Prediction of stem extension of lucerne (*Medicago sativa* L.) in early spring

Lauren Jones[*], Annamaria Mills[1], Xiumei Yang[2] and Derrick Moot[1]

[1] Dryland Pastures Research Group, Faculty of Agriculture and Life Sciences, Lincoln University, Canterbury, New Zealand.
[2] The New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch, New Zealand.

Abstract

The ability to predict the time of rapid stem extension in spring can be used to assist the development of lucerne grazing management plans. Therefore, the aim of this work was to validate the APSIM_Lucerne height function generated by Yang et al. (2021) for early spring. Two experiments in 2022 and 2023 used four winter defoliation dates (01/06, 03/07, 17/07, 01/08) to measure the time and rate of initial stem extension (height) in spring. The data were used to validate the APSIM_Lucerne height function which is based on thermal time accumulation targets modified by photoperiod. The current exponential decay curve in ASPIM showed a poor agreement (RMSE = 2.1) because it had limited data through the winter period. This was modified using the 2022 and 2023 field data, which showed the start of stem extension occurred at a photoperiod of 11.1 h. This was consistent with the original dataset. The change in photoperiod direction was accounted for calculating a weighted mean photoperiod from the start of the regrowth rotation (in a decreasing photoperiod) up to the 11.1 h increasing photoperiod until the end of rotation. This improved (RMSE = 1.49) the prediction of plant height and is recommended for implementation into the APSIM_Lucerne framework. In the field, the start of maximum stem extension occurred at an 11.1 h in both years, which suggests this is the critical photoperiod required before rapid stem extension occurs. However, this remains to be validated in other environments.

Keywords
Alfalfa, heightchron, stem extension

Introduction

How abiotic factors affect the growth and development of lucerne (*Medicago sativa* L.) can inform management decisions (Moot et al., 2003). The rate of lucerne phenological development can be calculated by thermal time (Tt) with individual pheno-phases also affected by photoperiod (Pp) (Yang et al., 2021). Phenological development affects feed quality (Brown et al., 2006; Kalu & Fick, 1983), and dry matter partitioning (Moot et al., 2003) and, therefore, must be accounted for in grazing management and parameterising crop simulation models. Furthermore, stem height is a major contributor to lucerne quality with each 10 cm averaging 900 kg DM in spring and 600 kg DM/ha in autumn (Mills et al., 2016). Lucerne was found to have a strong exponential decay function between heightchron (height per unit temperature) and the mean rotation Pp. This slope described a decrease in heightchron from ~5ºCd/mm to <1ºCd mm as photoperiod increased from a 10-hour photoperiod to a 16-hour photoperiod (Yang et al., 2021). Yang et al. (2021) calculated a lucerne height function using long-term datasets of field dormancy (FD) 5 rated cultivars of lucerne grown in 42-day rotations. This function was then implemented in APSIM NextGen lucerne model in APSIM plant modelling framework (PMF) developed by the Agricultural Production Systems Research Unit in Australia to predict crops growth and phenological development over time. The model was then tested using 28-, and 84-day rotation lengths. However, the height function has not been validated in winter and early spring due to lack of data. Specifically, there is currently no data to quantify the heightchron below a 10-hour photoperiod. Therefore, an extended dataset that included winter and early spring measurements is needed to accurately predict stem height. This experiment aimed to extend the APSIM_Lucerne model for prediction of plant height during the winter and early spring period, which has a minimum 9 h photoperiod, and validate the predictions up to, and after, the previously defined critical photoperiod of 11.1 h. To do this a field experiment was established with different defoliation dates in 2022 and repeated in 2023.

Methods

Field experimental data

Two experiments were located at Iversen Field (-43.6493201, 172.46528; WGS84 Web Mercator), Lincoln University, Canterbury. The experiments used an established stand of "Force 4" lucerne, which has a fall dormancy rating of 4 (FD4). Experiments were run over two years as completely randomised block designs with four defoliation dates and three replicates to mimic the time of a recommended autumn/winter "clean up" defoliation (Moot et al., 2003). For both years the defoliation dates were 1/06, 3/07, 17/07, and the 1/08. A Lawnmaster lawnmower set at ~40 mm to remove all leaf and stem without damage to the crowns (basal buds remained intact) was used to defoliate the crop.

Meteorological data

Rainfall (mm), solar radiation (MJ/m^2/d), wind speed (m/s), air temperature (°C), and vapor pressure deficit (MPaa) were recorded at the Broadfields meteorological station (Agent Number 17603; https://cliflo.niwa.co.nz/), located 2 km north of Lincoln University. Thermal time (°Cd) was calculated using the "Moot Model" (Moot et al., 2001). This is a three-stage broken stick function with four cardinal temperatures, a base temperature of 0 °C, a breakpoint at 15 °C, an optimum of 30 °C, and a maximum of 40 °C. Heightchron (°Cd/mm) calculated the thermal units required to produce 1 mm of stem.

Model description

The APSIM_Lucerne plant modelling framework (PMF) from the agricultural production simulator was used as a modelling platform for validation of lucerne development during winter and the first regrowth rotation each spring. During this period photoperiod increased from ~9 h to ~13 h. Height is calculated as a function of accumulated thermal time, modified by photoperiod in APSIM_Lucerne model. During the Juvenile stage heightchron occurs at a constant of 3 °Cd/mm. In subsequent regrowth cycles heightchron is calculated as $y = 0.62 + 97660 * \exp(-x)$ from stage of EndJuvenile until StartFlowering. Heightchron during the reproductive stage is calculated as $y = 2.85 – 16560*\exp(-x)$, but this was not considered in the current study.

Statistical analysis and model evaluation

All statistical analysis was performed in R studio (Version 2023.12.0+369). A root mean squared error (RMSE) and the Nash-Sutcliffe efficiency (NSE) coefficient were carried out to assess the average difference between values predicted by the model and the observed values and evaluate model performance for each of the cutting dates in both years. Initially, exponential decay functions were fitted to the combined data from the 2022 and 2023 datasets as well as those used to calibrate the model. A one-way analysis of variance was performed to compare mean heightchron between 2022 and 2023.

Results and Discussion

The 2022 and 2023 experiments are explained in further detail by Jones (2024). In summary, the 2022 and 2023 datasets showed that the start of rapid stem elongation in spring was consistent at an 11.1 h (± 0.2) photoperiod, irrespective of the defoliation date during autumn and winter. Thermal time accumulated among winter defoliation treatments ranged from 56 to 715 °Cd. This suggests that the trigger point for stem extension is a critical photoperiod of 11.1 h (± 0.2). During the winter dormancy phase, prior to an 11.1 h photoperiod, heightchron was consistent at 3.5 °Cd/mm. This was not different between 2022 and 2023 ($P = 0.16$). There was also no difference in mean heightchron (1.42 °Cd/mm) after an 11.1 h photoperiod was exceeded between 2022 and 2023 ($P = 0.27$).

In 2022, the simulation results showed an acceptable agreement (Figure 1) for each of the defoliation dates: 01/06 (RMSE = 36%, NSE = 0.87), 03/07 ((RMSE = 54%, NSE = 0.68), 17/07 ((RMSE = 62%, NSE = 0.56), and 01/08 ((RMSE = 50%, NSE = 0.71). However, in 2023 the model overpredicted height (Figure 1) for each of the defoliation dates: 01/06 (RMSE = 96%, NSE = -1.09), 03/07 ((RMSE = 78%, NSE = 0.33), 17/07 ((RMSE = 86%, NSE = 0.17), and 01/08 (RMSE = 77%, NSE = 0.31). The difference between 2022 and 2023 was the stem height at stem extension. Due to a warmer winter mean stem height was 140 mm in 2022, compared with 99 mm in 2023. This suggests that the heightchron function in APSIM_Lucerne needs further calibration. In both 2022 and 2023 plant height reached a maximum of ~350 mm by the 12th of October. In 2022, APSIM predicted that lucerne height would reach ~320. In 2023, APSIM predicted that plant height would reach ~500 mm. These results suggested that the height function in APSIM required adjustment.

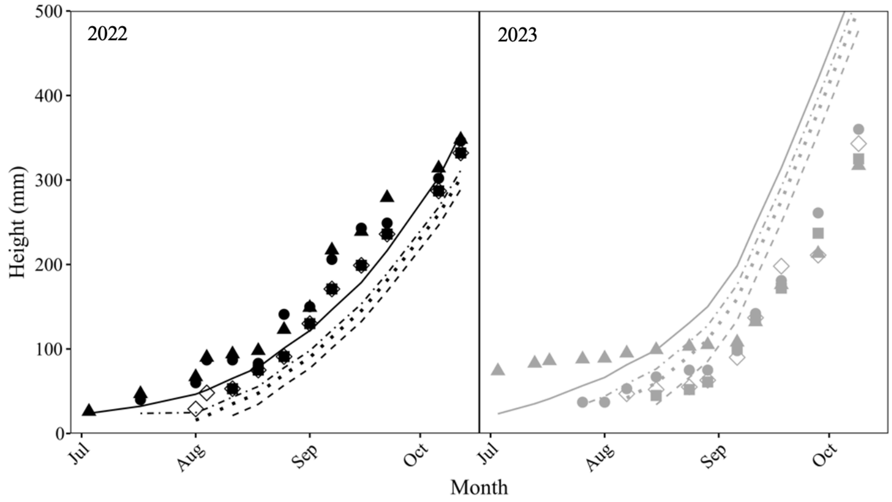

Figure 1. Lucerne height over time for lucerne defoliated on four different dates, 01/06 (▲), 03/07 (●), 17/07 (◇), or the 01/08 (■) from two field experiments at Lincoln University Canterbury, New Zealand. The lines indicate the predicted values for the 1st of June (-), 3rd of July (-.-), 17th of July (..), or the 1st of August (--).

In APSIM_Lucerne height during the vegetative stage (from EndJuvenile until StartFlowering) is currently calculated as y = 0.62 + 97660 * exp (-x. This slope (Figure 2) assumes a decrease in heightchron from ~5 °Cd/mm to ~1 °Cd mm as mean photoperiod increases from a 10-hours to 16-hours (Yang et al., 2021). To improve this function, data from the 2022 and 2023 experiments were added with Pp values from 11.5 h to 12.8 h. This extended the range to include mean heightchron values from ~7 °Cd/mm to ~1 °Cd. The slope calculated was y = -0.42 + 50.2 *exp(x*-0.24). This modified curve also showed poor agreement (RMSE = 2.1) with the heightchron values included in the initial height model calibration (Yang et al., 2021).

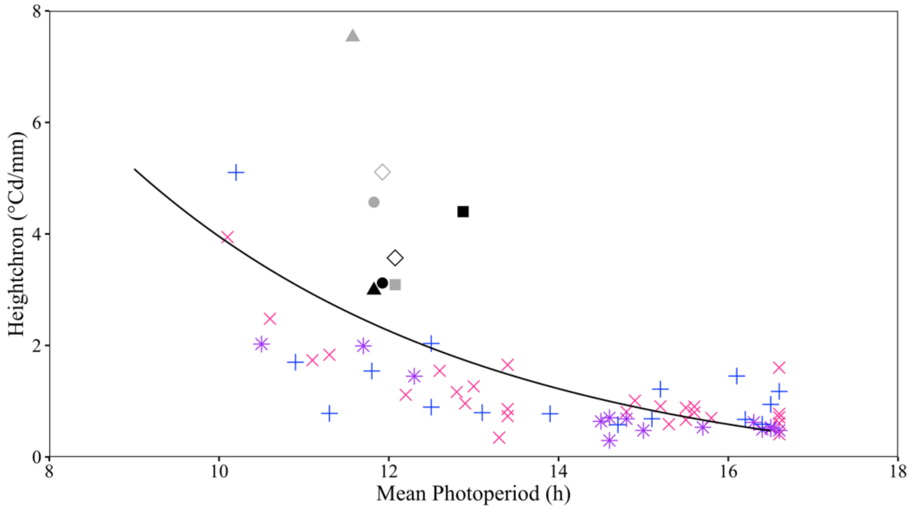

Figure 2. Heightchron against mean photoperiod of the rotation (h) for regrowth crops from 2022 (black symbols) and 2023 (grey symbols) experiments with defoliation dates on 01/06 (▲), 03/07 (●), 17/07 (◇), or 01/08 (■) as well as prior field experiments E4ILLF5 (*), E1ILL (x), E2ILL (+). All the experiments were conducted at Lincoln University, Canterbury, New Zealand. The exponential decay function is y = 0.8 + 217123 * exp (x * -1.09).

To improve the estimation of height, data from the 2022 and 2023 experiments were split into two phases. Phase 1 data was collected in a) a decreasing photoperiod prior to the critical photoperiod (11.1 h), or b) the rapid stem extension phase (post an 11.1 h increasing photoperiod). The slope calculated was y = 0.8 + 217123 * exp (x * -1.09) (Figure 3). This decreased the heightchron from ~7 °Cd/mm at a 9.9 h mean photoperiod to 0.65 °Cd/mm at a 12.8 h mean photoperiod. This relationship showed improved agreement (RMSE = 1.49) between observed and predicted values. Measurements used for calibration include the ~7 days from the previous defoliation date until basal stems appeared. To further improve this function estimation of the duration of the lag phase is required.

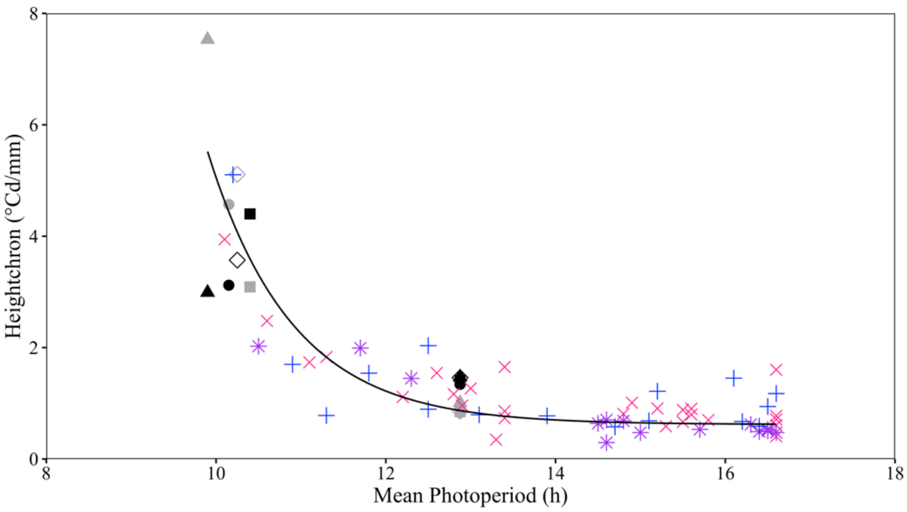

Figure 3. Heightchron against mean photoperiod of the rotation (h) for regrowth crops from 2022 (black symbols) and 2023 (grey symbols) experiments with defoliation dates on 01/06 (▲), 03/07 (●), 17/07 (◇), or 01/08 (■) as well as prior field experiments E4ILLF5 (*), E1ILL (x), E2ILL (+). All the experiments were conducted at Lincoln University, Canterbury, New Zealand. The exponential decay function is y = 0.8 + 217123 * exp (x * -1.09)

Conclusion

The current height model in APSIM_Lucerne showed an acceptable agreement in 2022 but required improvement for the 2023 dataset. To improve height prediction the exponential decay function should be changed from y = 0.62 + 97660 * exp (-x), to y = 0.8 + 217123 * exp (x * -1.09). This new function accounts for the calibration of heightchron from a 9 – 10 h photoperiod that the initial model lacked data for. To improve the model fit further data collection is required for the initial lag phase during a rotation. A key feature of all the field data was the establishment of a critical photoperiod of 11.1 h which could be used as a key indicator for the start of grazing in this environment.

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