Improving the integration of legumes in grain and sugarcane farming systems in southern Queensland

Summary
The project focussed on legume-dominated dryland cropping and coastal pulse/sugarcane rotations. Dryland activities focussed on diversifying cropping enterprises to include a ley pasture/grazing component with minimal financial and sustainability risks. Loss pathways for seasonal rainfall were explored and the efficiency and financial returns from different nutrient use strategies assessed. Coastal work focussed on performance and effectiveness of fallow legumes in terms of nitrogen (N) contributions and productivity and profitability of the subsequent cane phase. Soil health benefits associated with trash retention and reduced tillage in sugarcane and pulse phases were also assessed.

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Conclusions
Coastal systems
The role of legumes in coastal sugarcane farming systems has been consolidated, with peanut and soybean now producing consistently reliable production and profitable returns to growers, both from the pulse crop itself and also through increased cane productivity with fewer nematode issues. Extended fallows from cane are possible, with the choice of winter crop options not limited by the ability to host pathogenic nematodes that affect cane crops.

Effective inoculation strategies now employed by planting contractors and individual growers have ensured nodulation is reliable and crop N status adequate. While there is still some uncertainty about nutrient requirements for these pulses, especially for potassium (K) and pH ameliorants like lime, the residual value of these materials for the following cane crop was clearly demonstrated and should allow their input costs to be discounted across the entire crop cycle rather than purely against the pulse itself. Acceptance of these outcomes will require ongoing discussions and activities with agronomists and industry, as well as a concerted effort to embed this information in the 6ES nutrient management guidelines developed by staff of BSES Ltd.

This project has clearly demonstrated the importance of controlling or mitigating effects of compaction from previous sugarcane cycles before reduced or zero tillage (ZT) is adopted in these cropping systems, particularly where peanuts are the preferred fallow legume rotation crop. The severity of compaction (wet soils, heavy axle loads, wheel tracks every 1.8–2 metres) is unprecedented in grains industry experience, and may mean the strategic or zonal tillage (disturbance of the planting bed) is preferred over full direct drill. The project has shown this can be effective for the production of major fallow legume species, and that it allows direct sowing of sugarcane after legume harvest. Reducing tillage and retaining crop residues also enhances suppression of pathogenic nematodes.

Inland systems
The development of a capability to compare the profitability of mixed cropping/steer fattening operations with sole cropping in the SmartPeanut financial assessment software, has allowed growers to explore different management options. Analysis clearly shows that such systems are less profitable if cropping land (especially land sown to peanuts) is diverted to forage production. However, the seasonal fluctuations and risks associated with these mixed systems do appear to be lower, and the balance will depend on independent analysis of farm businesses.

Options explored to reduce fertiliser costs, or provide more effective approaches to soil fertility management, conclusively showed that a well managed synthetic fertiliser program based on nutrient budgets and regular soil testing was either as effective or better in terms of cost and sustainability factors. Maintenance of soil fertility was shown to be a major risk of adopting forage and/or hay production practices as part of a mixed cropping operation. The amounts of nutrient removed, and the inability to meet the cost of replacing them in later crop phases, collectively represent a major challenge to sustainability in the short–medium term.
While planned water balance studies were limited by flooding and equipment loss, available data suggests options to reduce evaporative losses through tillage and stubble management are minimal and increased cropping frequency may be the most effective way of improving systems water use efficiency.

**Recommendations**

**Coastal:**
- Effective inoculation strategies are a key factor in fallow legume performance, with large yield penalties occurring when inoculants did not result in rapid and extensive nodule establishment.
- Peat-based inoculum, especially combined with water-injection techniques, provided consistent and reliable nodulation under variable seeding conditions.
- Areas with poor quality groundwater (i.e. high chloride concentrations) are at risk of serious Cadmium (Cd) contamination if peanuts are grown as a break crop. While changes to the food safety standard for peanut have reduced the emphasis on Cd in kernels, growers using poorer quality irrigation water should be encouraged to choose other legume species as break crops.
- Growers choosing to have extended non-sugarcane fallows can safely grow cereal crops and grass species over winter without exacerbating pathogenic nematode problems.
- Trash retention and reduced tillage can enhance natural suppression of pathogenic nematode populations, but this only occurs in the surface soil layers and is not an effective management strategy alone. The potential to combine this with effective break species to slow pathogen resurgence during the sugarcane cycle should be explored further.
- Soybean crops can be grown without yield penalties using direct drill establishment after cane harvest, but peanuts definitely required seed bed disturbance to reduce risks of harvest losses. Cane crops grown after fallow legumes also benefit from disturbance of the bed area, although yield responses in early stages of the crop cycle are small.
- The extent of vehicle traffic in sugarcane systems and the current lack of strict controlled traffic management mean that until these issues are resolved, some tillage will continue to be required in the planting zones.

**Inland:**
- Successful peanut crops are a key factor in the profitability of inland Burnett cropping systems.
- Shifting from sole cropping into mixed cropping systems by reducing cropped area will provide a degree of income stability, but will also reduce farm profitability, especially if the area cropped to peanuts decreases. Diversification will be more feasible if the grazing/fattening venture is undertaken on lower value grazing areas.
- Increasing rates of nutrient removal from cropped paddocks in mixed cropping operations (i.e. hay production) cannot be entertained from either a sustainability or economic perspective in anything more than the immediate short-term. While nutrients can be replaced in the cropped phase, costs would be prohibitive.
- There are few options to reduce expenditure on nutrient inputs below those using a synthetic fertiliser program, based on periodic soil testing and a nutrient replacement strategy. The most promising option was based on the use of feedlot manures, but limited availability and supply at critical times are severe impediments. Other approaches that result in more frequent operations or slower planting rates (e.g. water injection) will be impractical for broadacre rainfed operations.
- Improvements in system water use efficiency are most likely to be derived from increased crop frequency rather than stubble or tillage management. This will have positive impacts on soil carbon.

**Outcomes**

The main benefits of this project were economic and environmental. In dryland areas the project has provided the underlying data and developed the tools necessary for growers to evaluate the true cost and returns that can be expected from diversifying from cropping into mixed farming operations. Reducing crop frequency to substitute for forage/grazing activity...
lowered risks of financial loss in the short term, but benefits were derived to the detriment of soil fertility status and any reduction in peanut cropping greatly reduced profitability. Only pure legume pastures produced N benefits for subsequent cropping but these came at a cost of limited forage production and carrying capacity and reduced profitability. Increased fertiliser use to address degradation from forage removal further reduced farm incomes. A thorough assessment of manures and alternate commercial fertiliser strategies to maintain soil fertility and productivity showed no benefits over a well planned and implemented program based on bag fertilisers, and in some cases programs were constrained by practicality and unbalanced or inadequate nutrient additions.

In coastal areas the project has clearly demonstrated the benefits of adopting reduced tillage and controlled traffic systems for peanut and soybean fallow crops as well as the following cane cycle. Inadequate controlled traffic systems and the resulting soil compaction limits the ability to adopt reduced tillage and was shown to reduce profitability of fallow peanuts by more than $1,000/ha. The most effective inoculation strategies and commercial inoculants were assessed for both legume species and clear guidelines were produced. The proportion of legume N derived from fixation and the net N benefit of fallow legumes was quantified for both experimental and commercial crops, with this information being incorporated into nutrient management regulations and the sugar industry’s Six East Steps fertiliser guidelines. Effects of short or long legume breaks and crop sequences were quantified in terms of cane productivity and farming systems benefits, and the key role played by soil and irrigation water chloride content on the Cd concentration and food safety of peanut crops was identified.

The impact of tillage and trash management during the cane-pulse crop cycle on soil carbon status was quantified, and the interactions between these management strategies and pathogenic nematode dynamics and crop losses were explored. The impacts of break species and rotation sequences on pathogenic nematodes have been determined and clear guidelines provided to industry to minimise economic impacts of this key pathogen.

Social impacts were limited to improving the communication and linkages between growers and advisors across the region, as well as providing sound guidelines and decision support tools to enhance decision making at the farm and industry level.

**Achievements/Benefits**

This overview of achievements is presented on a regional basis.

**Coastal**

The focus was on the legume fallow crop between sugarcane cycles and the benefits derived in the following crop cycle. Maximising legume N fixation: A major concern for growers of fallow legumes cane systems has been ensuring effective nodulation and fixation of atmospheric N. Soils have very low background rhizobial populations and failure to effectively nodulate can result in 50% lower crop yields. The project evaluated different commercial inoculums and application strategies for soybean and peanut, comparing peat-based products (slurry or water-injected) with liquid, freeze-dried, granulated or seed-coated formulations. While there were few significant differences between inoculum forms in terms of final yields or proportion of crop N derived from fixation, the peat-based inoculants combined with water injection provided the most uniform nodulation, and were most effective under suboptimal establishment conditions when seed was sown into dry soil and then irrigated. In collaboration with other GRDC-funded projects, information sheets on effective inoculation strategies were developed and promoted to industry.

In 2011/12 a survey of commercial peanut and soybean crops found that the above ground crop N derived from atmospheric N fixation (PNdfa) was typically 65–85% and from 150–330kg N/ha, indicating the industry had confidently adopted good inoculation practices. The only crop encountered with poor nodulation and low PNdfa was a crop grown after intensive vegetable production, where soil mineral N was very high. Despite these generally high PNdfa values in both commercial and experimental crops, large positive N balances did not occur once legume crops were harvested for grain/pods (i.e. N derived from fixation in residue minus N derived from soil removed at harvest). Values typically ranged from -100 to +50kg N/ha for soybean and -50 to +50kg N/ha for peanut. Allowing for belowground N improved the net balance by an average of 60kg/ha. This highlights major problems with the current treatment of N input from legume fallows in nutrient management guidelines.

**Cadmium management in peanuts**

Minimising Cd concentrations in peanut kernel has been a major restraint to peanut culture during sugarcane fallows, with high concentrations resulting in price penalties of $100/t. Liming has been a key minimisation strategy, but effectiveness of lime can be hindered by short turnaround times after cane harvest and dry conditions. Over consecutive seasons, the
effectiveness of lime applied between one and four months before peanut planting in year 1, and three, 12 and 16 months before planting in year 2 was evaluated. Time of application had no impact on kernel Cd, although treatments that resulted in lower (continuous legume production) or higher (grass pasture) organic matter resulted in higher and lower kernel Cd, respectively. Subsequent experiments showed soil chloride concentrations were the dominant factor in determining kernel Cd, and seasonal rainfall and irrigation water quality were the most important determinants rather than management.

**Adoption of reduced tillage and controlled traffic management**

There is uncertainty over the effectiveness of these management practices in sugar systems where soil compaction from harvester traffic is a major issue. Full conventional tillage was compared with zonal tillage and direct drill in both peanut and soybean break crops and subsequent cane crops and included factorial combinations of cane trash management (retained, partially removed as hay and burnt) prior to legume establishment. While soybean productivity was unaffected by tillage or trash management, residual soil compaction reduced the productivity of peanut crops by more than 1t/ha and crop gross returns by more than $1,000/ha. There was a trend for this remnant compaction to affect the subsequent cane crop, although effects were less evident.

**Nematode suppression**

Pathogenic nematodes are a major constraint to sugarcane productivity, especially in lighter textured soils. Trials showed both soybean and peanut were very effective at reducing nematode populations, but growers considering breaks longer than a single legume crop were concerned that winter cereals following or in between summer legumes may erode these benefits. The project showed that was not the case, as cool winter soil temperatures slowed nematode multiplication even when susceptible species were grown.

Resurgence in nematode populations after a legume break was slowed by trash retention and direct drill, although the project terminated before these effects were followed into ratoon crops. Effects were due to an enhancement of components of the soil nematode and fungal communities that predated the pathogenic species. The effects of cane trash and other residue mulches only extended into the top10cm or so of the soil profile and were not able to protect much of the crop root system. However, surface roots under trash were very healthy and responsible for a lot of nutrient uptake when soils were wet.

**Effects of rotation length and crop sequence on cane yield**

When cane prices were low, growers were considering 12-18 month breaks between cane cycles and were interested in the impact of longer breaks and the crop sequence during them on subsequent cane yields. The project showed peanuts could be grown in consecutive summers during extended cane fallows without a reduction in yield; that both wheat and field peas were able to be grown successfully between summer legumes; and that there were no significant increases in cane productivity with breaks longer than a single 9-10 month fallow in which a pulse crop was grown. The project was also able to successfully demonstrate that high nutrient inputs (especially K) in legume fallows could contribute to nutrient uptake in the following cane crop.

**Recovery of legume N by sugarcane crops**

Three plant cane crops were established in 2010 and 2011, and experienced unusually wet summer growing conditions that caused large losses of fertiliser and legume-derived N. Contrary to our earlier experiences, N fertiliser responses were recorded after soybeans and peanuts. These were relatively small (15% where no fertiliser N was applied and only 5% when 40kg N/ha was applied at cane planting) and were in response to only an additional 20–25kg N/ha accumulated by the crops. It is unlikely that these responses would have occurred in drier seasons, and highlights the impact of seasonal conditions on the value of legume N and fertiliser N requirement.

**Economic impacts of legume rotations and changes to tillage systems**

Agronomic and gross margin (GM) data outlining the benefits of incorporating fallow legumes and reduced tillage/controlled traffic in cane farming systems have been incorporated in the sugar industry farm economic analysis tool (FEAT) and case studies analysed. The results suggest benefits can be large (up to $400/ha) and still occur when sugar prices are high, although parts of the industry are still adopting a very conservative approach to some benefits.

**Inland**

Activities focussed both on key cropping systems issues identified by local growers and agribusiness.
Evaluating alternate fertility management strategies

Declining native fertility reserves and high fertiliser costs resulted in demand for an independent assessment of alternate commercial strategies being offered to growers to both maintain production but also remain sustainable. A large trial on a commercial farm, using commercial equipment, was established to compare a successful traditional fertiliser program (synthetic fertilisers) with alternative approaches based on manures, composts, mineral fertilisers, organic and biological materials. Five collaborating suppliers in the region agreed to participate, and to the full disclosure of results after the first year. Each nominated their inputs and approaches on a season-by-season basis, while productivity and profitability and system nutrient balance were monitored. The comparison was made over five crops in four years and over seasonal conditions that ranged from very dry to excessively wet. Most alternative approaches were within 5–7% of the productivity of the program run by the collaborating grower, although one produced 14% lower total yields. These represented lost returns ranging from $150–$730/ha. The best agronomic performers were feedlot manure, composted manure and the program offered by AgSolutions. Economic comparisons are still being assessed, but at this stage the only approach that comes close to the grower program would appear to be feedlot manure with supplementary N fertiliser. In this case, availability of product is an issue, while other systems were constrained by price (the composted product cost an extra $400/ha to apply for a $300 loss in returns) or practicality (liquid injection, seed treatments, etc.) for a broadacre opportunity cropping system.

Strategies for diversifying into mixed cropping and steer fattening

Land managers in the inland Burnett 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 or forage production are common approaches, with fodder grazed in situ or removed as hay. The agronomic implications of the most flexible system, in which short (2–3 years) crop-forage phases are rotated on existing cropped land, with fodder removed as hay rather than grazed in situ, were studied. Rapid establishment and fodder production resulting from direct drilling larger seeded forage species spread fodder production across the ley phase more effectively than traditional pastures established after conventional tillage (CT), although total biomass production was similar over an 18-month ley period. Forage or pasture legumes were able to contribute 50–80kg N/ha to the first crop after the ley, despite hay removal, and a further 20–25kg N/ha in a second crop season. These potential fertiliser savings were insignificant compared to the reduced forage production during the ley (grass and mixed grass-legume swards produced more than twice the biomass) and the need to replace the other nutrients removed in the hay (10–20kg P, 150–250kg K and 15–25kg S/ha). This substantial fertiliser investment upon return to cropping seriously challenges the viability of this system, even if significant proportions of the fodder are grazed in situ, rather than removed as hay.

Whole farm economic analysis of various mixed cropping strategies

The inclusion of a grazing module in the SmartPeanut whole farm economic analysis tool has greatly expanded the capability of growers and advisers to explore different strategies for dealing with variable and changing climates. While assessments have currently been limited to a steady state assessment of different scenarios, there are opportunities to take structures of interest from this preliminary analysis into personalised business models. Analyses conducted on a range of hypothetical mixed cropping enterprises, as well as real case studies, suggests there are no major improvements to average annual profitability achievable by diverting cropping land to grazing/fattening steers. This is particularly evident for peanut cropping, as this tends to dominate whole farm returns and any reduction in peanut area results in sharp declines in farm operating profit. The retention of all cropping equipment (used in forage cropping as well as traditional cropping), especially the specialised peanut equipment, was deemed an important part of mixed cropping strategies, to maintain flexibility to increase or decrease the cropping component in response to climate signals.

The much greater sensitivity of cropping profitability to seasonal downturns (i.e. lower yields and/or commodity prices) than grazing suggests that diversification into mixed cropping ventures may result in reduced losses in poor seasons and better farm cash flows. Ways of incorporating these findings into alternative farm business models (e.g. expanding the venture by purchasing or leasing lower value grazing land, rather than diverting existing crop land) and the impact on longer term financial viability needs more detailed assessment.

Opportunities to improve system water use efficiency

Moisture availability is the key limitation to production in these rainfed cropping systems, yet current estimates are that only...
approx. 45% of incident rainfall is used by crops. The rest is lost as evaporation (approx. 40-45%) or deep drainage (10-15%). Pre-existing facilities were used to assess both water loss pathways, but to a large extent this was thwarted by excessive wet weather, resulting in very high water tables and inundation of electrical monitoring equipment. The only completed experiment studied the impact of crop residues on evaporative losses, which showed that typical crop residue levels had little impact on evaporation.

Other research
There are a number of areas that require further research, particularly in coastal systems.

1. Uncertainty still exists around the adoption of reduced or ZT and controlled traffic in coastal farming systems. Previous studies, generally conducted under drier seasonal conditions, have shown no yield reductions and significant cost savings by adopting these approaches. However the current project findings suggest some form of zonal tillage may continue to be required, at least until better controlled traffic management systems can be implemented. This will allow broader rotation options and may provide improved yield stability in variable seasonal conditions. The key requirements for successful zonal tillage and any impacts on root system function, pathogen dynamics and productivity need to be determined.

2. The most vulnerable time for sediment and nutrient generation in a coastal farming system is sugarcane planting, with reduced tillage and minimal soil disturbance an effective mitigation strategy. The feasibility of modifying legume harvesting equipment to suit sugarcane row spacings needs to be investigated before tillage reduction prior to cane planting can be implemented. Existing peanut threshers were problematic in this regard, but recent Sugar Research and Development Corporation (SRDC) and natural resource management (NRM) group investments to develop a prototype peanut thresher to potentially overcome these limitations have been made. This equipment needs to be demonstrated to industry and the approach extended to other legume harvesting equipment.

3. Another factor of immediate relevance is the net contribution of new (fixed) legume N to the soil system, the fate of that N under differing climatic conditions, and the implications for fertiliser N requirement. Previous research suggested legume breaks obviated the need for N fertiliser in at least the sugarcane plant crop, and systems modelling has extrapolated those findings to include reduced requirements in later ratoons. However, results have shown that the new N returned in legume residues (i.e. derived from fixation rather than recycled soil N) may be minimal when grain is harvested, and under wetter seasonal conditions this N may not be enough to satisfy the demands of a plant crop, much less later ratoons. Various loss pathways may be involved in different situations. Nutrient management guidelines (and associated legislative framework in coastal systems) need to encompass these variable outcomes. An improved understanding of legume N dynamics is therefore needed, and this would also be relevant to dryland cropping systems looking to defray increasing fertiliser costs with an increased legume crop frequency.

4. Finally, further research is required to improve guidelines for fertiliser inputs in summer legume crops and to account for any residual nutrient in the following cane cycle. The concept of nutrient budgeting across a crop cycle needs to be developed and extended to industry, as do improved soil test-crop response functions for summer legumes on lighter textured soils.

Research opportunities in the rainfed inland systems are more limited and primarily relate to development of management strategies to improve system water use efficiency and reduce input costs. Current understanding suggests that both approaches may be accompanied by increased financial risks, and so a clear definition of risk frameworks and objectives would need to be developed with industry before this was progressed.

Additional information


Mike Bell, Gary Harch and Phil Moody 2012. Diversification from cropping into mixed crop-livestock systems – the


