Diversification from cropping into mixed crop-livestock systems – the sustainability risks posed by hay removal from pasture or forage blocks

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Abstract
Land managers in the inland Burnett region of southeast Qld are moving to diversify their enterprises from rainfed opportunity cropping to mixed cropping-grazing enterprises. Property expansion (purchase of grazing land) or rotating existing land between cropping and pastures/forage production are common approaches, with fodder grazed *in situ* or removed as hay. We have studied the agronomic implications of the most flexible system, in which short crop-forage phases (i.e. 2-3 years) are rotated on existing cropped land, with fodder removed as hay rather than grazed *in situ*. Rapid establishment and fodder production resulting from direct drilling larger seeded forage species more effectively spread fodder production across the ley phase than traditional pastures established after conventional tillage, although total biomass production was similar over an 18 month ley period. Forage or pasture legumes were able to contribute significant amounts of mineralizable N for subsequent crop recovery after the ley, despite hay removal. However, substantial nutrient removal associated with hay production will require a substantial fertilizer investment upon return to cropping, to avoid a rapid decline in soil productive capacity.

Key Words
Mixed cropping; direct seeding; nutrient budgets; legumes; nitrogen; soil carbon

Introduction
In response to variable seasonal conditions and low grain prices, an increasing area of cropping land in Queensland is changing from solely cropping to mixed cropping-grazing enterprises in an effort to minimize financial risk. This diversification commonly consists of either property expansion (purchase of additional grazing land) or rotating existing cropping land between rainfed opportunity cropping and production of pastures or forages, with fodder grazed *in situ* or removed as hay. In the inland Burnett area of southeast Queensland the current focus is on short crop-forage phases (i.e. 2-3 years), with an emphasis on flexibility to be able to respond to price or climate signals.

The shift in enterprise mix offers a number of challenges and possible benefits, in addition to a simple diversification of the enterprise income streams, while requiring an increased level of management expertise and broader technical skills. From a sustainability perspective, these farming system changes could be considered a response to declining native fertility reserves (Bell *et al*., 2010), with choice of an appropriate legume-based pasture or forage mix offering opportunities to restore soil C and N stocks (Singh *et al*., 2009). However, this opportunity may be seriously challenged by the practice of hay removal to maintain livestock fattening rates and provide feed security during periods of low productivity (eg. dry periods or early frosts). Native soil fertility has already been severely eroded in the Ferrosol soils of the inland Burnett as a result of negative or unbalanced nutrient inputs during a string of poor seasons (Bell and Moody 2001), and further removal in hay could erode soil fertility to the extent that grazing or cropping productivity is seriously compromised. An understanding of nutrient removal rates and remedial fertilizer application strategies, both during the ley and subsequent crop phases, will be an integral part of developing a sustainable management system.

The short term nature of the proposed forage/pasture phases also presents challenges. While an appropriate length of time is needed for traditional seedbed preparation and pasture establishment to ensure good germination and seedling survival (Cook 2007), growers will also need to rapidly establish a body of quality fodder capable of supporting live weight gains. These are compounded under the typical rainfed production systems in the inland Burnett, where summer-dominant rainfall is often unreliable and sowing opportunities are limited. As a result, there is interest in comparing fodder production using the proven reliability of establishment with direct drill sowing techniques (generally with larger seeded forage species) to conventional tillage and seedbed preparation required to establish more traditional (often smaller seeded) pasture species.

In this paper we explore these issues in a 4 year study where consecutive 2 year ley pasture/forage phases, were each returned to cropping in a 3rd summer season.

Methods

Experiments were established on two soil types - a higher fertility Red Ferrosol and a lower fertility Brown Ferrosol typical of the cropping lands of the inland Burnett (Table 1).

Table 1. Key soil parameters for the Red and Brown Ferrosol cropping soils used for the forage/pasture studies.

		pH_w	Organic C (%)	Total N (%)	Colwell P (mg/kg)	ECEC (cmol/kg)	Exch K (cmol/kg)	SO4-S (mg/kg)	Sand (%)	Silt (%)	Clay (%)
Brown Ferrosol	10cm	5.8	1.60	0.12	47	10.7	0.7	93	31	10	66
	20cm	6	1.46	0.11	12	11.6	0.3	86	28	9	67
	30cm	6.5	1.04	0.07	5	12.2	0.2	105	18	11	75
Red Ferrosol	10cm	5.4	1.73	0.16	59	10.7	1.1	126	28	14	63
	20cm	5.5	1.63	0.14	36	11.0	0.6	162	30	15	61
	30cm	6.0	1.09	0.10	12	10.8	0.3	141	21	15	68

Establishing pastures and forages

We established pasture/forage phases in separate experiments in each of the 2008/9 and 2009/10 summer seasons, after summer peanut-winter wheat and a summer maize-winter fallow crop sequences, respectively. The different pre-histories were chosen to compare summer versus spring establishment opportunities, but a lack of rainfall in spring 2009 meant that both sequences were sown in summer. Each experiment consisted of a 2 year pasture/forage phase followed by a return to annual summer cropping in a third year.

The pastures and forages were established using either conventional cultivation and seedbed preparation, or direct drilling into existing crop residues without tillage, using zero tillage row crop planters. Given the need for very shallow placement of small seeded species, and the difficulties with sowing some pasture seed with conventional planting equipment, different species were sown in the direct drill and conventional tillage treatments. The conventionally established plots were prepared to a fine tilth, after which seed of lucerne (*Medicago sativa cv. Sardi 10*), Rhodes grass (*Chloris gayana cv. Callide*) or a lucerne – Rhodes grass mixture were dropped onto the soil surface and incorporated shallowly with following harrows. In contrast, the direct drill treatments were left undisturbed after the preceding crop, with Burgundy bean (*Macroptilium bracteatum*) and silk sorghum (*Sorghum sp*.) sown as single or mixed swards in 45cm rows.

The slow establishment of the Burgundy bean in the first experiment, and the ineffectiveness of Burgundy bean in the mixed sward sowings, resulted in a change in the direct drill treatments in the second experiment planted in 2009. In this study the direct sown legume was Lablab (*Lablab purpureus cv Rongai*), which was sown in paired rows 35cm on either side of the old maize row as a pure sward, or sown in alternating 35cm paired rows with the silk sorghum in the mixed sward. The annual growth habit of the Lablab was overcome by re-sowing the legume into the appropriate plots in the spring of the second pasture season in 2010.

The pastures on the Red Ferrosol received no fertilizer in the establishment year, but on the Brown Ferrosol the sown pastures received 100 kg/ha of CK700 (32N, 8P, 0.8S) to help establish groundcover and minimise weed competition. In year 2, all sites received top dressed N (as urea) or compound N and S (ammonium sulphate) or N and P (CK700) fertilizers at rates of 100 kg/ha during summer.

Management of forage biomass

Pasture biomass was cut and returned to plots during establishment (to control crop weeds in particular), but subsequently cut and removed as hay using commercial mower/conditioners and a round-baler. Samples of cut material were dried and ground to assess dry matter production and analysed to calculate rates of nutrient removal. During late autumn-early winter of the 2nd growing season, final hay cuts were taken, the pastures allowed to regrow and then sprayed out with knockdown herbicides before preparing all plots for a return to cropping the following spring/summer. Soils were sampled and soil C and N stocks and nutrient status compared to similar samples collected prior to the pasture/forage phases.

Return to cropping

Both cycles were returned to cropping in the summer following pasture removal. At the time of pasture spray-out, soils were sampled to determine changes in total C and N stocks in the top 30cm of the profile. In the 1st cycle, conventional tillage was used to prepare land for cropping in both the tilled and untilled pre-pasture histories due to the compaction associated with hay making, but the 2nd cycle was split to conventional and zero tillage land preparation. Profile mineral N was determined a week after maize planting and crop yields and nutrient uptake were recorded.

Results and Discussion

Hay production

The direct drilling of forage species (silk sorghum and Lablab) into crop residues was much more effective than conventionally tilled pasture establishment at producing harvestable biomass in the year of establishment (Table 2a), although similar amounts of biomass were produced by legumes or grasses/mixed swards in either tillage system over the full 18 month ley phase. The advantage in legume hay production in DD systems in the establishment year was much greater in the 2nd experiment when Lablab replaced Burgundy bean. Lablab produced 5300 kg hay/ha in the establishment year, compared to no hay from the lucerne stand, while neither lucerne nor Burgundy bean were able to produce harvestable hay in the initial cycle. This was due more to the prostrate nature of the establishing Burgundy bean sward, as biomass production when severe frosts terminated growth averaged 4500 kg/ha in the DD Burgundy bean versus <900 kg/ha in the conventionally established lucerne stand. Neither sward was able to be cut for hay using available equipment.

Table 2. Biomass production (kg/ha dry weight) removed as hay in (a) the initial year of pasture/forage establishment, and (b) the full 18 month ley period. Values are the means of the 2008/10 and 2009/11 crop cycles.

Time	Soil	Grass		Legume		Mixed sward	
		DD	Conv. Till	DD∞	Conv. Till	DD∞	Conv. Till
(a) Establishment year	Brown Ferrosol	6230	3150	2370	0	5770	3360
	Red Ferrosol	8730	3920	2930	0	9360	2650
	LSD (0.05)	780 (Soil*Tillage*Species)					
(b) Full 18 month growing season	Brown Ferrosol	12480	14470	7320	6100	13760	14080
	Red Ferrosol	18740	20620	8180	8150	19420	18430
	LSD (0.05)	ns (Soil*Tillage*Species); 1390 (Soil*Species); 1840 (Tillage*Species)					

∞ *The DD legume data are an average of the Burgundy Bean from Year 1 and the Lablab from year 2.*

Although the soil type * tillage *species interaction was not significant for the cumulative biomass production there were highly significant species x soil type interactions. Hay production in both the grass and mixed sward treatments were much greater on the Red Ferrosol (19680 and 18930 kg/ha, respectively) than on the Brown Ferrosol (13480 and 13920 kg/ha, respectively). Differences were much less pronounced in the pure legume swards, although still statistically significant (8160 and 6710 kg/ha, respectively).

Nutrient removal in hay

Rates of nutrient removal in hay varied significantly with all treatment factors (Table 3), and represented a significant depletion of soil reserves in a short time. Gross margin analyses indicated that it would be uneconomic to address a removal of this magnitude either during the pasture phase or upon the return to cropping.

Table 3. Removal (kg/ha) of (a) N, (b) P, (c) K and (d) S in hay produced during an 18 month ley phase at Kingaroy. Values are the means of the 2008/10 and 2009/11 experiments.

		Grass		Legume		Mixed sward	
		DD	Conv. Till	DD∞	Conv. Till	DD∞	Conv. Till
(a) Nitrogen (kg/ha)	Brown Ferrosol	78	113	130	164	105	113
	Red Ferrosol	185	303	164	200	209	266
	LSD (0.05)	32 (Soil*Tillage*Species)					
(b) Phosphorus (kg/ha)	Brown Ferrosol	17.5	24.4	9.9	12.2	18.6	23.2
	Red Ferrosol	16.5	23.2	21.2	19.0	20.3	21.6
	LSD (0.05)	ns (Soil*Tillage*Species); 2.5 (Soil*Species); 3.1 (Tillage*Species)					
(b) Potassium (kg/ha)	Brown Ferrosol	218	243	170	150	255	241
	Red Ferrosol	359	441	243	228	391	387
	LSD (0.05)	ns (Soil*Tillage*Species); 34 (Soil*Species); 43 (Tillage*Species)					
(b) Sulfur (kg/ha)	Brown Ferrosol	8.8	34.0	14.4	18.9	11.4	35.0
	Red Ferrosol	16.5	89.7	18.9	25.6	18.8	76.5
	LSD (0.05)	7.4					

∞ *The DD legume data are an average of the Burgundy Bean from Year 1 and the Lablab from year 2.*

There were generally higher rates of nutrient removal on the Red Ferrosol, due to both higher productivity (Table 2) and also to higher background soil fertility reserves (Table 1). The latter was particularly evident for N, with removal rates/t of hay generally halving from year 1 to year 2 of the ley period on the Brown Ferrosol, but either being maintained or decreasing by <20% on the Red Ferrosol. Differences in K removal are similarly large, but were driven primarily by differences in biomass - there was no obvious decline in K concentration in biomass during the 18 month period at either site.

Rates of nutrient removal were also influenced strongly by species, with legumes removing more nutrients/t hay than the grass species, and Rhodes grass removing more S (2.3-4.4 kg/t) and Na (6.4-10.3 kg/t) than silk sorghum (0.7-0.9 kg S/t and 0.07 – 0.08 kg Na/t). The presence of lucerne in the mixed swards with Rhodes grass made no significant contribution to N removal, even on the N deficient Brown Ferrosol, highlighting the poor performance of the legume in that system. The DD legumes made a greater average contribution to the N availability in mixed swards with silk sorghum (an additional 24-27 kg N/ha), although this was due primarily to the strong effect of lablab in the 2nd crop cycle (mean of 46 kg/ha additional N in hay).

Soil nutrient and C status at maize planting

By the end of the 18 month pasture/forage phase soil carbon (C) stocks (0-30 cm) had consistently increased, but changes were small (viz. 2.5 – 3.5 t C/ha, or 5-7%) and occurred predominantly in the 20-30cm layer of the profile. Changes in total N reserves (0-30 cm) were undetectable, even in the pure legume swards. However, at the time of maize planting some 4-6 months after pasture sprayout and cultivation the pure legume swards had made a significant contribution to profile NO_3-N (0-30 cm). Using the Brown Ferrosol sites as an example, the lucerne treatments had mineralized an additional 56 kg N/ha (2008/10)and 91 kg N/ha (2009/11) compared to the Rhodes grass treatments. Lablab produced a similar mineralization benefit as lucerne in 2009/11 (81 kg N/ha), but the Burgundy bean grown in 2008/10 had a much smaller impact (only 18 kg NO_3-N/ha). Some of the explanation for lower NO_3-N in the 2008/10 legume treatments (especially the lucerne) may be related to the exceptionally wet spring and summer leading up to the maize planting window which may have exacerbated leaching or denitrification of any accumulated nitrate.

Other soil fertility measures were consistent with nutrient removal data (Table 3). No significant changes in soil pH were measured despite the acidifying effect of increased soil organic matter and associated ash alkalinity removal in the hay; the cumulative ash alkalinity removal was only equivalent to 250-450 kg calcium carbonate/ha, and these soils have a high pH buffer capacity. A reduction in Colwell P was recorded at both sites after the hay removal, with decreases of 13-19 and 15-17 mg Colwell P /kg recorded in the 0-10cm layer for the legume and grass/mixed sward plots on the Red and Brown Ferrosol, respectively. A further decline of 10-12 mg Colwell P/kg was recorded in the 10-20cm layer for the legume and grass/mixed sward plots on the Red Ferrosol. These changes were quantitatively consistent with the observed rates of P removal (Table 3). A similar consistency between K removal (Table 3) and measured changes in exchangeable K (0-30 cm) after hay removal was recorded for both soil types, with a highly significant linear relationship between measured K removed in hay and changes in exchangeable K ($r^2 = 0.75$). The greatest depletion was again in the top 10cm layer (45%-55% of the total), with similar declines in the 10-20cm and 20-30cm layers of both soil types.

Conclusion

Direct drill crop establishment is effective at distributing fodder production across short term ley periods. Legume species are available for use in these systems but unless grown in pure swards, do not contribute much to biomass production or subsequent reserves of mineralizable N. The large quantities of nutrients removed in hay represent major economic and sustainability challenges to this management system.

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