Validation of the APSIM-Lucerne model for phenological development in a cool-temperate climate.

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ABSTRACT

Phenological development of lucerne cv. Kaituna in a grazed and irrigated field experiment in New Zealand was used to validate the APSIM-Lucerne model developed in Queensland. Node appearance and timing of the early bud stage were measured over 9 crop regrowth cycles from 1997-1999. The model was calibrated with data from 1997/98 and validated with 1998/99 results. Accurate prediction of the time to early-bud was dependent on the inclusion of a photoperiod response and modification of thermal time accumulation at temperatures below 10 ^{o}C. Node appearance was systematically faster in spring and summer (35 ^{o}Cd per node) than in autumn (51 ^{o}Cd per node). Thus, a seasonally-dependent phyllochron combined with the modified temperature function were required to improve the root mean square deviation for node appearance from 25 to 12% of the mean.

KEY WORDS

ase temperature, early-bud, *Medicago sativa*, New Zealand, node appearance, thermal time.

Introduction

The application of crop simulation models for research, extension and on-farm application is dependent on their ability to accurately predict crop development and growth in regions outside those in which they were developed. Simulation of phenology in lucerne is important because development stage influences crop quality and suitability for grazing. Recently, lucerne development and growth were modelled by the Agricultural Production System Simulator (APSIM) (8). This simulates crop development, growth, yield and nitrogen accumulation in response to temperature, photoperiod, radiation receipts, soil water and nitrogen supply. The APSIM-Lucerne model was developed using functions derived from published literature, other crop models, and data from experiments in the subtropics. The model has not been tested in a temperate region where cooler temperatures and a wider range of photoperiod could affect development (9).

In this study, observations of node appearance and date of occurrence of the early-bud stage from an irrigated crop grown in New Zealand were used to validate the APSIM-Lucerne model. In this environment lucerne is routinely grazed by sheep, is dormant for two to three months in winter but yields up to 28 tonnes of dry matter per hectare per year (2). The aim of the present study was to determine if the APSIM-Lucerne model in its original or a modified form could be utilised to simulate lucerne development in a cool temperate climate.

Materials and methods

Experimental

The experiment was located at Lincoln University, Canterbury, New Zealand (43^{o} 36′S, 172^{o} 28′E, 11 m a.s.l.). The soil is a Wakanui silt loam (*Eutrochrept*, USDA Soil Taxonomy) of variable depth. Water holding capacity was about 340 mm to 2.3 m depth. Three 22 x 6.3m plots were sown with lucerne cv. Kaituna on 1 November 1996 and a target population of 250 plants m^{-2} was established. Irrigation was applied at 10 mm h^{-1} as required to maintain a soil moisture deficit of less than 100 mm in the top 1.0 m of soil.

Plots were grazed with sheep twice in the establishment season and on six occasions in the 1997/98 and 1998/99 seasons. Each grazing lasted 4-7 days and post-grazing plants were trimmed just above crown height (50 mm) to ensure only crop regrowth was measured in the subsequent regrowth cycle. The spelling time between grazing allowed lucerne to reach early-bud on 9 occasions.

Phenological development was monitored on 1 stem on each of 5 plants per plot tagged within 10 days of the end of grazing. The number of nodes and date of early-bud appearance (6) were recorded for each stem at 5-10 day intervals for 9 of the 12 regrowth cycles.

APSIM-Lucerne model

A full description of the physiological basis for APSIM-Lucerne was provided by Probert *et al*. (8). The following is a description of the relevant sections of the model dealing with node appearance (phyllochron) and time to early-bud.

For lucerne, thermal time is calculated using a “broken-stick” function (solid line in Figure 1) with three cardinal temperatures: base (5 ^{o}C), optimum (30 ^{o}C), and maximum (40 ^{o}C). Each day the phenology routine calculates today’s thermal time from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures. These daily thermal time values are accumulated into a thermal time sum that is used to determine the rate of appearance of nodes and the duration of each phenological phase.

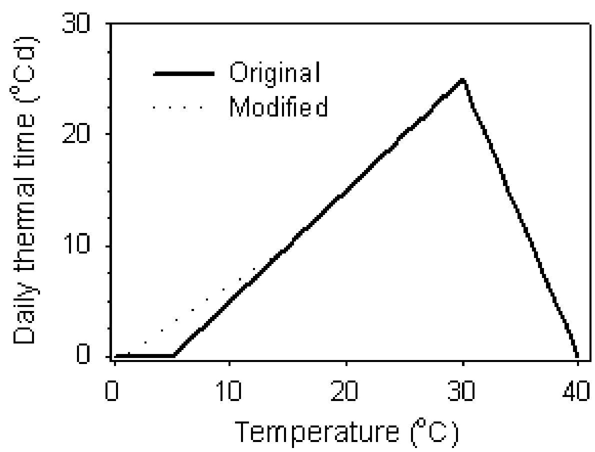

Figure 1: Response of thermal time to temperature for lucerne using original and modified cardinal temperatures.

For regrowth crops, a parameter value of 34 ^{o}Cd per node is used. When the stand is cut or grazed the stage of phenological development is set back to the beginning of a regrowth period that is assumed to be sensitive to photoperiod. The level of photoperiod response is cultivar specific but was unknown for cv. Kaituna lucerne.

Simulation analysis

The observed data from the 1997/98 year were used to determine whether cultivar parameter values were required for cv. ‘Kaituna’ for simulation analyses. These values were validated using observations from 1998/99 data by calculation of root mean square deviation (RMSD). Changes that produced minimum RMSD values for node appearance and time to early-bud were retained.

Results and discussion

Early-bud

The number of nodes at the time of early-bud differed with time of year in both 1997/98 and 1998/99 (Figure 2). For crops grown in spring or autumn, stems had about 12 nodes. For intermediate harvests, in summer, stems had up to five fewer nodes. This response indicates that the rate of progress to early-bud of cv. Kaituna was accelerated by the longer photoperiod in summer and retarded by the shorter photoperiod in spring and autumn. The accelerated progress towards early-bud at longer daylength was consistent with reports of lucerne as a long day plant (3).

Using the 1997/98 data, a negative linear response of thermal time from grazing until early-bud was calculated against increasing photoperiod (Figure 3). The coefficient of determination (R^2) for this relationships was improved from 0.76 to 0.86 when the thermal time response between 1 and 15°C was modified to accumulate faster at lower temperatures (Figure 1). With this modification, the thermal time requirement for early-bud decreased from 580 °Cd at 13.5 h to 380 °Cd at 16.5 h or by about 67 °Cd for each additional hour of daylength. Using the modification also decreased the RMSD from 2.4 to 2.2 days.

The improvement from modification of the temperature function is probably due to the true nature of the relationship between temperature and development being curvilinear, particularly for temperatures close to the base (1), although this has not be proven for lucerne. In New Zealand, lucerne crops frequently experience mean temperatures below 15°C, which are uncommon in, and would have little impact on simulations for, the subtropics. Wilson *et al.* (9) found a similar modification was necessary to improve prediction of maize development in a temperate climate when using a model calibrated from the subtropics.

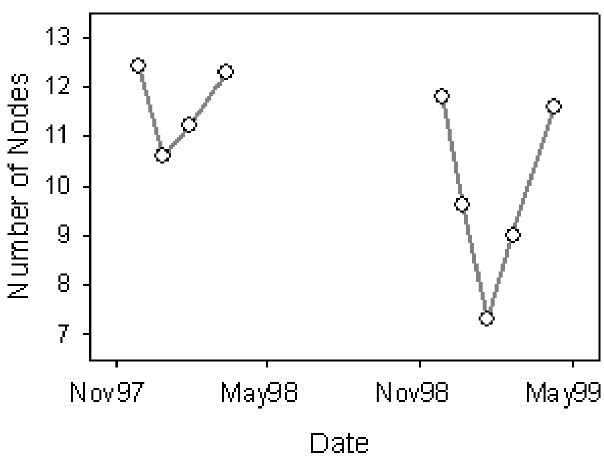

Figure 2: Number of nodes to first flower of lucerne grown in Canterbury, New Zealand.

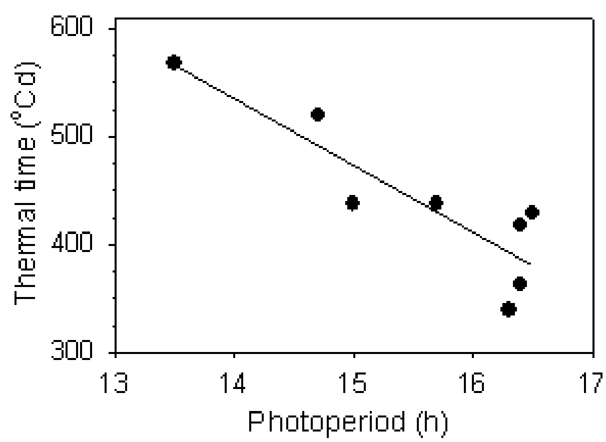

Figure 3: Accumulated thermal time to reach early-bud for lucerne, calculated using the modified temperature response shown in Figure 1, against mean photoperiod: $y = 1425 - 67.2x$ ($R^2 = 0.86$).

The linear nature of the relationship between time of early-bud and photoperiod was consistent for periods of increasing and decreasing photoperiod. There was no evidence of the hysteresis commonly found for annual crops (5) grown at the same location in New Zealand. To test whether the response continues below the 13.5 hour mean photoperiod would require controlled environment studies where the coupling of low temperature and short photoperiod could be broken.

Node appearance

The mean thermal time sum between appearance of successive nodes calculated from the 1997/98 season, using the original cardinal temperatures was 45 ± 4.2 °Cd compared with 41 ± 3.8°Cd using the modified regime (Figure 1). However, using either regime a systematic variation in this rate was observed. For the modified temperature response a shorter phyllochron was observed in spring and summer (35 $\pm$ 3.2 ^{o}Cd) than in the final two cycles in autumn (51 $\pm$0 ^{o}Cd), despite similar mean temperatures and radiation receipts. This change may indicate increased partitioning to the roots, meaning node appearance becomes source limited. The consequence was that a single rate of node appearance was inappropriate for the whole season. These result contrasts with controlled environment studies, which have shown a single phyllochron, could be calculated for lucerne (7) and which has been used frequently for predicting development of annual crops (4).

Additional observations showed there was no further increase in node number during May 1998, despite mean daily temperatures ranging between 6.5 and 16 ^{o}C. It seems likely that the first frost on May 5, prevented further node development.

The initial APSIM-Lucerne simulation run, using the original temperature configuration and a single phyllochron, underestimated the rate of node appearance in spring and summer and overestimated the rate in autumn (Figure 4). Thus, the observed results from the 1997/98 season were used to calibrate the model by including the separate phyllochron for spring/summer and autumn rotations. The longer autumn phyllochron was initiated on the same date (3 February) in 1998/99 for the final two cycles of the season. In addition, the model was configured to stop phenological development when the minimum air temperature reached 0 ^{o}C in autumn.

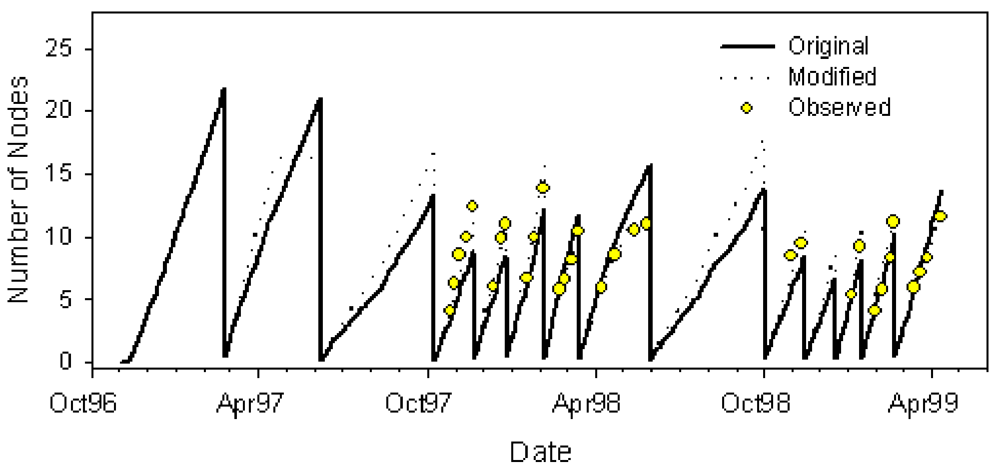

Figure 4: Observed and simulated number of nodes over time for lucerne using the original and modified temperature responses as defined in Figure 1.

After calibration, and inclusion of the modified temperature regime, the timing of node appearance was predicted with acceptable accuracy for all cycles (Figure 4) and the RMSD for the 1998/99 season decreased from 1.56 to 1.13 or to about 12% of the mean.

Conclusions

- Thermal time to early-bud of cv. Kaituna lucerne decreased by 67 ^{o}Cd for each hour change in the mean photoperiod between 13.5 and 16.5 hours.
- The observed phyllochron for cv. Kaituna was faster in spring and summer (35 ^{o}Cd) than in autumn (51 ^{o}Cd).
- After calibration, APSIM-Lucerne was able to predict early-bud and node appearance for an irrigated crop in New Zealand with acceptable accuracy.

ACKNOWLEDGMENTS

The Trimble Agricultural Research Fund, New Zealand, for financial assistance to D.J. Moot.

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