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ENHANCED MODELLING CAPABILITY TO CONDUCT CLIMATE CHANGE IMPACT ASSESSMENTS

Report for Contract CC MAF POL 2008-19 (126-3)

Prepared for MAF by AgResearch

June 2008

2020 SCIENCE

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ENHANCED MODELLING CAPABILITY TO CONDUCT IMPACT ASSESSMENTS

Previous worthwhile assessments of the consequences of climate change on agricultural systems have been carried out. However, none of these assessments has produced detailed impacts at the farm-scale and explored management responses. There are several advantages to operating at this scale, in particular that it is the scale at which famer decisions are made and therefore the point where adaptation and adoption must be aimed. Our approach requires detailed predictions of the biophysical impacts of climate change and an in-depth analysis of potential farmer responses.

To achieve this we will require a biophysical model, EcoMod, to project monthly pasture growth rates for future climate and CO_2 scenarios and farm system models, such as the FARMAX® suite, that can take the pasture growth projections and explore detailed short and long term management options that create profitable systems. Additionally we will use a model such as OVERSEER® to determine the environmental impact of the adapted farm system.

To achieve this level of assessment we have examined the functionality of the relevant models and the ways in which they might be linked together. Some of the improved functionality has been included as part of this project e.g. the representation of stomatal conductance in EcoMod, an ability to run simulation files with multiple weather files and five year export files of pasture growth rates from EcoMod. Other capability has been identified but not yet implemented e.g. enhancements to the FARMAX® suite such as seamlessly importing five year export files of pasture growth rates from EcoMod, new optimisation options, and data dumps to facilitate the construction of OVERSEER® files.

June 2008

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1. Aim

There is an urgent need for N.Z. to enhance its ability to conduct comprehensive impact assessments for pastoral agriculture under projected global change scenarios. The kind of assessment we see as being necessary has not been carried out before and should have the following characteristics:

1. impacts will be assessed at the farm level as this is where the decision making for adaptation will occur

2. climate projections will include climate variability and will provide a block of weather data (for 5 year or longer periods) allowing us to move away from simplistic single mean annual changes and assess the true impacts of climate change on farms systems and their capacity to recover from extreme events

3. projections of forage supply (pasture growth and feed quality), nitrogen and irrigation use will be made using an ecosystem model that includes the most up-to-date understanding of climate change impacts on ecosystem function. Our understanding of the biology of systems under climate change has increased markedly over the last five years

4. information on pests and diseases that will influence forage supply will be included in the forage supply assessment

5. using the forage supply information plus information on animal heat stress, we will run farm system models to produce yearly meat, milk and wool sales and financial data; these simulations will include detailed exploration of management options such as calving and lambing dates, fertiliser and irrigation use, stocking rate etc.

6. where management is not optimal in the future environment we will explore potential adaptive possibilities linking these options to social science research that will consider adoption

7. animal performance and fertiliser information from these simulations will then be used within OVERSEER® to model environmental impacts such as greenhouse gas emissions, nitrogen and phosphorus losses

To achieve this level of impact assessment, we have identified a number of steps that need to be taken initially, including:

1. modification of ecosystem models to capture the real impact of changes in CO_2, temperature and rainfall including long-term feedbacks on soil moisture and nutrient cycling

2. development of methods to smoothly transfer ecosystem model output data into farm system models

3. modification of existing farm system models to run multiple year scenarios that are essential for capturing future changes in climate variability e.g. can capture the impact of increased drought frequency

4. a better understanding of the functioning of various technologies such as animal health, pest control and fertilisers in the future environment

Steps 1, 2 and part of 3 are addressed in the current project and are reported here.

2. A Brief History of Impacts Assessments for Pastoral Agriculture

To emphasise the novelty of our impact assessment approach we here consider the characteristics of major climate change impact assessments that have been made in the past.

2.1 MafTechnology report 1990 (Korte et al., 1990)

This was the first report to use computer modelling to generate predictions of forage supply; changes in seasonal pasture growth rates due to climate change were simulated using a mechanistic model and a database (regression) model. The strength of this report was that the forage supply data were then fed into models of the sheep, beef and dairy sectors to give production outputs.

With hindsight it is clear that the limitations of the approach of this impacts assessment were that 1) the mechanistic model was inadequate to capture the interactions of the main drivers (CO_2, temperature, water); 2) an average change in pasture growth curves was used thus masking potential changes in variability; 3) the impact of pests and diseases was not taken into account; and 4) the animal production models were not designed to test changes in management and so were unable to look at current and potential adaptation.

2.2 Climpacts report 2001 (Clark et al., 2001)

A prediction of impacts on pasture production was included in the 2001 Climpacts report. The simulations were for four sites and produced changes in seasonal production. The model used was mechanistic but did not capture the biogeochemical feedbacks from elevated CO_2. In addition, the simulations stopped with average seasonal pasture production changes and did not use this information to generate projections for animal production.

2.3 Ecoclimate report 2008 (Wratt et al., 2008)

The most recent assessment is the Ecoclimate report. This assessment covers the whole country using interpolated surface climate projections. Pasture production is calculated on an annual basis using a simple predictive relationship between growth, soil moisture, temperature and soil particle size. Metabolisable energy for animal production was then calculated using a value for digestibility taken from the long term average assessed by remote sensing. These projections were then scaled to animal production in each region using production figures from (2001-2). The strength of this approach is that it allows coverage of the whole country and provides a net outcome at a national level. The climate scenarios used are also the most recently available and the economic analysis is comprehensive. Limitations of the approach are that forage supply is not simulated using a mechanistic model and does not include the potential impacts of elevated CO_2. This is a 'top-down' approach that uses annual mean predictions; this is a suitable approach for general economic analysis but not for on-farm assessment.

2.4 Summary

The previous impacts assessments have a number of limitations, most notably:

1. not using ecosystem models capable of capturing the complex impacts of climate change on pasture systems
2. not factoring in changes in the incidence of pests and diseases and animal health
3. only considering mean changes in seasonal or annual production
4. not taking predictions through to the farm level and considering farm management implications

5. not considering environmental consequences, including GHG emissions

3. Developing the tools

3.1 Overview

The work described below is designed to allow us to determine the impacts of climate change on pastoral agriculture as well as how farm management may need to adapt. In terms of adaptation, farm management may need to change dynamically within a year due to temporal changes in pasture growth and feed quality (Fuhrer 2003; Lüscher et al., 2004; Newton et al., 2006), heat stress conditions (Nienaber et al., 2007), irrigation requirements (Döll 2002), differences in prices of services and products (Darwin et al., 1995) and changes in selling schedules of farm outputs such as meat, milk, wool. These farm level adaptations cannot be explored using mean annual or even seasonal pasture growth projections (as used in the past) but require monthly data. In addition, decisions made in one year (on e.g. supplementary feed or stock numbers) will have flow-on effects to subsequent years making it essential to model impacts over a number of years not just a single average scenario.

To achieve the level of detail we are proposing requires an integrated approach using a model that can deliver accurate information on biophysical impacts and model(s) that can explore a wide range of management responses to these impacts. The models we are proposing to use are EcoMod (Johnson et al., 2008) which can predict monthly pasture growth rates for future climate and CO_2 scenarios by mechanistically representing nutrient cycling in soils, plant growth and the relationships between soils, plants and animals. The farm system models - FARMAX® Pro (www.farmax.co.nz; Marshall et al. 1991) and FARMAX® Dairy Pro which integrates FARMAX® Pro with dairy cattle equations from MOOSIM (Bryant et al., 2008) – will then use the pasture growth and quality output from EcoMod to explore detailed short and long term management options that create profitable systems. Finally, we will use OVERSEER® (Wheeler et al., 2008) to determine the environmental impact in terms of nitrate leaching and GHG emissions of the adapted farm system. The main purpose of this project is to address model capability and to develop a method to seamlessly integrate outputs from one model to the next.

3.2 Model linkages/dependencies

Summary requirements

The major system outputs to derive climate change impact assessments will include monthly pasture growth rates, nitrogen and irrigation use, change in soil carbon and nitrogen, meat, milk and wool sales, financial data, greenhouse gas outputs, nitrogen leaching and phosphorus losses. Three models (EcoMod, the FARMAX® Pro suite [Sheep/Beef and Dairy] and OVERSEER®) will form the essential components for undertaking climate change impact and adaptation assessments. The schematic presented in Figure 1 gives an overview of the proposed integration of the models, including:

1. Regional daily climate and CO_2 projections from NIWA, along with regional soil information will be used in EcoMod to set up representative regional farms.

2. EcoMod will then be used to project monthly growth rates from meteorological and soil data using a "cut trial" with and without irrigation and nitrogen inputs. **Outputs will include:** monthly pasture growth rates, feed quality, nitrogen and irrigation use, change in soil carbon and nitrogen.

3. Monthly pasture growth rates (with and without irrigation and nitrogen inputs) will then be entered into FARMAX®, preferably for time series of up to five years to determine the year to year flow-on effects.

4. Monthly heat stress indices derived from regional daily climate projections will be used in FARMAX® Dairy Pro to adjust animal performance due to heat stress conditions.

5. The FARMAX® suite will then be used to simulate the farm system and management scenarios including changes in calving and lambing dates, stocking rates and supplementary feed use. **Outputs will include:** yearly meat, milk and wool sales and financial data.

6. FARMAX® files which detail animal performance (milk, meat and wool), nitrogen used, supplements used and animal intakes will be used to construct Overseer files.

7. OVERSEER® will be used to model the environmental components of the farm system. **Outputs will include:** greenhouse gas outputs, nitrogen leaching and phosphorus losses.

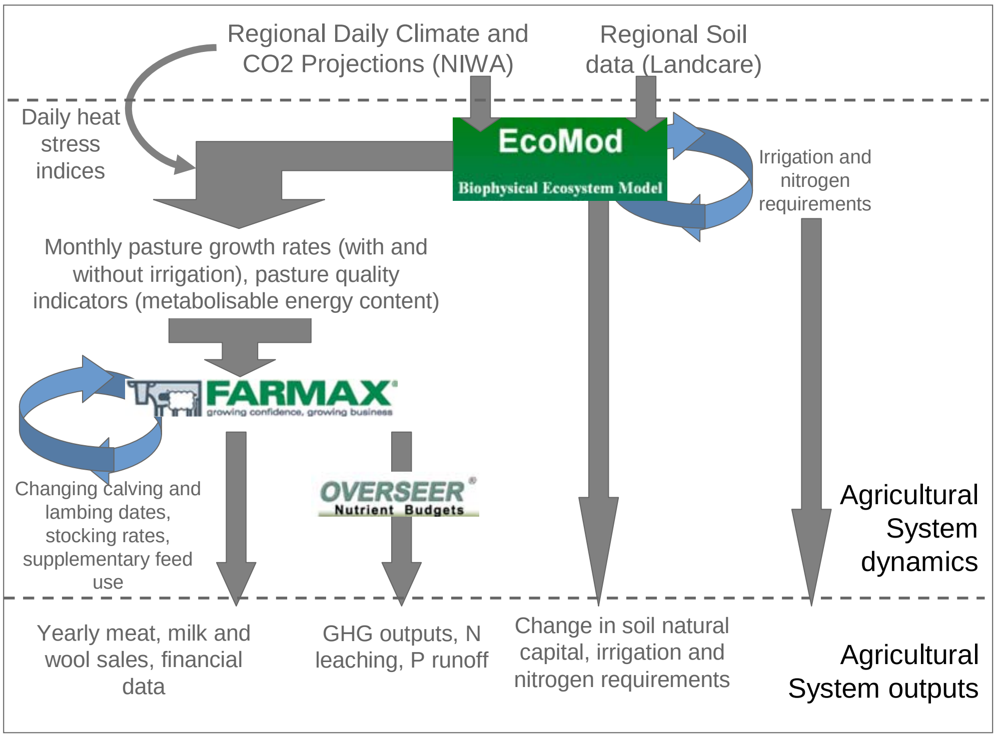

Figure 1: Integration of EcoMod, FARMAX suite and OVERSEER® to carry out impact assessments for climate change

3.3 Model suitability

3.3.1 Results of EcoMod testing

3.3.1.1 General model behaviour

Initial simulations were carried out to assess the capability of EcoMod to predict biophysical outcomes in line with previous findings of experimentally imposed climate change scenarios. In this set of simulations, a typical Taupo pumice soil with perennial ryegrass/white clover pasture grazed rotationally with dairy cattle was used with two climate scenarios. Firstly, a base Taupo 50 year daily weather file was generated stochastically from historical data with atmospheric CO_2 concentrations of 380 ppm (No Climate Change). Secondly, the same weather file but with yearly stepwise increases in temperature and atmospheric CO_2 concentrations that resulted in a 1.5 °C and 70 ppm increase in temperature and atmospheric CO_2 concentrations by 2050 (Climate Change).

The simulation results indicated that nitrogen leaching declined and nitrogen fixation, N_2O emissions and volatilisation increased in response to climate change (Figure 2). These findings are consistent with the findings of the review by Fuhrer (2003). Drainage was reduced due to elevated temperatures, which was a function of increased transpiration and evapotranspiration, all as expected (Tubiello et al., 2007). Both organic N and carbon increased in the climate change scenario suggesting reduced availability of mineral N, which is consistent with the findings of Lüscher et al. (2004) and Newton et al. (2006). Pasture intake was relatively unchanged due to the combined effect of a promotion of growth from enhanced photosynthetic activity, and suppression of growth due to reduced water availability and higher summer temperatures. Clover content in pasture increased by 7%, and this increase in clover content contributed to the elevated levels of nitrogen fixation. Both results are consistent with the review by Lüscher et al. (2004) and experimental data of Newton et al. (2006). These initial results suggest EcoMod can largely simulate soil nutrient cycling and plant growth in response to climate change.

Further detailed validation of EcoMod is now in progress using actual experimental data from the New Zealand FACE experiment and from the TasFace experiment.

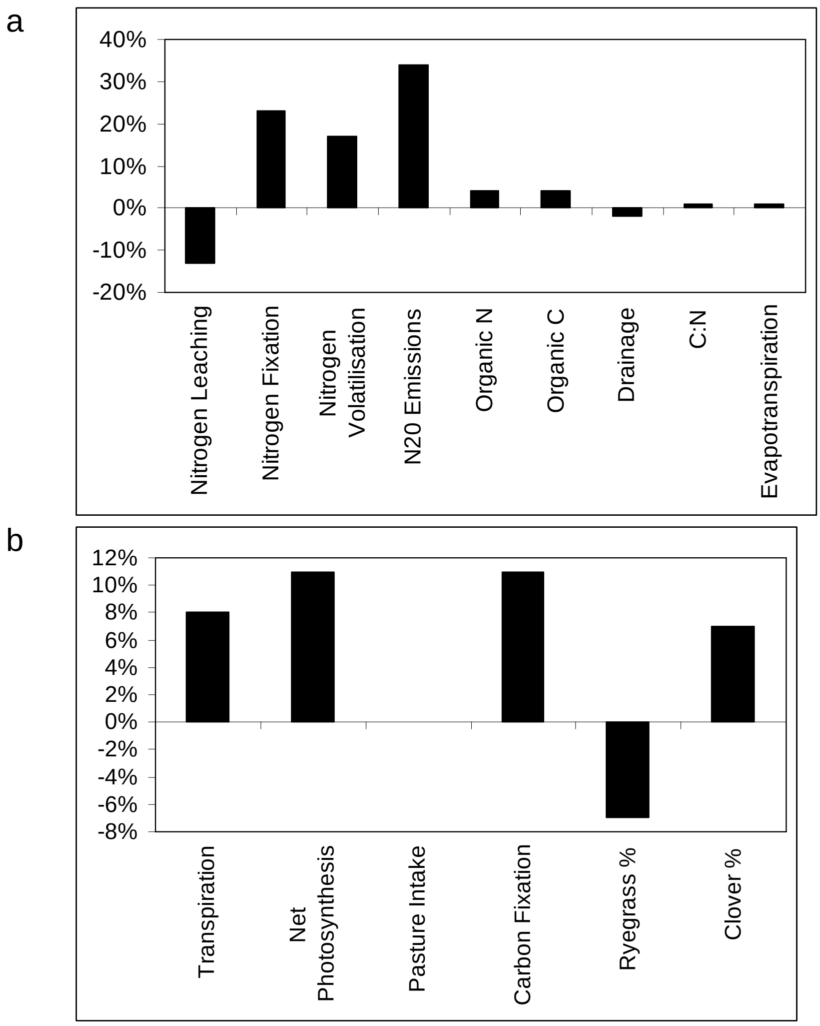

Figure 2: Percentage average changes in soil (a) and plant (b) parameters due to elevated temperatures and CO_2 concentrations.

3.3.1.2 Pasture composition

Additional simulations were run where the C4 species paspalum was included, along with perennial ryegrass and white clover. Under climate change the growth rate of paspalum in the sward increased, similar to the findings of White et al. (2000) who measured the biomass of pasture species after high temperature regimes were imposed. The result is consistent with the hypothesis that C4 grasses will experience a southern shift in future climates. We also observed a slight increase in the percentage of clover under climate change, although the shift was not as great as that observed with the ryegrass/white clover sward (section 3.3.1.1). Also observed was an overall increase in pasture growth due to climate change. This was most noticeable in February due to extra paspalum growth, and in winter and spring due to extra ryegrass and clover growth. Based on this preliminary analysis, the broad dynamic changes in pasture composition and growth appear to be represented in EcoMod however our confidence in these simulations will be enhanced by proposed experimental work to explicitly study C4/C3 interactions under elevated CO_2 and temperature in the New Zealand FACE experiment.

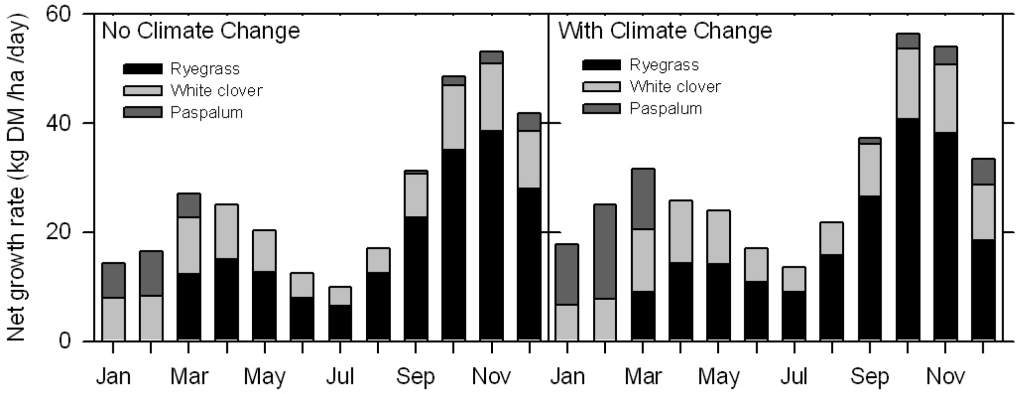

Figure 3: Net average growth rate of ryegrass, white clover and Paspalum in the sward of pasture for simulations with no climate change (left) and climate change (right).

3.3.1.3 Missing elements

During these simulations it was noted that EcoMod does not include a representation of stomatal conductance. Rising atmospheric CO_2 concentrations lead to a reduction in stomatal aperture and conductance which causes a reduction in leaf transpiration (Drake et al., 1997; see von Caemmerer et al., 2001 for New Zealand data). Consequently, plant water use efficiency usually increases in elevated CO_2 environments. This should help to offset the predicted 2 to 3% increase in potential evaporation per 1 °C increase in temperature (Fuhrer, 2003). Thus, the addition of a representation of stomatal conductance would enhance EcoMod’s predictive capabilities. This has been developed and tested in section 3.4.1.

3.3.1.4 Results of FARMAX testing

Initial simulations were carried out to assess the capability of FARMAX® Pro and FARMAX® Dairy Pro to simulate the flow on effect of modifications to pasture growth patterns. In this set of simulations, summer pasture growth was modified to simulate a summer drought. In Fig. 4a, the effect of a summer drought for a sheep and beef property is clearly illustrated in the current and following year. A lower pasture cover leading into the second winter makes the current level of production infeasible, as illustrated by the red line. In addition, the summer drought prevents the early harvest of supplements in the second year.

a
b
c

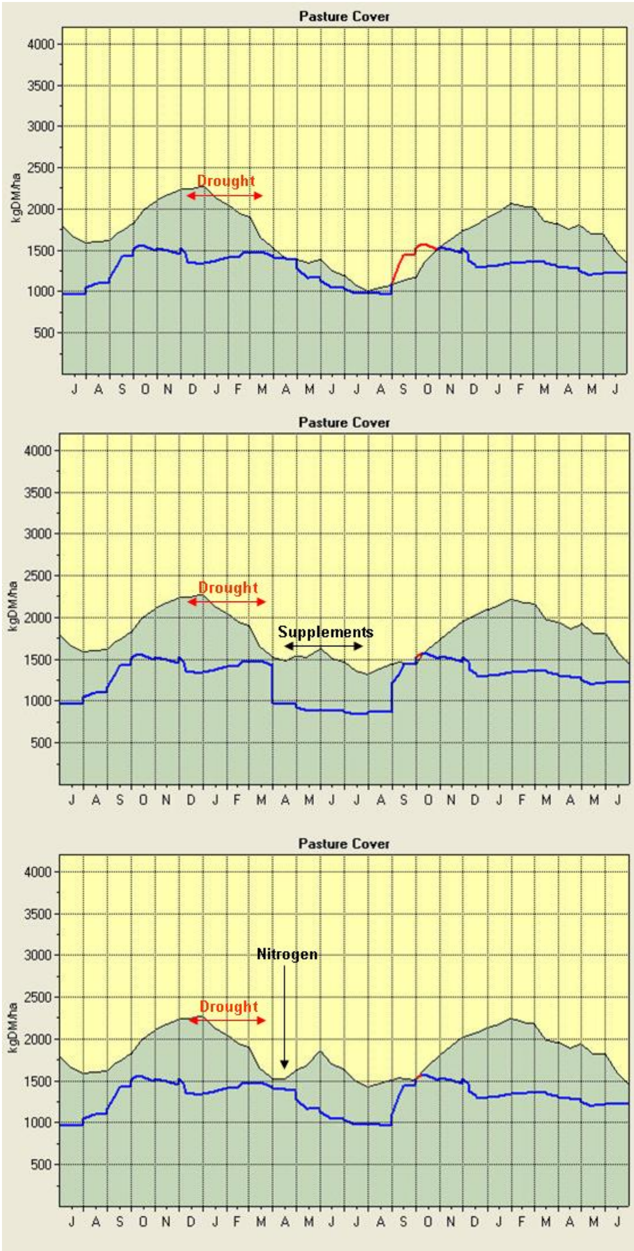

Figure 4: Effect of a summer drought on farm cover in the current and following years for a sheep and beef property using FARMAX® Pro (a), and the effect on farm cover when (b) feeding purchased supplements, or (c) applying nitrogen. **Note:** Black line represents predicted pasture cover and Blue line represents minimum pasture cover to achieve performance targets.

Managerial optimisation methods in FARMAX® Pro to overcome the pasture deficit caused by the summer drought include the feeding of purchased supplements (Fig 4b), or the use of nitrogen (Fig 4c) in April of the first year to boost winter growth. However, both incur a financial cost with the former dependent on supplementary feed availability. For instance, use of nitrogen and purchasing additional supplements reduced farm gross margin by 5 and 6% respectively. If we consider supplementary feed costs may increase by 50% due to the increased demand on supplements due to the summer drought then gross margin will reduce by 8%. These simulations also illustrate that pasture cover at the end of the two years is still below the cover at the start of the simulations. Therefore, animal performance would also be compromised in years 3 onwards due to the summer drought in the first year. For this reason we propose that the model be enhanced so that at least five year simulations are possible (see section 3.5).

In the FARMAX® Dairy Pro simulations (Figure 5), the low pasture covers (Figure 5a) lead to a reduction in pasture intakes in summer in the first year and consequently a dip in milk solids production (Figure 5b). To prevent excessive weight loss, once a day milking (green flag) was implemented from the end of February and all cows were dried off at the end of March due low pasture covers and low body condition scores. The effect of the summer drought on pasture cover (Figure 5a) flows onto the second July with this influencing pasture allowances and milk solids production (Figure 5b) in the second spring period. To increase low cow body condition scores (a flow-on effect of the drought), once a day milking was implemented again in the second year.

The sheep/beef and dairy simulations illustrate that the effects of summer drought, or climatic changes, affect not only the year in which they occur but also subsequent years. However, farm level adaptation such as supplementary feed use and nitrogen applications can ensure the effects of a summer drought on pasture cover and animal performance are minimised. Both FARMAX® Pro and FARMAX® Dairy Pro can be used to effectively model the effect of climate changes on pasture cover and animal performance, but most importantly to explore farm level adaptation options and the economic consequences of these managerial changes.

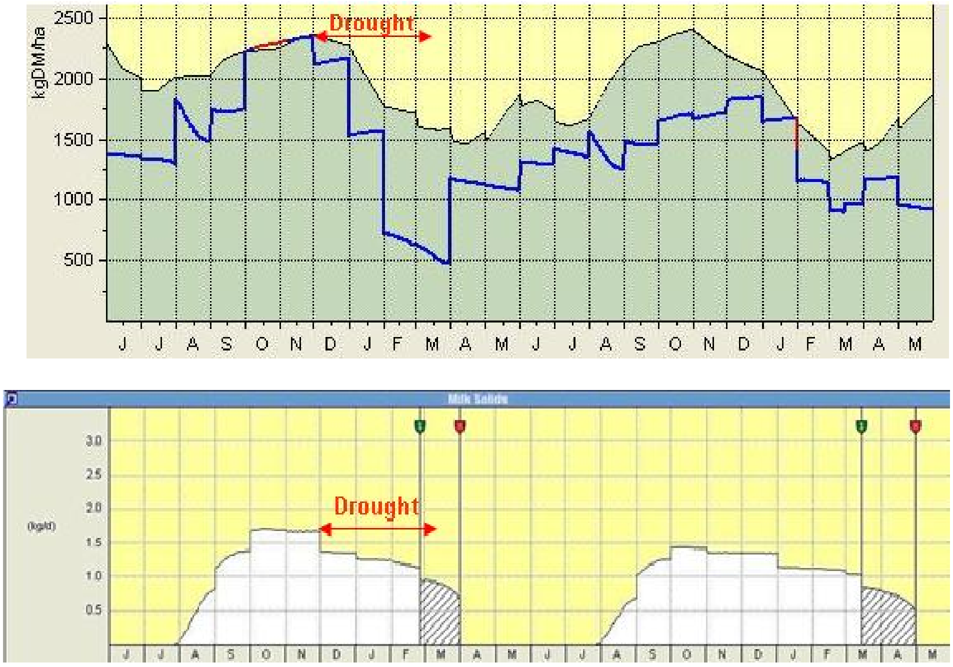

Figure 5: Effect of a summer drought on (a) farm cover and (b) milk solids production in the current and following years for a dairy property using FARMAX® Dairy Pro. **Note:** Black line represents predicted pasture cover and Blue line represents minimum pasture cover to achieve performance targets.

The simulations also highlighted some limitations of the FARMAX® suite.

1. Growth rates from an ecosystem model such EcoMod need to be manually inputted into the FARMAX® suite. A more automated, streamlined method is needed.
2. The existing two years may be insufficient to fully explore the farm level flow on effects of changes in pasture growth due to climatic events.
3. Reproductive success of dairy, sheep and beef is influenced by animal body condition score or live weight change post parturition (Thomas et al., 1987; Selk et al., 1988; Beukes et al., 2007). This phenomenon is not represented in the existing FARMAX® equations.
4. Monthly milk solids adjustments due to heat stress are represented in FARMAX® Dairy Pro based on region that the dairy herd is located. However, the intensity of heat stress events is likely to increase under climate change scenarios. Consequently, a facility is needed to alter the degree of heat stress based on the new meteorological files.
5. In FARMAX® Dairy Pro, an optimisation option is needed to “reduce pasture intake” when feed supply is short rather than a manual adjustment.
6. A comprehensive data dump of multiple result sheets from the FARMAX® suite is needed to easily generate OVERSEER® files and for easy farm system summarisation.

3.4 Ecosystem model development

3.4.1 Stomatal conductance

Stomatal conductance has historically not been represented in EcoMod, while increased evaporation due to higher temperatures is (see section 3.3.1.1). We saw this as a limitation in carrying out climate change impact assessments. Consequently, a representation of stomatal conductance and its interplay with atmospheric CO_2 concentration has now been incorporated into EcoMod as represented in Figure 6. Essentially this ensures canopy conductance reduces at elevated CO_2 concentrations leading to reduced pasture transpiration, or greater water use efficiency.

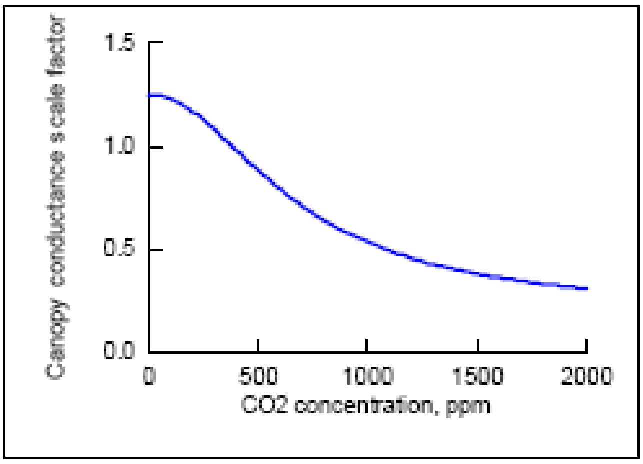

Figure 6: EcoMod representation of reduced canopy conductance at elevated CO_2 concentrations.

To test the effect of this representation, additional simulations were performed with and without stomatal conductance. A reduction in pasture transpiration was observed over time due to increased CO_2 concentrations (Figure 7). In percentage terms the effect on total pasture transpiration was small, consistent with the simulation findings of Thornley & Cannell (1997) and the experimental data of Newton et al. (2006).

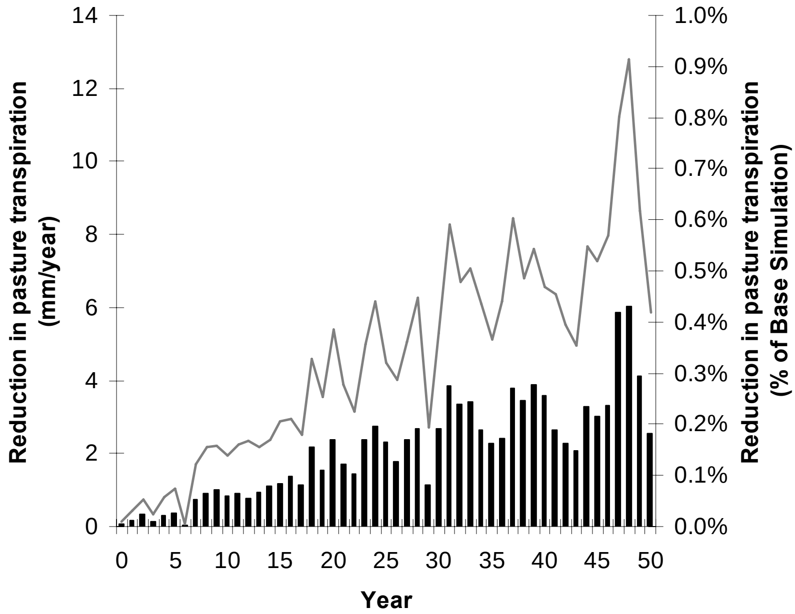

Figure 7: Reduction in pasture transpiration due to the inclusion of the stomatal conductance factor in mm/year (—) and as a percentage (■) of total pasture transpiration relative to the BASE simulation.

3.4.2 APSIM integration

While the current version of EcoMod (Johnson et al., 2008) includes most of the functionality to simulate pasture production under climate change (see section 3.3.1), it will be essential to have the capability to run many realisations of future weather resulting from the NIWA climate change projections. The current version of EcoMod requires user intervention to change the weather file and this will be a limitation on the adaptation simulations. Work is underway to link EcoMod into the CSIRO Common Modelling Protocol (Moore et al., 2007) used in the APSIM simulation model (Keating et al., 2003). This linkage will bring with it the ability to easily run many simulations with different weather files.

Progress to date (May 2008) has the EcoMod DLL loaded into the APSIM interface within an APSIM paddock (Fig. 8). Work is in progress to expose EcoMod variables so that the simulation can be controlled through APSIM's management scripting (e.g. grazing, irrigation, fertiliser application).

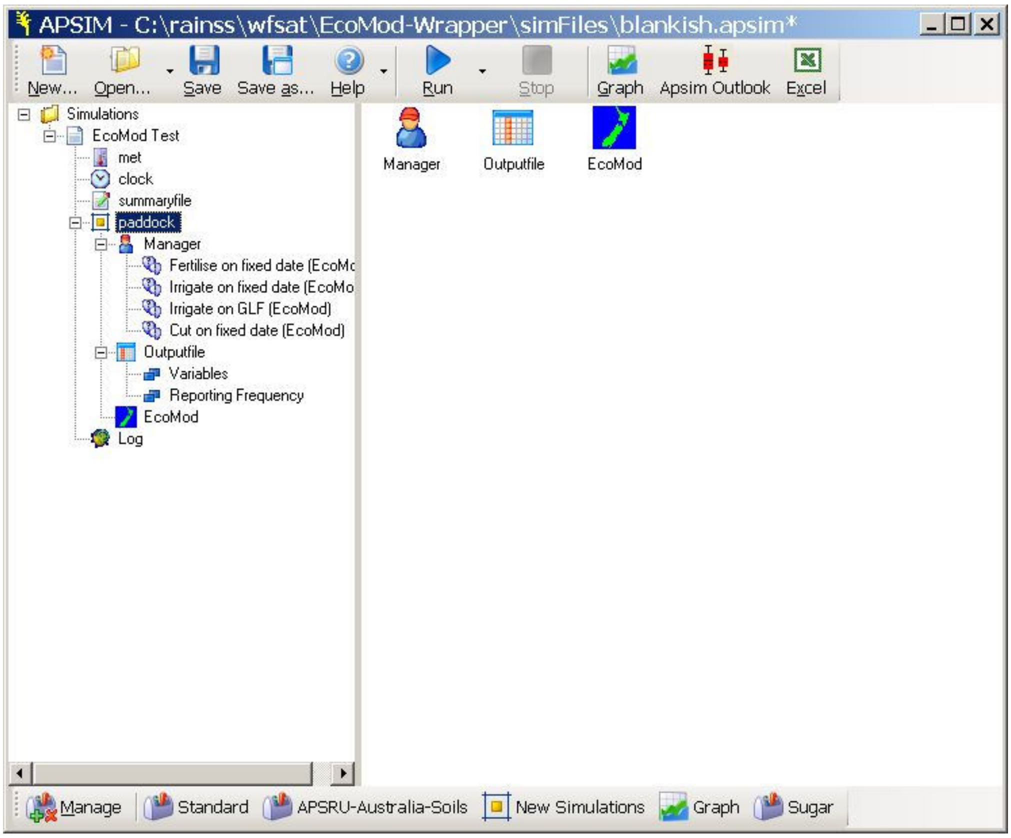

Figure 8: An APSIM paddock containing the EcoMod module

3.5 Farm model development

The design specifications for changes to the FARMAX® suite include:

1. Import of Pasture Growth Rates

Add the facility to select a text file for import of pasture growth rates. Growth rates to be identified by month, or optionally by month and year. File format to be confirmed, presumably CSV, one year per row. Five years of pasture growth rate data per file.

2. Five-Year Files

Extend the current FARMAX® suite applications to support up to five consecutive years in a single file to allow for simulation of recovery from drought. The existing interface, data structures and conventions to be preserved as far as possible, but with an expectation of proportionally higher memory footprint and slower calculation time. If necessary, recalculation of the model can be made a manually triggered process. The user can choose to view the whole period, or any 12 months within it. When the farm is extended from 1 to 5 years, the stock and land use patterns from year 1 will be copied into the subsequent years.

3. Prediction of Conception Rates

Explore the possibility of including equations to predict conception rate according to change in live weight and current body condition score. Currently, sheep conception rate is based on live weight only. AgResearch would need to provide the equations. The user would be able to override the result, as they can now. NB. The model would become a lot more dynamic, e.g. if changing pasture cover affected the subsequent birth numbers, especially in long-term mode.

4. Import of Monthly Heat Stress

Allow "heat stress factors" to be defined, displayed and edited monthly; also allow this to be imported from a text file in a similar manner to the pasture growth rates above. In this case, each factor would be associated with a specified month and year. If the user chooses not to define these factors, defaults will be substituted based on the specified region, as now. The interface associated with this feature will be able to be hidden, for those not using it.

5. Reduce Pasture Intake Option (FARMAX® Dairy Pro only)

Add a "Reduce Pasture Intake" option to the Modify menu in FARMAX® Dairy Pro. This would apply only for dairy cattle (i.e. after their first calving). In order to simultaneously support replacement or other stock, this could be presented as "Reduce Live Weight/Intake", such that either LW gain or intake is reduced. In any case, the user would be able to exclude mobs from the optimisation, as they can now.

6. Data Dump for Overseer and farm system summarisation

Add the facility to dump the key data from FARMAX® in one go to a single text file. The data would be in a form suitable for conversion into a file usable by OVERSEER® and farm system summarisation. The file to include: intakes (by sheep, beef, deer, dairy), supplement feeding, nitrogen use, milk, meat and wool production, BCS profile, stock reconciliation numbers, financial data, key performance indicators and cash flow.

3.6 Development of linkages between models

3.6.1 Ecosystem to farm model

A rigorous impacts assessment will require many simulation runs to fully expose the effects of climate change on the biophysical system. Therefore it is necessary that there are available automated methods for handling the large amounts of simulation data that will result. For this we have a simulation Post Processor that requires further development for use here. The current version is well-suited for ecosystem impacts but requires a robust link to the FARMAX® farm system simulation model. The general design of this link (through exchanged ascii file) has been decided in collaboration with FARMAX® developers.

3.6.2 Farm model to nutrient model

To create OVERSEER® files from FARMAX® output files we will adapt an existing Visual Basic for Applications macro. This macro will be developed to accommodate the full FARMAX® export file, with the option of creating different OVERSEER® files depending on the farm system being simulated. This will significantly reduce the time it currently takes to set up OVERSEER® files that do not conform to a simple structure.

3.7 Summary

1. To explore the effect of climate change on agricultural systems, and how these systems can adapt between and within years, we have constructed a framework where a biophysical ecosystem model (EcoMod) is linked with farm level models (FARMAX® suite and OVERSEER®).
2. The existing biophysical ecosystem model, EcoMod, with recent additions developed as part of this project, now realistically represents the major emergent properties arising from climate change that have been documented in the literature. These include altered pasture composition, temporal shifts in pasture growth, altered water use efficiency due to changes in stomatal conductance, reduced availability of mineral nitrogen and increased nitrogen fixation.
3. Existing features of the FARMAX® suite, and proposed developments, will allow us to easily determine the effect (production, economic and social) of climate change on sheep/beef and dairy systems and to explore the adaptive capacity of these systems. The environmental consequences of these adapted systems can then be determined using OVERSEER®.
4. Features to facilitate the easier transfer of data from one model to the next have been developed or are under development. These include the integration of EcoMod into the APSIM framework which will ensure simulations with different weather files can be run easily, and export of monthly pasture growth rates for integration into the FARMAX® suite.

4. Conclusion

We are now confident that we have the tools necessary to conduct a farm-scale impacts assessment. Further research is necessary to refine the ecosystem model projections and to include other factors such as impacts on pests and animal parasites but the components to establish the necessary framework and links are present and improvements can be made as new information becomes available. A farm-scale assessment will provide impact information at a completely new level to anything previously produced; this is a particularly powerful scale to explore because it is the scale at which farming decisions are made and therefore connects directly into adoption and adaptation. This approach is in contrast to the recent top-down EcoClimate assessment and would fit with currently available monitor farms or demonstration farms if they were instituted.

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