CSIRO PUBLISHING

Animal Production Science, 2009, **49**, 894–906 www.publish.csiro.au/journals/an

Poor adoption of ley-pastures in south-west Queensland: biophysical, economic and social constraints

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Abstract. The present review identifies various constraints relating to poor adoption of ley-pastures in south-west Queensland, and suggests changes in research, development and extension efforts for improved adoption. The constraints include biophysical, economic and social constraints.

In terms of biophysical constraints, first, shallower soil profiles with subsoil constraints (salt and sodicity), unpredictable rainfall, drier conditions with higher soil temperature and evaporative demand in summer, and frost and subzero temperature in winter, frequently result in a failure of established, or establishing, pastures. Second, there are limited options for legumes in a ley-pasture, with the legumes currently being mostly winter-active legumes such as lucerne and medics. Winter-active legumes are ineffective in improving soil conditions in a region with summer-dominant rainfall. Third, most grain growers are reluctant to include grasses in their ley-pasture mix, which can be uneconomical for various reasons, including nitrogen immobilisation, carryover of cereal diseases and depressed yields of the following cereal crops. Fourth, a severe depletion of soil water following perennial ley-pastures (grass + legumes or lucerne) can reduce the yields of subsequent crops for several seasons, and the practice of longer fallows to increase soil water storage may be uneconomical and damaging to the environment.

Economic assessments of integrating medium- to long-term ley-pastures into cropping regions are generally less attractive because of reduced capital flow, increased capital investment, economic loss associated with establishment and termination phases of ley-pastures, and lost opportunities for cropping in a favourable season. Income from livestock on ley-pastures and soil productivity gains to subsequent crops in rotation may not be comparable to cropping when grain prices are high. However, the economic benefits of ley-pastures may be underestimated, because of unaccounted environmental benefits such as enhanced water use, and reduced soil erosion from summer-dominant rainfall, and therefore, this requires further investigation.

In terms of social constraints, the risk of poor and unreliable establishment and persistence, uncertainties in economic and environmental benefits, the complicated process of changing from crop to ley-pastures and *vice versa*, and the additional labour and management requirements of livestock, present growers socially unattractive and complex decision-making processes for considering adoption of an existing medium- to long-term ley-pasture technology.

It is essential that research, development and extension efforts should consider that new ley-pasture options, such as incorporation of a short-term summer forage legume, need to be less risky in establishment, productive in a region with prevailing biophysical constraints, economically viable, less complex and highly flexible in the change-over processes, and socially attractive to growers for adoption in south-west Queensland.

Additional keywords: farming systems, forage lablab, livestock, short-term ley-pastures.

Introduction

Cropping soils of south-west Queensland have declined in soil organic matter and nitrogen (N) resulting from a history of extensive cultivation, leading to rapid N mineralisation and its removal through crop and animal production, leaching, denitrification and erosion (Dalal and Mayer 1986*a*; Dalal *et al.* 1995). From the current understanding, incorporation of medium- to long-term ley-pastures into cropping systems can

© CSIRO 2009 10.1071/AN09015 1836-0939/09/100894

reverse this decline in organic matter and N and potentially improve subsequent crop production (Dalal *et al.* 1991; Lloyd *et al.* 1991; Herridge 1992; Peoples *et al.* 1998*a*, 1998*b*). Ley-pastures have been also shown to maintain the soil structure, suppress crop weeds, break disease cycles and minimise the risk of soil erosion (Dalal and Mayer 1986*a*; Mayer 1988; McCowan *et al.* 1988; Steele and Vallis 1988; Bellotti *et al.* 1991; Dalal *et al.* 1995; Henzell and Daniels 1995; Doughton *et al.* 1996; Peoples *et al.* 1998*a*, 1998*b*).

Legumes in ley-pastures have long been considered to be a sustainable and profitable means of maintaining soil N fertility, forage quality and productivity in both permanent and ley-farming systems (Peoples *et al.* 1998*a*, 1998*b*, 2001). Evidence in the literature indicates that livestock on legume-based ley-pastures can make a significant contribution to economic and environmental sustainability of mixed farming systems in south-west Queensland, particularly where grazing occupies approximately two-thirds of the average property, but growers remain reluctant to adopt ley-pastures in cropping paddocks (Weston *et al.* 2000; Lawrence 2002; Pengelly *et al.* 2003; Whitbread and Clem 2006). This is despite soil N declining in the order of 25–45% in major cropping soils of southern Queensland (Dalal and Mayer 1986*b*), and more than four decades of research showing the benefit to subsequent crops of the soil N accumulation from forage legumes (Holford 1989; Hossain *et al.* 1996; Weston *et al.* 2000, 2002; Whitbread and Clem 2006).

The poor adoption of ley-pastures may primarily appear to be due to growers' perception of economic losses associated with ley-pastures in cropping systems. For example, McCowan *et al.* (1988) suggested that the acceptance of ley-pastures in the cropping systems by growers will largely depend on scientists' acknowledgement of economics as the primary determinant of change in farming systems, not the level of production or environmental benefits. However, biophysical and social issues may have also contributed to the poor adoption of ley-pastures, particularly, their being socially unattractive and the complexity of introducing ley-pastures into the existing cropping systems.

In the present review, we identify potential gaps in our understanding of the biophysical, economic and social dimensions of ley-pasture adoption, which, if addressed, may lead to socially and economically adaptive change, with improved ecological sustainability in south-west Queensland.

Biophysical constraints

Agro-climatic conditions

There could be up to four agro-climatic factors that negatively affect the persistence and production of ley-pastures in south-west Queensland (Fig. 1). These include (1) unreliable rainfall and frequent dry spells, (2) shallower soil profile, with poor water holding capacity (PAWC), (3) subsoil constraints (increased concentrations of naturally occurring salt and sodicity at depth) and (4) frost and subzero temperatures in winter, and hot and dry conditions in summer.

The dryland farming areas of south-west Queensland receive 60–75% of the annual rainfall during the summer months, with a mean annual rainfall of 600 mm, and annual evaporation in excess of 2000 mm (Fig. 2). Winter rainfall is unreliable, and hot and dry conditions in summer are common. Additionally, majority of cropping soils in south-west Queensland are shallow (60–80 cm deep), with prevailing subsoil constraints including soils being naturally very high in salt or sodicity at 60–80 cm depth (Dang *et al.* 2006). Although climatic conditions, combined with the soil type, soil fertility and PAWC, determine the productivity of the ley-pasture or grain crop, the PAWC and growing-season rainfall are the primary determinants of persistence and productivity of perennial ley-pastures in the marginal environment of south-west Queensland. Decreased PAWC of shallower soils, combined with frequent dry spells and subsoil constraints, can negatively affect the persistence and productivity of ley-pastures, particularly medium- to long-term ley-pastures (3–5 years). Furthermore, frost and subzero temperatures in winter, common in much of the south-west Queensland, generally stop the growth and reduce the quality of tropical grasses in winter (Clarkson *et al.* 1991), and reduce the species suitability of perennial tropical and subtropical legumes (Lloyd *et al.* 2009).

Fig. 1. A map of the study area, Maranoa–Balonne Catchment, including Roma, St George, Meandarra, Goondiwindi and Condamine in south-west Queensland.

Cropping systems

The wider acceptance of the existing fallow–cereal cropping, along with recent management changes, such as conservation

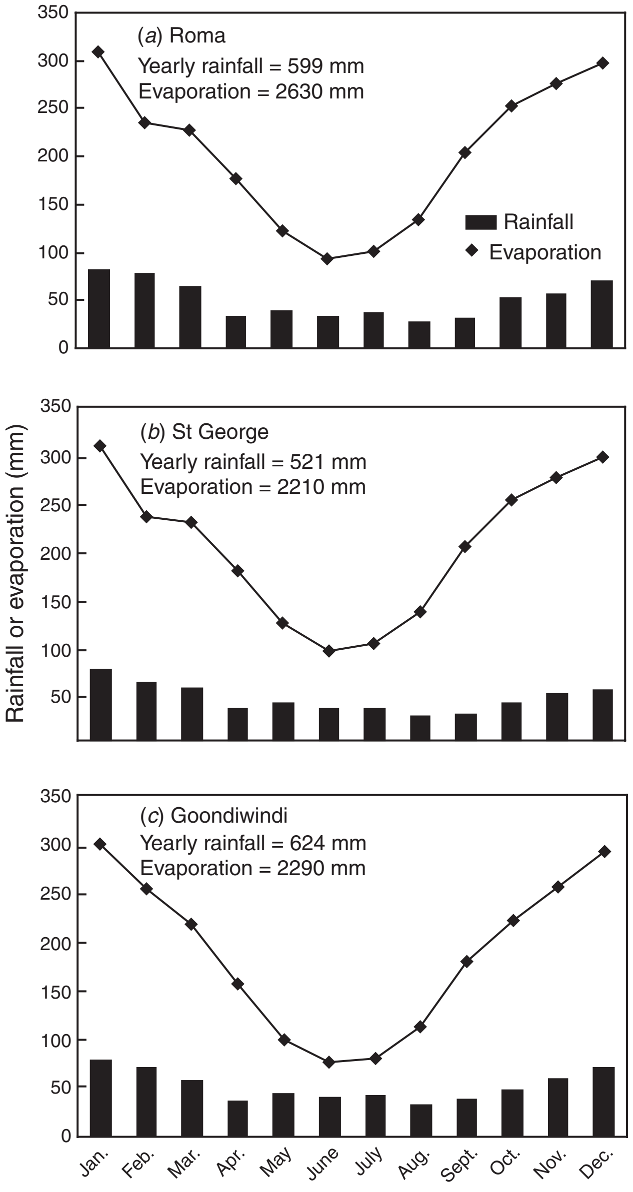

Fig. 2. Mean long-term monthly rainfall and evaporation for (*a*) Roma, (*b*) St George and (*c*) Goondiwindi in southern Queensland.

tillage and opportunity cropping for improved economic and environmental benefits, may have also acted as one of the physical constraints to adoption of ley-pastures.

The cereal cropping in south-west Queensland is largely dryland. Continuous wheat cropping, including a fallow period of variable length for moisture conservation, has been the most common practice (Bellotti *et al.* 1991; Thomas *et al.* 2001, 2007; Singh *et al.* 2004; ABARE 2005). This type of dryland cropping has been particularly dominant on the cracking clay soils of the brigalow (*Acacia harpophylla*) region and Mitchell grassland (*Astrebla* spp.) during the past 30–40 years. However, the severe decline in fertility resulting from frequent cropping over 30 years, along with increased infestation of weeds and diseases, such as root and crown rots, have made an increasing number of growers realise that continuous wheat production is not sustainable, with many adopting the use of minimum or zero tillage (conservation tillage) and diverse crop rotations and opportunity cropping for the past few years (Wylie 1996; Lawrence 2002; Thomas *et al.* 2007).

The common crop rotations include various combinations of wheat, chickpea, grain sorghum, and opportunity cropping, depending on soil fertility, PAWC and the previous crop. Two cropping systems (chickpea–wheat and continuous wheat cropping with fertiliser N) have been reported to be the most profitable ones from the two medium- to long-term experiments (5–10 years), the Warra Experiment (Dalal *et al.* 1998) and the Nindigully, Western Farming Systems Project (WFSP) (Thomas *et al.* 2001) (Tables 1–3).

Chickpea–wheat

The Warra and WFSP experiments have shown that the chickpea–wheat rotation (with or without fertiliser N for the subsequent wheat crop) is one of the most profitable rotations, compared with continuous wheat with no added N fertilisers. Chickpea can provide saleable grain, adds 15–40 kg N/ha to the soil and increases yield of the next crop (Tables 1–3). Moreover, chickpea in rotation with winter cereals can produce greater profit margins (subject to a higher seasonal price) by increasing the yields of subsequent wheat and barley crops by up to 30%.

Continuous wheat cropping with fertiliser nitrogen

The advantage of this rotation is that N is supplied to meet crop needs and market demands. However, longer-term application of N fertiliser in continuous wheat was found to be associated with increased levels of crown rot, which had an adverse effect on yield (Thomas *et al.* 2002). Other studies on cracking clay soils in south-west Queensland have found pasture legume N more effective than the fertiliser N, owing to better profile distribution of the pasture N, although the pasture phase also confers additional advantages by breaking of disease cycles and better infiltration and soil water storage (Littler and Whitehouse 1987; Armstrong *et al.* 1999).

The fallow period of a variable length in the current cropping system for moisture conservation, however, remains a serious environmental problem, because of the associated risk of potential soil erosion (Williams and Chartres 1991; Freebairn *et al.* 1993; Groose 1998). Intense episodic rainfall events during the fallow periods are particularly damaging, and cause most of the loss in sediments and nutrients, with up to 50% of the rainfall loss as runoff (Silburn *et al.* 1992; Miles 1993). Fallowing in summer may have little benefit for soil moisture storage (only 20–40% of the rainfall being stored during the 5–6 months' fallow), and soil erosion by both water and wind could be substantial in the absence of adequate ground cover (Groose 1998).

Current ley-pastures: options, management and limitations

The incorporation of legume-based ley-pastures into the cropping paddocks with degraded soil has been suggested as a successful technique for restoring the soil fertility and productivity in the region (Dalal *et al.* 1995; Doughton *et al.* 1996; Weston *et al.*

Table 1. Annual operating profits (A$) from the grain returns alone, on a 520-ha farm using six management scenarios and their production from the Warra Experiment (Dalal *et al.* 1998)

No crop was sown in 1991 because of drought

Year	Wheat + 0 N	Wheat + 50 N	Chickpea–wheat	Medic–wheat	Lucerne–wheat	Grass + legume–wheat
1987	163 986	194 114	76 929[A]	154 875	145 765	–[B]
1988	105 369	193 994	200 672	72 887	72 887	–[B]
1989	52 173	82 802	73 287	98 223	95 913	–[B]
1990	59 078	94 948	104 893	109 440	133 923	138 181
1992	146 084	175 451	178 644	140 045	133 280	154 560
1993	49 357	71 647	56 012	39 972	60 412	65 347
1994	–3966	13 150	45 742	22 152	54 712	32 293
Mean	81 726	118 015	105 168	91 085	99 556	97 595
Profitability of change		36 289	23 442	9359	17 830	15 869

[A] Chickpea crop was frost damaged.

[B] Grass + legume pasture growth (4–7 t/ha per annum; Strong *et al.* 2006). Forage value was not determined.

Table 2. Grain yield and gross margins for continuous wheat and wheat following chickpea (with or without N) at Nindigully (Thomas *et al.* 2001)

Rotation	Grain yield (t/ha)			Gross margin ($/ha)		
	1997	1998	1999	1997	1998	1999
Continuous wheat	2.20	1.12	2.58	79	–26	2
Continuous wheat + N	2.93	1.79	4.02	224	47	345
Wheat following chickpea	2.56	1.57	3.34	180	46	121
Wheat following chickpea + N	2.71	2.45	3.99	191	142	388
l.s.d. (*P* = 0.05)	0.26	0.35	0.27	48	109	52

Table 3. Continuous wheat (May and June sown), medic–wheat (second wheat crop following an 18-month medic pasture ley), lucerne–wheat (second wheat crop following an 18-month lucerne pasture ley), grass + legume–wheat (first wheat crop following a 3-year bambatsi panic plus legume pasture ley, ploughed in October 1999), grass + legume–wheat (first wheat crop following a 3-year bambatsi panic plus legume pasture ley, ploughed in October 2000) and chickpea (May and June sown) at the Nindigully trial in 2001 (Thomas *et al.* 2002)

Crop rotation	Soil water at sowing (0–1.2 m) (mm)	N fertiliser rate (kg N/ha)	N supply at sowing (kg N/ha)[A]	Grain yield (t/ha)	Grain protein (%)	Gross margin ($/ha)[B]
Wheat (May)	170	0	90	3.54	11.1	345
		80	170	3.55	12.7	325
Wheat (June)	170	0	90	2.92	10.0	215
		40	130	3.13	11.7	235
		60	150	3.00	13.4	255
		100	190	2.99	14.9	280
Medic-wheat	145	0	115	2.63	14.0	265
		60	175	2.48	16.0	210
Lucerne-wheat	150	0	165	2.55	15.8	250
		40	205	2.38	17.0	50
Grass + legume-wheat (Oct. 1999)	140	0	140	2.43	15.3	180
		40	180	2.37	16.4	15
Grass + legume-wheat (Oct. 2000)	65	0	120	1.42	17.4	60
		40	150	1.29	18.7	–70
Chickpea (May sown)	170	0	90	1.72	20.8	260
Chickpea (June sown)	170	0	90	1.57	20.1	190
l.s.d. (*P* = 0.05)				0.32	1.08	

[A] N fertiliser + soil nitrate-N at pre-sowing.

[B] Gross value of grain produced, less variable or operating costs (fallow and crop).

2002; Whitbread *et al.* 2005). The advantages and disadvantages of using medium- to long-term ley-pastures in crop rotation are numerous (Littler and Whitehouse 1987; Bellotti *et al.* 1991; Lloyd *et al.* 1991; Dalal *et al.* 1995; Henzell and Daniels 1995; Armstrong *et al.* 1999; Weston *et al.* 2000, 2002; McDonald and Lloyd 2002; Pengelly *et al.* 2003). Advantages may include (1) diversification of income, (2) complementarities of enterprises, (3) more efficient use of capital and labour, (4) N accretion, (5) improvement of soil structure, (6) improvement of soil biota, (7) maintenance of vesicular-arbuscular mycorrhiza, (8) weed control, (9) disease break, (10) more efficient use of water, (11) better ground cover and reduced erosion, (12) reduction of soil acidity, (13) reduction of salinisation and (14) recycling of nutrients from depth. However, the disadvantages may include (1) an increased cost of livestock management infrastructure, (2) bloating and other economic livestock disorders, (3) lack of stock and/or pasture expertise and increased complexity, (4) difficulty of terminating pastures, (5) herbicide residual problem, (6) drying out of soil profile, (7) compaction, (8) a loss of cash crop production during the interchange phase, (9) a lengthy fallow period to replenish soil water before returning to crop, and/or (10) additional capital being tied up in livestock if need to purchase.

Available ley-pasture options and management

The Warra and WFSP experiments highlighted the following three major options of ley-pastures into cereal cropping systems: grass + legumes, lucerne and medic (Tables 1–3). Both experiments emphasised that the grass component of a grass + legume pasture can contribute to significant increases in soil organic matter compared with the legume monocultures (Dalal *et al.* 1998; Thomas *et al.* 2001), further supported by pasture improvement programs on lucerne and medics in the region (Lloyd *et al.* 1991). Lloyd *et al.* (1991) suggested that incorporation of legumes enhanced the soil N, which was used by the grasses for producing more biomass and soil organic carbon through increased root mass (Dalal *et al.* 1998). This indirect effect of ley-pastures to increase soil organic C has been attributed by others to an increased root mass of associated grasses (Holford 1981; Dalal *et al.* 1995).

Grass + legume mixtures

The better mix of grass + legume pastures was a mixture of purple pigeon (*Setaria incrassata*) + Rhodes grass (*Chloris gayana*) + lucerne + annual medics. The mix of grass + legume pastures can provide continuity of quality feed throughout the year for at least 4 years (Dalal *et al.* 1998). Dalal *et al.* (1998) also reported that this ley-pasture was an effective way to increase soil organic matter, producing an extra 80 kg N/ha per year, boosting subsequent wheat yields and protein to prime hard, and was found to be a more profitable system than continuous wheat cropping without fertiliser N. From the same study, it was also noted that grass production for grazed pastures was nearly twice that of a pasture that was cut and removed (Strong *et al.* 2006). This indicated an additional advantage of grazing; namely, nutrient recycling from dung and urine in grazed pasture, promoting increased growth, particularly of N-starved grasses (Strong *et al.* 2006). However, the limitations of grass + legume system included an unreliable pasture establishment, requiring adequate stored water before sowing, and a greater depletion of soil water, which can reduce the yield of the subsequent cereal crop if water deficit is not replenished through practising a long fallow of at least 14–18 months (Dalal *et al.* 1998).

Forage legumes

The common legumes that are often recommended to be grown in combination with various warm-season perennial grasses consist of (1) perennial lucerne (*Medicago sativa* L.) and (2) temperate annual medics (*Medicago* spp.) (Dalal and Mayer 1986*a*, 1986*b*; Lloyd *et al.* 1991, 2009; Dalal *et al.* 1998).

Lucerne. This is the most common legume on cropping soils and widely used in southern Queensland and northern New South Wales although it fails to persist in sufficient plant densities for more than 2 years in Queensland (Pengelly and Conway 2000; Strong *et al.* 2006). Lucerne as a ley-pasture generally provides high-quality forage for grazing for 1–3 years. Twelve months of lucerne growth was found to leave ~80 kg soil N/ha for the next crop, and often found to be more profitable than continuous wheat cropping without added N (Tables 1–3). The limitations of this system include greater depletion of soil water, reducing the wheat yield until water deficit is replenished. Lucerne forage can also cause bloating in cattle, and sowing of lucerne under wheat, a common practice for lucerne establishment, can be unreliable in dry seasons (Holford and Doyle 1978; Dalal *et al.* 1991; Angus *et al.* 1996; Holford and Crocker 1997; Weston *et al.* 1997; Strong *et al.* 2006).

Lucerne uses more soil water than annual crops and pastures (Whitfield *et al.* 1992; McCallum *et al.* 2001; Strong *et al.* 2006) and can exhaust soil water from the whole profile within 1–2 years (McCallum *et al.* 2001; Ridley *et al.* 2001; Strong *et al.* 2006). Bowman *et al.* (2002) and Strong *et al.* (2006) concluded that the productive life of dryland lucerne stands in subtropical environments is limited by frequent periods of moisture stress and high soil temperature in summer.

Medics. Annual medics provide a self-regenerating annual ley-pasture, which can be sown with wheat. Medics provide high-quality winter–spring grazing, and may leave an extra 60 kg soil N/ha for the next crop, and like the other two previous ley-pasture systems are more profitable than continuous wheat cropping without fertiliser N. However, medic forage can bloat animals, and subsequent wheat crop may require extra N for prime hard grade when soil moisture is high. However, productivity of annual medics in south-west Queensland has not been impressive, except during exceptionally wet winters (Weston *et al.* 2002).

Jones and Rees (1997) evaluated a range of legume accessions for persistence and productivity in small plot trials in four clay soils of southern inland Queensland. Promising and short-lived perennial accessions included lines of *Vigna*, *Macrotyloma*, *Macroptilium* spp. and lablab (*Lablab purpureus*), whereas perennials were desmanthus (*Desmanthus virgatus*) and *Indigofera schimperi*. Similarly, Pengelly and Conway (2000) also highlighted several legumes for tropical and subtropical zones, including lablab, leucaena (*Leucaena leucocephala*), butterfly pea (*Clitorea ternatea*), caatinga stylo (*Stylosanthus*) and desmanthus, with advantages and disadvantages for their use in farming systems.

Limitations of ley-pastures

Although annual medics and lucerne in combination with grasses can provide high-quality forage, add N to the soil and improve landscape stability during the drought (Bellotti *et al.* 1991), the presence of dense companion grass in the year of establishment and the following year may reduce the population of legumes significantly, whereas in a good season highly productive lucerne and medics may cause death of cattle through bloat (Jones and Rees 1997; Cullen and Hill 2006). Jones and Rees (1997) also noted that although high soil seed reserves are usually advantageous for legume persistence in a ley system, they may be a disadvantage when the site is periodically used for cropping, depending on the number of seeds, their hardseededness and susceptibility of the legume to herbicides.

The pattern of N increase during the ley-pasture phase could be dependent on the initial concentration of total soil N, because grain yield and protein improvement after lucerne leys were recorded only on those soils that had relatively low total soil N (Holford 1981; Whitehouse and Littler 1984; Lloyd *et al.* 1991). Furthermore, lengthy duration (more than 1 year) may result in a significant loss of soil N. For example, McCowan *et al.* (1988) and Doughton *et al.* (1996) reported that ~40% of N in crop residues mineralised in the first year on a red-brown earth, whereas a further 7 years were required to mineralise an additional 25% of N. They concluded that frequent short leys offer more efficiency in mineral N supply, because there was a rapid decline in the marginal benefit with leys longer than 1 or 2 years. However, it was also pointed out that the shortening of the ley phase must be weighed against the cost of frequent transition from pasture to crop and back, which may involve a high risk of a failure associated with establishment (Bellotti *et al.* 1991).

In this context, Armstrong *et al.* (1997) suggested that if the primary aim of the incorporation of ley-pastures into the crop rotations is to supply N for subsequent cereal crops, then one season of legume growth is enough, rather than perennial ley-pastures, where establishment, persistence and regeneration over several seasons are rarely perfect. They reported that better wheat growth was recorded in plots previously sown to lablab for just 4 months compared with continuous wheat. A greater N benefit is possible through annuals, as decomposition rates of plant material would be faster, whereas roots of perennials would be alive and less prone to decomposition (after Armstrong *et al.* 1997).

Armstrong *et al.* (1999) further suggested that the poor growth of perennials during winter and spring was likely to limit the period over which they could support liveweight gain by stock, compared with fast-growing and high-yielding annual summer forages, such as lablab. They noted that when there was above-average rainfall in late autumn and early spring, there was little dry matter produced by the perennial legumes, such as lucerne and siratro (*Macroptilium atropurpureum*), and all legumes produced most dry matter between January and April, irrespective of rainfall in central Queensland (Armstrong *et al.* 1999). Similar results were also noted in a study in southern Queensland, where perennial lucerne and butterfly pea produced least dry matter between February and April compared with annual lablab and biennial burgundy bean (*Macroptilium bracteatum*) (Singh *et al.* 2004). Also, on average, over several years the ley-pasture mixtures (medics, lucerne + medic, and lucerne + medics + grasses) from the medium- to long-term experiments (Warra and WFSP) resulted in no more than 3–4 t/ha pasture yield (Dalal *et al.* 2004; Strong *et al.* 2006; Thomas *et al.* 2009). However, these medium- to long-term experiments were conducted in ideal soils, representing only good cropping soil without any subsoil constraints, whereas, majority of soils in south-west Queensland are affected with moderate to high subsoil constraints (Dang *et al.* 2006).

Nevertheless, any rotation of ley-pasture phase with cropping needs to be economically viable and socially attractive to growers for their consideration of adoption, irrespective of biophysical constraints or limited choice of suitable ley-pasture options.

Economic constraints

The economic viability of ley-pastures in the Australian subtropics was suggested to depend on initial establishment and re-establishment of various ley species after a crop, the contribution of biological N from the ley-pastures to the farming system, the control of pasture species during the crop phase, and the feed value of ley-pasture and crop residues to grazing livestock (Jones *et al.* 1991). However, Bellotti *et al.* (1991) and Clarke and Russell (1977) noted that the potential benefits from the ley-pastures in marginal croplands needs to be weighed against the cost of developing a ley-farming system in northern New South Wales and southern Queensland, where low and unpredictable rainfall dictates that costly inputs are minimised.

In southern Queensland, however, the relative economic benefits from ley-pastures have always been highlighted, compared with continuous wheat, particularly under conditions of low N fertility (Lloyd *et al.* 1991, 2009; Wylie 1996; Thomas *et al.* 2001). Lloyd *et al.* (1991) compared steady-state budgeting to evaluate the impact of lucerne or medic leys on the western Darling Downs (Queensland) farms, with established infrastructures for grain and livestock production. The operating profits indicated that the ley-pastures on mixed farms with old cultivation were likely to be more profitable than the conventional farming systems (Lloyd *et al.* 1991). Similarly, Wylie (1996) and Thomas *et al.* (2001) also reported that the relative gross income for wheat following rotation with lucerne and/or medic was higher than for the continuous wheat without application of N fertilisers. However, in these studies, the cost of establishment and termination of lucerne and the additional time to refill the soil profile was not accounted for, or in other words, the full cycle of ley-pasture and crop system was not considered.

In contrast, Dalal *et al.* (1998) and Thomas *et al.* (2001) reported that regardless of the year, continuous wheat with annual application of fertiliser N was always profitable, followed by rotation with annual grain legume, such as chickpea–wheat rotation (Tables 1, 2). On the other hand, rotation with medium- to long-term (2–3 years) ley-pastures, such as medic–wheat rotation, was occasionally worse, and lucerne–wheat and grass + legume–wheat rotations could be a good risk, relative to the option of no change (Table 1) (Dalal *et al.* 1998). Furthermore, Thomas *et al.* (2002) reported that the grain yield of the second wheat crop following 18 months of either medic or lucerne ley or 3 years of Bambatsi panic (*Panicum coloratum*) plus legume was lower than that of continuous wheat, resulting from slightly lower soil water reserves following the ley-pastures (Table 3, WFSP). However, the higher soil nitrate-N concentration following the ley-pastures resulted in a higher grain protein content of wheat. Where no N fertiliser was applied to wheat following medic and lucerne, gross margins were similar to those of continuous wheat with N fertiliser application of 60 kg N/ha. The gross margin was considerably reduced where 40 kg N/ha was applied to wheat following lucerne (Table 3), as a result of a high level of screenings (18%).

It is surprising to note that there is very little information on ley-pastures in rotation with cropping where livestock has been included in the analysis, in the south-west Queensland. In one experiment, however, annual gross margins from pastures were estimated from sheep liveweight plus wool production, less variable costs associated with pasture establishment and animal husbandry and wool-selling expenses (Thomas *et al.* 2009, from Nindigully study, WFS Project). When sheep production from pastures was included in the gross margins, the total gross margins were greater for pasture–wheat rotations than for the continuous wheat where no N fertiliser was applied to wheat crops, and the total gross margins were still lower than for continuous wheat where N fertiliser was applied to target prime hard-grade grain protein in wheat (Thomas *et al.* 2009).

The use of various economic models has become a common practice in recent years to evaluate and compare the cost–benefits differences between farming systems. Limited research dollars from funding bodies, along with shorter (2–3 years) project phases, make it impossible to plan and implement medium- to long-term on-ground trials on ley-pastures in rotation with cropping. Nevertheless, economic evaluations of various farming systems in recent projects (Maranoa–Balonne and Border Rivers Grain & Graze Projects), using simulation and case studies for 2006 and 2008, also indicated that the common cropping practice, fallow–wheat with addition of fertiliser N, is more profitable than the ley-pastures in rotation with cropping (Table 4; Strahan 2008). The reduced gross margins from the ley-pastures in 2008 were due to the higher grain prices in the current market and the costs associated with establishment and termination of ley-pastures, even when returns from the livestock on ley-pastures was included in the evaluations (Strahan 2008). Most of the evaluated farms (nine case studies) highlighted decreased profits when some cropping areas were substituted for pastures, whether in 2006 or 2008 (Table 4). Strahan (2008) also highlighted the economic realities of demand and supply, and costs and prices for influencing the management decisions on land use (cropping or ley-pastures). In particular, farms on reasonable to good regions are better suited to cropping when grain prices are high and cattle prices are low. A pasture phase in the rotation may be profitable when grain prices are low and cattle prices are high. In contrast, marginal cropping regions, where differences in gross margins between cropping and pastures are less pronounced, are better suited to mixed enterprises (livestock and cropping) and longer pasture phases. However, with high grain prices these marginal farms are unlikely to substitute cropping into a pasture phase (Strahan 2008).

An uncertainty about economic benefits of ley-pastures from the past and recent evaluations appear to have also contributed to a poor adoption of ley-pastures in the region, with prevailing biophysical constraints to growth and persistence of ley-pastures.

Table 4. Profit changes on mixed farms from pasture phases in the Border Rivers and Maranoa–Balonne catchments, using the prices and costs in 2006 and 2008 (Strahan 2008)
Higher grain prices were recorded in 2008

Site	Price structure	Profit from current cropping system ($/ha)	Profit from mixed (changed) ($/ha)	Profit change by substituting pasture for some cropping ($/ha)
Toobeah	2006	26.0	20.6	–5.4
	2008	29.4	20.1	–9.3
Talwood	2006	35.9	19.2	–16.6
	2008	32.8	14.3	–18.5
Weengallon	2006	20.0	18.7	–1.3
	2008	24.0	21.4	12.5
Moonie	2006	3.2	5.1	–1.9
	2008	134.8	23.0	–111.8
Warialda	2006	58.2	60.5	2.3
	2008	142.6	105.2	–37.5
Pallamallawa	2006	25.5	10.4	–15.1
	2008	82.0	41.0	–41.0
Wallumbilla	2006	11.1	2.9	–8.1
	2008	17.3	14.3	–3.0
Thallon	2006	88.6	60.7	–27.9
	2008	88.4	50.5	–37.9
Mt Abundance	2006	56.0	57.1	1.1
	2008	41.3	61.8	20.5

The unproven economic benefits from ley-pastures were earlier recognised by McCowan *et al.* (1988), who also suggested that growers' perception and management of their farms with new management tools, such as ley-pastures, would primarily be determined by (short-term) economics, and secondarily by long-term ecological considerations. Gruen (1959) and Vere and Muir (1986) also reported that widespread adoption of ley-pastures before 1970 in southern Australia was largely economic, as investment returns from sown legume pastures were greater than from any other form of farm development. Evidence from the past and recent economic evaluations emphasises the need to value the longer-term benefits of ley-pastures (e.g. for natural resource management and benefits), if their inclusion in the farming system is to be justified on economic grounds; however, there may also be social barriers to adoption.

Social constraints

Social principles for extension and barriers to adoption have been reviewed, discussed and highlighted over several years (Lockie *et al.* 1995; Vanclay *et al.* 1998; Vanclay 2004; Pannell *et al.* 2006). Vanclay (2004) provided a comprehensive review on the social principles for agricultural extension to assist in the promotion of natural resource management. It highlighted 27 principles around socio-cultural practices in relation to adoption of a new technology. One of those principles appeared to be clearly linked to the poor or non-adoption of ley-pastures in south-west Queensland, in that 'farmers have legitimate reasons for non-adoption'. This was further categorised into 12 legitimate reasons (Vanclay 2004). Some of those relevant reasons could be as follows: the new technology is too complex, not compatible with farm and personal objectives, not flexible enough and not significantly more profitable than cropping, capital outlay is too high, too much additional learning is required, risk and uncertainty are too great owing to biophysical constraints, and there may be conflicting information on type, necessity and benefits of ley-pastures.

Integrating a medium- to long-term ley-pasture in cropping paddock is very complex. Triggers to get in and to get out of a ley-pasture system are not easy to understand or predict in a highly variable climatic and market conditions (Strahan 2008). A sown ley-pasture in a cropping paddock requires major changes in the management of the farm, such as additional burden of livestock management, with more requirement of labour force, which is rarely compatible with other operations on a mechanised cropping farm. There is a need of a very high capital outlay for establishing a livestock component on the farm, requiring not only additional learning, but also very likely reduced capital flow, increased capital investment and economic loss associated with establishment and termination phases of ley-pastures. A medium- to long-term ley-pasture phase is not flexible enough, and farmers are likely to miss the opportunity for cropping in a favourable season and getting higher prices for grains.

A national social research project on mixed farming systems interviewed growers from around Australia, including growers from south-west Queensland, and highlighted two key social issues that appeared to have contributed to the poor adoption of ley-pastures in south-west Queensland, namely complexity of introducing ley-pastures into cropping systems and poor adaptability of existing medium- to long-term ley-pasture technology (McGuckian 2008). Many growers consider ways to make life simpler and easier in their farming systems (pers. comm. with the following growers and consultants in the region over a period of 6 years: Lindsay Ward, Charles Nason, John Nolan, Max Aisthorpe, John Kerlin, Bede O'Mara, Stuart Pilcher, Dale Kirby, Michael McCosker, Neville Boland and Mark O'Donahue). Integrating ley-pastures in a mixed farming system is not an easy task, and requires complex decision making because of greater capital investment for infrastructure, intensive labour requirements and the complexity of understanding the triggers for a changeover from cropping to ley-pasture and *vice versa* (McGuckian 2008; Lloyd *et al.* 2009).

There has also been conflicting information on how and what to grow during ley-pasture phase in south-west Queensland. For example, most promoted and widely recognised legume-based ley-pastures have been winter-active perennial lucerne and annual medics, with some warm-season grasses (Lloyd *et al.* 1991, 2009; Whitbread and Clem 2006). Winter-active legumes may be ineffective in improving soil conditions in a region with summer-dominant rainfall, and most grain growers are reluctant to include grass in their ley-pasture mix, as including grass can be uneconomical for various reasons. Lucerne and medics in mixes with grasses, generally, cannot compete and contribute little for either improving the quality of pasture or N-fixation. This has been seen in various on-farm trials where the growth of buffel grass (*Cenchrus ciliaris*) dominated over lucerne and/or medic mixes (e.g. D. K. Singh, pers. obs. at Mulga View Site, WFSP; L. Ward, pers. comm.). On the other hand, productive lucerne and/or medic pastures without grasses can cause bloating in animals. Whitbread and Clem (2006) also recognised that the adoption of all *Medicago* spp. might be restricted because of the risk of causing bloats in cattle. Additionally, severe depletion of soil water following perennial ley-pastures (grass + legumes or lucerne) can reduce the yields of subsequent crops for several seasons, as also highlighted previously in the biophysical constraints section. Because of the economic situation of many marginal farmers, they simply cannot afford such down-time, and it makes more sense for them to continue with a system from which they are confident that they can get return, than to invite the uncertainty (Vanclay 2004).

The importance of a ley-pasture phase (legume + grass) for increasing the ground cover, soil organic matter and N benefits may be comparable to recent management changes in cropping, such as, conservation tillage (reduced cultivation and more stubble cover), opportunity cropping (grain legumes), double-cropping, introduction of more productive cereal varieties, and the wide-scale use of N fertilisers. In particular, conservation tillage regarded as a change in practice, rather than the standard practice, may have resulted in many benefits comparable to the use of ley-pastures, such as reduced erosion and greater crop productivity in Queensland (Thomas *et al.* 2007). Conservation tillage and intensive cropping with added N fertilisers may have caused increases in total net annual production, yield and soil organic content, similar to the benefits from ley-pastures (McCowan *et al.* 1988; Buyanovsky and Wagner 1998; Follett 2001; Chan 2008). These changes could maintain the ecological sustainability (McCowan *et al.* 1988). These recent understandings may have been providing conflicting views on the importance of a system, ley-pastures or intensive cropping, for increasing the soil organic matter, and might be influencing the grower's decisions on adoption of ley-pastures.

Furthermore, promoting adoption of any new technology on the basis of telling only about the success of the technology on few places, and without providing some case studies where the technology might have failed because of e.g. poor establishment, grazing management or poor persistence, may discourage growers from accepting the advice about ley-pastures for mixed enterprises as they might have been aware of the failures of that technology in their own or in other regions. Research must inform the good and the bad of a technology, instead of recommending the best bet of the systems (McGuckian 2008). In this context, a survey of more than 600 farmers in Wimmera found significant doubts about the efficacy of many best practices for natural resource management (McGuckian 2008). Similarly, Pannell *et al.* (2006) noted importance of understanding growers' perceptions of relative benefits and triability of a new technology, before promoting its wider adoption.

Failure to consider growers' perceptions may in part explain the poor adoption of the existing ley-pasture technology in south-west Queensland. For example, lucerne and medics have been widely promoted for adoption in south-west Queensland (Lloyd *et al.* 1991). There is, however, a limited success of perennial lucerne in south-west Queensland because of shallower soil depth and occurrence of high salt and sodicity in the majority of soils, except in few good cropping paddocks with deeper soil depths (Singh *et al.* 2004, 2009). Similarly, establishment and productivity of lucerne and medics would be limited because of frequent dry spells, except during the few wet seasons. Establishment failures and reduced productivity of sown pastures, mostly lucerne, medics and grasses, are generally noted as poor management practices (Cook *et al.* 2008). Poor establishment of sown pastures (for a variety of mixes) was also noted in a survey, in 2004, where the cost and unreliability of establishment was found to be the most significant ($P < 0.05$) reason for the slow rate of implementation of ley-pastures, with over 50% of growers surveyed agreeing that the cost of establishment of ley-pastures was too high and their establishment was unreliable (Sibson 2008).

The poor and unreliable establishment and persistence of ley-pastures has also been highlighted in various studies in the past, and until recently (Thompson *et al.* 1983; Cook *et al.* 1993; Ward 1993; Clements 1996; Macleod and Cook 2004; Thomas *et al.* 2005; Sibson 2008; Lloyd *et al.* 2009; Singh *et al.* 2009). Bellotti *et al.* (1991) and Clarke and Russell (1977) noted that low and unpredictable rainfall in subtropical and tropical regions resulted in a lower investment into establishing and maintaining ley-pastures. Others may have argued that poor management practices and low-input methods (poor seedbed preparation, inadequate fertilisation of establishing pastures, aerial seeding, limited passes with offset discs or chisel ploughs or sod-seeding) might be resulting in unreliable and delayed pasture establishment (Macleod and Cook 2004; Cook *et al.* 2008; Sibson 2008; Lloyd *et al.* 2009). Nevertheless, the unreliable and delayed pasture establishment, whether from the hostile agro-climatic conditions in the region or from the low-input methods, and high establishment costs for intensive methods (sowing seed into prepared seedbeds), are the valid reasons for the poor adoption of ley-pastures, as noted over the years (Thompson *et al.* 1983; Cook *et al.* 1993; Clements 1996; McDonald and Clements 1999; Macleod and Cook 2004; Lloyd *et al.* 2009; Singh *et al.* 2009).

It is important to note that growers create their own knowledge through experimentation and trials. If the knowledge that is transmitted via extension is similar to and consistent with the understanding of the farmers, only then is it adopted (Vanclay 2004). Therefore, promoting the adoption of medium- to long-term ley-pastures on the basis of limited success of lucerne + medic + grass, and without proper trialling (absence of grazing pressure and incomplete rotation with crops), is most likely to result in resistance by growers for their wider adoption in south-west Queensland. The poor adoption has been well demonstrated in an earlier survey between 1995 and 2000 (Table 5).

Research, development and extension efforts: recent developments

Recent research, development and extension (RD&E) efforts highlight the importance of trialling some new biennial and perennial legumes such as a winter legume sulla (*Hedysarum coronarium*) and a summer legume burgundy bean for likely adoption in various parts of south-west Queensland. Whitbread *et al.* (2005) and Whitbread and Clem (2006) compared some of the perennial legumes (perennial and annual lablab, burgundy bean and butterfly pea) for their use in mixed farming systems on clay soils (better soils) in southern inland Queensland.

RD&E efforts through collaborative projects, Western Farming Systems and Maranoa–Balonne and Border Rivers Grain and Graze Projects (involving CSIRO, Queensland Primary Industries and Fisheries, Queensland Murray Darling Committee, Queensland Department of Natural Resources and Water, The University of Queensland, Ward Agriculture Pty Ltd, and funded by Grain Research and Development Corporation and Meat and Livestock Australia), have recently recognised the importance of incorporating a short-term summer forage legume in cropping systems as an alternative to the poorly adopted medium- to long-term ley-pastures (Singh *et al.* 2004, 2009; Whitbread *et al.* 2005). Whitbread and Clem (2006) suggested a greater role of tropical annual legumes such as lablab and cowpea (*Vigna unguiculata*) and some perennial tropical legumes as an alternative to the poorly adopted temperate legumes (lucerne and medics) in the Australian subtropics. In particular, large-seeded annual lablab can be easily established and highly productive, even in the drier conditions (Hendricksen and Minson 1985; Pengelly and Conway 2000; Singh *et al.* 2009). In a recent survey, in south-west and central Queensland, growers

Table 5. Changes in respondents' nitrogen management strategies between 1995 and 2000 (Lawrence 2002)

Nitrogen management strategies	Mean proportion of wheat country (%) 1995	2000
Nitrogen fertiliser	14	43
Grain legumes	7	13
Ley-pastures	10	11

generally saw no problems or limitations in expanding the area of lablab on properties where it was grown, whereas all lucerne growers perceived that bloating was a problem for expanding the area of lucerne (Cullen and Hill 2006).

GRDC- and MLA-funded projects have also provided the knowledge and understanding to growers on how to grow better pastures through the LeyGrain, an action-learning extension process (Lloyd *et al.* 2009). The LeyGrain package provides information to growers about the benefits and suitability of various types of grass + legume pastures for different land types, and emphasises a better preparation of the seedbed, with adequate fertiliser application, similar to the cropping practice, for better establishment of ley-pastures. A PhD student Ms Katie Sibson, from the University of Queensland, as a part of Grain and Graze Project, also conducted experiments under controlled and field conditions to determine the effect of temperature and sowing depth on the germination and establishment of various grasses and legumes. Findings from her study suggested that sowing ley-pasture species in winter and spring, either with a winter cereal, into the stubble of a winter cereal, or alone, can be successful and may be a means of reducing the unreliability of ley-pasture establishment. However, if sown early in the spring–summer, legumes (except lablab) and grasses would establish best when sown no deeper than 1–3 cm. Lablab produced a 100% emergence, compared with <5% emergence for other legumes.

It is important to note that unless the sowing of other small-seeded legumes and grasses, except lablab, is carried out precisely in the top 1–3 cm, they would be likely to fail to germinate, even with the proper seedbed preparation and fertilisation (Sibson 2008). We also noted poor germination and establishment of burgundy bean and butterfly pea if sown slightly deeper, 3–5 cm deep, compared with 100% emergence by lablab (Singh *et al.* 2009). Furthermore, in one of our experiments, the lack of follow-up rain during early November resulted in complete seedling mortality for the well established burgundy bean and butterfly pea, more than 50% mortality also occurred for the 1-year old established lucerne stands, with only lablab surviving the dry spell for about 1 month and growing well later on, with rainfall in the late November–early December (Singh *et al.* 2009). These findings clearly indicate that no matter what we do with the seedbed preparation and fertilisation for a better germination and establishment of ley-pastures, considering a shallower planting of small-seeded legumes and grasses would still be a risky option in our soils, which are subject to a rapid surface drying (Singh *et al.* 2005). Moreover, there is still limited information on the performance and persistence of suggested legume pastures (whether it be lucerne, medics, burgundy bean or lablab), particularly when subjected to various grazing pressures and biophysical constraints. The likely triability of these options in terms of production and economics needs more time and depends on the grower's interest to test one of these options in their cropping paddocks. It is almost essential that the new ley-pasture options not only need to be productive and economically viable but also socially attractive to growers for their consideration of adoption in south-west Queensland.

Conclusions

The biophysical, economic and social constraints as highlighted in the present review apparently indicate various reasons for a poor adoption of existing ley-pasture options by growers in their cropping systems. In particular, extreme temperatures, shallow soil with subsoil constraints and poor PAWC would most likely limit the longevity, persistence and production capacity of any medium- to long-term ley-pastures in south-west Queensland. The poor economic benefits as shown in the previous farming systems studies (Warra and WFSP), and from the evaluation of ley-pastures (with included income from livestock production) in the current mixed farming systems studies (Strahan 2008) do not support likely better economic returns from the adoption of medium- to long-term ley-pastures than from the standard practice of continuous wheat with added N fertiliser. Therefore, economic benefits from integration of any ley-pasture technology should be properly trialled and evaluated before promoting its adoption. Findings from recent RD&E efforts clearly indicate that, no matter what we do with the seedbed preparation and fertilisation for a better germination and establishment of ley-pastures, considering a shallower planting of small-seeded legumes and grasses would still be a risky option in a soil subjected to a rapid surface drying. Incorporation of a short-term summer forage annual legume (Armstrong *et al.* 1997; Whitbread *et al.* 2005; Whitbread and Clem 2006; Singh *et al.* 2009) may appear to be economically more viable, although there is a need to recognise the longer-term benefits from ley-pastures (e.g. for natural resource management and ecological sustainability) if their inclusion in the farming system is to be justified. Future RD&E efforts should consider that new ley-pasture options, such as incorporation of a short-term, large-seeded summer forage legume, need to be less risky in establishment and productive (particularly when subjected to various grazing pressures and dry spells in a region with prevailing biophysical constraints), economically viable, less complex and highly flexible in the changeover processes, and socially attractive to growers.

Acknowledgements

We acknowledge financial support from GRDC for the Western Farming Systems and Maranoa–Balonne Grain & Graze Projects in this region. We also acknowledge valuable time and suggestions given by Dr Ron Hacker and reviewers for improving the quality of this manuscript.

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Manuscript received 23 February 2009, accepted 18 May 2009