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APSFarm: a new framework for modelling mixed cropping and grazing farm businesses

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Abstract: The long-term viability of mixed grain and graze farm businesses relies on having a diverse mix of enterprises with both pasture and cropping systems. Identifying the mix of enterprises and allocation of resources that maximise profitability needs better integrative and interdisciplinary modelling tools. In Australia, farm managers continuously fine tune tactics and strategies to keep their farm business profitable over time. Present climate variability, the cost-price squeeze, and the possible inclusion of agriculture in the Australian Emissions Trading Scheme by 2015, will require that agriculture in general, and graziers in particular, design short and long-term adaptation strategies. In this paper we describe the development of APSFarm, a more integrative and interdisciplinary whole-farm systems model and its application in a participatory research framework to identify more resilient designs of a mixed grain and graze farm business.

In this study, APSFarm was used to model a mixed cropping and grazing farm in central Queensland that is opportunistic and responsive to the highly variable climate and to prices. The whole-farm simulation of different soils, cropping and grazing systems, provides production indices and environmental impacts of the farming system. We used APSFarm to compare current management practices with two alternative strategies: (i) increased land area and resources for the cropping enterprises, thereby decreasing the grazing enterprise; and (ii) increased area and resources for the grazing enterprises. These alternative strategies were evaluated in terms of trade-offs between profit and environmental outputs. These help us identify strategies that better cope with the variability in climate and prices.

Results indicate that returns from a farm with a significant livestock enterprise had lower average returns but encountered lower extremes of returns. From the scenario studied, a farmer who is more averse to risk may choose to increase grazing area which may reduce downside risk especially during dry periods, and have little effect on average returns. Whilst there is a larger variation in income from cropping, there is the potential to make more money. There are tradeoffs of this practice change on environmental impacts with simulations showing that changing paddocks from annual cropping to perennial pasture reduced runoff by 25%, drainage by 65% and soil loss by 50%.

In discussions with participating farmers, additional work would be required to identify optimum crop and pasture choices, changes in land use, and the expected impacts from long-term changes in climate and mitigation policy. We conclude that the use of integrative and interdisciplinary modelling tools such as APSFarm, can assist farmers make better decisions by having better informed discussions in relation to the management and design of complicated mixed grain and grazing systems.

Keywords: *cropping, pastures, grazing, management, simulation, gross margins*

1. INTRODUCTION

1.1. The need for mixed cropping and grazing models

There is increasing demand for more integrative and interdisciplinary systems modelling tools capable of dealing with mixed farming systems. This is demonstrated by continuing industry funding for such projects as ‘Sustainable Farming Systems’ and ‘Grain and Graze’. If we take a long-term view of farm business, taking into account the variable climate in Queensland coupled with changing markets, the most profitable enterprise mix is likely to involve both crop and pasture rotations (Wylie, 2007). Collaborating producers in Central Queensland stated that in drier than average years, when there aren’t as many opportunities to grow crops, grazing keeps their farm business viable. Climate variability and market volatility make the diversification of farm businesses into mixed grain and graze systems a good risk management strategy. For example, the strength of the livestock market in the last ten years resulted in around 200,000 ha of marginal cropping land being returned to pasture (Routley, 2007). There is a need for bio-economic modeling capability to dynamically simulate mixed farming systems to help identify and quantify the production and economic outcomes of alternative management strategies at the whole-farm level. This capability would also allow us to quantify benefits for natural resource management outcomes, and to identify strategies for adapting to climate change.

1.2. Existing whole-farm simulation modeling platforms

In the southern states of Australia, the GRAZPLAN family of decision support tools is used for simulating grazing systems on temperate pastures (Donnelly et al., 2002). These tools are not suitable for Queensland's beef production systems on tropical and subtropical pastures (McLennan 2005). Whole-farm bio-economic models, such as MIDAS (Kingwell and Pannell, 1987), have been widely used in southern Australia to assess the impact of alternative feed-base options and/or changes to enterprise mix on farm profitability. These are static frameworks and do not capture the dynamics of changing enterprise mix or seasonal variability (Bell et al., 2008). Therefore there was a need for a bio-economic model that could be used to dynamically simulate Queensland's mixed farming systems.

In Queensland, APSIM (Keating et al., 2003) is commonly used for simulating cropping systems, and GRASP (Rickert et al., 2000) is used for pastures and woodland. Only a limited capability previously existed within APSIM to simulate pasture production, and no well-developed capability to simulate animal production. We needed to combine APSIM and GRASP to dynamically simulate both cropping and grazing in a fully integrated system. APSFarm (Rodriguez et al., 2007), which is a whole-farm version of APSIM, was identified as an ideal framework for the integration of cropping and grazing enterprises on the whole-farm.

APSFarm is a multi-paddock dynamic simulation environment that uses the APSIM model to simulate the allocation of land, labour, time, irrigation water, livestock, machinery and other finance resources at the whole-farm level (Rodriguez et al., 2007). APSFarm extends APSIM in the areas of multiple paddocks, economics and farm level management rules that specify resource sharing at the farm level (de Voil et al., 2009, these proceedings). In this paper we describe how we further extended APSFarm to include the capacity to model other pasture legumes and grasses (butterfly pea, buffel and native grasses, leucaena under-sown with grass pastures). We also describe how we modelled animal production from different forage sources, allocation of animal herds to paddocks and moving mobs of animals between paddocks. For the first time in Queensland we have a model that dynamically simulates both cropping and grazing in a fully integrated system.

1.3. Aims of the present study

The capacity to change enterprise mix is an important risk-management strategy under variable climate and market conditions (Wylie, 2007). Our aim is to develop an improved understanding of the tradeoffs involved in adjusting enterprise mix to optimise whole-farm economic and environmental performance in response to changing climatic and market conditions. In this paper we describe (i) the development of the pasture-grazing modules for the APSFarm model, and (ii) its application in a real farm case study, to evaluate trade-offs between economic and environmental outputs of two alternative farm business strategies. Trade-offs are discussed in terms of gross margins, drainage, runoff and erosion.

2. METHOD

2.1. Description of the APSIM model with GRASP

APSIM's design philosophy is that a soil provides a central focus to ephemeral crops and pastures that come and go in response to management actions. This design facilitates modular construction, each module being a component of the farming system, some permanent (e.g. soil) some long-term (e.g. lucerne), some short term (e.g. oats), yet all initiated by a management intervention. Broadacre cropping components and the nutrient and water dynamics of rotation systems have been described in detail (Keating et al., 2003). The standalone pasture model GRASP is a deterministic, point model of native pastures, trees and stock designed for semi-arid and tropical environments. It has been well tested in Queensland with a good understanding of parameter values from approximately 100 sites across northern Australia (Day et al., 1997). GRASP was ported into the APSIM framework in 1995, splitting it into three separate APSIM components; the core grass biophysical model, a simple tree model, and a grazing model. The water and nutrient components of the standalone model became superfluous and APSIM's existing modules were used instead. Once in the APSIM framework, the grazing component is able to take biomass from both pastures (i.e. GRASP's native pasture) and APSIM crops, as common inter-module communications protocols are implemented.

The grazing component of GRASP is a simple potential growth model that limits animal growth by feed deficit. Each feed source in the system has a defined potential growth rate, obviating the need for nutritional and digestibility properties in the crop and pasture modules. Growth rates for animals from different pastures are obtained from grazing trials (Day et al., 1997) and from participating farmers and agronomists (Table 1). Neither the pasture nor grazing component in APSIM has been used extensively to date.

GRASP Pastures	**Summer**	**Autumn**	**Winter**	**Spring**	**Total year**
	D-J-F	***M-A-M***	***J-J-A***	***S-O-N***	
Buffel grass	70	35	10	35	150
Butterfly pea	70	75	15	25	185
Lablab	16	80	24	0	142
Forage oats	0	30	90	60	180
leucaena_CQ	85	85	30	30	230

Table 1 Grazing model parameters of expected live weight gain for different forages (kg/hd/season) used for the case study farm.

2.2. Model Structure of APSFarm

APSFarm is a whole-farm systems simulation model composed of multiple instances of the paddock scale model APSIM. An APSFarm simulation consists of several paddocks, each containing soil and crop components that are all managed by a single top level manager component, alongside meteorological, economic and grazing components. Crop and pasture sequences are implemented as a state transition network where transitions between states (e.g. from fallow to a certain crop) are made when rules permit (eg. rainfall criteria are met). These rules describe both paddock scale (e.g. correct season of planting for the crop, enough water is available to sow the crop) and farm scale (e.g. what area of which crop to plant) management actions. Forage crops are treated in a similar way; however their agronomic management is combined with the management of grazing animals.

In each simulation, "mobs" of animals (uniform groups based loosely on age, weight and sex similarity) are brought into the system, are directed to graze crops or pastures growing in paddocks and finally are moved out of the system. The number of each mob can be manipulated as a response to feed shortage. Over time, these mobs change physically. For example, weaners mature into steers and heifers, and are separated out into different mobs and grazed in different paddocks. Each mob is associated with one instance of a grazing component; which by itself does nothing more than remove biomass from the crop currently being grazed, and increases (or decreases) its own weight. When a mob is moved from one paddock to another, the stocking rate of the grazing component is adjusted, and the feed source changed for that mob. When a mob is moved to a feedlot, the grazing component is disconnected, and liveweight gain is modelled as a constant value per day. The grazing enterprise usually has major components such as forage crops, grasses and feedlots, and a myriad of tactics that respond to crop failures or feed surpluses. A graphical outline of the decision tree of an example case study is given in **Figure 1**.

As with grain crops, grazing management has an event-based interaction with the farm economic component, which includes establishment cost for pastures, feed supplement costs, freight costs, veterinary costs and feedlot costs for grain and mixing. Animals that enter or leave the system have a cost or price, the number and weight of which are known.

2.3. Description of the example case study farm

We conducted a series of interviews with farm managers and consultants to set up an APSFarm simulation for a case study farm in central Queensland. The farm is a 3600 ha mixed cropping and grazing business with fertile cracking clay soils, and has been cultivated since 1985. The farmers are opportunistic in their tactical management in response to changes in seasons and prices. The cropping enterprises include grains, forages, legume pastures, grass pastures, and leucaena under-sown with improved grass pastures. The farm manager prefers to grow about 60% summer crops and 40% winter crops. The business also includes a feedlot, where beasts are fed a grain diet. Heifers are fed for 70 days for the domestic trade and steers are fed for 100 days for the Jap Ox market. Management of mobs of animals on the farm is driven by age and feed availability. The flow diagram (Figure 1) illustrates how mobs of animals are purchased, moved around the different paddocks, sent to a feedlot for finishing and finally sold. The classes of animals modelled were weaners (6 - 12 months), heifers (12 - 18 months), steers (12 - 18 months) and cull cows (> 12 months). In the discussions we encouraged stakeholders to provide questions and case studies for scenario analysis.

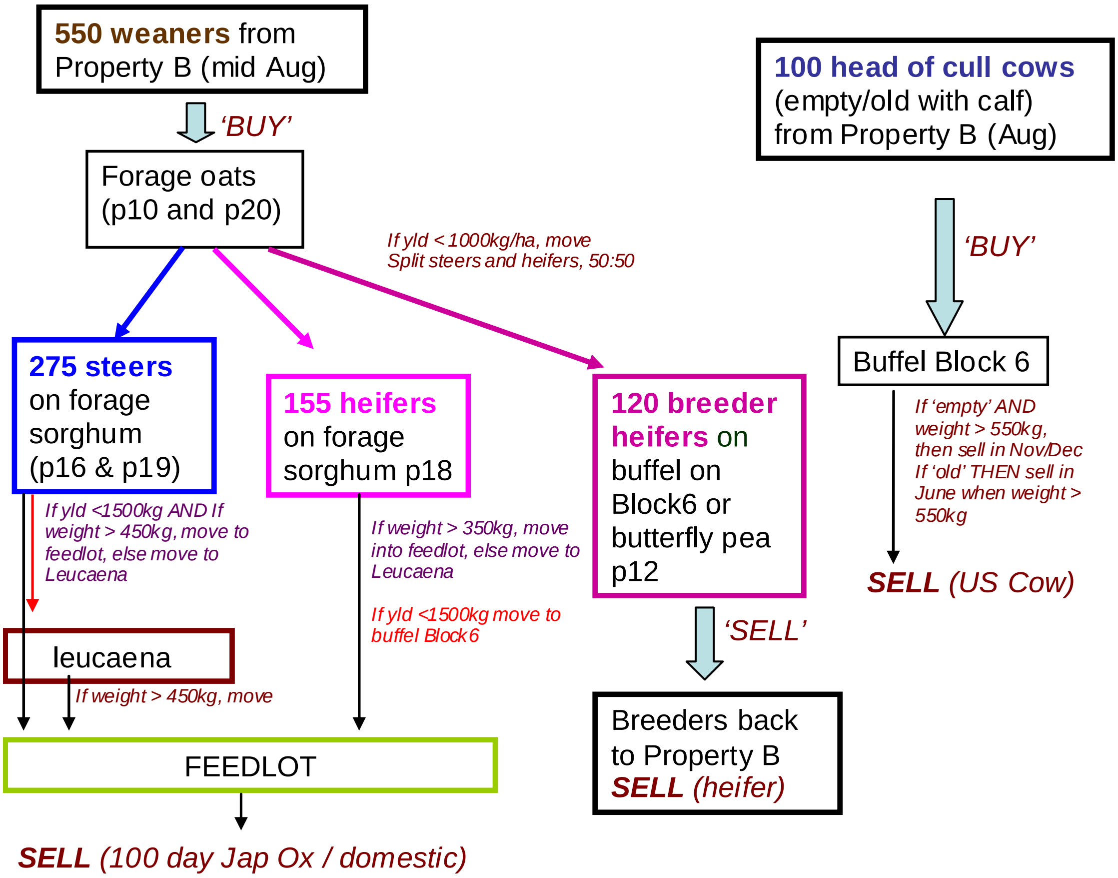

Figure 1. Flow diagram of how mobs of animals are moved around the farm based on feed availability.

2.4. Modelling crops and pastures

APSIM was used to model all crops (wheat, sorghum and chickpeas) and forages (sorghum and oats) using planting rules provided by the growers. The perennial legume pasture, butterfly pea, was calibrated using data collected at the Gatton and Emerald Research Stations. The GRASP model in APSIM was used to model all grass pastures (native grasses, buffel, and purple pigeon grass). We also calibrated GRASP to reproduce yields of leucaena under-sown with Floren bluegrass, rhodes grass and bambatsi. Initially all growth parameters for grasses were set to averages for pasture communities obtained from data sets collected at 74 sites throughout Queensland using a methodology specifically designed to obtain a minimum data set for model parameterization (Day et al., 1997). These parameters can be used as a starting point to model pastures in Queensland. We adjusted these parameters for the different pasture types on the property based on experimental data from other sites with similar pastures (Day et al., 1997), discussion with the land owners and pasture agronomists, and our own observations.

2.5. Application of the APSFARM model to the case study

Building a simulation model of the case study farm is an iterative process that builds on a series of interviews and discussions with the farmers and local agronomists. Over a period of several months, a complete description of the farm and key farm-level and paddock-level management decisions was developed, while constructing the simulation model. During this process, participants developed questions for scenario analysis and discussion. Of major interest was the question of “what are the optimal proportions of grain and grazing components in this farm business”, and underlying this question is the issue of tradeoffs – what gains and losses are made by varying proportions.

We developed a base scenario that represented the current state of the mixed farm, and two alternate scenarios where we firstly increased the area of the grazing enterprise by converting several cropping paddocks (totalling 475 ha) to forage crops, and adding 200 head of weaners. In the 2nd scenario we increased the area of cropping (by 330ha), discontinued the breeder replacement component of the animal herd (250 head), and introduced new machinery to manage the increased crop area. This scenario analysis shows the trade-offs between profit and environmental impact by changing enterprise mix.

APSFarm was run for a 30 year period from 1975 to 2005, exposing the system to both wet and dry episodes. Annual gross margins are calculated for each scenario using 2008 costs and prices. Annual environmental impact (runoff, drainage & erosion) is also calculated, allowing the outcome of each scenario to be presented as a distribution that spans a range of seasonal types. The key point of discussion is how the distributions change between scenarios. Box plots are used as a convenient means to summarise differences in the distributions of simulated farm gross margins over the 30 years of the simulation study. The mean is shown as the solid line in the middle of the box. The upper and lower borders of the box show the 75 and 25 percentiles of the simulated results. The upper and lower short horizontal lines represent 100 per cent and 0 percentiles, respectively.

3. RESULTS AND DISCUSSION

All scenarios showed larger variation in income from cropping and a more stable income from livestock over the 30 year period from 1975 to 2005 (Figure 2). The median gross margin is very similar across all scenarios but there is a greater proportion of higher returns from Scenario 2 which has more cropping area. In 75% of years, the gross margin will be $250/ha/year or less in Scenario 2, compared to Scenario 1, which is $150/ha/year or less. Similarly, the magnitude of the lowest return was reduced form -$200/ha for scenario 2 to -$150/ha for scenario 1. Hence, having a larger cropping area on the farm has the potential to make more money in some years, but also some greater losses.

Sequences of wet years, for example in the early 1980s, provided larger returns from both cropping and grazing. Sequences of dry years, for example in the early 1990s, gave reduced returns from cropping (data not shown), whereas cash flow from the grazing enterprise was maintained. This illustrates very clearly why many producers with a long-term perspective keep some cattle on their properties. The farm managers on the case study property mentioned in discussions that in drier than average years in central Queensland, when there aren’t as many opportunities to grow crops, grazing keeps them viable. Grain cropping offers the potential for higher gross margins with an associated increase in risk, and grazing offers lower returns while reducing risk (Wylie 2007).

There are tradeoffs in switching between the cropping and grazing enterprise on environmental impacts, such as fertility decline, runoff, soil erosion and salinity through increased deep drainage. Preliminary simulations show that changing paddocks from annual cropping to perennial pasture reduced runoff by 25%, drainage by 65% and soil loss by 50%. These results are similar to those of Owens et al. (2007) for deep drainage and runoff modelling for similar soils in central Queensland. Perennial pasture systems provide greater and more permanent ground cover than cropping systems, which thereby reduces water losses through drainage, runoff and consequent erosion. This is complementary to plant water use, because soil water not used by plants may contribute to drainage and runoff (Owens et al., 2007).

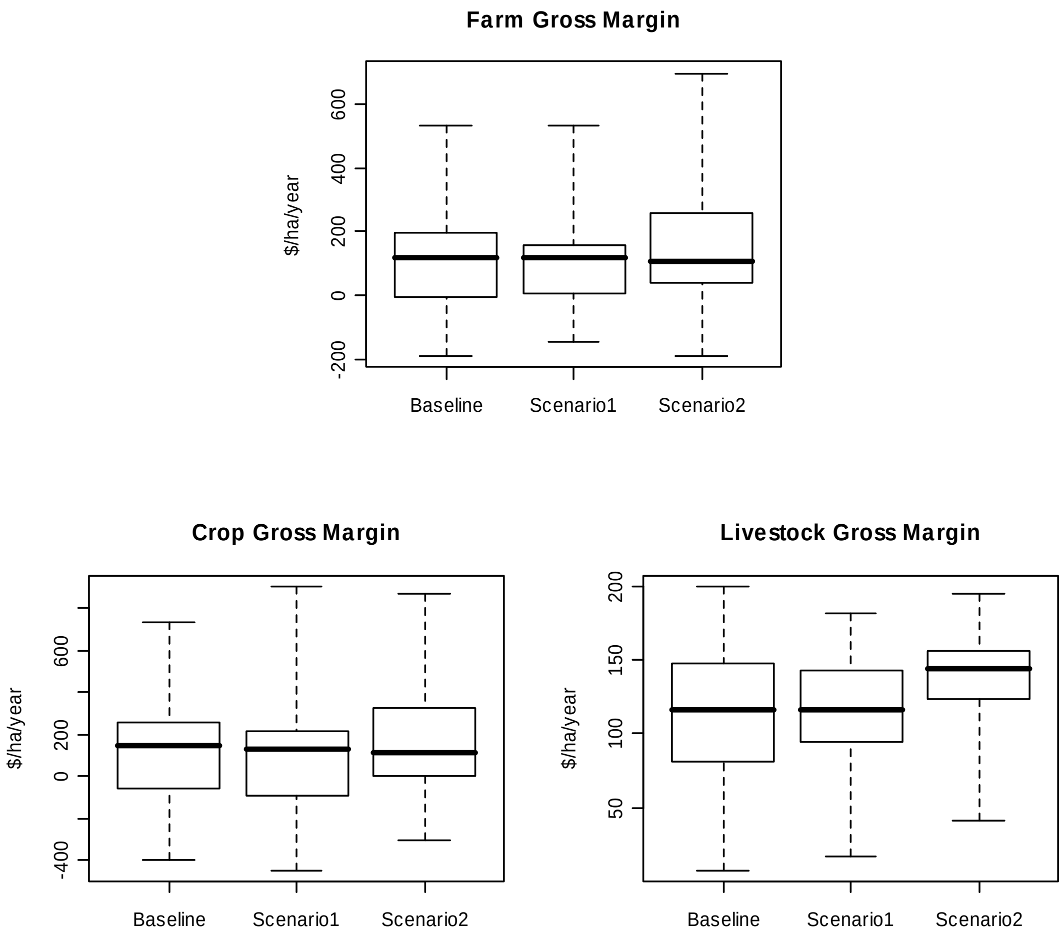

Figure 2 Gross margins for cropping enterprise, grazing enterprise and whole-farm for the baseline simulation and scenarios. The crop and livestock gross margins are calculated per area of total cropping or grazing land. (Baseline - Current enterprise mix on the case study farm; Scenario1 - increased grazing area and reduced cropping area; Scenario2 - increased cropping area and reduced grazing area)

This model has been an excellent discussion tool during the interview process with farm managers and consultants and can continue to help answer questions in mixed enterprises. Questions such as, “should we keep our mixed cropping and grazing enterprises separate or integrate them, i.e. cattle never go onto cropping paddocks?” or “what is the impact of increasing cropping area and reducing grazing area on overall farm profitability and natural resource impacts?” or “what are the impacts in the cropping paddocks on nitrogen buildup, wheat protein increase and soil moisture after a deep rooted legume pasture phase?”

4. CONCLUSION

We have developed an integrated model to simulate a mixed farm with cropping and grazing enterprises. It has the capacity to model animal production and move animals between paddocks based on feed availability. Model predictions obtained with APSFARM for the base and scenario simulations are in broad agreement with local expert opinion. From the scenario studied, a farmer who is more averse to risk may choose to increase grazing area which may reduce downside risk especially during dry periods, and have little effect on average returns. We can use this model to help improve the economic and environmental performance of mixed farming operations resulting from effective integration of cropping and grazing enterprises and better matching of land use to land capability. This work will help develop better adapted farming systems with increased flexibility and more sustainable economic growth. The animal production modelling components will continue to be improved over the next few years.

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