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Original paper

Use of a pasture growth model to estimate herbage mass at a paddock scale and assist management on dairy farms

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ABSTRACT

Knowing the amount of herbage mass available on the farm (ideally measured weekly) is an important step in achieving high pasture utilization on pastoral dairy farms in New Zealand, but the information must be used in a timely manner to make efficient management decisions. However, most New Zealand dairy farmers do not measure their pastures regularly. This project aimed to develop a simple alternative, in the form of a prototype software tool (Pasture Growth Simulation Using Smalltalk, PGSUS) to predict herbage mass at an individual paddock level, which reduces (not eliminates) the requirement for physical data collection and provides more information from the measurements taken. The main data requirements are pasture herbage mass for each paddock and grazing or cutting events. A climate-driven pasture simulation model is used to predict herbage mass between intermittent pasture measurements. The pasture model contains certain empirical parameters that are fitted to the observed data for each paddock individually, using all the previous data to "train" the model. PGSUS requires daily weather data, including mean, minimum and maximum air temperature, solar radiation, rain and potential evapotranspiration. Data from the Virtual Climate Station Network (VCSN) from NIWA (National Institute of Water and Atmospheric Research Ltd., New Zealand) are used to drive the model. Preliminary testing was done on two commercial dairy farms, one in the Waikato (North Island) and the other in the Canterbury (South Island) regions of New Zealand. Up to 28 days without measurements, PGSUS estimated herbage mass with correlation of approximately 0.9 and with small bias.

1. Introduction

New Zealand has a combination of climate, soils and pastures which enables cattle to be grazed on pasture throughout the year. These conditions give the opportunity for the production of low-cost milk; however, to ensure farm profitability this opportunity needs to be capitalised upon through efficient and optimal farm management practices. Profitable dairying in New Zealand relies on a set of management decision rules (Macdonald and Penno, 1998) that aim to optimise per hectare profitability. This high per hectare profitability, associated with high pasture utilization, can best be achieved through above ground herbage mass measurement and subsequent accurate pasture allocation (Hedley et al., 2006).

Assessing pasture mass is the first step towards effective management decisions (e.g. daily pasture allocation, surplus conservation, supplementary feeding), but the information must also be soundly utilized to make these decisions. A management tool being used on New Zealand dairy farms is the "feed wedge", which is a useful technique being promoted by DairyNZ (www.dairynz.co.nz), that requires periodically walking and measuring herbage mass in all the paddocks of the farm (the "farm walk"), typically using a rising plate meter (L'Huillier and Thomson, 1988) or sometimes visualy (Macdonald et al., 2007) and other methods (Dalley et al., 2009). It is a simple picture of the farmer's paddocks ranked according to their herbage mass (from highest to lowest mass). The feed wedge is a concept used to describe how much pasture feed is likely to be available for animals in the near future, which in turn drives decisions about daily feed allocations, grazing rotation speed, and the use of feed supplements. The desired outcome of these decisions is that animal requirements and pasture growth are kept in balance to optimise pasture utilization. Pasture management decisions are made by comparing the individual paddock distribution of the herbage mass against a target line connecting desired pre- and post-grazing herbage masses (Van Bysterveldt and Christie, 2007).

To be useful, and have a chance of being adopted, a decision support model should address a real problem or opportunity that is of current and immediate concern to the user (Campbell, 1977). In this case, there is an opportunity and also a problem. The opportunity

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is represented by the productive advantages of grazing management based on objective pasture measurements. The problem is that the majority of dairy farmers in New Zealand do not regularly measure herbage mass due to the time required to collect, store and analyze the data. Current methods used to collect this data, are tedious and time consuming (Barrett and Laidlaw, 2005), and with on-farm labour scarcity (Tipples and Morriss, 2002), the benefits of collecting such data need to be very clear to the farmer.

The aim of this study was to develop a simple, partial alternative to estimate herbage mass, in the form of a prototype software tool (Pasture Growth Simulation Using Smalltalk, PGSUS). This tool would minimise (not eliminate) the requirement for physical data collection and provide more information from the measurements taken. The methodology involves estimating herbage mass at the paddock level using intermittent observations and supplementing these with a climate-driven pasture model. Similar concepts have already shown promising results (Baars and Rollo, 1987; Prewer et al., 2002). Now the widespread computer ownership and internet connectivity of New Zealand dairy farmers make the concept technically feasible. PGSUS is designed to predict the 'feed wedge' at any point in time, up to 2–3 weeks after the last farm walk. The results produced by this tool are not prescriptive; it does not tell the farmer what to do. The way it would support farmers' decision making would be by providing timely herbage mass estimations, which the farmer can then apply in many ways, including the feed wedge.

The concept proposed here implies fitting a relatively simple, climate-driven, pasture model (McCall and Bishop-Hurley, 2003, modified by Romera et al., 2009) for each paddock on the farm and using the current pasture state to estimate growth. There is, of course, a trade-off between model simplicity and realism. But, in principle, more realism is not necessarily better, as thoroughly discussed in a special issue on simple or realistic modelling in the journal Computational & Mathematical Organization Theory (Coen, 2009). There are arguments in favour, and against, simplicity and realism (in terms of accuracy, scientific understanding, model development cost and usability of the model). The choice depends on the question that needs to be answered (Cioffi-Revilla, 2009). More complexity and detail may be beneficial in many circumstances, but this does not guarantee more accuracy (Seligman, 1993; Sinclair and Seligman, 1996; Buede, 2009) due to increased uncertainty in the input data and model parameters (Håkanson, 1995). Therefore, unnecessary or unjustified complexity should be avoided (Ward, 1989; Sterman, 2000; Levis, 2009). A simple, yet well tested, proven and available model seemed the appropriate approach for this concept. Nevertheless, the project is not restricted to using this particular pasture model in any fundamental way, i.e. there is no inherent reason not to incorporate a better, perhaps more comprehensive pasture/soil model (e.g. include soil nitrogen dynamics, more detailed soil water modelling, and considering spatial variability within paddock) in future versions, if required and if the necessary input data were available.

More realism here would involve higher spatial and time resolution and more bio-physical processes represented in greater detail (i.e. a more mechanistic model). Higher resolution could improve model realism and possibly prediction accuracy (Woodward and Rollo, 2002), but model scale must match with the scale of observation in the input and calibration data sets (Law and Kelton, 1991; Gallant and Reed, 1999). In our case, weather inputs are daily; pasture measurements are weekly at best; and there is usually only one mean herbage mass estimate per paddock. For this project the input data to feed a more complex model would have been unavailable to the users. The approach followed here tried to minimise the need for difficult input data from the user (Wight and Hanson, 1993), particularly detailed soil descriptions (as opposed, for example, to a model like APSIM, Keating et al., 2003), soil nutrient content, and pasture composition (species and cultivars).

This paper reports on the development and preliminary testing of PGSUS to estimate herbage mass at the paddock level on commercial dairy farms in New Zealand.

2. Materials and methods

The main data types required are pasture herbage mass for each paddock and defoliation events (grazing or cutting). A climate-driven pasture simulation model (Romera et al., 2009) is used to interpolate between the intermittent pasture measurements. The pasture model is initialized, for each paddock, with observed data (from the farm walks or grazing/cutting residuals) entered by the farmer, from which the pasture model estimates daily growth rates (using current weather data) and pasture herbage mass for the successive days between pasture measurements. This process starts again every time a new pasture reading for a paddock is entered.

The pasture model contains certain empirical parameters that are fitted to the observed data (see Section 2.1). All the data stored for that paddock are used to "train" the model. At first, pasture measurements need to be done weekly and the better the data (i.e. more frequent measurements, no missing data and more spatial coverage within paddocks), the faster the "training", until the system eventually develops empirical "models of each paddock". Once model predictions are considered accurate enough (PGSUS has inbuilt goodness-of-fit indicators), the user can reduce the frequency of the measurements. Ideally, it would be desirable to only have to measure pre- and post-grazing masses, while the model estimates all other herbage masses.

2.1. Underlying model description

The following two sections present the models used to estimate pasture growth. Model choice is not a crucial element of this concept. This particular pasture-soil water model was chosen mainly because of its simplicity (few parameters that could be fitted), availability of the source code and because it was well known to the team who developed PGSUS (already using the model for other applications). It could have been any model responsive to weather; even a statistical one. The last two sections describe model training and weather data.

2.1.1. Pasture model

The model is based on McCall and Bishop-Hurley (2003) adapted by Romera et al. (2009). This is a relatively simple model of a general nature which, although developed and tested for ryegrass-based pastures in New Zealand, it could be parameterized to other temperate grasses and situations. The pasture model contains a major state variable, green herbage mass to ground level (G; kg DM/ha), for which the rate of change (or net accumulation) is determined by the balance between new daily herbage growth (N; kg DM/ha/day) and daily herbage senescence (HS; kg DM/ha/day):

$$\frac{dG}{dt} = N - \mathrm{HS} \quad (1)$$

The new growth rate is calculated as:

$$N = (\alpha \times I \times g_T \times g_w \times c(G) - r(G)) \times 10 \quad (2)$$

where α is the relationship between daily solar radiation and net photosynthesis (g DM/MJ). I is the incident solar radiation (MJ/m^2/day) g_T is the temperature growth factor (function of air temperature, values ranging from 0 to 1) g_w is the soil water factor (actual evapotranspiration [AET]/potential evapotranspiration [PET], values ranging from 0 to 1), $c(G)$ is the green canopy light interception capability (values ranging from 0 to 1), $r(G)$ is the daily