Sustaining multiple production systems 3. Ley pastures in the subtropics

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Abstract

During the 1990s, wheat protein and yield from many cropping soils (mainly vertisols) in the subtropical wheat belt will continue to decline as soil fertility is gradually depleted. One option for maintaining crop yield and quality is ley farming. It has had limited application when soil fertility has been adequate for crops and where the use of N fertiliser has been a viable option. Temperate legumes of the genus *Medicago* (lucerne and annual medics), and tropical grasses are available for use in leys, but there are currently no suitable tropical legumes.

The increases in yield and quality of grain crops recorded after lucerne and annual medic leys in various experiments are reviewed and related to changes in soil N and other factors. Leys provide more enduring benefits to subsequent crops than does the application of fertiliser N.

Ley farming is productive, sustainable, and provides a greater hedge against climatic and economic risks than cropping alone. However, it requires a wider range of management skills, and the challenge remains to stimulate wider adoption of this system.

Resumen

El rendimiento y la proteína del trigo de muchos de los suelos de cultivo del cinturón de producción de la región sub-tropical continuarán reduciéndose durante 1990 como consecuencia del agotamiento gradual de la fertilidad del suelo. La rotación de cultivos es una opción para mantener el rendimiento y la calidad de las cosechas. La rotación de cultivos ha tenido una aplicación limitada cuando la fertilidad del suelo es adecuada para el cultivo y cuando el uso de la fertilización con N es una opción viable. Las leguminosas del género Medicago *(alfalfa y medics anual), y las gramíneas tropicales son disponibles para ser usadas en la rotación de cultivos, pero actualmente no se tiene una leguminosa tropical que sea adecuada para tales propósitos.*

Se examinaron varios experimentos en los que se registró un incremento en el rendimiento y en la calidad del grano cosechado después de una rotación con alfalfa y medics anual. Dicho incremento se relacionó con los cambios en el N del suelo y con otros factores. La rotación de cultivos provee a los cultivos subsiguientes de un beneficio más duradero que la fertilización con N.

La práctica de rotación de cultivos es productiva, sostenible, y provee de una mayor protección contra los riesgos climáticos y económicos que el monocultivo. Sin embargo, requiere de un amplio rango de habilidades de manejo, y persiste el reto de estimular la adopción amplia de este sistema.

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Introduction

Traditionally, a ley is arable land sown to grass during a resting phase from cropping. In contemporary agriculture, ley farming is a system in which grasses and/or legumes are grown in short-term rotation with crops, thus intensifying the crop-fallow system. Ley pastures have been used for centuries in farming systems in the temperate environment of Europe, for example, the Norfolk 4-Course Rotation (Sanders 1954). In Australia, ley pastures have been incorporated in farming systems in the wheat-sheep belt of southern Australia since the 1930s (Puckridge and French 1983; Reeves 1987). Since the 1950s, the extent and duration of the ley phase in these temperate farming systems has not remained static, but has become a function of the relative economic outcomes of crop and animal production, due to new technologies that change the world-wide marketing of commodities, and widely fluctuating costs of fuels and fertilisers (McCown *et al.* 1988).

In the subtropics, cropping monocultures have evolved owing to the structural stability and inherent fertility of arable soils, the majority of which are vertisols containing large proportions of smectitic and illitic clays. For example, in Queensland, 70% of these arable soils are cracking clays (Weston *et al.* 1981) which constitute 90% of the area currently cropped. As the organic matter and N fertility levels of these soils have declined with time, so too have the protein quality and yield of cereal grain crops grown on them (Dalal and Mayer 1986a; 1986b; 1986c), leading to the need to supply N to the cropping system (Waring and Teakle 1960; Littler 1963). This has been supplied mainly as fertiliser. Few farmers have adopted ley farming systems, but two systems in use on the Darling Downs are in the vanguard of the development of sub-tropical leys. One involves a lucerne (*Medicago sativa*) ley of three to four years' duration (Brown 1987) and the other uses snail medic (*M. scutellata*) in a shorter rotation with grain and forage crops (Von Pein 1987).

In 1991 ley farming has become more attractive economically as soil fertility and grain prices have declined. This paper will review the biological benefits of ley pastures in the subtropics and examine the economics of adopting ley pasture systems.

Ley species for the subtropics

Legumes

Lucerne and some annual medics (*Medicago* spp.) are successful temperate ley legumes which are well adapted (Clarkson *et al.* 1991). They grow well as swards or in combination with summer-growing grasses whose growth patterns are complementary. In mixed pastures, forage of high quality is produced throughout the year. However all *Medicago* spp. cause bloat, and this is their greatest deficiency. Currently there are no commercial tropical legumes for ley systems although there is research interest in the genera *Desmanthus, Indigofera, Glycine* and *Vigna*. In general, the tropicals originate from centres of origin with leached, acid soils rather than from vertisols, and do not compete successfully with grasses for water on cracking clay soils (Keating and Mott 1987). Successful tropical ley legumes would need to be superior to the summer-growing lucerne, which has the added advantage of producing quality forage into the winter months. However, there is a niche for self-regenerating summer-growing annuals to replace annual forage legume crops in intensive cropping systems.

Lucerne: Lucerne is a successful ley species because:

(i) It establishes readily when sown alone, or with crops or pasture grasses.
(ii) It is a short-term perennial, which, although declining in density and productivity with time (Lloyd *et al.* 1985), is highly productive during its first 18 months. This is partly because of its ability to exploit soil water at depth (> 2 m) through the development of a deep taproot (Holford and Doyle 1978).
(iii) It fixes large quantities of N, from 1.5 to 2% of its dry matter (DM) production.
(iv) Mature lucerne is easily removed at the completion of the pasture phase by ploughing, and is not a weed in subsequent crops.

However, lucerne extracts soil water to wilting point during the first 18 months after its establishment, at depths below the roots of wheat (Holford and Doyle 1978). After a lucerne ley, crop yield is restricted unless the soil water profile is restored, which depends on fallow length and rainfall. The potential penalty to grain yield in the first crop after a ley on black earths is 8 kg/ha for every 1 mm of available soil water less than a full profile to 1.2 m depth (Holford and Doyle 1978; Anon. 1990). Thus, after a four-month fallow following lucerne, Holford and Doyle (1978) measured a 33% depression in grain yield compared with continuous wheat at Tamworth in New South Wales, whereas after a nine month fallow, R.C. Dalal, W.M. Strong and E.J. Weston (unpublished data) measured a 10% depression at Warra in southern Queensland.

We have determined the probability of replenishing the moisture reserves after lucerne in three soil types with different fallow periods for 15 locations in the Queensland wheat belt by using long-term (> 100 years) climatic records. Data from one of those locations are presented in Table 1. We assumed a mean fallow rainfall storage efficiency of 20% on all soils and locations (D. Freebairn, unpublished data) and available water-holding capacity per metre soil depth of 220 mm (black earth), 150 mm (medium

Table 1. Probability of replenishing soil moisture to one metre from wilting point in three soils, with different fallow lengths, to plant in July at Miles on the western Darling Downs

Fallow		Probability of replenishment (%)		
Starting month	Length (months)	Black earth (220 mm)	Brigalow clay (150 mm)	Loamy duplex (80 mm)
May	14	10	27	95
September	10	2	10	91
December	7	0	5	59
Rainfall needed (mm)		1100	750	400

brigalow clay) and 80 mm (loamy duplex) (Clarkson *et al.* 1987). The probabilities of obtaining those amounts of rain for each length of fallow were obtained from the Commonwealth Bureau of Meteorology through the QDPI's Climate Data Bank (Willcocks and Lloyd 1988).

Thus, a grain yield penalty in the first crop after lucerne on a black earth is almost certain and on a brigalow clay it is highly likely. Only on loamy duplex soils (which constitute a small area of land sown to wheat), are first-year yields unlikely to suffer. The probabilities vary only slightly across the Queensland wheat belt, though they increase to the north and east of Miles, and decline to the south and west. In practice, it may be necessary to sow a grazing crop of oats first after a lucerne ley, because fallow water recharge has been inadequate to grow wheat.

Annual medics: The value of annual medics as a ley pasture both parallels and contrasts with that of lucerne:

(i) Medics establish easily with wheat and regenerate from seed annually.

(ii) DM production and N fixation of annual medics are proportional to winter rainfall (Clarkson 1989) with herbage yields ranging from 0 to 10 000 kg/ha/yr, and N fixation from 1.7 to 1.8% of DM in favourable environments and 0.7 to 1.2% of DM in marginal environments (Clarkson 1986).

(iii) Their harvest index of seed is reduced in marginal environments by high temperatures and low humidity (Clarkson 1989). Nevertheless, seed reserves in brigalow pastures grazed by cattle are maintained at adequate levels for persistence and production in permanent pastures, but decline when cropping frequency is increased in ley pasture systems (Heida and Jones 1988). High levels of hard seed measured in Mediterranean environments (Crawford *et al.* 1989), although often achieved in the subtropics, are shorter lived, probably because higher humidity prevents the seed from drying out (N.M. Clarkson, unpublished data).

(iv) Unlike lucerne, annual medics do not deplete soil water more than continuous wheat (R.C. Dalal, W.M. Strong and E.J. Weston, unpublished data). Thus, the benefits of an improved soil N status are more likely to be expressed as increased grain yield and protein in the first year of cropping than when following lucerne.

(v) Despite their residual hard seed, annual medics are unlikely to become a weed in cropping systems; medics are generally suppressed by the crop and are readily removed with a herbicide.

Grasses

Some tropical grasses are suitable for ley pastures in the subtropics. Cropping sequences following leys which include free-seeding or rhizomatous grasses should initially involve a summer fallow to control the grasses.

Grasses for cracking clay soils: Purple pigeon grass (*Setaria incrassata*) is a free-seeding species with embryo dormancy and an ability to colonise cracking clay soils from seed. Silk sorghum (*Sorghum spp.* hybrid) is a rhizomatous, free-seeding grass which harbours sorghum midge. Sometimes its seed is contaminated with Johnson grass (*S. halepense*). However, despite these deficiencies as ley species, easy establishment and moderate persistence (three to five years) make both grasses useful in leys on these soils.

Grasses for loamy soils: Buffel grass (*Cenchrus ciliaris*) is a free-seeding grass with embryo dormancy. It develops a large crown and root system, and a longer fallow may be needed to decompose these residues before cropping. Rhodes grass (*Chloris gayana*) is well adapted to loamy brigalow soils where rainfall exceeds 575 mm/yr. Digit grass (*Digitaria smutzii*) is better adapted to solodic brigalow soils than buffel grass.

Grain yield and protein improvement after lucerne leys

Benefits to succeeding crops

The benefits have been assessed by integrating data from five grazed experiments conducted on soils with a long history of cropping (Table 2), and one with a relatively short history of cropping (Russell 1980). On old cultivations, the yield benefits from lucerne averaged 25%.

On all sites with a long history of cropping, there were substantial and consistent benefits to grain yield and protein from a 3½-year ley, even at one location where there had been little accruement of N (D.L. Lloyd, unpublished data) (Figure 1). It appears that the ley affects factors other than soil N, as the benefit that was obtained by the application of N fertiliser to crops for up to seven years (Table 2), was less than that obtained with the ley. Lucerne leys of 1½ and 2½-years' duration produced similar grain yield responses, but with a shorter duration of benefit to grain protein compared with the longer ley.

How lucerne provides these benefits

Improving soil N fertility: Changes in soil total N status during the ley phase at locations associated with yield benefits in Table 2, are presented in Figure 1. In addition, Holford (1989) found similar benefits to grain sorghum after a lucerne ley, which were also attributed to an improved soil N status. R.C. Dalal, W.M. Strong and E.J. Weston (unpublished data) have measured an increase of 80 kg/ha N after a one-year lucerne ley on a brigalow clay at Warra.

On soils with relatively low soil total N (at Tamworth and at Jondaryan) there were substantial increases in soil total N due to the ley (Holford 1981; Whitehouse and Littler 1984), with which improvements in wheat yield and protein (Table 2) were strongly correlated. The patterns of both N increase during the ley phase and N change in the crop/pasture system, were dependent on the initial level of soil total N. On the fertile soil at Narayen (Russell 1980) there was no increase, at Jondaryan (Whitehouse and Littler 1984) the asymptote occurred after two years, and at Tamworth (Holford 1981), there was no asymptote after four years. Similarly, in an eight year ley system with a 50% cropping frequency (four years crop, four years pasture), soil total N decreased by 7% where the N fertility was high (0.3%) (Russell 1980) but increased by 15% on a soil with lower total N status (0.125%) (Whitehouse and Littler 1984) and a longer history of prior cropping.

Improving soil structure: Lucerne produces little benefit to crop production through improving soil structure as it does not improve the soil organic C status of loamy-surfaced soils (Holford 1981) which are dependent on that component for structural stability. It does increase soil organic C on cracking clay soils by 3-10% (Holford 1981; Whitehouse and Littler 1984; D.L. Lloyd,

Table 2. Benefits of a 3½-year lucerne ley on grain yield and protein content of succeeding wheat crops on soils with a long history of cropping

Experiment	Soil	Location	Average annual benefit to the first 4 crops		Duration of benefit[1]	
			Yield	Protein	Yield	Protein
			t/ha	%	(years)	
Holford (1980)	Black earth	Tamworth NSW	0.4	3.3	5(4)	7
Holford (1980)	Red-brown earth	Tamworth NSW	0.4	3.3	4(3)	5
Littler (1984)	Black earth	Jondaryan Qld	0.5	2.7	7(7)	8
Harty *et al.* (1966)	Black Earth	Warwick Qld	0.5	0.7	9 (not measured)	2
Lloyd (unpublished data)	Black Earth	Norwin Qld	0.5	0.0	3(2)	0

[1] Years after the ley during which *some* benefit from lucerne was measured, and number of years for which the yield benefit was greater than provided by using N fertiliser (in parenthesis).

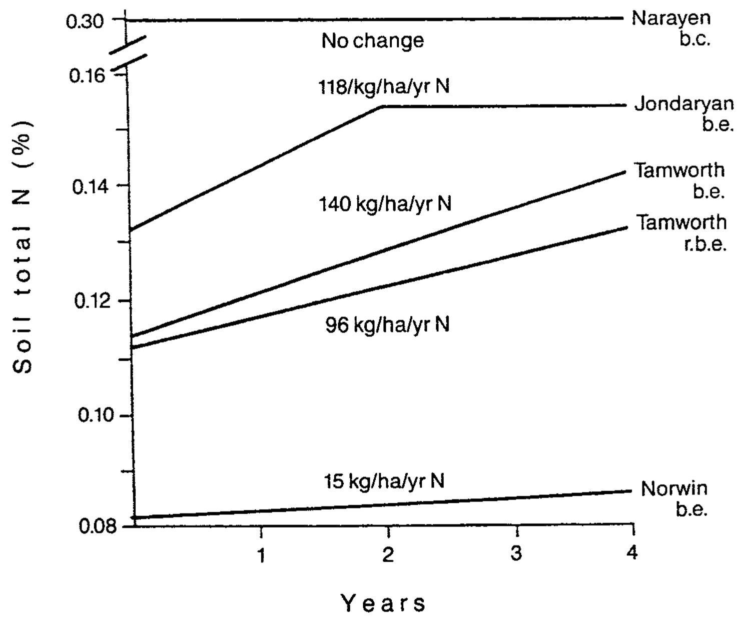

Figure 1. Changes in the soil total N status during lucerne leys on brigalow clay (b.c.), black earth (b.e.) and red-brown earth (r.b.e.) soils.

unpublished data) but these soils are structurally stable.

Reducing soil compaction: Lucerne breaks the plough layer, facilitating root penetration and water infiltration (D.L. Lloyd, unpublished data). The effect of this on crop production has not been measured.

Reducing weeds: A four-year lucerne ley reduces wild oats populations to manageable levels (Littler 1984; D.L. Lloyd, unpublished data). The level of control depends on the palatability of weeds, the grazing pressure applied, and the duration of the ley.

Controlling pests and diseases of grain crops: Lucerne leys break the disease cycles of crown rot (*Fusarium graminearum*), common root rot (*Cochliobolus sativus*) and yellow spot (*Pyrenophora tritici-repentis)* of cereal grain crops, but not root rot of chickpea (*Phytophthora megasperma* f.sp. *medicaginis*). Lucerne leys also help to control wheat sickness or the long-fallow disorder of wheat by breaking the host cycle of the root lesion nematode (*Pratylenchus thornei*) (R.C. Colbran, unpublished data), and stimulating soil populations of VAM which decline during periods of long fallow (Thompson 1987).

Grain yield and protein improvement after annual medic leys

The benefits and their association with soil total N

On soils with a relatively low total N status at three locations, Clarkson (1986) found significant though variable benefits from four-year medic leys to grain yield (from −0.02 to 1.4 t/ha) and protein (from −0.8 to 5.2%). In addition, R.C. Dalal, W.M. Strong and E.J. Weston (unpublished data) have measured increases in grain yield of 0.7 to 1.4 t/ha and protein of 5.2% after a one-year medic ley on a brigalow clay soil. These crop benefits are due partly to an improved soil N status which was increased by 35 - 60 kg/ha/yr (Clarkson 1986), 50 kg/ha/yr (R.C. Dalal, W.M. Strong and E.J. Weston, unpublished data) and 71 kg/ha/yr in an unrelated study (Lloyd and Hilder 1985). The benefit from medics was consistently related to winter rain through its effect on herbage yield and N fixation. Nothing is known of benefits to following crops, other than the provision of N.

Economic analysis of ley pasture systems

There has been a widely-held belief that the incorporation of a ley phase in crop/fallow systems in the subtropics is uneconomic. In a paper of this scope, it is not possible to account for the commodity-price dynamics that occur over time. Hence, comparative steady-state budgeting was used to evaluate the impact of adopting two sustainable farming systems (lucerne and snail medic leys), on the operating profit of a 2 500 ha mixed farming enterprise on the western Darling Downs with established infrastructures for grain and livestock production.

The analysis (Table 3) assumes an area of 800 ha of old cultivation in each system. The lucerne ley system assumes that half the cultivated area has a lucerne-wheat rotation with benefits to wheat yields and protein. In the system using medics, a greater diversity of crops is possible, less area is farmed, more livestock are carried and there is greater working capital invested than in both other systems. A small premium in price is allowed on wheat with higher protein content after each legume ley. The estimated operating profits are based on conservative yields and prices and realistic costs. Prices and costs allow for increases in wheat yields and protein concentration after the ley, but do not allow for increased productivity per animal or the additional benefit of the rotations to weed control. The operating profits indicate that, under these conservative assumptions, the ley farming systems on mixed farms with old cultivation are likely to be more profitable than the conventional farming system.

The favourable economic effect of incorporating both leys into the conventional system is due to increases in wheat yield and price being

Table 3. Economic analysis of mixed farms employing conventional, lucerne ley and annual medic ley farming systems. Crops include wheat (W), oats (O) and sorghum (S) in the conventional system; those crops and lucerne (L) in the lucerne ley system; and some of those and barley (B), mung beans (MB), lab-lab bean (LL) and snail medic (SM) in the annual medic ley system.

Attribute	Conventional	Lucerne ley	Annual medic ley
Livestock — cattle	150 breeders turning off 2 yr olds	150 breeders turning off 2 yr olds	200 breeders turning off 2 yr olds
— sheep	1600 wethers	1600 wethers	2000 wethers
Farming system /summer winter/	/-W/-W/-W/-O/S-/--/S	/-W/-W/-W/-O/S (50%) /-W/-W/-WL/L/L (50%)	/-W+SM/LL SM/- W+SM/ -B+SM/MB SM/- W+SM/ -O+SM/MB
Wheat yield (t/ha)			
Long fallow	2.5	2.5	
Short fallow	2.0	2.0	
Sown with lucerne		2.35	
1st year out of lucerne		2.0 + 3% protein benefit	
2nd year out of lucerne		2.35 + 3% protein benefit	
Long fallow + SM			2.5 + 3% protein benefit
Short fallow + SM			2.25 + 3% protein benefit
Barley yield (t/ha)			2.0
Mung bean yield (t/ha)			0.4
Sorghum yield (t/ha)	1.2	1.2	
Lucerne hay yield (t/ha)		0.8	
Wheat price ($/t)			
After fallow	110	110	
After lucerne and medic		120	120
Sorghum price ($/t)	100	100	
Hay price ($/t)		100	
Barley price ($/t)			110
Mung bean price ($/t)			400
Wool price ($/kg)	5	5	5
Cattle price ($/kg)	0.9-1.1	0.9-1.1	0.9-1.1
Gross Income	**227 700**	**238 000**	**251 000**
Variable Costs[1]	**60 700**	**60 800**	**76 100**
Gross Margin	**167 000**	**177 200**	**174 900**
Fixed Costs[2]	**70 000**	**70 000**	**67 500**
Operating Profit	**97 000**	**107 200**	**107 400**
Sustainability	**LEAST**	**BEST**	**BEST**
Hedge against risk	**LEAST**	**BETTER**	**BEST**
Need for management skills	**LEAST**	**GREATER**	**GREATEST**

[1] Variable costs cover fuel, oil, repairs, maintenance, seed, fertiliser, chemicals, cartage, veterinary costs, commission, losses, shearing costs, etc.

[2] Fixed costs include rates, insurance, registration, accountancy fees, general running costs, permanent labour and depreciation.

achieved with no reduction in wheat area for the lucerne system, and a reduction of 100 ha in the area cultivated in the snail medic system. In the lucerne system, the contraction in area of the less valuable crops such as oats and sorghum makes it possible to introduce lucerne into the system and maintain the stock numbers. It is anticipated that there would be surplus lucerne for hay-making and sale. In the snail medic system, as a consequence of the reduced area of cultivation, less machinery is needed. The combined result of the new asset structure and enterprise mix is that working capital is higher in the ley systems.

If commodity prices vary but the area sown to wheat remains constant within each ley farming system, changes in comparative economic outcomes will be negligible (Lloyd and Smith 1989). However, significant and sustained changes in commodity prices will alter the proportions of land used for grain and animal production (McCown *et al.* 1988).

Conclusions

Ley farming systems proposed or in current use on rundown soils in the subtropics improve the productivity and enhance the sustainability of mixed farming enterprises. They can be profitable and provide a better hedge to risk by forcing farmers to diversify to a wider range of cereal and legume grain crops. However, they are more complex, requiring a wider range of management skills and, where the infrastructures for animal production have been removed (as on the Darling Downs), crop yield and quality will probably be maintained with N fertiliser. The challenge remains to stimulate the adoption of ley systems.

Although the 1990s will be the vanguard years for the adoption of ley farming systems in the subtropics, there are, nevertheless, a number of areas that require immediate research:

(i) Agronomic studies of competition between crops and undersown lucerne and annual medics comparable to the studies of Brownlee and Scott (1974) in southern Australia, and the determination of optimum sowing rates to maximise the subsequent benefit of the ley.

(ii) Studies of seed dynamics of annual legumes (particularly medics) in ley pasture systems, to develop management strategies which maintain legume populations that ensure maximum benefits are obtained from the ley.

(iii) Studies of the influence of herbicide residues associated with minimum/zero till cropping systems, on legume establishment and growth.

(iv) Modelling lucerne and annual medic primary production and animal production from leys, to enable the effects on the whole farm system to be determined and the duration of ley phases to be optimised.

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