LUCI – From Single Season Crops to Continuous Sequences

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EXTENDED ABSTRACT

New Zealand has a long history of land-use change. In Canterbury, there has recently been a shift from irrigated cropping or dry land sheep production to dairy. The effects of this change in land use on the amount of nitrate being leached to groundwater are of particular concern. Assessment of the risks associated with any land use requires an accounting system that properly tracks the inputs, outputs, retentions and losses of water and nitrate over long periods of time, both in steady state and in transition. Farming systems are complex in terms of time and space necessitating validated models that take into account processes simulating the effects of major nutrient sources and sinks on appropriate time scales and that balance soil and plant processes.

In this paper we describe how we moved from a single crop model that predicted production, leaching and drainage through the lifetime of a crop to a system that addresses the above requirements. The model we developed can be initiated at an arbitrary point in time, run for an arbitrary length of time through many seasons. It keeps track of the state of the soil, predicts production, leaching and drainages from arbitrary sequences of crops and pastures, and accounts for some returns from animals.

The LUCI (Land Use Change and Intensification) Framework Model (LFM) has evolved from a suite of models that began with the Sirius Wheat Model (Jamieson et al. 1998, Jamieson and Semenov 2000). That model was designed to investigate the effects of variations in nitrogen and water on wheat production and quality. The first step in the process of evolving the LFR was to disentangle the soil, plant, evapotranspiration management and weather modules into distinct interacting objects.. This allowed a crop other than wheat to be substituted into the model. Such substitutions led to independent models for potato and maize. Simulations using these crop-specific models extend only over the lifetime of the crop, so that leaching was calculated only during that interval. However, the final water and N status of the soil was recorded at the end of the simulation.

The latest version of LFM extends these individual models by providing a framework that maintains the state of the soil from a cropping event through the fallow period between cropping events to the next crop.

The LFM operates from weather scenarios that exist for the period of investigation. It uses a soil percolation and leaching model based on the cascade model of Addiscott and Whitmore (1991). This model has been extended to include an organic nitrogen and carbon cycling day-step model derived from SOCRATES (Grace and Ladd, 1995) and CENTURY (Metherall et al 1993).

Each crop rotation is controlled by a seasonal growth model that manages the interaction among the weather, soil and crop models, with management, such as fertilisation and irrigation, determined by appropriate rules.

The LFM model may be run continuously for several years, switching among crops in rotation. Validating the component models is a continuing process – testing production, leaching and drainage estimates against field measurements (Zyskowski et al. 2007). Methods of aggregation account for local heterogeneity effects on leaching (Snow et al 2007a,b).

1. INTRODUCTION

New Zealand has a long history of land-use change. A recent example, in Canterbury, is the shift from irrigated cropping or dryland sheep production to irrigated dairy production. The change brings a concern that the new systems may carry increased risk of nitrate leaching into groundwater. To assess risks, in any land-use system, we need a way of calculating the soil mineral nitrogen and water balances that take account of inputs of N and water to the system, offtake in crops and pastures, likely cycling through animals and so forth. Account needs also to be taken of changes in management or crop rotations over many years. Because of the complexity of farming systems and changes over time, combined crop-soil models are an ideal way to assess the impacts of nitrate leaching. Such systems should balance the detail of their plant and soil process descriptions so that they are not too data-hungry, but give acceptable accuracy in their results. Ideally, the system will reasonably accurately predict production as well as drainage and leaching because then economic as well as environmental analyses of the changes may be made.

In this paper we describe how we moved from a single crop model that predicted production, leaching and drainage through the lifetime of single a crop to a system that can be initiated at an arbitrary point in time, run for an arbitrary length of time through many seasons, and will keep track of the state of the soil, predict production, leaching and drainages from arbitrary sequences of crops and pastures, and take account of some returns from animals.

1.1 Where we started

The starting point was the Sirius wheat simulation model described by Jamieson et al. (1998) and Jamieson and Semenov (2000). The model was developed to help investigate the effects of water and N on wheat yield and quality. The model contained the necessary building blocks to extend to a multi-season, multi-crop model. Components describing the state of the system all operated on a a time step of one day. The system contained a crop model whose state depended on daily weather and the water and nutrient status of the soil, a soil model whose state depended on the weather and the state of the crop, and an evapotranspiration model that depended on the weather, and the states of both crop and soil. A necessary part of the system is a mechanism for handling weather data, an essential input to the system. In the original Sirius wheat model, the soil model component was based on the percolation and N cycling model of Addiscot and Whitmore (1991). Although nitrate movement and leaching were calculated, they were a by-product rather than the object of the research.

Sirius is a well-tested model in many environments (Jamieson and Semenov, 2000). Its ability to predict the effect of variation in water and N supply led to the development of an application, the Sirius Wheat Calculator (Armour et al. 2002), a decision support system (DSS) designed to help schedule irrigation and nitrogen. Because environmental accountability was one of the drivers throughout its development, the leaching predictions, provided by the soil model, were a necessary feature rather than a by-product.

The crop, soil, weather and evapotranspiration modules were separated into interacting objects. That meant that conversion from wheat model to a potato model, for instance, simply required the replacement of the wheat module with a potato module. Everything else remained the same. This led to the development of models for potato, maize, forage brassicas and ryegrass/clover pasture all based on the same model architecture. These became the basis for additional DSSs, e.g. the Potato Calculator (Jamieson et al. 2003, 2006) and the AmaizeN Calculator (Li et al. 2006). Additional information about the development of these DSSs is given by Li et al. (these proceedings). Like the original Sirius model, the length of the simulation is from crop planting/sowing to crop maturation/harvest, thus leaching is calculated only for the duration of crop growth. The state of the soil at harvest maturity is defined.

1.2 The next step

The minimum period of interest for assessing leaching risks is an annual cycle. In Canterbury, New Zealand, leaching risk is greatest in winter, and some crops (e.g. potatoes, maize) do not grow during winter. Winter leaching, even in winter crops such as wheat, may depend substantially on the state of soil left after a preceding crop. In a sense, this increases the need to include at least two crops in sequence over longer than an annual cycle. The common thread is the state of the soil, its mineral N and water content. For a single season, organic N changes in soil are not particularly important, but over many seasons inputs of organic N are as important as losses and changes in the quality of organic matter, because they impact on processes such as mineralisation. However, the essential architecture for putting together a system model exists in the individual crop models. What is needed is a way of keeping track of the state of the soil, even through periods of fallow between crops, and takes account of the cycling of soil organic matter. Such a system can then provide, as output, the required input for models that account for percolation and leaching through the vadose zone, and be used by aquifer simulation models such as AquiferSim (Bidwell et al. 2005) to assess downstream consequences.

2. THE LUCI FRAMEWORK MODEL (LFM)

The LFM takes an XML document (see appendix A) describing the cropping rotation system and from this creates as output an XML document that describes the variables of interest.

Thus, the model operates from a single controlling function that takes as input the first XML document, and outputs the second.

The essentials of the controlling function:

1. Set up the weather data.
2. Create the soil object from the XML description.
3. Load and run each crop in the rotation.

2.1 The weather model.

Weather in the LFM is simpler than that implemented in the DSSs because is no requirement to switch between historical and future scenarios (Li et al., these proceedings). The model assumes that the weather data specified in the XML are adequate to run the cropping system described. Weather data required to run the LFM are minimum daily temperature (minimum, maximum ^{o}C), solar

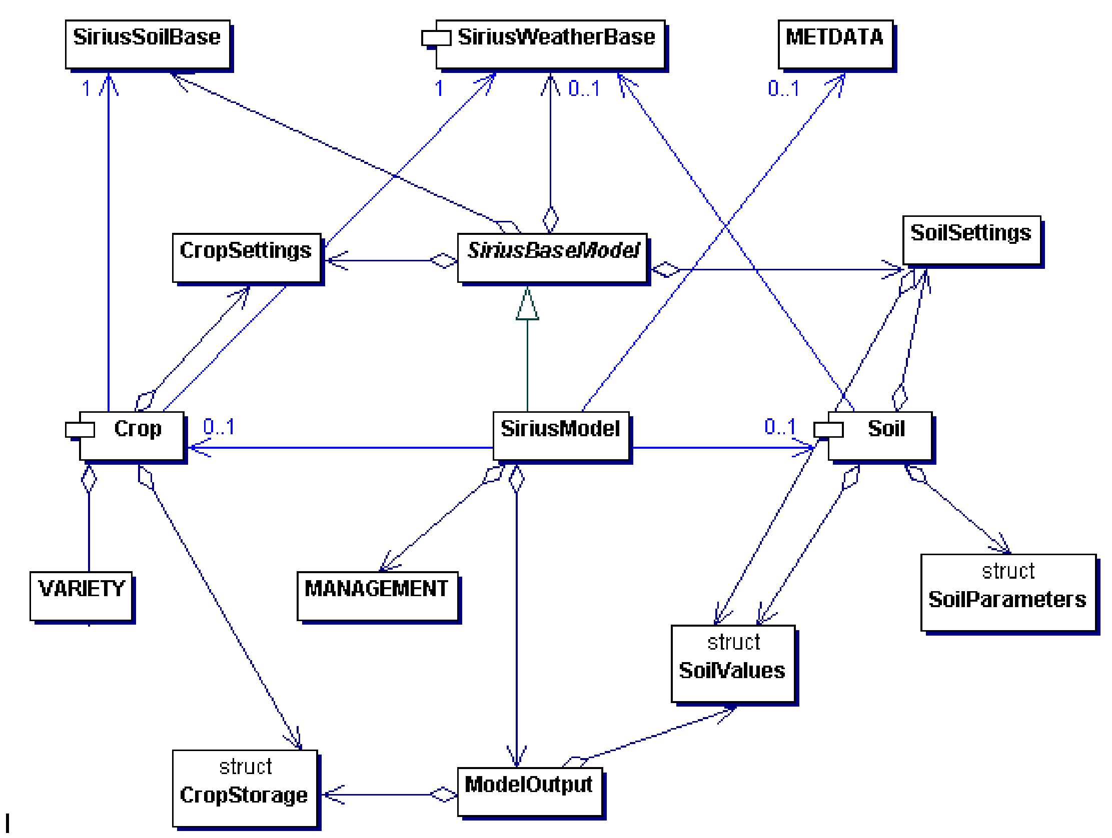

Figure 1. An outline of the class diagram of the SiriusModel. The SiriusModel is a seasonal model that processes the crop, soil, METDATA day-step models and co-ordinates the transfer of required information from one model to another.

radiation (MJ/m^2) and daily rainfall (mm). The model will make use of wind run (km/day) and vpd (kPa), if these are available The absence or presence of these latter data determine the method use to calculate potential evapotranspiration.

2.2 The soil model

The soil model in the LFM is an extension of the original model from Sirius, but replaces the simple N mineralisation model with an organic nitrogen and carbon cycling day step model derived from SOCRATES (Grace and Ladd, 1995) and CENTURY (Metherall et al 1993). This new model initialisation requires the specification of organic pools, but N mineral pools are initialised the same way they were in the original model by providing a mineral N description of the profile, or using default values assuming a previous crop

2.3 The Crop model

The crop models use a seasonal shell such as SiriusModel (Figure 1). This controls the submodels such as the crop and soil day-step models. The seasonal model also accepts a management file that details the sowing/planting date of the crop and also the amounts/timing of irrigation and nitrogen applications. A more detailed overview of the architecture is given by Li et al. (these proceedings).

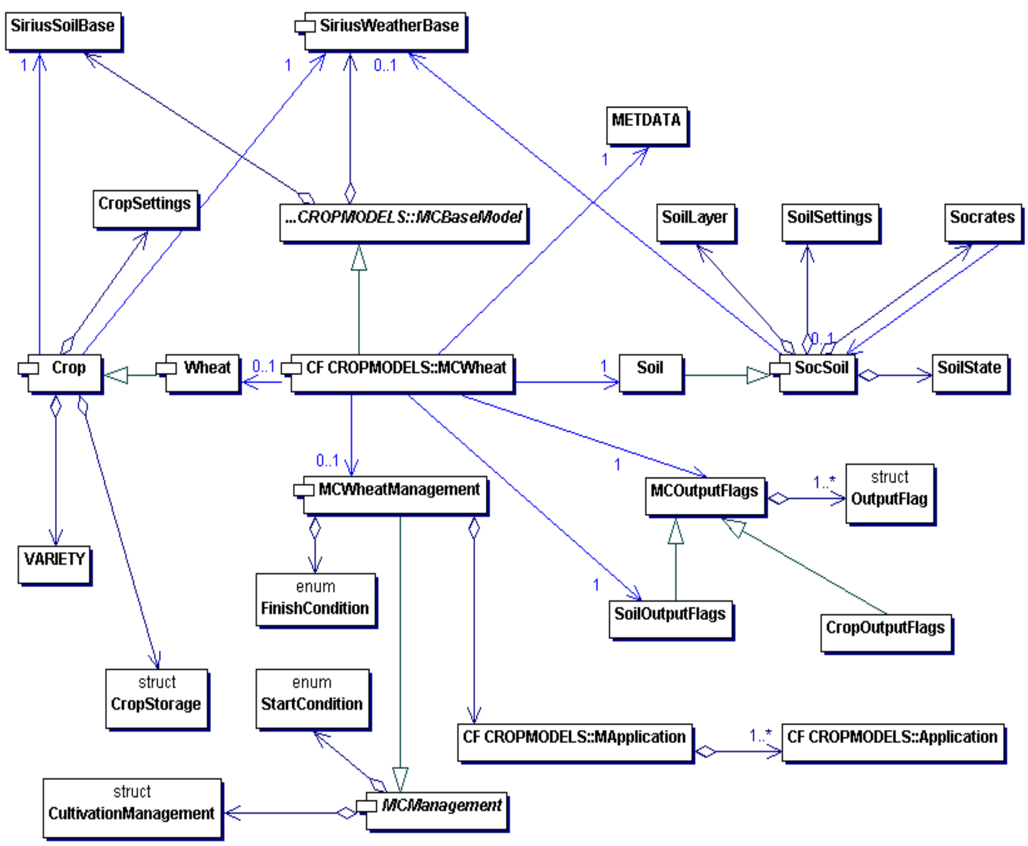

Figure 2. An outline of the class diagram of the MCWheat, the seasonal model for wheat in the LUCI framework model. This is a seasonal model which processes the crop, soil, METDATA and management day step models and co-ordinates the transfer of required information from one model to another.

The advantage of specific independent seasonal model for each crop is the ability to track seasonal effects such as anthesis and crop maturation based on the day step model used. So for the LFM the concept of the seasonal model was maintained. Thus, the addition of each new crop involves incorporating a new seasonal model. Here we use the wheat model as an example (Figure 2).

Each new seasonal model is derived from MCBasemodel, a pure virtual class that defines several virtual methods that must be implemented by the new model.

- Initialise (const XML) − Initilise the model from an XML document.
- LoadParametersFromXML(const XML) − reset parameters from XML.
- SetupManagement(const XML)
- Run() − run through the season model.
- GetDailyWeather() − Load the daily weather.
- GetDailySoil() – process interaction between crop and soil. Run the soil daystep.
- ResiduesReturn() – Add crop residues to the soil.

The seasonal model does not create the soil object but receives it in the state left by the previous crop. It does, however, control the management of the interaction between the crop and soil models.

The crop day-step model is the sole responsibility of the seasonal model, so is created and maintained internally by the seasonal model.
Management of the crop and soil is also the responsibility of the seasonal model. Each new crop defined has a corresponding management that is defined from MCManagement, a class based around the simple management class used in the original models. However, the management of a crop in the LFM has been extended because the start and finish dates of the crops may no longer be fixed by the growing season but may be defined by the previous and subsequent crops or by crop variables other than maturity. There is also a requirement for other management modules such as cultivation practice for crops, or more specific requirements such as grazing management and effects on pasture.

3. DISCUSSION AND CONCLUSION.

We have successfully converted a suite of single season crop models, focused primarily on crop growth and response to N and water, into a multi-season crop rotation model, focused primarily on the interaction between the crops and soil.

The LFM may be run continuously for several year switching from one crop to another in rotation. Some components require further testing, but it is now possible to use the model for its intended purpose − to investigate the influence of land use and management on nitrate leaching. It is already being used to investigate methods of aggregation to simulate the effects of temporal and spatial variability on both production and leaching (Snow et al. 2007a,b) and of model accuracy (Zyskowski et al. 2007).

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APPENDIX A.

An example of an input file used by the LUCI framework model. This example is replicating a treatment in a N leaching trial reported by Francis et al 1995.


```
<?xml version="1.0"?>
<Sequence xmlns="http://www.crop.cri.nz\LUCI" xml:lang="en" lang="en">
 <Info>
     <title>Templeton Leaching</title>
     <Locations>
       <Weather>C:\LUCI\WeatherData\</Weather>
     </Locations>
 </Info>
 <Paddock>
     <PaddockName>Field 4 Leaching </PaddockName>
     <WeatherStation>Lincoln</WeatherStation>
     <Soils>
     </Soils>
      <FileSource>C:\LUCI\SoilData\CFR-Central.dat</FileSource>
     <SoilVersion>SiriusScocrotes</SoilVersion>
     <Soil>
       <Proportion>100</Proportion>
```

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        <SoilNProfile>
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             <Nitrogen>11</Nitrogen>
            </Layer>
            <Layer>
             <depth>20</depth>
             <Nitrogen>38</Nitrogen>
            </Layer>
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             <depth>80</depth>
             <Nitrogen>8</Nitrogen>
            </Layer>
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             <depth>100</depth>
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            </Layer>
        </SoilNProfile>
       </Soil>
 </Paddock>
 <Rotation>
       <StartDate>1994-2-1</StartDate>
       <FinishDate>1995-3-1</FinishDate>
       <Crops>
        <Crop>
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            <Start>
             <Condition>Date</Condition>
             <Date>1994-2-1</Date>
            </Start>
            <Finish>
             <Condition>DATE</Condition>
             <Date>1994-11-1</Date>
            </Finish>
        </Crop>
        <Crop>
            <Type>WHEAT</Type>
            <Start>
             <Condition>FOLLOW_PREVIOUS</Condition>
             <Date>1994-11-1</Date>
            </Start>
            <Finish>
             <Condition>DATE</Condition>
             <Date>1995-3-1</Date>
            </Finish>
            <Files>
             <CultivarFile>c:\program files\Crop &amp; Food
Research\WheatCalculator\DataFiles\WHGENE4DSS.DAT</CultivarFile>
            </Files>
```

<Cultivar>Sapphire</Cultivar>
<ManagementSchedule>
</ManagementSchedule>
</Crop>
</Crops>
</Rotation>
<CropOutput>
<DataFlag>GreenDM</DataFlag>
<DataFlag>GrainDM14pc</DataFlag>
</CropOutput>
<SoilOutput>
<DataFlag>TOTAL_N</DataFlag>
<DataFlag>AVAIL_N</DataFlag>
<DataFlag>ORGANIC_N</DataFlag>
<DataFlag>ORGANIC_C</DataFlag>
<DataFlag>DAILY_NLEACHED_60</DataFlag>
<DataFlag>DAILY_DRAINAGE_60</DataFlag>
</SoilOutput>
</Sequence>