

## **A cohort model for simulating forage brassica crops with variable plant size**

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### **Abstract**

Forage brassica crops are grown to supplement pastures in grazing animal production systems. A model is being developed that will predict yields of diverse types of forage brassica, sown throughout the year in a wide range of climates and soils. In many of these crops, plants germinate and emerge over an extended period. This results in variable plant size, which either persists or leads to self-thinning in the population. It is a particular problem for modelling brassica types such as kale which have relatively low populations, large average plant size and slow development (leaf appearance) rate. This paper describes a cohort-based model, which separately simulates plants in distinct size class hierarchies within the populations. It has been developed as part of the overall model that simulates canopy development, radiation interception and utilisation, and biomass production and partitioning. Biomass is partitioned to each cohort on the basis of its leaf area, which is a measure of its capacity to generate biomass, and each cohort grows and develops separately. Model predictions of aggregated biomass production for kale agreed closely with values measured in crop populations with mixed plant sizes.

### **Media summary**

A method is being developed for predicting yields of forage brassica crops with very uneven plant size resulting from variable germination and emergence.

### **Keywords**

yield prediction, intra-specific competition, resource partitioning, forage brassicas

### **Introduction**

Diverse types of forage brassica crops are grown to supplement pastures in grazing animal production systems. About 250,000 ha are grown annually in New Zealand. We are developing a generic radiation and temperature driven model for these crops (Wilson et al. 2004). It simulates canopy development, radiation interception and utilisation, and biomass production and partitioning, and can account for the effects of sowing date and plant population.

A particular problem in forage brassica crops is that plants usually germinate and emerge over an extended period and this results in variable plant size that either persists or leads to self-thinning in the population. The first version of our model ignores this problem. It simulates the growth and development of an average plant in the population, which develops in thermal time, and then accumulates biomass for all plants in the population each day. The approach works well for brassica types in which individual plant performance is relatively unimportant – those with high plant population and fast development (leaf appearance) rate and, therefore, rapid canopy development. However, it is not satisfactory for modelling brassica types with low populations, large average plant size and slow development rate.

In this paper we describe how our preliminary model was extended by developing and adding a cohort-based model, which separately simulates plants in distinct size class hierarchies within the populations. We also present results from field experiments that were conducted to produce information for developing the model, and for testing it by comparing predictions with results from independent experiments.

### **Methods**

Data were obtained from the same experiments as described by Wilson et al (2004). Kale was sown on two dates, at three plant populations, and at two locations. Kale consists mainly of leaves and a large storage stem component, is usually grown at relatively low populations (40 to 100 per m<sup>2</sup> in the experiments), develops slowly, has large average plant size with considerable diversity among plants, and loses a significant proportion of plants by self-thinning especially at higher populations. Therefore, the growth and development of individual kale plants has a substantial influence on crop performance per unit area.

Plants were counted regularly during the emergence periods. During growth, regular measurements were made on plants that were separated into three categories: large, medium and small. Measurements included number, area and senescence of leaves, and dry weights of leaf, stem and storage root components. The cohort model was designed and parameterized using data from the first sowing at one location (Lincoln). It was tested by comparing results from simulations with data from all sowings at the other location (Hastings).

### Model description

The model simulates a population, that like a real crop, consists of plants of varying sizes, at various stages of development, and competing unevenly for resources as a result of emergence over an extended period. This is achieved by simulating cohorts of average plants of different age (McMaster et al. 1991).

Typically, full emergence of brassica seedlings occurs over a period of about five days in warm conditions to about 20 days in cool conditions. The model starts with a population of seeds, and a new cohort emerges each day in response to a non-linear relationship that is driven by thermal time. The final number of cohorts depends on temperatures during emergence. Thus each daily cohort consists of a number of plants with similar growth and development attributes which subsequently are simulated separately from other cohorts.

Simulations for each cohort follow the same rules as described by Wilson et al. (2004). However, the shift from simulating a whole population of average plants to a population consisting of cohorts of a range of plant sizes presents several challenges. These include production of leaf area, interception of radiation and production of biomass, partitioning of biomass among the cohorts, and loss of plants caused by inadequate resource availability.

Canopy leaf area index ( $L$ ) is calculated each day by summing the area of leaf in all cohorts:

$$L = \sum^P L_c N_c \quad (1)$$

where  $P$  is number of cohorts,  $L_c$  is leaf area of an average plant in cohort  $c$ ,  $N_c$  is number of individuals in cohort  $c$  per unit area. The value of  $L_c$  for each cohort is calculated using the rules for leaf area production and loss described by Wilson et al. (2004).

Daily biomass production ( $dB$  in g/m<sup>2</sup>) is calculated at the population or canopy level as the product of the amount of radiation intercepted by the canopy and a constant radiation-use efficiency ( $RUE$ ; 1.2 g/MJ). Radiation intercepted is calculated as the product of the amount of incident radiation ( $Q$  in MJ/m<sup>2</sup>) and the proportion that is intercepted. The latter is found as a function of canopy leaf area using Beer's Law with an extinction coefficient ( $k$ ) of 0.75:

$$dB = Q(1 - \exp(-kL)) * RUE \quad (2)$$

The biomass produced each day is partitioned among cohorts as a function of the proportion of the total leaf area that is in each cohort, on the basis that this is a direct measure of its capacity to generate new biomass:

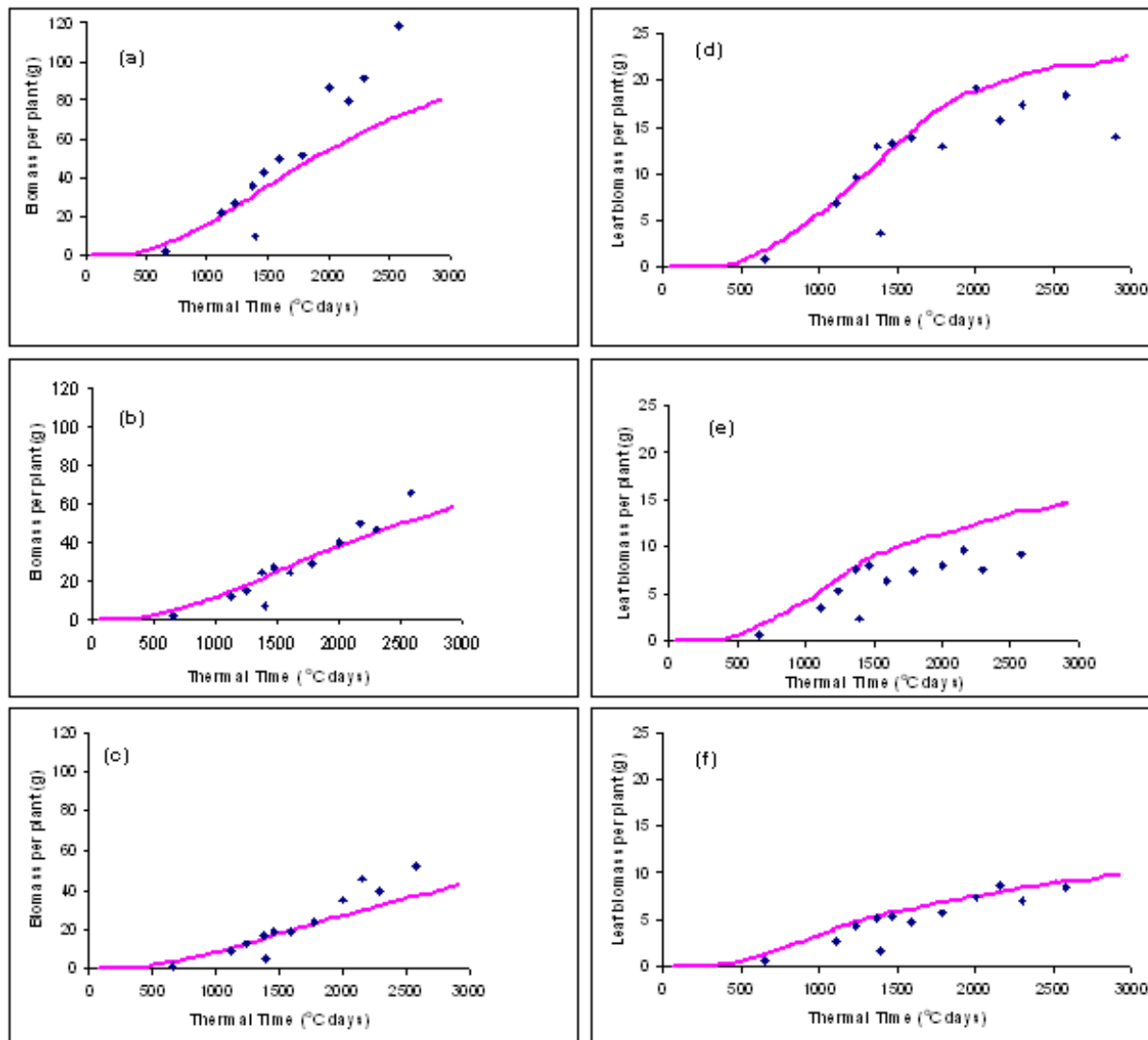
$$dB_c = dB(L_c N_c) / L \quad (3)$$

Thus earlier, larger plants receive more biomass and grow faster than later, smaller plants. Plants within each cohort receive an equal share of its allocation of biomass, and so they all grow and develop similarly.

Losses occurred at all populations so that plant numbers at maturity were well below the initial established populations. Losses were greater at the higher populations. Self-thinning is simulated by assuming that it begins when leaf senescence starts, at about the time of canopy closure. Subsequently, a constant proportion of the population is lost per unit of thermal time (0.01% per °C day). Losses continue until an optimum population is reached. This is 25 plants per m<sup>2</sup> for kale, irrespective of the initial population. Plants are assumed to senesce progressively from the smallest, latest cohorts.

## Results

Comparisons between values simulated by the model and the development dataset (Lincoln) are in Figure 1. Growth of the average plant was simulated accurately except later in the season when the model underestimated growth, especially for the large plants at the low population (Figure 1(a)-(c)). Leaf mass per plant was simulated accurately although, again, the modelled values were too high later in the season at the lower populations (Figure 1(d)-(f)). The discrepancies occurred because higher plant mortality than anticipated combined with a bias in the sampling method caused overestimates in the measured biomass per plant. The method required a sample from a small quadrat in each plot, and also stipulated a minimum number of plants per sample. As a result, sample selection was biased towards an area in each plot with larger plants, where less self-thinning had occurred. Therefore, at the lower populations, modelled biomass per plant was accepted as more closely describing reality than the measured values.



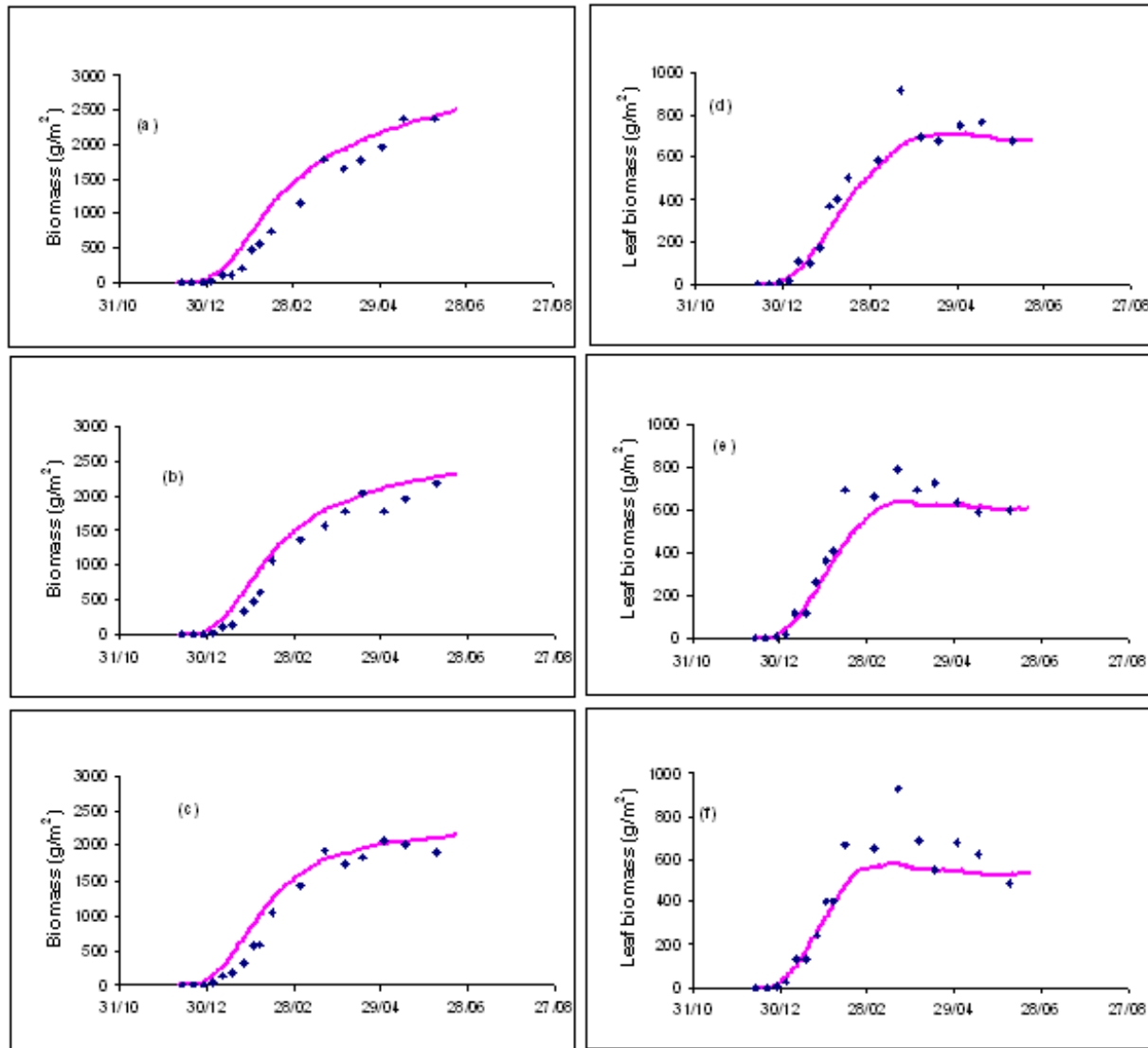
**Figure 1.** Average biomass per plant versus thermal time ( $T_b = 0^{\circ}\text{C}$ ) for the first sowing of kale at Lincoln. Results are total biomass per plant in crops with (a) low, (b) medium and (c) high plant populations and leaf biomass per plant in crops with (d) low, (e) medium and (f) high populations. Solid lines are simulations and data points are measured values.

The model was tested by comparing simulated values with data from the other site (Hastings). Simulated values of total biomass per unit area closely matched measured values at all three populations throughout the season (Figure 2(a)-(c)). Leaf biomass per unit area was also simulated accurately except that the model underestimated the mid-season values at all populations (Figure 2(d)-(f)), probably because leaf senescence was either started too early or over-estimated.

## Conclusion

Variable time from planting to emergence is the primary cause of diverse plant size that commonly occurs within crop populations (Benjamin and Hardwick 1986, Wyszomirski et al. 1999). Our model proposes an approach to simulate the growth of plants in these diverse populations. It predicted yield with reasonable accuracy by simulating growth of kale plants in cohorts of different plant size and number caused by variable seedling emergence, and then aggregating the results. This framework for capturing the effects

of variable plant emergence has extended our development and testing of the brassica forage models. Further research is required to determine the optimal period for defining cohort size, and how resource limitations affect biomass partitioning with changing plant population.



**Figure 2. Simulated and measured biomass of kale at Hastings. Results are total biomass in crops with (a) low, (b) medium and (c) high plant populations and leaf biomass in crops with (d) low, (e) medium and (f) high populations. Solid lines are simulations and data points are measured values.**

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