

CAPTURING LEGUME DERIVED NITROGEN IN THE VARIABLE CLIMATES OF THE NORTHERN AUSTRALIAN GRAINS BELT

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Abstract

The adoption of legume-based ley farming techniques in the summer dominant rainfall zone has been slow. Substantial declines in soil fertility, increases in the incidence of plant and soil borne pathogens, a period of sustained cattle prices and the availability of well adapted legumes have lead to a resurgence of interest in the system. This paper argues that research and extension should be aimed at helping farmers develop flexible rotation systems that adapt to changing market circumstances and production technologies. This requires the more complex issues of management to be addressed. These include the strategies necessary to maximise the accumulation of N in the ley, to optimise its use during the subsequent crop and to improve and quantify the value of grazing from the pasture phase. Some examples of this research from the northern grains belt are presented.

Introduction

In the temperate southern Australian farming areas, ley-farming systems, *i.e.*, alternately growing crops and short-term pastures, have been used for more than 50 years to maintain soil fertility, break the cycles of plant and soil-borne pathogens and provide high quality forage for livestock enterprises. Until recently, interest in ley farming in the summer dominant rainfall (SDR) zone, has been limited for 2 main reasons. Firstly, many of the soils used for cereal production in these areas are self-mulching clays derived from basaltic parent material with high initial N reserves. Secondly, while lucerne and annual medics (*Medicago* spp.) have been introduced successfully in many mixed farming enterprises in southern Queensland and northern NSW, their use in central Queensland has been limited due to low and unreliable winter rainfall, disease constraints and serious bloat risk in cattle.

The SDR zone (*syn.* northern grains belt) covers an area of about 12m ha in central and southern Queensland and northern NSW. Across the region average annual rainfall ranges from 450 to 700 mm with the northern part of the zone receiving 74% in the summer months and the southern part 54 %. Average winter rainfall ranges from 175 to 280 mm with the southern areas receiving more than the north. Total rainfall decreases significantly from East to West (NAPLIP 1999). As a consequence of this spatially and temporally variable environment, complex farming systems based on cereal, fibre and livestock production have developed.

In many of the soils used for cropping in the SDR zone, soil organic matter (SOM) has declined to an extent where external N additions are required to maintain the high grain protein levels which are characteristic of this region. In the region, declines in SOM, C and nutrients have been documented by Dalal and Mayer (1986). Additionally, and in some cases related to the loss of SOM, soil structural decline has been documented (Connolly *et al.* 2001; Whitbread *et al.* 2000). Subsoil constraints, a consequence of sodic subsoils or high sodium concentrations resulting in restrictions to rooting depth and plant available water capacity, have been highlighted in recent years as major constraints to reliable crop production. Widespread drought, low returns to cereal production and rising input costs have also exacerbated the pressures on farmers. In the face of these pressures, as well as persistent high cattle prices over the last 5 years, there has been renewed interest in legume-based pasture systems.

The benefits of using legume-based pastures to overcome soil fertility decline have been well documented (Dalal *et al.* 1991; Dimes *et al.* 1996; Jones *et al.* 1996). Much of the early research built on the experience of southern Australia and the use of winter-growing legumes (Johnson and Lloyd 1991; Lloyd *et al.* 1991; Irwin *et al.* 2001). Recent research efforts have focused on tropical legumes for use on clay soils and several perennial summer growing legumes are now known to be well

adapted to lower rainfall (700 to 800 mm MAR) areas in central and southern Queensland (Clem *et al.* 1996; 2001; Jones and Rees 1997; Pengelly and Conway 2000). These include perennial legumes such as Milgarra butterfly pea (*Clitoria ternatea* cv. Milgarra), Endurance lablab (*Lablab purpureus* cv. Endurance) and burgundy bean (*Macroptilium bracteatum* cvv. Cardaga and Juanita) described by Whitbread *et al.* (2005).

Fitting legumes into the northern grains belt

The role that legume-based pastures may play in the SDR zone is strongly determined by the soil type, rainfall and the farming system. In areas where animals and forage are of minimal importance, for example, in many parts of the eastern Darling Downs and northern NSW, farming enterprises rely on the production of high yields of quality grain and malting barley. Farmers aim to maintain the soil resource for maximum nutrient supply and favourable conditions for plant growth. Fertiliser application is common to supply nutrients that may be limiting. Unless there are significant soil constraints such as soil structural decline and nutrient depletion, it is unlikely that medium to long term pasture leys will be used in these systems. Technologies such as controlled traffic, conservation tillage, crop residue retention, herbicide usage and rotational cropping are used to maintain production. The use of pulse legumes, have to some extent, provided potential N inputs as have green manure systems to a very limited extent.

In the mixed farming systems of the SDR zone, the scope for the use of legume-based pasture leys is greater. Farms generally have a mix of soil types varying in their suitability to cultivation. Soil types that are less suitable for cropping (due to soil depth, fertility, slope, location, structure etc.) are often under permanent pastures or long term pastures with occasional short cropping sequences. Soils that are more suitable to cropping are commonly used for annual forage (forage sorghum, oats) or grain production systems.

To date in this region, the adoption of ley legume technologies has been slow (Weston *et al.* 2000). In the southern part of the zone, lucerne and annual medics (*Medicago* spp.) have been successfully used in many mixed farming enterprises. Their use in central Queensland has been limited due to low and unreliable winter rainfall, disease constraints and serious bloat risk in cattle. Where large scale adoption of legume-based pastures has taken place, it has been due to changes in enterprise mix in response to commodity prices, rather than the development of a ley system. An example of this can be found in central Queensland where the area sown to *C. ternatea* has increased from 500 ha in 1996-97 to 30000 ha in 1999-2000 (Doughton *et al.* 2001) and to about 200,000 ha presently (M. Conway pers. comm. Conway *et al.* 2001). Many of these areas sown to *C. ternatea* were previously cropped and to date most of them remain under pasture (Cullen and Hill 2006).

Capturing the benefits of legume phases

McCown (1996) concluded that the benefits of ley legume pastures for both crop and animal production were not captured as efficiently in the northern regions as they were in southern Australia, and subsequently that ley pastures would be established only if economic signals favored animal production over cropping. Weston *et al.* (2000) highlighted the need to quantify the benefits associated with ley legume pastures in order to increase adoption. To continue and increase the rate of adoption of leys in farming/livestock systems, the more complex issues of management now need to be addressed. These include the strategies necessary to maximise the accumulation of N in the ley, to optimise its use during the subsequent crop and to improve and quantify the value of grazing from the pasture phase.

This paper will report on some of the work that has been undertaken in the northern grains region in recent years to better quantify the grazing value of legume-based pastures and the responses of crops to pasture phases.

Capturing the benefit of legumes during the pasture phase – live weight gain

Clem (2004) and Whitbread and Clem (2004;2005) reported some aspects of animal production from a range of annual forage and pasture types grown on a vertosol in the Burnett region of Queensland. On the forage treatments [Lablab (*Lablab purpureus* cv. Highworth); *Macrotyloma daltonii* CPI 60303; *Vigna trilobata* CPI 13671; Butterfly pea (*Clitoria ternatea* cv. Milgarra); Burgundy bean;

Macroptilium bracteatum CPI 27404) grazed for short periods (from 70 to 200 days) at high stocking rates (0.4-1.25 ha/head), live weight gain/head ranged from 0.35 to 0.86 kg/head/day while overall gains averaged over the 4 seasons from 1998/99 varied from 59 to over 126 kg/ha/year (Figure 1). Steers grazing lablab consistently gained weight at high rates with up to 0.86 kg/head/day, and over 4 years lablab produced the most live weight gain/ha. Growth rates of steers on *M. daltonii* were less than those recorded from other pastures despite high legume dry matter yields, and ranged from 0.35 to 0.66 kg/head/day due to lower acceptability to grazing of this legume relative to the other legumes. Cattle were observed to avoid grazing this legume. In comparison, *V.trilobata* was noticeably the most palatable of the legumes and steer growth rates were higher, with a range of 0.55 to 0.79 kg/head/day. The perennial legumes, butterfly pea and burgundy bean provided higher live weight gain than the annual legumes that had to regenerate from seed each year.

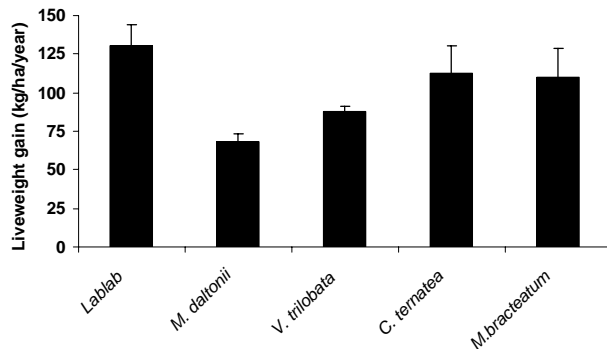


Figure 1. Live weight gain of steers grazing forage legumes. Annual legumes averaged over the 1998/99 to 2000/2001 seasons and perennials averaged over the 1998/99 to 2001/2002. Bars represent the s.e.m calculated across the years.

At the same experimental site reported in Clem (2004) and Whitbread and Clem (2004; 2005), Hill *et al.* 2006 (unpublished) analysed the growth pathways of steers grazing grass/legume pastures [Grass (*Bothriochloa insculpta* cv. Bisset) *Dichanthium sericeum* and *Megathyrus maximus* (Syn *Panicum maximum* var *trichoglume*) cv. Petrie; Butterfly pea cv. Milgarra with grass; Caatinga stylo (*Stylosanthes seabrana* cvv. Primar and Unica) with grass]. Compared with the forage type legumes reported above, grazing periods were longer (270 to 324 days) and at lower stocking rates of 1.25 ha/steer. In the first season steers began grazing the pastures in early August 2003 at an average live weight of 173 kg. These steers gained weight in spring and summer; during autumn 2004, steers on the two legume pastures continued to gain weight, whereas steers on the grass pasture maintained weight (Figure 2). In the second season steers began grazing the pastures in June 2004 at an average live weight of 249 kg (Figure 2). The steers on the legume pastures maintained weight during winter and early spring 2004, whereas those on grass pastures lost weight. The growth pathways for the remainder of the season were similar to 2003/2004, although growth rates began to fall earlier in autumn 2005 due to the drier conditions than in 2004. In both seasons the final live weight did not differ significantly between the legume pastures, but it was significantly higher on the legume pastures than the grass pasture ($P < 0.05$); the difference between the *S. seabrana*/grass and grass pastures was 80 and 140 kg in 2004 and 2005, respectively.

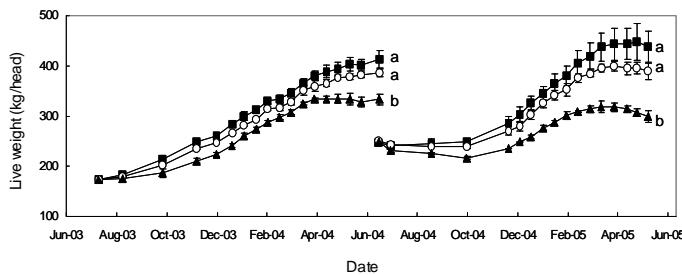


Figure 2. Growth pathways of *Bos indicus* crossbred steers grazing grass (▲), *C. ternatea*/grass (○) and *S. seabrana*/grass (■) pasture systems over two seasons, 2003-2005. Error bars represent standard

error of the mean. Values for the final weight with different letters are significantly different within each season ($P = 0.05$).

Hill *et al.* 2006 (unpublished) found that the weight gain reported in Figure 2 was positively correlated with the green leaf herbage mass and that this relationship was improved slightly by including crude protein content of the diet as a variable. The equation was tested against data from the same trial and observed live weight gain was predicted in an independent test with a root mean square deviation of 0.262 kg/head/day. The results obtained in this study indicated that live weight gain on different pasture types could be predicted using information about the quality of the pasture on offer and of the diet selected (determined using faecal near infrared spectroscopy (fNIRS) (Coates 2000; 2002). This information along with on-going field trial work will enable more predictive capacity of pasture growth and live weight gain – this will help us provide farmers with better information about likely pasture growth rates and animal production on legume-based pasture systems in the SDR zone.

Capturing the benefit of legumes after the pasture phase – crop production

The variability, uncertainty and seasonal distribution of rainfall in the SDR zone presents a challenge for the capturing the benefits of N buildup during the pasture phase. The use of simulation modelling has been an approach that recognizes that field experimental work alone cannot capture the required number of permutations and combinations of treatments, soils and seasons differing in rainfall amount and distribution. Since 1986 the APSRU team has worked on developing a cropping systems simulator, namely the APSIM framework (Keating *et al.* 2003 www.apsru.gov.au).

To date, APSIM has been used to simulate the effect of preceding legume leys on subsequent crop production using two different approaches. In the first approach, Jones *et al.* (1996) used the model to simulate the entire rotation (1978-1983) by simulating the legume pasture phase (*Stylosanthes hamata* cv. Verano), its effects on SOM and the subsequent crop production. In the second method, Turpin *et al.* (1996) estimated the changes that a lucerne ley had on the SOM pools and modelled crop production only during the subsequent 8 wheat crops. Both of these methods resulted in the authors concluding that the model was capable of accurately simulating crop response to N inputs following a legume ley. There have however, been limited attempts to test if the modelled legume phase changed the SOM status of the soil accurately and if this can be measured and validated in the field. If simulating a grazed ley phase, the effects on SOM and water are complicated by the impacts of grazing on plant production, plant litter and manure returns and N losses from the system (Probert *et al.* 1998).

Most recently, Whitbread and Clem (2005) have reported on the N dynamics and growth of grain sorghum following grazed annual legume leys or a grass pasture (part of the grazing experiment already reported in this paper) in a no-till system in the South Burnett district of Queensland. Two years of the tropical legumes *Macrotyloma daltonii* and *Vigna trilobata* (both self regenerating annual legumes) and *Lablab purpureus* (a resown annual legume) resulted in soil nitrate N (0-0.9 m depth), at sorghum sowing, ranging from 35 to 86 kg/ha compared with 4 kg/ha after grass only pastures. Average grain sorghum production in the four cropping seasons following the grazed legume leys ranged from 2651 to 4012 kg/ha (Table 1). Following the grass pasture, grain sorghum production increased from <1200 and 1800 kg/ha in the first 2 crops, respectively, to grain yields that were comparable to the legume systems by the third year.

Table 1. Grain production (average of the 0N and 80N treatments) of the 4 sorghum crops following a grass pasture or 2 year legume leys (kg/ha).

	1999/00	2000/01	2001/02	2002/03
<i>M. daltonii</i>	2825 bcd ^A	3056 bcd	2825 bcd	3154 a ^B
<i>V. trilobata</i>	2401 cd	3727 abc	2492 bcd	-
<i>L. purpureus</i>	4098 ab	5254 a	2637 bcd	3165 a
Grass	1858 d	1776 d	3455 bc	-

^AMeans (1999/00, 2000/01 and 2001/02) followed by a different letter are significantly different according to DMRT at $P \leq 0.05$. ^BMeans (2002/03) followed by a different letter within columns are significantly different according to DMRT at $P \leq 0.05$.

APSIM was used to simulate soil mineral N in the period following the termination of the 2 year *M. daltonii* (Figure 3) and *L. purpureus* (Figure 4) pastures. There was generally good agreement between measured and simulated values of nitrate at sowing and harvest following the legume treatments. There was a general decline in the amount of nitrate in the profile after harvest with each succeeding sorghum crop. N accumulation between crops varies between 26 and 43 kg/ha of N. When crop N uptake exceeds the soil N mineralisation rate, the soil nitrate content declines until such a time that crop N demand is reduced and the soil water and temperatures are adequate for soil N mineralisation.

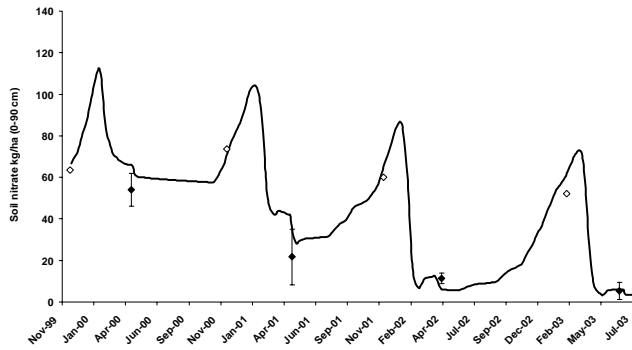


Figure 3. Soil nitrate N content (0-0.9 m) during a cropping phase (0N) that was preceded by 2 years of *M. daltonii* pasture. The solid line represents the simulated value. The open points are the measured soil nitrate values prior to sorghum sowing and the closed points are the measured soil nitrate values after harvest. Vertical bars represent the s.e.m. of the measured data- where bars are absent, the s.e.m. is smaller than the symbol.

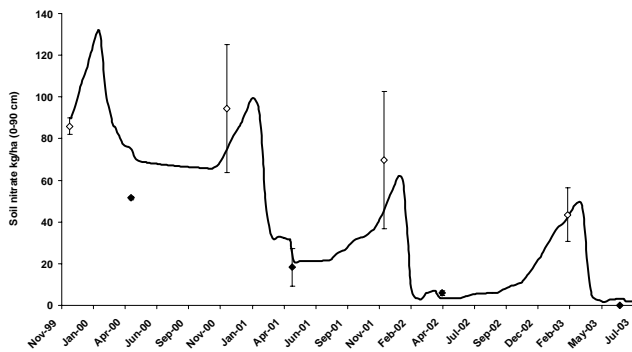


Figure 4. Soil nitrate N content (0-0.9 m) during a cropping phase (0N) that was preceded by 2 years of *L. purpureus* pasture. The solid line represents the simulated value. The open points are the measured soil nitrate values prior to sorghum sowing and the closed points are the measured soil nitrate values after harvest. Vertical bars represent the SEM of the measured data- where bars are absent, the s.e.m. is smaller than the symbol.

Using APSIM to extrapolate the field experimental results

Simulating the transition between the pasture phase and a crop

To analyse the long-term effect of seasonal conditions on unfertilised sorghum production in the first season following the termination of a pasture, APSIM was initialised with the soil water and mineral N conditions that were measured following each of the pasture treatments. Simulations were then run from 1954 – 2004 using the long-term weather data collected at the station during this period. Each year, the sorghum crop was sown between November 15 and January 15 when at least 30 mm of rain was received over 5 consecutive days. As all soil conditions were reset to the same parameters each season, the effect of climate on sorghum grain production was predicted following each pasture treatment. It was assumed that all treatments (including the grass treatment) had a soil depth of 1.2 m and therefore a PAWC of 202 mm. Following a grass pasture, grain production did not exceed 3000 kg/ha and approximately 60 % of the time grain production was between 1000 and 2000 kg/ha (Figure 5). There was only a small improvement in potential yield when the grass treatment soil was initialised to the drained upper limit indicating that low soil N was the major limitation to grain yield. Initialising the model with the soil nitrate and water data measured after any of the 2 year legume leys, grain production was found to range from 3000 to 4500 kg/ha in >75 % of the seasons between 1954 and 2004.

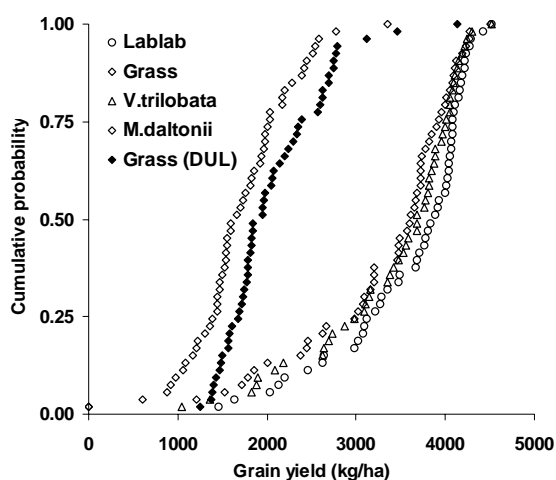


Figure 5. The cumulative probability of sorghum grain yield (with no added fertiliser N) in the seasons from 1954 to 2004 using the soil water and N starting measured in the field after 2 seasons of *M. daltonii*, *L. purpureus*, *V. trilobata* or a grass pasture.

Simulating the residual value of a pasture phase

Simulation was used to investigate the residual effect of the 2 years of *L. purpureus* pasture phase on sorghum yields and soil nitrate over the 10 subsequent summers. The simulation was initialised with the plant and root residues, soil water and mineral N conditions that were measured following this pasture treatment. The rainfall record for the years 2005-2009 is a repeat of the weather records for the years 2000-2004. Field measured data for grain yield (Table 2) and soil nitrate (Figure 6) is included for the first four crops grown after the legume pasture. The high variation in measured grain yields in crops 1 and 3 makes interpretation of this data difficult. There was good agreement in observed and predicted for crops 2 and 4 and data for other treatments presented in Whitbread and Clem (2005) indicated an RMSE=1019 kg/ha. Simulated grain yields ranged from 1948 to 4477 kg/ha during the period with no indication of yield decline as soil nitrate declined (Figure 6).

Table 2. Predicted and observed sorghum grain yield (standard error of the mean in brackets) for the period of the experimental trial (2000-2003) and predicted grain yield for a simulated sorghum crop grown continuously using weather records from the period 2000-2004

Year	Crop	Predicted	Observed
2000	1	2933	4134 (1006)
2001	2	4477	4841 (31)
2002	3	3986	2766 (1143)
2003	4	3071	2766 (158)
2004	5	1948	
2005	6	3578	
2006	7	3770	
2007	8	3119	
2008	9	2441	
2009	10	3973	

The simulation of soil nitrate shows close correlation with the measured pre-planting and after harvest data for first four sorghum crops. After the fourth crop, soil nitrate after harvest is negligible and thereafter, between harvest and sowing of the next crop, mineralisation of nitrate from SOM provides about 40 kg/ha of N. Soil organic C at this site was 1.7 % in the topsoil which could maintain N mineralisation for some decades (Dalal and Mayer 1986).

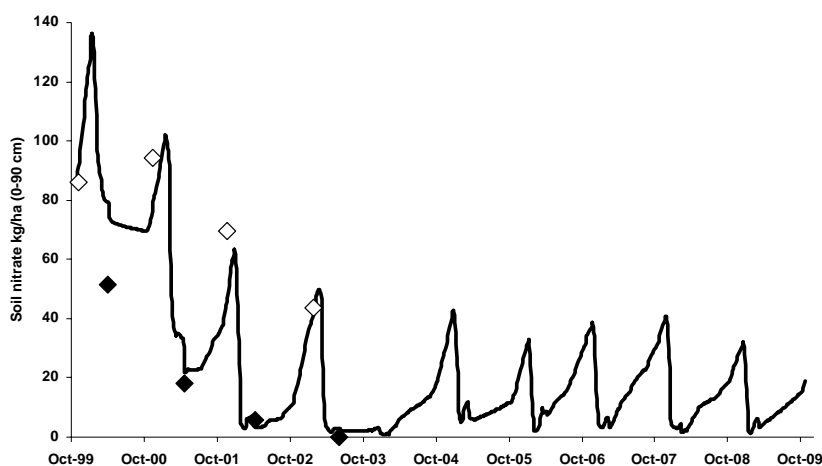


Figure 6. Simulated soil nitrate N content (0-0.9 m) during 10 years of simulated sorghum cropping with no added N that was preceded by 2 years of *L. purpureus* pasture. The open points are the measured soil nitrate values prior to sorghum sowing and the closed points are the measured soil nitrate values after harvest.

Future research efforts

In ley pasture systems, managing for a desirable pasture composition and influencing the rate of transition from legume dominance through to a legume-grass mix or grass dominance has received little attention by researchers. Managing this composition and transition is desirable for many reasons including; maximising N build up early in the ley; using grasses to capture N and build up SOM; maximizing pasture quality for animal production; provision of disease breaks; maintaining cover; reducing potential weed burdens in the subsequent crop phase. Information on pasture growth rates, seed production and hardness, seedling recruitment, persistence and the influence of grazing pressure are needed for many of the newer species used in ley pasture systems in the SDR zone (especially *M. bracteatum*, *C. ternatea* and *S. seabrana* mentioned in this paper – there are several temperate legumes and sub-tropical grasses that fit this category also). For other species that have been studied in the past, more effort at packaging the information and defining the knowledge gaps is required.

The transition between the pasture phase and the crop is the period when there is high potential for the soil fertility benefits to be lost. Significant concentrations of soil mineral N have been shown to build following a legume pasture (Whitbread *et al.* 2004) and N loss by denitrification on vertosol soils has

been demonstrated by Pu *et al.* (2001). Large leaching losses of mineral N on sandy soils in the semi-arid tropics and sub-tropics have been demonstrated by many authors (Noble *et al.* 1997;1998 Whitbread *et al.* 2004). In the SDR zone, development of systems that maintain soil cover, conserve pasture residues and delay the mineralization of soil mineral N during this transition period need to be developed. These systems will be based on the use of grazing and herbicides to terminate the pasture phase, and zero tillage systems to plant the next crop. Novel systems such as planting a mop up forage sorghum crop following a legume ley suggested by Doughton *et al.* (1996), or planting a large seeded legume such as lablab following a grass pasture to offset the cost of N tie up need to be assessed in collaboration with farmers. Selecting new forage germplasm material that may have characteristics (polyphenols, leaf coatings –see Palm *et al.* 2001) that modify plant residue decomposition rates should also be an issue considered by the research community (G. Blair pers comm.; Konboon, *et al.* 2000).

Recent development of a Lablab (*L.purpureus*) model (Hill *et al.* 2005), a Mucuna (*Mucuna pruriens*) model (Robertson *et al.* 2004) and improvements in the APSIM Lucerne (*Medicago sativa*) model (Dolling *et al.* 2004) are improving our capability to simulate and analyse the interactions between ley legume and crop systems. Recent technologies such faecal near infrared spectroscopy (fNIRS) (Coates 2000; 2002) which can determine pasture intake and quality are improving the capability of predicting animal production from tropical legume-based pastures. These tools are important in helping farmers develop flexible rotation systems that adapt to changing market circumstances and production technologies in the highly variable and complex environments of the SDR zone.

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