Grass Growth Modelling: to Increase Understanding and Aid Decision Making On-Farm

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The XX International Grassland Congress took place in Ireland and the UK in June-July 2005. The main congress took place in Dublin from 26 June to 1 July and was followed by post congress satellite workshops in Aberystwyth, Belfast, Cork, Glasgow and Oxford. The meeting was hosted by the Irish Grassland Association and the British Grassland Society.

Proceedings Editor: D. A. McGilloway

Publisher: Wageningen Academic Publishers, The Netherlands

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Key points

1. Crop and grass growth models have been developed over the last 50 years, or so, but general appreciation of their benefits and potential has been recognised only relatively recently. The most popular application of grass growth models has traditionally been for knowledge understanding.
2. There is growing awareness of the potential of models in decision support systems (DSS) applications to aid pasture management and grassland budgeting on dairy farms.
3. Although some models have been developed for DSS, their widespread uptake in industry has been slow; challenges still exist which need to be addressed in order to improve their precision and user-friendliness.

Keywords: simulation, grassland budgeting, forecasting, decision support

Introduction

A mathematical model may be defined as a concise mechanism for providing a numerical description of a process or an object (Sheehy & Johnson, 1988). In simple terms, a model is a representation of a real life system, although often it is an artificial and highly simplified representation. Modelling has led to the accelerated knowledge of many commonly accepted agricultural processes and systems and provides an irreplaceable mechanism for predicting and preparing for future scenarios and offering decision support, even at a global level. Models traditionally have been used to advance understanding of the system while more recently they have been adopted into on-farm DSS including those for grazing management.

Grass growth is highly variable, even under standard management conditions. For example, in Northern Ireland in variety trials managed to a strict and consistent protocol at one site, mean growth rate over 15 years between simulated grazing in early-mid April and late April-early May was 60 kg DM/ha/day but the range was from 21 to 100 kg DM/ha/day (T. G. Gilliland, personal communication). If this level of variation can be expected under 'standard' management conditions, clearly variation of sward growth for a given time of year on-farm is likely to be even more pronounced as sward age, grazing and fertiliser management vary. This variability in sward growth rate is one of the factors which results in poor or variable utilisation of herbage produced on-farm, as farmers are unable to manage grazing with precision. For example, in a survey of utilisation by grazing of herbage grown on five dairy farms in southwest England, efficiency of utilisation varied from 51 to 83%. By increasing predictability of grass growth and animal requirement, feed budgets can be drawn up with confidence. Taking this a stage further, decision support systems can be designed, based on growth models, the interaction between the herbage produced and the animals' intake, to be a grazing management aid. An important component of such a system is the herbage growth model. While its output will be influenced by the presence of the grazing animal (briefly documented later), a major objective in building DSS for grazing management is to produce a reliable model of grass growth based on relatively simple environmental variables so that it can be used on-farm.

This paper will highlight the types of models used for the modelling of grassland production and their various applications and purposes. A number of existing grass models will be highlighted, as will the benefits of using models and their associated limitations.

Classification of models

In practice, grass growth models help to rationalise the complex interacting effects of weather and soil components on grass growth. Although they describe a complex system, models vary in their complexity; the more complex the model, the greater is the requirement for inputs. Empirical models are, in general, the simplest, based on experimental data and often consisting of simple regression relationships between input and observable output variables. However, empirical models do not lend themselves to describe complex systems, such as the physiology of grass production, due to their many contributing and interacting components. Equally, empirical models can rarely offer any insight into the biological mechanism at work within the system. Their simplicity, however, ensures that they have been used extensively to estimate crop yields (Jame & Cutforth, 1996) including grass production. For example, Corrall (1988) ambitiously collected grass growth and weather data from a series of trials around 30 locations across Europe. Others include a simple model to aid grassland management in England (Rook *et al.,* 2001), while two developed in Ireland (Brereton *et al*., 1996; Han *et al*., 2003a) provide relatively good estimates of herbage production and are based on meteorological parameters.

However, empirical models are specific to the circumstances under which they were developed. A model developed in the UK could not readily be applied in, for example, Australia, North America, Sweden or Spain, where prevailing climatic conditions, and probably soil type and local topography, are very different. The level of restriction is in practise much greater than this and micro-elements rather than macro-elements are generally responsible for precluding the widescale uptake of any empirical model. For example the model of Han *et al*. (2003a) was produced in Ireland based on a permanent grassland pasture and therefore would only be applicable to a permanent pasture sward. Likewise, empirical models such as linear regression equations describing the relationship between light interception and crop growth are often reasonable under average weather conditions but fail to deliver accurate outputs in adverse conditions when good predictions are particularly required (Monteith, 1981).

Mechanistic models, as alternatives to empirical models, are process-based as they describe the underlying processes described by theory and knowledge of the main biological principles. Mechanistic models are generally transparent (Thornley, 1998) and facilitate the scrutiny of the underlying processes of the system. Mechanistic models, while more complex, may contain empirical elements or sub-models. Such models tend to be more readily adopted in grassland modelling because of their superior robustness, accuracy and flexibility of application. For grassland systems, the main models are mechanistic and include the Hurley Pasture Model (Thornley, 1998), the Australian GrassGro model (Moore *et al*., 1997) and the EU GrazeGro model (Barrett *et al*., 2005), itself based on the mainly mechanistic Wageningen LINTUL model (Spitters & Schapendonk, 1990). Most of the models discussed further in this paper are mechanistic.

Table 1 A selection of recent models developed for grass growth prediction

Reference	Purpose/objective	Type	Application
Barrett *et al*., 2005	Grassland production and quality	Dynamic/mechanistic	European GrazeMore DSS and Northern Irish GrassCheck grass prediction service
Topp and Doyle, 2004	Policy	Dynamic/mechanistic	Forecasts of yield productivity in different agro-climatic zones in N Europe
Han *et al*., 2003	Grassland production and quality	Linear empirical	Silage production in Irish permanent pasture pasture swards
Rook *et al*., 2001	Grassland production	Empirical	Improved grassland management for grazing in England
Woodward, 2001	Grassland production and quality	Dynamic/mechanistic	Improved grassland management in New Zealand
Brereton *et al*., 2001	Grassland production	Empirical	Improved grassland management under Irish grazing conditions
Rodruegez *et al*., 1999	Climate change	Dynamic/mechanistic	Assessing elevated atmospheric CO_2 concentration
Thornley, 1998*	Biological understanding	Dynamic/mechanistic	Improved understanding
Schapendonk *et al*., 1998	Grassland production	Dynamic/mechanistic	Land use evaluation, crop yield forecasting and climate change impact
Moore *et al.,* 1997	Grassland production	Dynamic/mechanistic	Grass growth for GrazePlan decision support system in Australia
Mohtar *et al*., 1996	Grassland production	Dynamic/mechanistic	GRASIM decision support system in USA
Topp and Doyle, 1996	Effects of climate change	Dynamic/mechanistic	Grassland (perennial ryegrass and white clover) production in Scotland
Gustavsson *et al*., 1995	Grassland production	Dynamic/mechanistic	Improve management of timothy silage swards in Sweden
Parsons *et al*., 1988	Biological understanding	Dynamic/mechanistic	Understanding dynamics of grazed grass/clover swards
Corrall, 1988	Grassland production	Empirical	Pan-european grass production for growth prediction of irrigated and non-irrigated perennial ryegrass and timothy swards.

*The Hurley Pasture Model has been developed over many years and encompasses many publications and sub-models and routines (overviewed in Thornley, 1998).

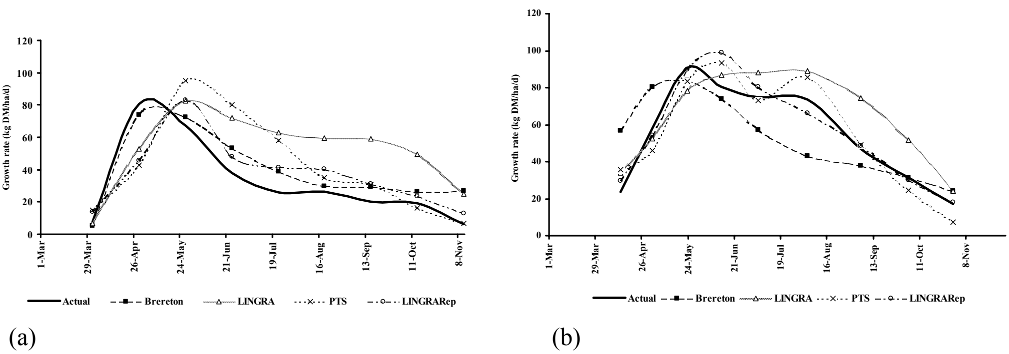
Application of models

The application of grass production models is vast. During their early development, they were often used for knowledge synthesis to gain greater scientific insight (de Wit, 1965). More recently, however, emphasis has shifted to more practical and operational use. Some recently published models and their application are presented in Table 1.

Models are useful for research and development, education and training. They can be more useful than experimentation when experimentation is not feasible or when hypotheses need to be framed before an experiment is designed. Models can also be used to transcend time and to speculate over future or historic events. Grass growth models have been used to predict the impact of climate change on grassland productivity and other vegetation (Holden & Brereton, 2002). Rodreguez *et al*. (1999) used an adaptation of LINGRA (Schapendonk *et al*., 1998) to investigate the impact of climate change and elevated levels of atmospheric CO_2 on grass growth, while Topp & Doyle (1996) developed a model to predict the specific impact of global warming on milk and forage production in Scotland. Models are also used for land and vegetation-zonation programmes. Topp & Doyle (2004) have adapted their earlier model to compare productivity and profitability of a number of grasses and legumes for silage production in different agro-climatic zones across northern Europe, while LINGRA grass growth model has been used in the Crop Growth Monitoring Scheme (Bouman *et al.,* 1996) and also used by the Joint Research Centre of the EU for crop yield forecasting in the EU (Vossen & Rijks, 1995). Potential impact of restrictions imposed by the EU on nitrogen application have also been investigated (Topp & Doyle, 2004). In recent years, grass growth models have been used most frequently as predictive tools to aid decision making by reducing uncertainties about grass production systems.

Model comparison

Due to the wide range of models available, testing may be necessary within the range of circumstances and conditions for which the models will be used. Brereton and O'Riordan (2001) and Barrett *et al.* (2004) have tested the suitability of models, varying in their degree of complexity, for prediction of seasonal grass growth curves, based mainly on meteorological inputs. The models tested in both studies were adaptations of those of Brereton *et al.* (1996), Schapendonk *et al.* (1998) and Johnson and Thornley (1985). As Brereton and O'Riordan (2001) were mainly interested in a model to predict grass growth under Irish conditions, they tested output against data for 5 years from a research centre in a grass growing region in Ireland. Barrett *et al.* (2004) were primarily interested in finding a model which would predict grass growth under the range of conditions encountered in western Europe and tested the models against data from two centres (south east England and Northern Ireland) covering a total of 28 centre seasons. In the comparison of Brereton and O'Riordan (2001), while LINGRA produced the closest fit to actual data, the least mechanistic of the three i.e. Brereton *et al.* (1996) could be easily parameterised for the specific site and so predict growth adequately. The comparison of Barrett *et al.* (2004) supports the suitability of the model of Brereton *et al.* (1996) for specific sites, in this instance the site in SE England (Figure 1, Table 2) but taking the two sites together, LINGRA, modified to take account of the reproductive phase, provides the best prediction of growth. Indeed, on the basis of this latter comparison, the modified LINGRA was used as a basis for development of a grass growth model for the EU Grazemore DSS.



(a) (b)

Figure 1 Mean seasonal growth rates (kg DM/ha/day) at (a) Hurley and (b) Belfast (legends shown on graph)

Table 2 Comparison of THE precision (kg DM/ha/day) of models tested (actual growth was 34.5 and 56.7 for Hurley and Belfast, respectively; MPE is mean prediction error)

Model	Hurley			Belfast		
	Bias	R^2	MPE	Bias	R^2	MPE
Brereton *et al*. (2001)	+5.5	0.67	0.55	-1.1	0.20	0.55
LINGRA	+19.4	0.27	1.00	9.3	0.54	0.42
Johnson & Thornley (1985)	+11.5	0.34	0.79	0.5	0.62	0.33
LINGRA (reproductive)	+5.7	0.48	0.70	1.3	0.65	0.32

These comparisons raise the issue of complexity and suitability. The most complex (those based on Johnson and Thornley, 1985) are not necessarily the most suitable for predicting daily grass growth. They may also have a requirement for inputs, which are not generally available. On the other hand, the least mechanistic was less robust when tested under contrasting conditions. So parameterising it for one set of circumstances could weaken its ability to predict satisfactorily for other conditions.

Model construction

Models applied to grassland can be categorised in more than one way as they have been built mainly to satisfy regional requirements for prediction of herbage growth and quality. For example, while models developed in western Europe and New Zealand tend to be primarily built for perennial ryegrass with or without white clover e.g. Thornley (1998), Topp & Doyle (1996), Wu & McGechan (1999), Barrett *et al*. (2005), Brereton *et al*. (1996), Parsons *et al*. (1988), Groot & Lantinga (2004) and Woodward (2001), those developed in Northern Europe have focussed on timothy and meadow fescue (Gustavsson *et al*., 1995) and for the drier south of Europe, tall fescue and cocksfoot (Duru & Ducrocq, 2002). The multispecies swards containing a high proportion of annual species in southeastern Australia have influenced the form of herbage production models in that region e.g. the pasture growth submodel in the decision support system GRAZPLAN (Moore *et al*., 1997). However, the development of a model in a specific area or region need not confine its use to that geographical zone. Variants of the Hurley Pasture Model or its simpler precursors are used in many temperate grassland regions throughout the world far removed from southeast England!

In recent times modellers seem more willing to re-develop and adapt existing models for their own requirements than develop entirely new models, serving to improve the development of tried and tested models. For example, Topp & Doyle (1996) based their model on Johnson & Thornley (1985) but introduced some adaptations to meet their specific requirements, particularly in relation to elevated carbon dioxide levels, and with some other modifications related to nitrogen uptake and moisture stress. In turn, Wu & McGechan (1998) adapted the Topp and Doyle (1996) model, including introducing the Swedish SOILN model. The chain has been continued with further development of these models (McGechan & Topp, 2004). There are other examples such as modification of the original LINTUL model (Spitters & Schapendonk, 1990) to LINGRA (Schapendonk *et al*., 1998) for perennial ryegrass swards, modification at other centres to meet specific requirements (e.g. adapted for Timothy, Höglind *et al*., 2001), to study climatic change (Rodruegez *et al*., 1999) and to be more generally applicable to grazing by introducing further functions (Barrett *et al*., 2005).

On-farm requirements of grass growth models

The main objective of many grass growth models is to improve grassland management at farm-level by predicting grass production, ranging from origins in the Southern Hemisphere (Moore *et al*., 1997; Woodward, 2001) to Northern Europe (Höglind *et al*., 2001; Gustavsson *et al*., 1995). Some primarily predict grass production and, in some instances, quality for grazing (Barrett *et al*., 2005) and for silage production (Gustavsson *et al*., 1995: Han *et al*., 2003b; Groot & Lantinga, 2004) while others predict both (e.g. Moore *et al*., 1997).

Synchronising herbage supply with herbage demand is the fundamental objective of grassland management for dairy farmers operating pasture-based systems. Grassland budgeting is simple but as it must precede production of herbage, its accuracy is severely limited by the uncertainty of future herbage supply. Therefore, grass growth prediction models clearly have a role to play in the management of pasture and paddock planning on dairy farms by limiting the uncertainty of grass supply figured into the calculations.

Traditionally, farmers can estimate paddock and farm grass covers by measuring sward height with a sward stick (Barthram, 1986) or rising plate meter (Mitchell, 1982) or making a visual estimate by 'eye-balling' herbage mass (Stockdale, 1984). Other more sophisticated methods have been developed such as the pasture probe capacitance meter (Vickery *et al*., 1980). Otherwise, destructive methods such as grass clipping and weighing from a known area can be employed (Frame, 1993). All these methods however, are time consuming and also have a relatively low level of precision (O'Donovan *et al*., 2002; Frame, 1993). O'Donovan *et al*. (2002) concluded from a comparison of methods that the most accurate estimation of herbage mass was by visual assessment. However, this assumed the operator was well experienced and had sufficient opportunity to 'calibrate' their eye against real data from cut herbage, which is difficult on-farm. The rising plate meter is the most popular method of herbage mass measurement on-farm. In a recent study, the rising plate was found to require considerable re-calibration throughout the season (Barrett & Dale, 2005) to the point that it would make it impractical on a farm.

Models, however, can be used to replace such laborious methods, while also having the advantage of being predictive. They can be used for both strategic and tactical planning in advance of growth and can be used to run endless examples of 'what if' scenarios, quantifying the outcome when inputs are varied. There is evidence that grassland farmers are favourably disposed to the use of models in management. In a preliminary survey of 80 farmers throughout Europe to gauge their attitude to a grassland management decision support system (Mayne *et al*., 2004) they cited prediction of grass growth (and herbage intake) as a priority requirement from a DSS but considered prediction of grass quality to be unnecessary for grazed swards

Linking into a DSS

The construction of models in their basic forms often would not be appropriate for use in DSS without the addition of a user-friendly interface. The interface must facilitate the input of required parameters, allow necessary degree of manipulation of data and must provide output information, all in a user-friendly and intuitive way. For complete system programs, grass growth models must be linked to herbage intake models to facilitate both the production and utilization elements of the system. This represents a major challenge but two examples are the GrassGro model incorporated into the GRAZPLAN DSS and the GrazeGro model used in the

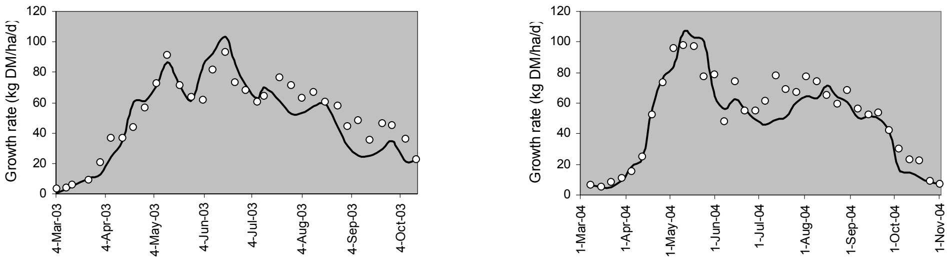
GrazeMore DSS. GRAZPLAN is a commercially available program developed in Australia but has also been used to good effect in Canada (Cohen *et al*., 2003). Secondly the GrazeGro model has been interfaced in the GrazeMore DSS together with the INRA produced GrazeIn model (Delegarde *et al*., 2004).

A simple example of farmer decision support

The GrazeGro model is currently being used in Northern Ireland in a farmer-funded programme, GrassCheck, that monitors and reports grass growth and quality on a weekly basis to industry via the farming press (Barrett & Laidlaw, 2005). It is a prime example of the direct on-farm benefits that can be gained from the application of a grass growth model. The previous 3-week's growth is monitored every week on plots across the Province and growth for the next two weeks is predicted using the GrazeGro model. Farmers can, therefore, make management decisions with relatively high confidence based on current and future estimates of grass production. Removing uncertainties from the management system is of great importance to the dairy farmer and this is a pioneering instance where the output from a modern model has been made directly available to the public for application. This project was supported by farmer demand (and farmer funding) and farmers have reported the usefulness of monitored growth rates, but in particular, the prediction of growth.

Figure 2 shows actual and predicted growth rates for 2003 and 2004. GrazeGro predicted growth very closely, indicated by high goodness of fits, with R^2 = 0.85 and R^2 = 0.89, for 2003 and 2004, respectively. This considerably exceeds the value suggested by Woodward (2001) (i.e. R^2 = 0.50 or above) to be sufficient for models for on-farm growth prediction. However during local validation, considerable differences in measured growth rates were found between sites that were managed identically and were situated close to each other. Regressions of weekly estimates of growth of each of the three sites at ARINI on each other were poor considering the expected similarities in growth rates due to similar managements. For Site 1 vs. Site 2, R^2 = 0.73; Site 1 vs. Site 3, R^2 = 0.57 and for Site 2 vs. Site 3, R^2 = 0.89. All macro difference are accounted for, as all sites experienced the same fertiliser and cutting regime and were within 0.5 km of one another, therefore climatic conditions were similar, as was topography and soil classification. However, there were sufficient additional, genotypic, environmental or historical management differences to cause relatively large differences in growth rates.

This reinforces the difficulty in providing grass growth prediction as a service for a wide range of pastures. In this case, the system was simplified, as growth was determined from small plots that were cut on the same day after 21 days regrowth. In reality, on the farm, circumstances are more complex and additional factors influence the sward. In paddocks there are problems of poaching damage (important in Ireland), rejected herbage, different soil types and differences in pH and nutritional status, even within paddocks, as demonstrated by modern soil sampling techniques using GIS and GPS technology (Bailey *et al*., 2000; Jordan *et al*., 2003). A model capable of operating under such circumstances is optimistic but must be a realisable target. However, as always, a balance has to be struck between inputs, which are appropriate, readily available to the farmer and easy to upload against output, which is feasible, if not strictly accurate, and in which the farmer has confidence. However, simplicity of the software presenting the model must be realistic. Arnold & de Wit (1976) recognised that intuitive user-friendliness is essential.



(a) (b)

Figure 2 Grass growth rate measured from plots on a weekly basis in Northern Ireland (○) and the predicted growth rate as determined from the GrazeGro model (——) in (a) 2003 and (b) 2004

Problems with grass growth decision support models

While the use of DSS is gathering in popularity, they are still underutilised as they are perceived to be more appropriate for researchers or other specialists than general on-farm users. Also, as grass growth models depend on weather measurements their predictive power is limited by reliability of weather forecasts. Some efforts can be made to circumvent this by using average weather conditions to estimate average growing conditions. Models are often based on data from plot or even glasshouse experiments and applied to fields which may have many unknown or unquantifiable variables and limiting factors. Addressing this creates difficulties for both the modeller and the user, as input parameters must be increased to account for as many of these factors as possible. The many input parameters must be balanced against the difficulty and, often, expense of input collection. Parsons *et al*. (2001) have clearly outlined the problems with increased complexity required when scaling theoretical models up to field level with the associated increase in spatial variability and heterogeneity, usually associated with grazing. Also, while defoliation of grazed swards has been well quantified and incorporated into sub-models of herbage production, detailed modeling of the other components (excretal return and treading) have been less well quantified. Reference has already been made to the modeling of the consequence of deposition of excreta on N transformation in the soil (McGechan & Topp, 2004) for dairy cows. In GRAZPLAN, primarily developed for sheep grazing, treading is taken into account in determining the rate of loss of standing dead material into the litter pool, through stocking rate (Moore *et al*., 1997). Many other functions may be required to make a grass growth model fully applicable to the grazing environment

Conclusion

The various problems with grass growth models, and particularly their decision support application, hinder their progress and widespread uptake. The perfect decision support model must be complex and all-encompassing yet robust and simple to use. All models are simplifications but for developers the decision needs to be made as to how simple the model can be while still being appropriate for the intended application. For decision support easy input with at least moderate accuracy is required. Whilst major gaps still exist in some of the knowledge for grass growth modelling, particularly in the area of plant quality, problems with a deterministic model capable of representing the complexities of the typical on-farm conditions still require much greater development and remain a major challenge for scientists, agronomists and modellers. Equally, promotion and education about the benefits of grass models and DSS should be a key priority to help promote their uptake and drive further progress in their development and accuracy.

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