Predicting yield and biomass nitrogen of forage crop rotations in New Zealand using the APSIM model

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Abstract

The New Zealand dairy industry has set a forage productivity target of 45 t dry matter/ha/year. The potential of different crop rotations to achieve this target is best assessed with a combination of field experiments and system modelling. The production of twelve crop sequences was measured in a 2 year field trial at Lincoln, Canterbury, New Zealand. These crops included three summer (maize, kale and barley) and five winter (oats, Italian ryegrass, forage rape, tick beans and triticale) crops combined into different rotation sequences. The highest yields came from the sequence maize-wheat-maize-triticale (30 t/ha/year). Sequences with kale as summer crop yielded slightly less, e.g. kale-wheat-kale-triticale produced 26 t/ha/year. We compare estimates of yield, light interception, biomass and crop nitrogen from the the Agricultural Production Systems sIMulator (APSIM) model with those measured from these two sequences. The objective was to test the suitability of APSIM to estimate forage productivity under different crop/season/management combinations. The yield of summer crops was accurately simulated root mean squared deviation (RMSD) of 1,314 kg/ha/year or 17% mean. This was a result of closely capturing light interception which was simulated with a RMSD of 143 MJ/m^2/year (10% mean). Nitrogen amounts in harvested biomass were simulated with a RMSD of 55 kg N/ha/year (18% of the mean). However, the model underestimated the highest N amounts harvested for kale (460 kg/ha/year) and triticale (350 kg/ha/year) by ~20%. These results highlight the potential of the APSIM model as a systems analysis tool for the analysis of crop sequences in New Zealand.

Key Words

Crop rotations, crop modelling, APSIM, nitrogen uptake, radiation interception.

Introduction

The New Zealand dairy industry has set a number of ambitious goals for forage productivity. This includes the target of 45 t of dry matter/ha/year, with average metabolisable energy content of 11 MJ/kg, from dairy support land. To achieve such high forage productivity it is necessary to identify optimal combinations of summer and winter crops in sequences that efficiently utilize available resources such as sunlight, water and soil nutrients. Crop and management combinations can be investigated using field experiments and simulation modelling. The performance of 12 different crop-sequences was recently investigated in a 2-year field experiment in Canterbury, New Zealand (de Ruiter *et al.* 2009; de Ruiter *et al.* 2010). Three summer crops (maize, kale and barley) and five winter crops (oats, Italian ryegrass, forage rape, tick beans and triticale) were tested in various combinations. The highest annual productivities were obtained using maize as the summer crop. The maximum measured yield was 30 t/ha/year for the maize/wheat/maize/triticale sequence, followed by ~26 t/ha/year when kale was the summer crop. In this paper we perform a modelling exercise to compare field measurements with simulations using the Agricultural Production Systems SIMulator, APSIM (Keating *et al.* 2003). APSIM was set to simulate yield, radiation interception and nitrogen uptake of two selected crop sequences containing maize or kale as summer crops, and wheat and triticale as winter crops. The aim is to evaluate current APSIM capability to reproduce measured results and identify possible points for improvement of simulations.

Methods

Measured data

Measured data were obtained from a 2-year field experiment with 12 summer-winter forage crop sequences. Crops were grown on a Paparua silt loam (sand at 300–500 mm) soil at Lincoln, New Zealand (43?64'S; 172?45'E) from October 2007 (de Ruiter *et al.* 2009; de Ruiter *et al.* 2010). The 12 crop sequences were arranged in a split-plot design with four replicates. To investigate yield and nitrogen uptake, we selected two contrasting crop sequences with different summer crops but similar winter crops (Figure 1). Summer crops were either maize (*Zea mays* cv. 'P39G12') or kale (*Brassica oleracea* cv. 'Gruner'). Winter crops were wheat (*Triticum aestivum* cv. 'Morph') in the first year and triticale (*Triticale hexaploide* cv. 'Double-take') in the second year.

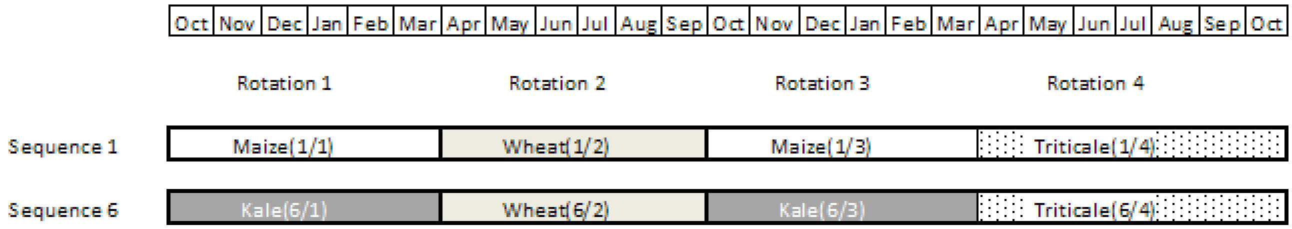

Figure 1. The two selected crop sequences from de Ruiter *et al.* (2010) for analysis in this study. Nomenclature in parenthesis refers to sequence number followed by rotation number.

Crop management

The paddock was previously in lucerne (*Medicago sativa*) so a substantial amount of nitrogen (N) was provided to the crops by mineralisation. Crops received additional fertiliser and irrigation to ensure that growth and development were unconstrained either by nutrients or water supply (de Ruiter *et al.* 2009). Soil water measurements indicated that crops were not water stressed throughout the experimental period. In addition, frequent chemical control of weeds, pests and diseases was provided to ensure crop growth rates approached potential for the site.

Field measurements

Above ground biomass was measured from 0.5 m^2 quadrat samples fortnightly. Fractional light interception was measured at 6–14 day intervals using image analysis from photographs to discriminate green leaf from background soil (Steven *et al.* 1986). Plant N was measured with a TruSpec CN Determinator using EDTA standards. Sampling methods are described in de Ruiter *et al.* (2010).

Modelling methodology

The APSIM model version 7.1 was used to simulate crop yield, fractional light interception and crop N uptake on daily time steps. The main model inputs are daily weather data (temperature, solar radiation and precipitation) and the occurrence of management events (e.g. sowing, harvest, application of fertilizers and irrigation) for each crop rotation. The soil organic matter content was set to ensure high rates of N mineralisation from the previous lucerne crop root residues and grazing animal excrement. Daily meteorological data were obtained from the Broadfields Station (National Institute of Water and Atmospheric Research, New Zealand), which is located near the experimental site.

Results and discussion

APSIM simulated both the time course of biomass accumulation and final yields with reasonable accuracy - root mean squared deviation (RMSD) of 10% mean (Figure 2).

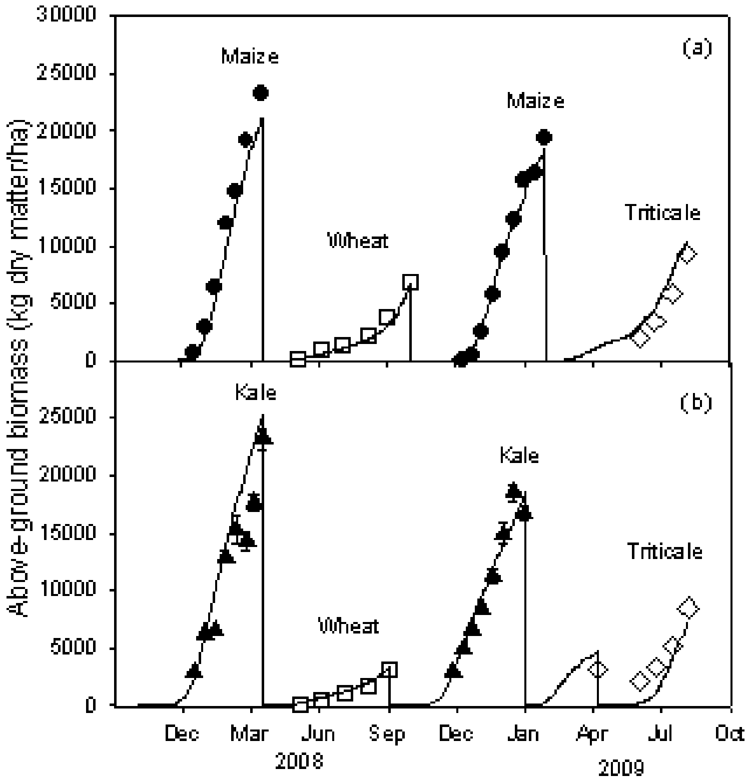

Figure 2. Measured and simulated above-ground biomass (kg/ha) for model runs (—) for crop sequences include maize (●), kale (▲) as summer crops and wheat (□) and triticale (◇) as winter crops.

APSIM closely simulated total intercepted radiation (R^2 = 96%) for all sequences (Figure 3a). Intercepted solar radiation was previously shown to be a key factor explaining yield differences in these crop sequences (de Ruiter *et al.* 2010). The overall RMSD for intercepted radiation was 182 MJ/m^2 (13% of the mean) with a slightly better fit for Sequence 1 (173 MJ/m^2) than Sequence 6 (188 MJ/m^2). Kale crops intercepted up to 40% more radiation than maize but yielded nearly the same amount of biomass (~20 t/ha/year). Consequently, the conversion of light into biomass (*i.e.* the radiation use efficiency, RUE) was higher in maize, as expected for a C4-type crop (Sinclair and Muchow 1999).

There was good agreement between estimated and observed biomass N with an RMSD of 48 kg N/ha (16% mean) for Sequence 1 having a slighter better fit (Figure 3b). Kale crops had the highest N amount retrieved in the biomass (~460 kg/ha), which were underestimated by 15% in the model in both years. The kale model used was a re-parameterization of APSIM canola (Brown *et al.* 2009) which overestimated leaf senescence. This limitation will be resolved by the inclusion of a more advanced kale model into the APSIM framework (Zyskowski *et al.* 2010). The N content of triticale crops was underestimated following kale and overestimated following wheat. Triticale was implemented as a cultivar of wheat and additional development will be required to account for differences in N uptake between the two crop types. In spite of this APSIM did predict that biomass N harvested in triticale would be higher than wheat. This was consistent with measurements (Figure 3b).

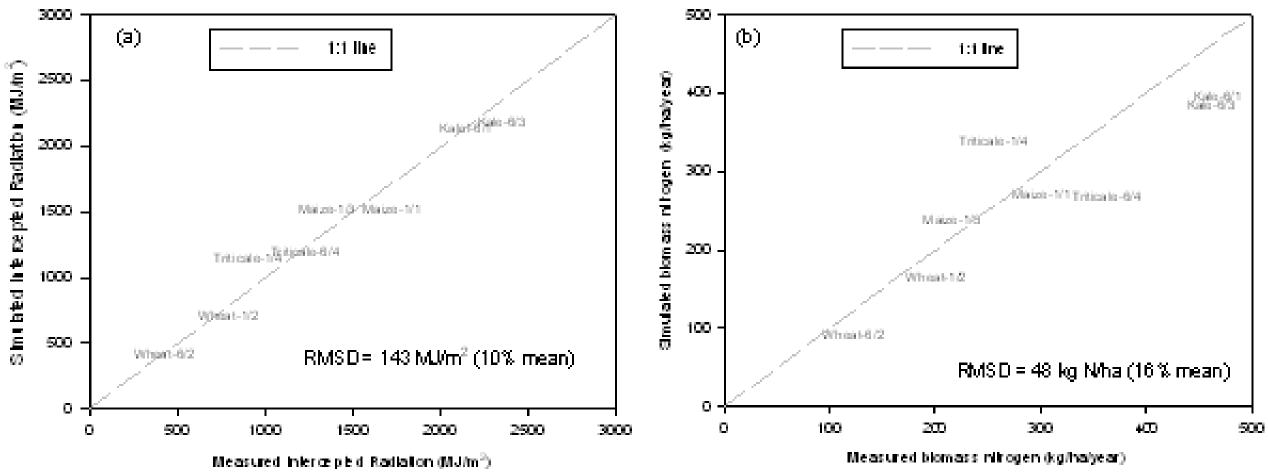

Figure 3. Measured and simulated (a) solar radiation interception (MJ/m^2) and (b) nitrogen uptake in the end of each rotation cycle. Crops are identified by the sequence (1 or 6) followed by the rotation (1 to 4) number. Simulations include re-setting soil N to measured values at the beginning of winter crops.

High N uptake by triticale may be explained by the autumn defoliation and winter/spring regrowth management. The early grazing removes leaves with high N content (Gastal and Lemaire 2002), and stimulates new leaf growth. During regrowth, the crop will then expand new leaves, increasing N uptake in the canopy, in addition to further stem and grain biomass accumulation. The accurate simulation of these soil and plant N dynamics is therefore critical to estimate crop N uptake and N leaching from crop systems.

Conclusion

The APSIM model was successfully used to simulate yield of crop sequences in a New Zealand environment. Soil and crop nitrogen dynamics were identified as critical aspects to be captured by models for accurate simulation of sequential crops under N limitation in addition to the prediction of N leaching from crop systems. Current results encourage the further use of the APSIM model as a systems analysis tool to explore crop sequences in a New Zealand environment.

Acknowledgements

Funding was provided by FRST Contract C10X0604, DairyNZ, Fonterra and Meat and Wool NZ. The authors gratefully acknowledge the skilled and persistent efforts of the team who managed and measured the rotation trial, and the APSRU team in Toowoomba for assistance with APSIM.

References

Brown H, Zyskowski R, Salle M, Sim R, Malley S (2009) Simulating kale growth and N uptake using the APSIM modelling platform. *Proceedings of the New Zealand Agronomy Society*.

de Ruiter J, Fletcher A, Maley S, Sim R, Fletcher A (2009) Aiming for 45 t/ha per annum: Yield of supplementary feed crops grown in sequences designed for maximum productivity. In 'Proceedings of the New Zealand Grasslands Association '. (Ed. NZG Association) pp. 107-116.

de Ruiter J, Maley S, Chakwizira E, Fletcher A (2010) Determinants of productivity in cropping sequences for dairy systems in Canterbury, New Zealand. . In '2010 "Food Security form Sustainable Agriculture"

Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand. Web site www.agronomy.org.au'.

Gastal F, Lemaire G (2002) N uptake and distribution in crops: an agronomical and ecophysiological perspective. *Journal of Experimental Botany.* **53**, 789-799.

Keating BA, Carberry PS*, et al.* (2003) An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**, 267-288.

Sinclair TR, Muchow RC (1999) Radiation use efficiency. *Advances in Agronomy* **65**, 215-265.

Steven MD, Biscoe PV, Jaggard KW, Paruntu J (1986) Foliage cover and radiation interception. *Field Crops Research* **13**, 75-87.

Zyskowski R, Fletcher A, Brown H (2010) Nitrogen uptake and distribution in kale. . In 'In '2010 "Food Security form Sustainable Agriculture" Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand. Web site www.agronomy.org.au'.'