lower variability of farm income with a fallow system compared to annual cropping; whereas Kingwell and Tennant (1987) found that the opportunity costs of income foregone outweighted the yield benefit of fallow.

Grain legume - cereal systems

The development of grain legume-cereal farming systems is a more recent phenomenon. Hamblin (1987) reviewed the expansion of grain legume production in Australia. In southern Australia, lupin (Lupinus angustifolius) sowings have increased from zero to over 1 million ha since 1970, and the area sown to field pea (Pisum sativa) has increased from about 30,000 ha to 350,000 ha in the same period. Rapid adoption has occurred because the grain legumes fulfill the same function as legume pastures in providing nitrogen, but have significant additional advantages in some environments.

Lupin-cereal systems have a specific adaptation to deep coarse textured soils. For example, in Western Australia there are approximately 2 million ha of deep sands and earthy sands which retain only 50-70 mm of water per metre depth of profile and have soil nitrogen levels of 0.01-0.03%. Because rainfall is concentrated in winter, wetting fronts penetrate deeply and mobile nutrients can be rapidly leached beyond the root zone. In this environment, plant productivity is determined by the plants ability to access both water and nitrogen. Legumes, dependent on atmospheric nitrogen have a major advantage, however this can only be exploited to the extent that roots can tap water in the deep, free draining profiles. Mediterranean lupin species are deeper rooted than the pasture legumes and as a consequence have a significantly higher biomass productivity (Table 5). Nitrogen fixation is closely related to plant biomass and thus nitrogen inputs are also greater from the deeper rooted legumes.

Table 5. Root depth, seed yield and nitrogen yield for crop and pasture species on a deep earthy sand. Data from Hamblin and Hamblin (1985) and J. Hamblin (unpublished data)

	Root depth (cm)	1982 Seed yield t/ha		1982 Nitrogen yield kg/ha		1983 Wheat t/ha
		biomass	grain	biomass	grain	
Lupinus angustifolius	187	3.09	0.99	93	50	0.62
Lupinus cosentinii	205	3.84	0.84	111	42	0.49
Medicago truncatula	70	0.64	-	22	-	0.35
Medicago polymorpha	95	0.68	-	17	-	0.29
Trifolium subterraneum	40	0.77	-	13	-	0.26
Triticum aestivum[A]	95	1.83	0.6	-	-	-

[A] Wheat fertilized with 200 kg/ha nitrogen, all other species dependent on an active Rhizobium-plant symbiosis.

The critical impact of the introduction of lupins has been through its rotational or 'residual' effects on the cereal crop. From 130 comparisons at 58 sites between 1973 and 1985, wheat following lupins yielded 1.87 t/ha compared to 1.29 t/ha for wheat grown on wheat (Rowland, Mason and Hamblin 1988). Responses of this magnitude are not restricted to coarse textured soils of low nitrogen status but have also been recorded on red-brown earths in southern and south-eastern Australia (Reeves 1984, Rowland 1986).

The reasons for the increased productivity in the cereal year include cycling of nitrogen and other nutrients, cereal disease control and weed control. A single lupin crop may have a nitrogen yield from above ground biomass of 100-150 kg/nitrogen in an environment where total soil nitrogen seldom exceeds 500 kg/ha. After accounting for removal in grain (1.0 t/ha @ 5.5% N = 55 kg/ha), 50-100 kg/ha N is potentially available to the cereal crop. The dynamics of decomposition and of mineralization of nitrogen from this material have not been established, however there is little doubt that a substantial proportion is available to the following cereal crop.

The non-nitrogen effects of the lupin include the interruption of disease cycles for the cereal pathogens yellow spot (Pyrenophora tritici-repentis) and take-all (Gaumannomyces graminis), improved opportunities for weed control, cycling of potassium (Rowland 1986) and improvement in soil structure (Reeves 1984). The alternating cycle of broadleaf and graminaceous crops allows strategic control of grassy weeds in the lupin year and of broadleaf weed species in the cereal crop.

Conclusions

Farming systems in southern Australia have evolved as solutions to agricultural production in an environment characterised by low and variable rainfall and nutrient deficient soils. Fallow systems, introduced in the 1890s addressed both these problems by storing some water to supplement annual rainfall, and by increasing the mineralization of soil nitrogen. Fallow systems have been economically stable, but have been so only by operating at well below their potential productivity. Replacement of fallow by pastures or crops and better management of soil water should enable greater productivity.

Ley systems provide nitrogen for non-leguminous crops, improve soil structure, and allows diversification into animal enterprises.

Bioeconomic models, for example MIDAS (Kingwell and Pannell 1987), suggest that there is a positive net effect of interactions between crop and pasture enterprises in Mediterranean farming systems. That is, ley systems, those including crops and pastures, are more profitable. Extension of this approach to consider uncertainty of season (Morrison, Pannell and Kingwell unpublished) also suggest that a conservative management strategy that includes a significant proportion of pasture is most profitable in the long term.

The major benefits of nitrogen accretion under pasture legumes is offset in part by the transfer of weed, pest and disease problems from pasture to crop. Grain legume - cereal rotations are a novel solution that retains the nitrogen input on soils of low nitrogen status, but allows control of the grass weeds so detrimental in pasture-cereal systems. Legume leys and more recently grain legumes provide farmers with greater flexibility in responding to economic signals; whilst retaining the twin imperatives of managing nitrogen and water in an environment where both are deficient. Possibly this flexibility combined with rapid innovation and adoption of new practices form the bright face of primary industry's exposure to world market forces.

For the future, there is the economic necessity to continue to increase productivity from these systems. How is this to be achieved?

Improved plants and animals - those with improved genetic capacity to use the limited environmental resources are one means of increasing productivity. One hundred years of wheat improvement in southern Australia has increased yield from potential by approximately 80% (Perry and D'Antuono 1989). In comparison, breeding of pasture legumes, grainlegumes, oilseeds and other crops is still in its infancy in Australia, however the 45% yield increase achieved in Lupinus angustifolius (based on WADA variety trial data) between Uniharvest the first truly adapted commercial cultivar released in 1972 and Gungurru (1988) is some indication of the potential that is still to be exploited.

Improved management - allowing the plant to fully exploit its potential in a particular environment - is the second source of greater productivity. Broad, general agronomic advice on rotations, times of sowing, fertilizers, weed control etc has been the mainstay of agronomy. This is now being displaced by agronomic advice specific to environments, or to cultivar, or to both. Critical in future will be the use of information to reduce uncertainty. This may be information about the state of the farming system such as weed seed banks, pathogen levels, soil nutrient and water status, all relevant to strategic planning. Further in the future, but getting closer, is tactical management using 'real-time' information from the growing crop. Here, measurement, simulation and economic modelling may all be integrated to assist in increasing productivity.

Australia is emerging from an exploitive phase of agricultural development and in future the task for scientists and farmers will be to increase productivity whilst increasing the stability and long term sustainability of our farming systems. An exciting future for agronomy.

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