Roles of grain legumes in sustainable dryland cropping systems

R.J. Delane[1], P. Nelson[1] and R.J. French[2]

1 Department of Agriculture, P.O. Box 110, Geraldton, W.A. 6530
2 Department of Agriculture, Dryland Research Institute, Merredin, W.A. 6415

Introduction

There is now clear consensus among most rural producers, scientists, bureaucrats and politicians that many of Australia's farming systems are unsustainable, using present methods. While broadacre agriculture has been considered by some to be technically sustainable (6), economic pressure placed on farmers due to declining terms of trade is indirectly responsible for the instability of many farming systems. The current awareness stems from irrefutable evidence that our crop and animal production methods have resulted in both dramatic and insidious forms of land degradation. However, the sustainability of our farming systems has been questioned for some time, and at least three symposia dating from 1983 have dealt largely or wholly with this issue (1,2,3). Sustainable agriculture is now in vogue; so much so that one rural magazine now carries the slogan "Striving for Sustainable Agriculture" as its banner (4), and Australia now has a National Association for Sustainable Agriculture (NASAA). It should then be easy to define a sustainable farming system, particularly if the definition is restricted to cropping.

Farming systems are a combination of biological, physical, economic, social and political interactions (5) and it is important to consider all these factors to develop systems which are both productive and sustainable. The social and political factors are particularly important (6,7) and sustainable land use may only be achieved through changes in attitudes, policies and practices throughout Australian society (8). However, we have limited our discussion of sustainability to biological and physical aspects, with some reference to economic issues, since physical and biological factors affecting agriculture are manifest ultimately in economic terms. For this purpose, a sustainable cropping system is defined as "a productive system which maintains (or improves) the productive capacity of the land and economic viability, while minimizing energy and resource use." Implicit in the definition is the view that the system will be sustainable for the foreseeable future using existing and developing technology. However, history teaches us that we should not be complacent just because newly developed farming practices appear sustainable(9). Pragmatism and flexibility are key factors in the search for sustainable systems. A farming system which is technically unsustainable may have a very useful short-term role, provided any negative effects on the environment are readily reversible (e.g. continuous cereal cropping has rarely been considered an ideal system, but was essential in some areas to restore cash-flow and economic viability following a period of drought years).

The rotation of crops and pastures is as old as agriculture itself and rotations were once considered the essential basis of a productive, permanent and economic agricultural system (10). Virgil recognized the value of legume-cereal rotations over 2000 years ago: "Or changing of the season, you will sow there yellow wheat, whence before you have taken up the joyful pulse with rustling pods, or the vetch's slender offspring and the bitter lupins brittle stalks and rustling grove." The planning of crop rotations was based on strong traditional principles so that each parcel of land remained a permanent food producing resource to be handed down to future generations.

Technological innovations in agriculture have enabled some of the principles of rotations to be ignored, and the complexity and volatility of modern commodity and financial markets has placed great pressure on traditional systems. However, the increased level of management essential for success in broad-scale agriculture today has brought with it an awareness of the need to closely examine all aspects of each farming system.

Grain legumes in cropping systems

The status of grain legumes in Australia has been recently reviewed (11) and various authors have examined broad aspects of legume-cereal rotations (12,13,14,15). Grain lupins (principally Lupinus augustifolius) and field peas (Pisum sativum) are the principle grain legumes produced in Australia (Table 1); in 1986, these two species accounted for 901 of winter grain legume production and 861 of total production (11). ABARE (16) has forecast 1988/89 production of: lupins 973,000 tonne; peas 533,000 tonne and soybeans 127,000 tonne. Significant quantities of chickpeas, faba beans, lentils, cowpeas, mungbeans, pigeon peas and Phaseolus beans are also produced (11,17,18,19). This review concentrates on the roles of the two principle winter grain legumes, lupins and peas, with some specific reference to other legumes.

Table 1: Estimated area of grain legumes grown in Australia in 1986 ('000 hectares) (from (11)).

CROP	TOTAL AREA
Chickpeas	80
Fababeans	39
Lentils	2
Lupins	774
Peas	365
Total (winter)	1260
Cowpeas	24
Mungbeans	25
Pigeon peas	8
Phaseolus beans	10
Total (summer)	67
Grand Total	1327

In order to draw conclusions about the roles of grain legumes in sustainable cropping systems, we have examined individually the many advantages, as well as disadvantages of including grain legumes in cropping systems. These are linked to discussion of the biological, physical and economic aspects of sustainable cropping systems.

Advantages Of Grain Legumes In Cropping Systems

High protein cash crop

1988/89 grain legume production will contribute approximately $416 million toward gross farm production (4.9% of all crops) and $206 million toward Australian farm exports (4.6% of all crops)(16). Forecast prices for lupins and peas in 1989/90 are $200/tonne gross and $200-275/tonne gross, respectively (20,21). At current yield levels, grain legumes are attractive propositions. However, since the rotation selected by a farmer is largely determined by short-term profitability, their attractiveness in the longer term will always be strongly influenced by relative commodity prices.

Residual nitrogen

Apart from their direct value as a cash crop the best documented beneficial effect of grain legumes has been the effects on the soil, principally in terms of residual nitrogen (22,12,23,24,13,26). It has been estimated that approximately 50% of the residual effect of grain lupins comes from residual nitrogen (34). Mean values of 130 trials from 58 sites show an average yield improvement for wheat/lupins (1.87 t/ha) compared with wheat/wheat (1.29 t/ha) of 45Z (24). These values suggest that the economic value of the residual N from lupins alone is worth over $50 million.

All grain legumes have the potential to improve the N status of the soil for the following crop, however, the leve1 of residual N will depend on: the amount actually fixed, the N harvest index, grazing of crop residues and those factors which affect the breakdown of the residual organic N and leaching and volatilization of the mineralized portion. Summarized data for the estimated N fixation and residual N of grain legumes under Australian conditions have been presented by (11) and (27)(see Table 2). More recent estimates for lupins were 72-228 kg/ha N (28), while (29) reported that lupin tops and roots contained 535 kg/ha N. On average, lupins fix 153 kg/ha N of which 69 kg/ha N is added to the soil, while figures for peas were 58 kg/ha N and 11 kg/ha N, respectively (30). Australian values are in general agreement with those reported elsewhere (31).

Table 2: Estimates of N fixed (kg/ha) by various grain legumes (from (11)).

CROP	RANGE OF N FIXATION	AVERAGE
Chickpeas	1 - 114	57
Faba beans	30 - 600	329
Lentils	35 -115	75
Lupins	30 -258	35
Peas	17 - 119	68
Cowpeas	25 - 354	189
Mung beans	58 - 107	82
Pigeon peas	13 - 113	63
Phaseolus beans	64 - 121	92

There are several examples of yield increases in the second year following legumes. In one case (32), lupins, faba beans and peas exhibited second year responses; in the Rutherglen work (33) lupins (L.albus and L.augustifolius) increased wheat yields in the second year, whereas faba beans, peas, chickpeas and vetch did not.

Wheat protein content

At a time when international markets demand high quality wheat, grain legumes have a vital role to play. The decline in grain protein content with wheat cropping following pasture ley is well-documented (13), but data for wheat following grain legumes is less available. No consistent improvement in protein content of wheat/lupin compared with wheat/wheat was observed by (34) despite low protein values, and (35) has discounted any major impact of grain legumes on wheat protein content in W.A.. Although growing peas on heavy soils may improve wheat protein levels (35), this additional N input is not always desirable in low rainfall areas. However, significant improvements in grain protein content by including lupins or peas in the cropping system have been demonstrated on several occasions (Table 3).

Table 3: The grain protein response of wheat to previous crop legumes (32).

LOCATION	PROTEIN LEVEL (%) AFTER		
	WHEAT	LUPINS	PEAS
Ergowra	9.65	10.95*	11.18*
Cowra(1)	11.27	13.62*	13.85*
Manildra	13.65	12.50	13.58
Cowra(2)	13.30	13.03	12.68

* significant increase

Nutrient cycling

The need to efficiently use soil and applied nutrients is widely recognized, nowhere more so than on the infertile sandy soils of W.A., southeastern S.A., the Victorian Mallee and the Pilliga Scrub of N.S.W.. Lupins are well-known for their ability to thrive on soils where potassium deficiency limits the growth of sub-clover (36). The deep root penetration of L.augustifolius (37,38,39) allows this species to extract soil potassium which is less available to cereals and pasture species, and the ability of lupins to recycle potassium in some situations where soil K status is low has been clearly demonstrated (24).

Integrated weed control

The Gramineae and Leguminosae are the two most important plant groups for world agriculture, and crop rotations involving these species used to be considered the best option for weed management. This is still generally true, despite the availability of a wide array of herbicides which can selectively control either monocot weeds in legumes, or dicot weeds in cereals. This greatly reduces the need for highly selective herbicides in the following crop (e.g. grass weeds in cereal crop), and it is now common practice to attempt total grass weed control during the legume phase, and complete broad-leaf weed control during the cereal phase of the rotation. This does not obviate the need for either knock-down herbicides (glyphosate, paraquat/diquat) or broad-spectrum herbicides such as chlorsulforon in wheat, simazine in lupins and faba beans, and cianazine in peas and chickpeas, but may markedly reduce the area sprayed and the rates used. Given growing farmer and community concern regarding the safe use of chemicals and chemical residues (1,5,40), this may contribute significantly to sustainability of these systems, in the broader sense.

The advantages of integrated weed control in cereal-legumes rotations are highlighted by the Western Australian experience with brome grass (Bromus diandrus and B.rigidis). Prior to the introduction of lupins onto the northern sandplain soils, continuous wheat production was the normal cropping system. With no chemicals available for in-crop control of brome grass, farmers resorted to cultural control methods. Excessive cultivation, often four or five workings, resulted in:

- excessive cultivation costs
- 4 week delay in seeding and low yields. For each week delay in seeding after June 1 there is an average yield loss of more than 100 kg/ha (41)
- an extremely fragile soil surface which was very susceptible to wind erosion
- B.rigidis, which has staggered germination, still being a problem in some crops.

Clearly , this cropping system was not sustainable even in the short term, due to physical, biological and economic reasons. The introduction of lupins, use of the broad-spectrum herbicide simazine together with post-emergence applications of various grass herbicides (42) has virtually eliminated brome grass from the wheat-lupin rotation. A major impediment to the sustainability of the local cropping system has been overcome.

Other herbicide innovations and integrated weed management are reducing the importance of other difficult weeds in this and other cropping systems.

Break disease and pest cycles

Alternating crops with different disease susceptibilities can control pathogens which have narrow host ranges and which cannot survive for long periods away from a suitable host. Rotation is most effective against soil-borne diseases (e.g. take-all in wheat, cereal cyst nematode (CCN), Rhizoctonia spp., Pleiochaeta root rot in lupins, Phytophthora in chickpeas) but can also help control air-borne diseases (e.g. Septoria glume blotch and yellow spot (Pyrenophora tritici-repentis) in wheat, Pleiochaeta leaf spot in lupins, black spot in peas). Take-all (Gaeumannomyces graminis), CCN (Heterodera avenae), bare patch (Rhizoctonia solani) and common root tot (Cochliobolus sativus) cereal root diseases result in the largest potential cereal production losses (43), and discussion is concentrated on these diseases.

The cereal-pasture ley system has major benefits in terms of disease break, however, the continued presence of grasses in the pasture phase reduces its effectiveness for disease control. A strong relationship exists between grass content in the previous season and take-all risk in the subsequent

wheat crop (44). However, grasses become more dominant as soil fertility increases under the pasture phase, and despite data to the contrary (45), grass weeds in pasture are still considered valuable feed sources for stock. From this point of view, the cereal-grain legume rotation is easier to manage, since grass weeds are undesirable in both phases of the rotation.

Good disease management by rotation is essential in many situations to minimize disease in both the legume and cereal phase of the rotation. Disease control is a significant factor in improved wheat yields in a lupin-wheat rotation (46), and this rotation may be beneficial to the control of diseases in both crops (22)(Table 4). Similarly, incorporation of lupins onto the cropping system may markedly reduce the incidence and severity of common root rot (47); growth of peas in rotation may have a similar effect on the incidence of CCN, and take-all in wheat (Table 5).

However, legume-cereal rotations will not markedly reduce the incidence of Rhizoctonia bare patch, where the disease strain ZG1 (AG-8) attacks both cereals and legumes. While cultivation (51), particularly deep tillage (52) may reduce the incidence and severity of this disease, any additional cultivation may be undesirable from the viewpoint of wind erosion.

Table 4: Mean incidence (% infection) of fungal diseases in wheat (W) and lupins (L) grown in rotation (mean of 3 sites/year) (from (22)).

DURING YEAR 1		DURING YEAR 2		DURING YEAR 3	
%		%		%	
W Trace	(<1)	WW	8 x	WWW	36 x
L Trace	(<1)	LW	2 x	LWW	2 y
		WL	12 b	WLW	1 y
		LL	63 a	LLW	1 y
				WWL	12 b
				LWL	18 b
				WLL	54 a
				LLL	51 a

Wheat diseases - Take-all, Fusarium spp. and Eyespot.
Lupin diseases - Pleiochaeta setosa and Fusarium spp.
Values in the same column with common postscript letters do not differ at P>0.05 (x, y for wheat; a,b for lupins).

Table 5: Effect of the previous crop on the incidence of take-all and grain yield of wheat at Avon, S.A. 1979 (from (48))

PREVIOUS CROP	% OF WHEAT PLANTS WITH TAKE-ALL	GRAIN YIELD OF WHEAT (t/ha)
Wheat	67	1.7
Pasture*	58	1.4
Oats (avon)	14	2.3
Medic**	10	2.8
Peas	8	3.0

* Pasture = Mixture of medics, ryegrass, barley grass and wild oats.
** Medic = Sown snail medic.

Soil structure/biological plough

Improved soil structure following lupins has been reported from Australia, Brazil, France, Hungary, Italy and Spain (53). At Rutherglen, a good leafy lupin crop improved soil structure, but a poor lupin crop left

the soil in poorer condition than after a wheat crop (22). A 14% increase in water-stable aggregates and 67% improvement in rainfall infiltration has also been reported for wheat/lupins compared with wheat/wheat (54). Similar improvements in soil structure might be expected where high dry matter producing crops of other legumes are grown. More dramatic improvements in soil structure have been demonstrated through use of direct drilling (5,55). Therefore, farming systems which permit minimum tillage or direct drilling will help maintain or improve the structure of responsive soils (cf. 56).

Grain legumes growing on unstructured, sandy surface soils such as those on which much of W.A.'s lupin crop is produced, are unlikely to have worthwhile effects on soil structure. However, these soils suffer from sub-soil compaction, which may dramatically reduce the growth and yield of susceptible species (57,58). This type of soil compaction can be alleviated by deep tillage, however, minimizing of the number of tractor passes is essential to prevent rapid recompaction of these soils (59). Minimum tillage, reduced N fertilizer application and integrated weed control through use of lupins in the rotation offers some prospect for such management of soil compaction.

There may be an additional advantage of incorporating a tap-rooted legume such as lupins into the farming system. At normal lupin plant densities, the biological plough effect (i.e. creation of root pathways through the compacted zone) was estimated to improve wheat yields by 100 kg/ha (60).

High water use

The attainment of potential yield (maximum yield per millimeter of rainfall) from crops and pastures has been strongly advocated in recent years (61). Wide variations in water use efficiency have been reported for cereals and legumes (62,63,64,39) and there is certainly much room for improvement. However, situations exist where increased water use per se may be as important as increased water use efficiency or increased short-term profitability.

The spread of dryland salinity following clearing for agriculture continues at a rapid rate, and the contributions of recharge areas of poor productivity (deep sands, sand/clay, acid Wodjil soils, etc) is of particular concern (64). Increases in the rate of groundwater recharge following clearing of 20-65mm/year are common (94, 101). At some locations in the south-coastal agricultural area of W.A., the water-table is reported to be rising at about 1 meter/year (65).

Crop and pasture species and rotations can markedly affect the amount of water contributed to the water-table (Table 6). The barley-lupin rotation may be the only conventional winter cropping system able to generate sufficient dry matter and utilize enough moisture to preserve the land resource in some salinity-prone areas. However, early winter drainage may remain high under these rotations, and (38) have estimated drainage of 140mm under L.augustifolius grown on a deep sand. Clearly, if deep drainage, water-table rise and spread of salinity represent a major limitation to sustainable agriculture in some areas, then some legumes (e.g. lupins and lucerne) have a more useful role than traditional pasture and cereal-pasture rotations. However, they do not by themselves provide a solution, and significant areas of re-vegetation or agro-forestry may be necessary to stabilize and sustain agricultural production in these areas.

Table 6: Potential recharge under different rotations at Kondut and Cunderdin, Western Australia (from (66).

ROTATION	MEAN ANNUAL RECHARGE (mm)	
	Kondut	Cunderdin
Wheat/Clover	86	150
Wheat/Clover/Clover	99	154
Wheat/Wheat	47	139
Wheat/Lupins	64	100
Barley/Lupins	44	72

Integration with livestock production

The advantages of grazing livestock on grain legume stubbles are well-recognized (67,68,69,70,71,72). However, evidence suggests that the main benefits come from grain left on the ground at harvest. It is not unusual to leave 200-250 kg/ha of lupin seed on the ground after harvest (70) and similar losses are common with peas.

The lupinosis disease, caused by ingestion of toxins produced on lupin stubbles by the fungus Phomopsis leptostromoformis has caused widespread sheep deaths and production losses (73). However, the breeding of Phomopsis-resistant lupin cultivars (74) has greatly reduced this problem and will dramatically improve the value of lupin stubbles for summer grazing (75). Although this genetic innovation will significantly improve the economic and biological sustainability of the whole farm, the reduction in lupinosis risk will encourage heavier summer grazing. This will undoubtedly lead to overgrazing and wind erosion of fragile surface soils (76), seriously questioning the physical sustainability of this farming system. Similar questions remain for pea-cereal rotations. Pea stubbles are very fragile and severe summer wind erosion may occur despite relatively low grazing intensities. Strict maintenance of the physical sustainability of this farming system may necessitate zero grazing. Leaving up to 250 kg/ha of peas on the soil surface (77) may be a dubious practice from both an economic and biological view point; grazing will be foregone and the remaining seed is also a source for pea weevil carry-over from season to season.

Better use of machinery

Inclusion of grain legumes, particularly lupins, into farming systems may markedly improve the efficiency of machinery use (measured as capital investment per hectare of crop). Some cereal-legume rotations facilitate minimum tillage or direct drilling, with associated reductions in machinery and energy usage. Provided adequate stubble is retained (76), lupins can be safely sown into dry soil well before cereal sowing places any demands on farm machinery. This practice is now well-established in Western Australia (69) and is likely to become more widespread due to: (i) increased awareness of the advantages of early sowing of cereals (77), (ii) more widespread use of post-emergence herbicides in lupins,(iii)more widespread use of earlier sowing when air temperatures are higher as a means of brown leaf spot (Pleiochaeta setosa) escape in lupins. Lupins mature earlier than cereal crops in many production areas permitting more efficient use of harvesting machinery. Peas which may be sown later than both lupins and cereals (78), and are generally harvested before these crops, offer similar advantages in terms of machinery utilization. While some additional investment in seeding, harrowing, rolling and harvesting equipment may be necessary for optimum management of some grain legumes, the overall utilization of farm machinery will be improved, and the cost reduced.

Erosion control

Any sustainable farming system must avoid, or at least minimize wind and water erosion. A major advantage of the lupin-cereal rotation across much of southern Australia is the fact that it facilitates trash farming (79,80). That is, through the combined effects of disease break, integrated weed control and soil structure improvement it should be possible to sow the cereal crop using direct drilling or minimum tillage, and to direct drill the lupin crop into cereal stubble. The advantages of the latter for leaf disease and wind erosion control are well-documented (76,81). Weed control problems and the need for a very even seed-bed may inhibit full implementation of direct drilling in the pea-cereal rotation. .pa

There is some evidence that soil structural improvements from direct drilling and gypsum application may actually increase the risk of summer wind erosion from pea stubbles (82).

Diversification/continuous cropping

Enterprise diversification as a means of biological and economic risk spreading is a well-established practice, made imperative by wide fluctuations in market prospects for cereals, grain legumes and animal

products. Clearly, grain legumes have an important role to play in the economic sustainability of dryland agriculture. Their development also allows continuous cropping to be practiced where this is the preferred option for reasons of economics, management (remote farm or poor stock water supply), personal preference (does not like stock) or land conservation (stock exacerbate wind erosion potential; deep drainage and salinity).

Disadvantages of grain legumes in cropping systems

No farming enterprise is without pitfalls, and there are several significant disadvantages or problems associated with growing grain legumes.

Soil acidification

The introduction of subterranean clover and annual medics, and development of appropriate cereal-pasture rotation represented a revolution in Australian agriculture; a period of declining grain yields was replaced by a period of fertility restoration and improved grain yields (13,14,83). The general feeling that the pasture legumes offered a panacea for Australian agriculture was highlighted by the view that skillfully managed, all-pasture or ley-farming systems should be indefinitely sustainable (13). However, decreases in soil pH under sub-clover pastures are now well-documented (84,85) and a decrease of one pH unit can be expected after 4050 years under pasture (86). The acidification processes involved are expected to operate in the same way, but to differing degrees under a cereal-grain legume cropping system:

- increased organic matter content. The weak acids contained in this organic matter reduce the soil pH toward the pK of the organic acids.
- nitrate leaching. Nitrate originating from organic N is readily leached from many Australian soils, and may contribute to soil pH reduction well below the depth of organic matter accumulation (86).
- cation uptake. The greater absorption of cation nutrients than anions by plants, and removal of the slightly alkaline plant products results in a depletion of cation and pH decrease (85).

Although both lupins and peas are capable of high dry matter production (>10 tonne/ha), smaller increases in soil organic matter content may be expected under grain legumes than long pasture leys, particularly where pea stubbles are baled and removed. However, both nitrate leaching and cation absorption may cause more rapid acidification under some grain legumes, especially lupins, than under present legume pastures. The ability of lupins to fix large amounts of N and the residual value of this N for subsequent crops has been discussed above. L.angustifolius is well-adapted to coarse-textured, infertile soils, and the crop is grown on about 600,000 ha of readily leached soils in W.A. alone. Some paddocks have now been under a lupin-cereal rotation for 20 years or more (10-12 lupin crops) and an attempt is now being made to quantify any acidification on these soils (87). Lupins also remove large amounts of potassium in the grain, with further removal and re-distribution under grazing, and extract significant amounts of this nutrient from depth (24). Lupin tops have relatively high alkalinity (87), suggesting that they may be causing significant acidification via cation removal. This is of particular concern on the deep, poorly buffered sandy soils.

Lime application will correct surface acidification in some situations (88,89), but good agricultural lime is expensive (in short supply). Devising a means of correcting subsoil acidity may not be so simple. In both cases, accurate data on rates of acidification, critical pH levels for various species and cost-effectiveness of ameliorative measures are essential.

Non-wetting

Water repellent or non-wetting soils are an increasing problem in southern Australia. Approximately one million hectares of sandplain soils may be affected on the south coast of W.A. alone (90) and large areas are also affected in South Australia (91). Unpublished estimates by W.A. Department of Agriculture officers put the total area of non-wetting soils at 5 million hectares and non-wettability may cost W.A. producers as much as $20 million per annum (92). Increased wind and water erosion, and deep drainage may result from poor plant growth and reduced ground cover.

Coating of soil particle surfaces with hydrophobic organic compounds is the dominant process causing water repellence (93), and the problem is usually worst on sandy soils. While a number of native species (e.g. mallee, mallet, marri) also cause water repellence, it is residues from agricultural legumes, particularly clovers, medics, lucerne and lupins which are the greatest cause for concern. The problem is likely to increase most rapidly where legumes are highly productive since water repellence is a function of both the level and source of organic matter (Table 7).

Table 7: The effect of different rotations on the level of water repellence on a long-term rotation trial (from (90)).

ROTATION	MED* TEST VALUE			RATING
	Mean	S.D.	n	
CL:CL:CL:CL:L:W	2.27	0.15	6	Moderate
CL:CL:CL:CL:W:L	2.33	0.32	6	Severe
CL:CL:L:W	2.02	0.34	4	Severe
CL:CL:W:L	1.95	0.19	4	Moderate
CL:W	2.20	0.14	2	Severe
L:W	1.60	0.14	2	Moderate
Cont.L	1.90	0.85	2	Moderate
Cont.CL	2.30		1	Severe
Cont.W	0.25	0.35	2	Very low

MED=Molar ethanol drop test (95); RATING=Related to MED (95)
CL=Clover; L=Lupins; W=Wheat; Cont.=Continuous

Together with soil acidification, increased water repellence on sandy soils represents a significant threat to the sustainability of all farming systems which involve a productive legume phase. To date, use of press-wheels and other furrow-forming ground tools, and application of wetting agents are the most promising management options. Incorporation of wheat and barley stubble improves the wettability of strongly water-repellent soils (93), and management which maximizes cereal dry matter production

together with the level of retained and incorporated stubbles may prove useful. Lengthening the rotation to legume-cereal-cereal would reduce the non-wetting problem, but perhaps at the expense of economic sustainability.

Soil/rainfall/nutrient requirements

There is little doubt that grain legumes have narrower soil type adaptation than cereals. All require a well-drained soil, and all except lupins prefer soil pH in the range 6.0-9.0; lupins grow best on acidic soils (pH 4.5-7.5). However, the need to carefully select soil types for all farm enterprises is now well accepted. Economic pressures have encouraged farmers to seek the best returns possible from each enterprise, and 'paddock selection' or 'paddock culling' is now widespread. However, rainfall and soil type variability often combine to cause excessive yield instability in grain legumes, which is a significant deterrent to increased production.

The major grain legumes generally require more rain than cereal to achieve similar yields. This would be expected on the basis of differences in dry matter and seed composition (96), and computed values of transpiration efficiency are lower for the grain legumes (39). Lupins and other legumes which have very slow early growth may also lose considerably more stored moisture via soil evaporation, and stubble retention may have an important role in minimizing this loss (39). For deep, coarse sands and dry seasonal finishes, the deep rooting habit of lupins may give them an advantage over cereals in terms of water use and yield. The advantages which peas hold in low rainfall areas are obvious: rapid leaf area expansion, and early flowering. A significant breeding effort is directed toward improving the soil type adaptation and early vigour of L.angustifolius, and incorporating earlier flowering and maturity as a means of drought escape (97).

Some grain legumes will continue to demand higher applications of some nutrients, or additional nutrients. For example, lupin production requires manganese application on infertile sands, particulary in seasons with low spring rainfall, and this species is particularly sensitive to cobalt deficiency (98). Similarly, chickpeas and lentils may require foliar sprays of zinc and manganese on some soils (48). However, provided the specific nutrient requirements of grain legumes are not excessive, nutrient demands are not expected to affect significantly the sustainability of legume-cereal cropping systems.

Susceptibility to pests and diseases

The legumes are susceptible to a wider range of insect pests over a longer period of crop growth than cereal crops, and are prone to dramatic reductions in plant stand density and yield due to diseases. In lupins, significant yield reductions may result from brown leaf spot (Pleiochaeta setosa), Rhizoctonia root diseases, P.setosa root rot, cucumber mosaic virus and bean yellow mosaic virus, and be attacked by red-legged earth-mite, lucerne flea, aphids and bud-worm (Heliothus). The latter insect is of most widespread concern, since it is major pest of most grain legumes (11,18,19,99) as well as attacking many other wild and crop species. Peas present two special insect control problems: (i) developing pea pods are so palatable that very young Heliothus (1st or 2nd instar) may enter the young pods and be inaccessible to all but systematic insecticides, (ii) pea weevil continues to be a threat to the biological and economic sustainability of the pea industries of southern Australia. Similarly, the black spot complex is a significant disease in all pea growing areas.

Plant breeding and the evolution of improved management techniques is expected to relegate some of the pest and disease problems of crop legumes to a readily manageable level. However, as grain legume production expands onto more marginal soils and into less favourable production areas, the biological sustainability of the legume phase of the cropping system will depend on careful pest and disease management.

Higher managerial skill

It is partly due to their greater susceptibility to pests and diseases that the grain legumes require a higher level of monitoring and management. However, other factors such as seed quality, soil type selection, plant density, crop establishment and harvesting also require greater attention. While there is little doubt that the advantages of growing grain legumes out weigh the disadvantages ("no pain; no gain") in low input, extensive farming systems, the need for improved management techniques represents a significant challenge to researchers, extension staff and producers. If sustainable agriculture is to become a reality, then the greatest majority of farmers must adopt the correct practices. The technical solutions must be consistent with the skills of the farm manager if there is to be widespread adoption (9).

General discussion and conclusions

A range of factors have led to agricultural land being degraded, or exposed to the risk of deterioration in the long term: greater intensity of land use; development of more marginal land for arable agriculture; greater financial pressure due to international market trends and government policies. Even common farming practices considered to be safe, sustainable systems have lead to subtle changes to the chemical, physical or biological fertility of the soil. However, there is now widespread awareness of the need to develop and maintain sustainable, productive farming systems, using all available knowledge and techniques. The solutions to current and future problems demands from agronomists and producers a strict analysis of the factors limiting productivity and sustainability of farming systems, together with a flexible approach to developing optimum systems for different soil types, areas, etc.. There is unlikely to be any panacea to current or future problems; rather, there will be many solutions or partial solutions.

The introduction and very rapid adoption of grain legumes into cereal cropping systems is potentially as important an innovation as the adoption of pasture legumes some 40-50 years ago (103). Grain legumes should be seen as one avenue for improving productivity, profitability and sustainability. Individually, they are highly suited to particular cropping systems where they will make a dominant contribution, but in other situations their role will be minor. We believe that due recognition of the advantages and disadvantages

of grain legumes in different cropping systems allows forward planning of the short and long-term roles of these crops in sustainable agriculture. Several relatively simple examples are given below.

Example 1: Medium textured soil; medium rainfall.

MAJOR LIMITATIONS TO PRODUCTION			
Cereal	Lupins	Peas	Common Long-term
Low soil N	Leaf disease	Summer erosion	Soil structure
Root disease	B/L weeds	Insects	Water erosion
Grass weeds	Soil variation	B/L weeds	Acidification
	Unstable yield	Leaf disease	Salinity

Rotation of lupins or peas with cereals(1-3 years) will minimize the impact of productivity limitations such as diseases, weeds, insects, soil fertility. Facilitation of stubble retention and direct drilling will add dramatically to improvements to soil structure, which may in turn, increase productivity, reduce water erosion and decrease deep drainage (salinity). Livestock integrate well with this cropping system except for summer erosion risk of the pea stubbles. Clearly, further improvements in knowledge are necessary for many aspects of these cropping systems, and improvements in productivity and profitability are possible without threatening sustainability. While improved productivity and deeper water extraction by lupins may reduce the salinity risk, this will only be part of the overall solution to this problem. Soil acidification is perhaps the only problem which will be exacerbated by a productive legume phase.

Example 2: Coarse textured sand; medium-high rainfall.

MAJOR LIMITATIONS TO PRODUCTION		
Cereal	Lupins	Common Long-term
Low soil N	Leaf disease	Wind erosion
Root disease	B/L weeds	Acidification
Grass weeds	Insects	Salinity(drainage)
Soil compaction		Water repellence
Leaf disease		Rhizoctonia bare patch
		Nutrient decline

Some of the sands on which the lupin-cereal rotation is used are amongst the most coarse-textured, fragile, readily leached and nutritionally deficient in the world. It follows that any sutainable farming system developed for these soils will need to be conservative. The rotation of legumes and cereals will minimize disease, pest and weed problems. Similarly, N fixation by lupins and efficient extraction of nutrients such as K will minimize nutrient applications necessary to sustain agriculture on these soils. Deep root penetration and improved productivity will increase water use but there will still be significant groundwater recharge, contributing to salinity in susceptible areas. Direct drilling and stubble retention are made possible by this rotation and are essential for minimization of wind erosion.

The long-term threats to sustainability of agriculture on these soil types are substantial. The only way to prevent wind erosion on these soils is to maintain adequate surface cover throughout the year. The low productivity of poorer soil areas and prefernce of sheep for sandy areas means that wind erosion will continue to be a problem while grazing is integrated with crop production. Strategic fencing and alternative management of erosion-prone areas or minimal grazing will be necessary to ensure that ground cover is maintained above critical levels. The ultimate solution requires highly efficient harvesting so that little grain is left on the ground, minimizing the temptation to graze lupin stubbles. Additional inputs and new management techniques will be necessary to minimize the impact of nutrient decline (from low base levels), acidification (poor buffering capacity), deep drainage and development of water repellance.

The increase of Rhizoctonia bare patch disease under continuous cropping with direct drilling and stubble retention may present a difficult problem; a cost-effective fungicidal remedy is unlikely, and innovative tillage/sowing techniques may become essential. The introduction of lupins onto these soils has dramatically increased both productivity and environmental stability, and some farms have operated this system for over 20 years.

However, the lupin-cereal rotation cannot be considered sustainable on the poorer soil types. using existing management methods.

Whole-farm economic models (e.g. MIDAS (102)) have encouraged agronomists to consider the economic interaction of different rotaions and farming operations, and have highlighted gaps in our knowledge. A similar catalyst, perhaps economic and political reality rather than a computer model, may encourage agronomists to focus on the full range of physical, biological and economic interactions flowing from changes to one component of the farming system. Researchers and extension workers have rarely had such a receptive rural audience, acutely aware that productivity and prosperity must be linked to soil conservation and biological sustainability. Improved grain legume and cereal agronomy, and widespread adoption of appropriate legume-cereal rotations will make a major contribution toward the productivity and sustainability of Australian broadacre agriculture.

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