Crop Livestock Enterprise Model (CLEM) – a tool to support decision-making at the whole-farm scale

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Abstract
Farm management decisions can be complex, involving allocation of limited resources to competing tasks, each of which influences the final outcome. This makes it difficult to evaluate the impact of different practices on farm resources, including labour and machinery, fodder, crops, livestock and water, as well as whole farm income and externalities such as greenhouse gas emissions. The Crop Livestock Enterprise Model (CLEM) is a dynamic, bio-economic model developed to simulate the effect of diverse activities on whole of farm resources and at scales ranging from large farm businesses to smallholder subsistence farms. CLEM is a modular simulation tool included within the Agricultural Production Systems sIMulator (APSIM next generation) modelling framework. CLEM highlights the outcomes of practice change by providing simulated information to support better-informed management decisions such as identification of: the profitability of alternative practices, the likelihood of resource shortages, and the changes in labour required from adopting new technologies.

Key Words
APSIM, IAT, NABSA, simulation

Introduction
Farm management is complex and requires the oversight of many, diverse components including farm biophysical properties (e.g. soils, water supply, crops and livestock), changing technology, labour supply and farm economics. These variables interact spatially and temporally and are further impacted by variable climates. As a consequence, it can be difficult to evaluate the effect of a change in management on the farm system. Whole-farm simulation models can therefore provide a useful tool to integrate these different factors and thereby evaluate the trade-offs between different management options.

The Integrated Analysis Tool (IAT) is an example of a whole farm simulation model that was developed in the early 2000s to explore the impact of changes in management on smallholder farming systems (McDonald, 2015). It comprises three core components: long term crop and forage yields (provided as a separate input and obtained from other models or expert advice), a model for predicting ruminant growth and reproduction, and a model for simulating economic performance including considerations of the availability of land and labour resources. The impact of climate, soil properties and management on the performance of crops and forages are captured in the separate input files often taken from other simulation models, field data or expert opinion. Livestock feeding, growth and reproduction are represented in the livestock component. The profitability of farm management practices is determined by IAT within the framework of crop, forage and livestock production, and subject to predetermined limitations of land and labour availability. The IAT structure can be modified to suit local conditions and so is transferable to smallholder farms in many locations, thus contributing to its value as a tool to analyse different whole farm systems. The Northern Australian Beef Systems Analyser (NABSA) model (Ash et al., 2015) was developed from the IAT and is applicable to extensive beef systems. It has been used to evaluate the benefits and trade-offs of potential management options on beef farms such as the adoption of genetic improvement in cattle that could improve reproduction and growth efficiency, the use of nutrient supplementation, and changes to the quality of forage by using introduced pastures and forage crops.

While the IAT and NABSA have provided useful functionality and valuable insights into different farm management options, they also possess limitations that are now timely to address. The models were developed using the Microsoft Excel® platform and had large and inflexible requirements for data for each setup, difficulty in adding additional functions, and output files that were difficult to customise. In addition, the models were only available from the original developers (current and former CSIRO staff). We developed a modern version of these models to preserve their value and functionality, overcome the previous limitations and implement new functionality desired by the users. The Crop-Livestock Enterprise Model (CLEM; https://research.csiro.au/foodglobalsecurity/data-and-tools/models/clem/) incorporates the capabilities of both IAT and NABSA while placing the model in a modular framework that provides for centralised distribution, maintenance and development. The purpose of this paper is to introduce the CLEM model and describe its capability.

The CLEM model

The CLEM model is provided with the Agricultural Production Systems sIMulator Next Generation (APSIM NG; Holzworth et al., 2018) framework, thus providing a modern object-orientated and event-based programming environment. The style of the model developed is modular, so building simulations in CLEM is very flexible because of the range of components available, with further components readily added.

The APSIM NG user interface consists of a tree structure that contains the model components needed for simulation, with CLEM providing a suite of additional components. Several CLEM simulations can be created to explore alternative scenarios (e.g. a single simulation, Boorowa_Sheep_NativePasture, in Figure 1). Each simulation includes the clock to identify the duration of the simulation. Simulations can also include data files listing crop and forage yields (an input to CLEM derived from other simulation activities or created through expert opinion or literature review). CLEM simulations operate on a monthly time step.

In CLEM, *resources* are the assets available for use on the farm and can include land, labour, crops, forage resources, livestock and cash (Table 1). Resources are subdivided into operational groups. For example,land can be subdivided based on defining properties such as soil type or topography. Labour and livestock can be subdivided into individuals according to age and gender. Financial resources may be divided between different cash accounts to track expenditure and income. Resources that are produced on the farm but do not fit into other categories can also be allocated to different product stores (e.g. wool, methane gas, wood products). Ruminant nutrition and growth are based on the Nutrient Requirements of Domesticated Ruminants (Freer et al., 2007).

Activities have been developed to cover the wide range of tasks performed in the farming system and include planting crops, managing herd numbers, transporting animals, harvesting crops, and paying bills. The resources that an activity applies to can be specified using filters and activities can be implemented based on user-defined timers. This allows the user to set up specific situations such as feeding stock supplements only to lactating females. The resources and activities can be included in many combinations, providing great flexibility to model setups. Reporting consists of transaction logs, resource balance sheets and the capacity to graph the simulated results in a variety of ways.

Table 1. Examples of components that can be managed at the whole farm level within a CLEM simulation.

Resources ('assets')	Data from external input files	Activities that apply to each resource (including 'transmutation')	Examples of timers applied to activities
Land, access to common land	-	Purchase, sell, support activity (e.g. grow crops, graze stock)	Land use specified by month
Finance	-	Convert between resources by purchase and sale of resources)	Purchase additional fodder if existing resources consumed
Labour	-	Use for activities (e.g. cut and carry fodder), purchase labour, sell excess labour off-farm	Crop management activities (e.g. sow, irrigate, harvest) at specified times
Crop yields	Grain yield	Harvest, sell, process to create new products	Harvest, reprocess and sell at specified times
Animal feed types (cut and carry crop residues, on-farm pasture, common land pasture, supplements)	Crop stubble biomass, pasture biomass	Purchase, sell, graze, livestock growth	Specify daily cut and carry amounts
Livestock	-	Purchase, sell, grow, breed, wean, milk	Wean at specified animal growth phase or weight

An example of a CLEM application

An example of the CLEM model set up is demonstrated in Figure 1. The information used to describe this property was obtained from a project undertaken in the Boorowa area (CSIRO, n.d.) and is used to demonstrate how a baseline scenario of sheep grazing on native pasture appears in the CLEM tree structure. Our objective in this project was to determine whether a sheep enterprise on native pastures in good condition (our baseline) had profits that were both higher and less variable than from degraded native pastures. Additional variations to the baseline management that could potentially be investigated with additional simulations with CLEM have been illustrated in Figure 1.

The property consisted of 1,000 ha of land, divided between Hilly Country and Flats (Figure 1). In the baseline scenario, native pasture was grown on all land, but in other scenarios, alternative land uses such as sowing improved pasture or crops could be investigated. The labour resource required to operate the property was the farm owner in the baseline scenario, with labour costs such as crutching and shearing treated as an expense per sheep in the activities section. However, if it was more appropriate to account for the cost and availability of labour per individual worker, then this could be defined as a resource so that labour shortages could be identified and the cost of alternative scenarios which require external labour could be calculated. For the baseline scenario, ruminant resources were a first-cross merino flock producing wool and lambs, with cohorts based on age. Different flock structures or livestock types could be investigated in alternative scenarios. The amount and quality of different animal forages for the baseline were in the Graze Food Store (pasture) and Animal Food Store (lupin supplements for flushing and wheat grain for feed gaps).

The timing, labour and costs associated with the baseline farm activities included managing access to grazing pasture (Manage pasture) as well as a range of flock management tasks from breeding to shearing (activities are contained within the Manage flock folder; Figure 1). The activities required to describe alternative scenarios are highly flexible, with some possible alternatives described in, but not limited, to those listed in Figure 1.

The effect of all tasks described in activities were reported as changes in resource balances and as transaction ledgers. For the baseline farm, the amount and variability of annual farm income reported in the finance resource balance was especially important for addressing the research questions from the project. For other research questions, the reports of importance may differ and focus on outcomes such as identifying shortfalls in cash flow or lack of labour availability.

Conclusion

CLEM captures the whole-farm simulation capability of IAT and NABSA and replaces them with a highly flexible, transparent and user-friendly interface. CLEM is a valuable tool for investigating the effect of alternative management scenarios on farm profitability, cash flow and changes in farm resources including the identification of resource constraints.

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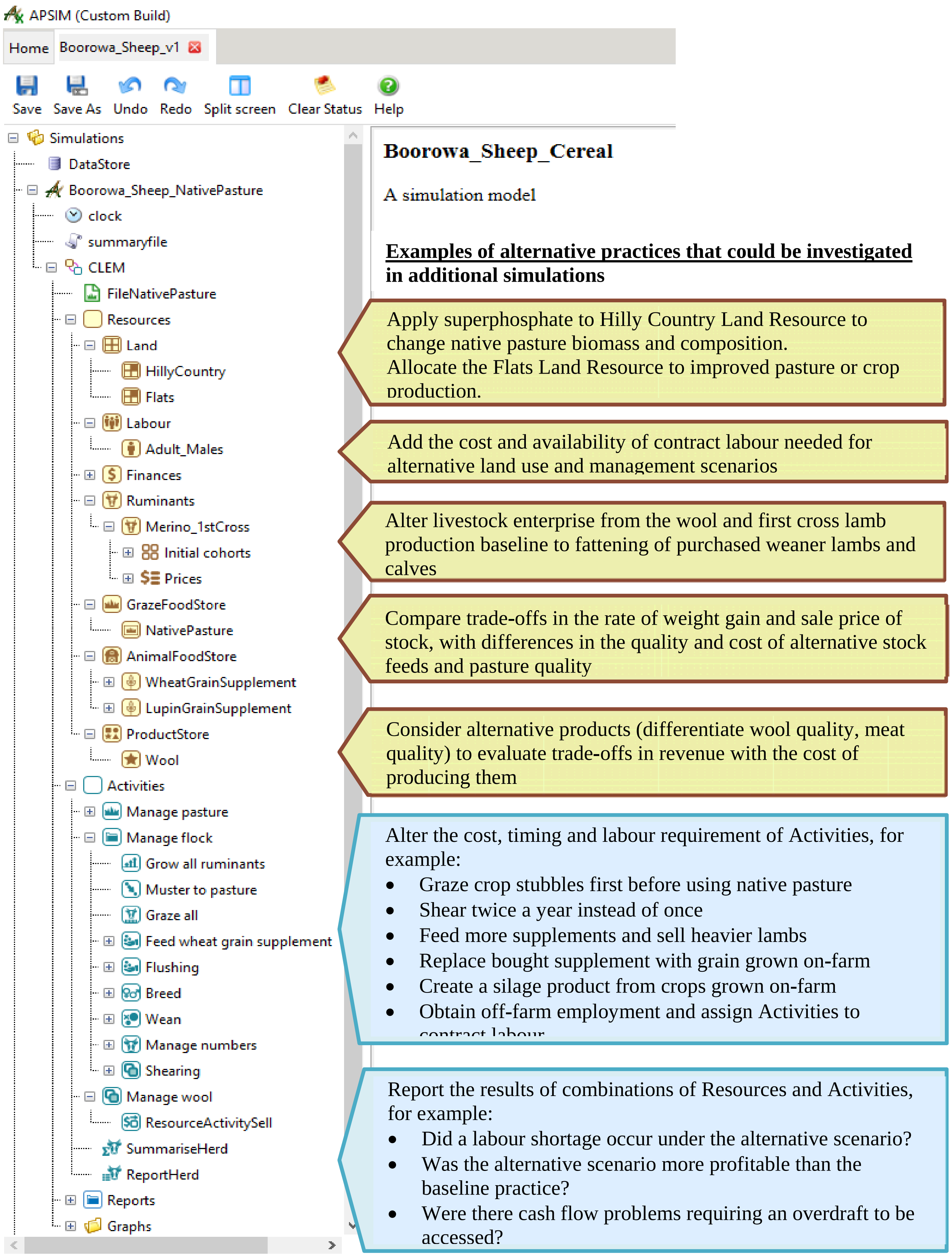

Figure 1. Example set up of the resources and activities available in the CLEM user interface used to simulate a sheep production enterprise. Some potential variations to farm management are provided on the right.