Modelling nitrogen uptake and its distribution in kale

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Abstract

A simulation model of nitrogen (N) uptake and distribution is presented for kale. The model replicated experimentally observed total N for 14 kale crops, which had taken up between 150 and 600 kg N/ha, with a RMSE of 95 kg N/ha.

Keywords

Kale, Forage brassicas, Nitrogen uptake, Nitrogen distribution

Introduction

More than 25,000 ha of kale are grown each year in New Zealand and grazed as supplementary feed during winter (Gowers & Armstrong, 1994). Kale requires large amounts of N compared with other crops, but can produce yields in excess of 20 t/ha (Wilson et al., 2006, Fletcher et al. 2007, Brown et al. 2007) if sufficient N fertiliser is applied. The appropriate fertiliser N rate will depend on soil N supply and potential crop yield, and will differ from site to site (Wilson et al., 2006). However, under excess N supply, kale may accumulate large amounts of N beyond those required to reach maximum yield. This may have negative impacts on animal production, and can increase N losses when kale crops are grazed. In order to make informed N management decisions, growers need quantitative knowledge of N uptake and distribution within the crop. A series of experiments has been carried out to quantify the growth and N accumulation patterns of kale (Wilson et al. 2006, Zyskowski et al. 2004, Fletcher et al. 2007, Brown et al. 2007). This paper presents a mechanistic simulation model that integrates this knowledge to predict crop N uptake and distribution under different treatments.

Method

Data from the first sowing date of Fletcher et al. (2007) was used to develop the model and calibrate the initial parameters. This data set was chosen due to it being well managed with several N treatments (0, 150, and 500 kg/N applied per hectare) in addition to having a time series of measurements of the crop biomass and N status throughout the season. The data from the second sowing date of Fletcher et al. (2007), and the other trials (which included different sowing date and N rates), were then used as an independent test of the model's outputs. The cultivar used in all trials was 'Gruner' and the model parameterisation represent this cultivar.

Model description

The plant model is derived from one for forage brassicas that determines potential yield using a canopy-based method (Zyskowski et al. 2004), but adapted and parameterised specifically for 'Gruner' kale. It incorporates functionality to simulate N uptake, partitioning and responses to N shortage. The effects of N supply on crop growth and N uptake were based on the approach described by Jamieson et al. (2008), where N is partitioned into various pools within the plant based on a hierarchy of demands.

Nitrogen supply

Nitrogen supply is considered to be a function of available N (AvN), the root depth of the crop and a plant uptake factor (K_n) that decreases as soil water content declines. The AvN was assumed to be the nitrate and ammonia present in the root zone of the crop (Jamieson et al 1998) and the kale root zone was assumed to extend downward at a rate of 2 mm/^{o}C day.

Nitrogen uptake

N uptake from the soil (SN) is the minimum of supply, demand and a maximum daily uptake (SS_{max}) of 12 kg/ha/d (SS_{max}). Demand is set as the sum of N required to produce the daily biomass and fill labile pools, as described below.

$SN = Min(SS_{\underline{max}}, K_n \,.\, AvN, Ndemand)$

Nitrogen demand and partitioning

Daily N uptake is partitioned into leaf growth, stem growth and labile pools (LN) in the leaf and stem, depending on their order of priority. Leaf growth is the highest priority, followed by stem growth, labile stem N (LN_{st}) and labile leaf N (LN_{lf}). The N required for leaf growth is set by potential leaf area index expansion (dGAI) and a minimum specific leaf N (L_{MN}) of 2.5 g/m^2. The N requirement for stem growth is a function of the biomass partitioned to stem and a minimum stem N content of 1%.

The LN_{st} is dependent on the mass of standing leaf biomass and is constrained to a maximum N content of 3% or 200 kg/ha (whichever is lower). The LN_{lf} follows similar rules to the stem with an upper limit of 6% or 300 kg/ha.

Growth

New plant growth is dependent on the availability of N in the labile pool (AL). N is deposited into the labile pool from uptake by the roots and remobilisation from senescing leaves. The AL is the product of the size of the labile N pool and a remobilisation factor (K_{AL}) of 0.3. Thus, only 30% of the labile pool is available each day for new growth.

When the canopy is in the growth phase, AL is partitioned to stem growth first, however when in the senescence phase all AL is first used for stem growth. If AL exceeds that needed for leaf growth (N_{LG}) then there is no limitation to leaf area growth and leaf. However, if AL is less, then new leaf area growth (LAG) is limited:

$$LAG = \begin{cases} dGAI, & AL \geq N_{LG} \\ \dfrac{AL}{L_{MN}}, & AL < N_{LG} \end{cases}$$

Leaf biomass is determined by a geometric factor that partitions daily biomass increase between leaf and stem fractions. Under N shortage, leaf biomass growth will be constrained if leaf area growth is constrained and specific leaf weight reaches a minimum value of 72 g/m^2.

Stem growth is limited by N as per the leaf. However, the limitation operates on the new stem biomass (G_B) at a rate of 1 g/kg (N_{ST}) generated.

$$NG_S = \begin{cases} G_B, & AL \geq N_{SG} \\ \dfrac{AL}{N_{ST}}, & AL < N_{SG} \end{cases}$$

When N supply from the labile pool is insufficient to meet the demand driven by leaf and stem growth, then crop growth is reduced so that the minimum N content of the two fractions is maintained. When N supply is limited, stem growth is first reduced, followed by leaf growth.

Senescence

During leaf area senescence (GAI_S) N in the leaf labile pool is recycled to the stem labile pool. However, structural leaf N is lost from the system as plant litter.

Implementation

The model was written in C# and incorporated as a module into APSIM 7.1 (Keating et al 2003). Thus, we were able to simulate the range of trials conducted. As well as the experiments and treatments described by Fletcher et al. (2007), we also simulated the sowing date trial of Brown et al. (2007), which measured leaf and stem N content at harvest.

Results

For the development dataset (first sowing date of Fletcher et al. 2007) the model simulated well N uptake and partitioning for the first three months (Figures 1–3). However, we were unable to adequately replicate the senescence phase of the crop. The model appears successful in handling sub-optimal N.

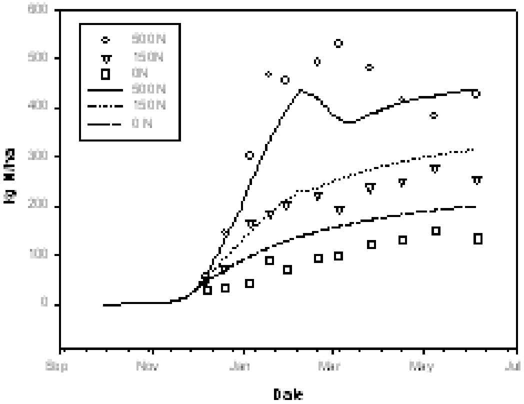

Figure 1. Total nitrogen observed (symbols) and simulated (lines) for the first (6/10/06) sowing of kale.

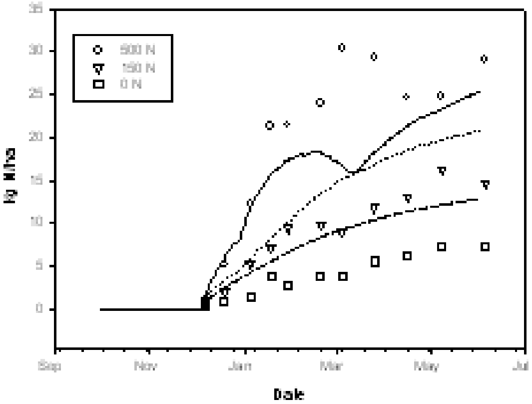

Figure 3 Stem nitrogen observed (symbols) and simulated (predicted) for the first sowing of kale

RMSE = 33.9 Kg N/ha

Simulated total leaf uptake kg N/ha

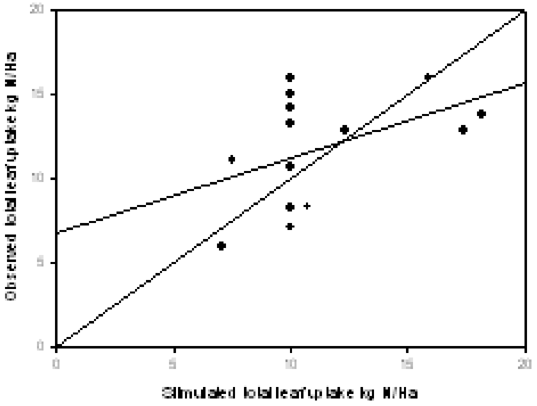

Figure 5. Simulated vs observed leaf N uptake at final harvest for 14 nitrogen and sowing treatments

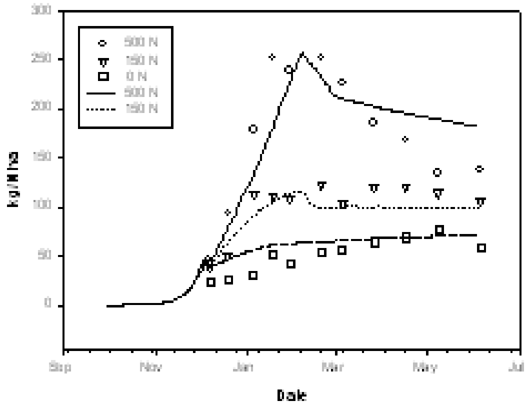

Figure 2. Leaf nitrogen observed (symbols) and simulated (predicted) for the first sowing of kale

RMSE = 95.1 Kg N/ha

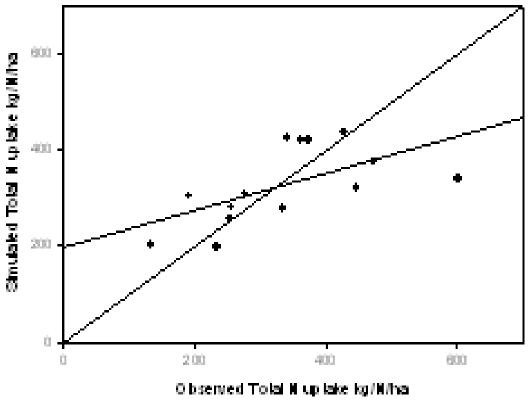

Figure 4. Simulated vs observed total N uptake at final harvest for 14 nitrogen and sowing treatments

Total N uptake

The simulated crop N uptake for all simulated experiments (Figure 4) has a RMSE of 95.1 kg/N/ha. A large proportion of this error is due to the under prediction of N uptake in the high N treatment (500 kg/N/ha) of the second sowing of the Fletcher et al. (2007) experiment, where it predicts only half of the final N taken up.

Leaf N

The model predicted leaf N of the trials (Figure 5) with a RMSE of 33.9 kg/N/ha. It resulted in an even distribution of points along the 1:1 line and an aggregation of simulated leaf N, equilibrating around 100 kg N/ha when under slight N stress.

Discussion and Conclusions

This model is a first step toward understanding N uptake and distribution in kale. Initial tests of the model gave acceptable simulations of N uptake. Under limiting or near optimal N management this model may adequately predict N uptake. However, it may not appropriately handle luxury N uptake when large amounts are available to the plant. Other issues relate to the ability of the model to predict N dynamics under senescence. The biomass senescence model in this simulation uses a simple loss of leaf area and biomass based on thermal time, once senesce is initiated, but kale senescence appears to be more complicated; the model does not predict N uptake and distribution when high LAI values accumulate.

In conclusion, we have developed a basic model of N uptake and distribution for kale, but further refinement is required to better explain leaf N dynamics under high N supply and during senescence.

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