Lucerne management optimization – new insights from experimentation and modelling

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Abstract

Lucerne (*Medicago sativa* L.) has long been used as a major source of energy and protein for livestock worldwide. In a sequence of field experiments at Lincoln University, New Zealand, the impact of environmental factors on carbon assimilation, canopy expansion and seasonal dry matter (DM) partitioning to roots has been quantified for lucerne crops under contrasting defoliation regimes. Results showed that the early-spring and late summer are critical periods for assimilate mobilization and storage in roots when partitioning to roots increased from 5 to >45%, respectively. Most of the yield difference between crops defoliated every 28 or 42 days (12 and 23 t DM/ha/year, respectively) was explained by light interception. In addition, frequent defoliations reduced radiation use efficiency (RUE) during the early stages of regrowth, when the limited pool of root nitrogen reserves in these crops limited leaf photosynthesis. Derived relationships were integrated in a dynamic lucerne simulation model. Modelling exercises explained shoot and root seasonality in response to photoperiod and temperature and unveiled possible seasonal patterns of root maintenance respiration. Findings are expected to support management decisions and enhance the accuracy of lucerne simulation models used both for predictive and scientific purposes. For example, the use of frequent defoliations can be strategically allocated to spring and early-summer without the risk of compromising long term productivity of lucerne stands because assimilates are not accumulated in roots during this period. On the other hand, the most effective period for root reserve accumulation is late-summer.

Key Words

Alfalfa, modelling, roots.

Introduction

Lucerne (*Medicago sativa* L.) is an important forage in crop-livestock in Australia and grazing systems in New Zealand. Optimization of yield and stand longevity, depend on understanding crop responses to environmental factors and their interaction with management practices, particularly defoliation regimes. Conceptually, shoot yield can be viewed as the product of (i) intercepted photosynthetically active radiation (PAR_i), (ii) the efficiency of conversion of PAR_i into biomass (radiation use efficiency, RUE) and (iii) the fraction of DM retained on shoot biomass (Monteith, 1977). The quantification of the physiological processes that control each of these three components of yield can be used to optimize management decisions and to develop mathematical models to study or predict lucerne production. For lucerne crops, the seasonal allocation and depletion of biomass in roots is poorly quantified despite its major impact on ultimate yields (Khaiti and Lemaire, 1992). For this purpose, the dynamics of seasonal shoot and root biomass of 'Kaituna' lucerne crops in response to defoliation frequencies and environmental factors were studied in a two year field experiment at Lincoln University, Canterbury, New Zealand. The response of root biomass (Teixeira *et al.*, 2007c), yield components (Teixeira *et al.*, 2007b), canopy forming processes (Teixeira *et al.*, 2007d) and radiation use efficiency (Teixeira *et al*,. 2007a) were quantified and integrated in a lucerne simulation model (Teixeira *et al.*, 2008). In the current paper, we develop an overall analysis of these results and discuss the practical implications of these for current lucerne management.

Methods

The experiment was located at Lincoln University Field Service Centre, Canterbury, New Zealand (43?38'S and 172?28'E). Details of the experimental site and methods were published in previous studies by Teixeira *et al*. quoted above. To impose contrasting levels of root reserves, irrigated lucerne crops were grazed by sheep at two defoliation frequencies: a short (28 days, SS crops) or long (42 days, LL crops) regrowth cycle for two years (2002 to 2004). Grazing durations were not more than four days. Measurements of shoot yield and its components (plant population, shoots/plant and shoot weight), root biomass, canopy development (leaf area index, LAI), light interception and leaf photosynthesis were taken weekly. From four replicates, 0.2 m^2 shoot samples were cut at crown level. In the same area, lucerne plants were excavated at 300 mm depth. After each grazing plots were mown above crown level to homogenize the grazing residual (i.e. post grazing leaf area). Temperature and radiation were recorded each hour on site.

Results and discussion

Annual shoot yield was reduced (P<0.05) by ~50% in frequently defoliated crops to 12 t DM/ha in SS crops from 23 t DM/ha in LL crops. Within grazing cycles, shoot biomass ranged from over 6 t DM/ha in mid-summer to negligible regrowth during winter. This seasonality of shoot biomass was largely (R^2=0.90) explained by the amount of light intercepted by canopies, with an overall radiation use efficiency for 'annual' shoot yield (RUE_{shoot}) of 1.6 g DM/MJ PAR_i (P<0.01) regardless of defoliation regime. Nevertheless, a seasonal pattern was observed when RUE_{shoot} was analysed for each individual cycle (Figure 1). The RUE_{shoot} was higher (P<0.05) during early spring (>1.6 g DM/MJ PAR_i) than autumn (~1.2 g DM/MJ PAR_i) independently of defoliation regime.

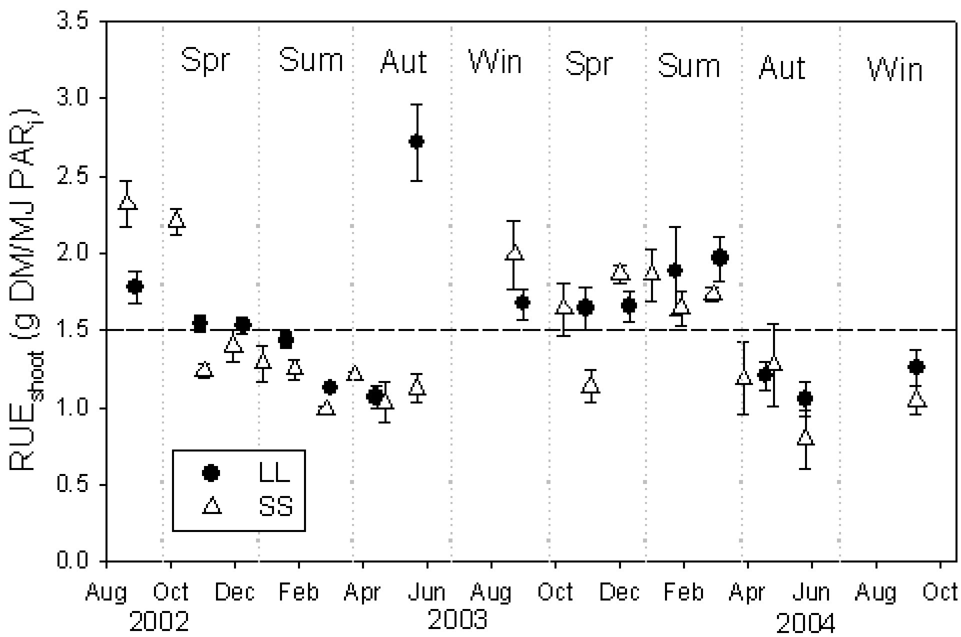

Figure 1. Radiation use efficiency for shoot yields (RUE_{shoot}) of lucerne crops defoliated at a 28-day (SS) or 42-day (LL) regrowth cycle at Canterbury, New Zealand. Horizontal dashed line indicates overall seasonal average of RUE_{shoot}

The decline in RUE_{shoot} in mid-summer/autumn was caused by an increase in the rate of DM partitioning to roots during this period. The allocation of daily assimilated DM to roots increased from less than 5% in early-spring to more than 45% in mid-summer/autumn. In fact, frequent defoliations caused a 15% decline in leaf photosynthesis of frequently defoliated crops (P<0.05) prior to the expansion of the ~ 4th main stem leaf. At later stages of regrowth, the lower growth rates of SS crops were explained mainly by decreased canopy expansion that limited light interception due to the occurrence of smaller leaves in axillary and primary nodes of these crops. Less importantly, a longer phyllochron (thermal time accumulation per main stem leaf) was observed in SS crops in autumn. However, during spring and summer phyllochron was similar for both crops at 34?Cd/leaf (degree days at base temperature of 5?C) and was longer at low photoperiods (<12.5 h). This indicates that lucerne development was less sensitive to the level of root reserves than growth processes but both responded to environmental signals.

The seasonal partitioning pattern of RUE was consistent with the highest amounts of root biomass in mid-summer/autumn for both treatments (Figure 2). After January 2003, the frequently defoliated crops had on average 2 t DM/ha less of crown plus taproot biomass than LL crops through the experimental period (Figure 2).

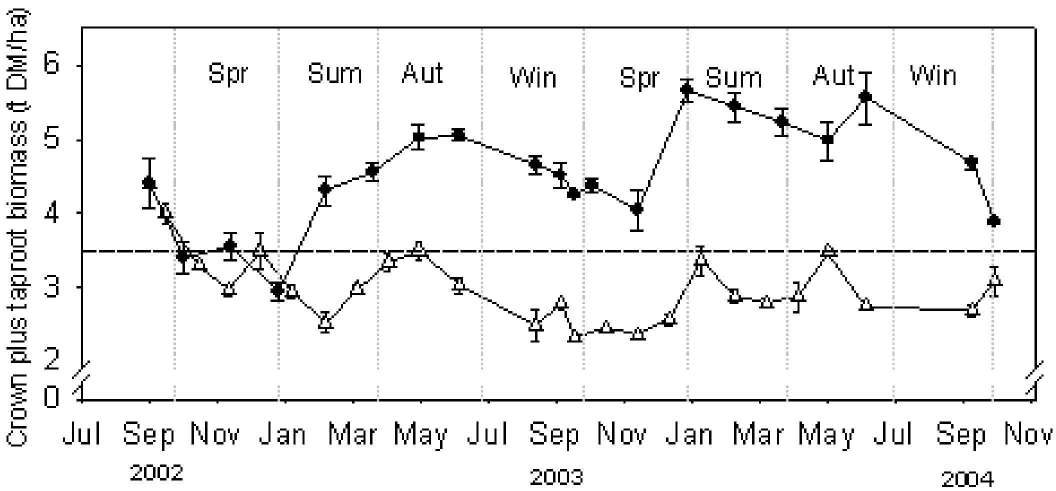

Figure 2. Crown plus taproot biomass at 300 mm depth) of lucerne crops defoliated at a 28-day (SS, white triangles) or 42-day (LL, dark circles) regrowth cycle, at Canterbury, New Zealand.

These results highlight the importance of mid-summer as a critical period for root reserve accumulation when high rates of carbon assimilation (due to high temperature, incoming radiation and rapid canopy cover) coincide with high partitioning rates of biomass to roots. The implication is that infrequent defoliations at this time (e.g. >35 days) may be an effective management tool to replenish root reserves. By contrast, photosynthates are retained in shoots during early-spring/summer and root biomass is depleted to support shoot growth with N reserves and root respiration with C reserves (Avice *et al.*, 1997). Plant population was not affected by frequent defoliations but self-thinned exponentially from 120 plants/m^2 in 2002 to 60 plants/m^2 in October 2004. Therefore, the reduction of root reserves was not the primary cause of plant death in frequently defoliated crops and that yield was compensated by the increase in other yield components such as stems/plant and stem weight.

The seasonality of shoot biomass accumulation and depletion of LL crops was simulated by a model that incorporated the quantitative relationships derived from field experiments. Above ground biomass, canopy development and leaf appearance were satisfactorily simulated (RMSD<25% of mean). However, root biomass dynamics were only accurately simulated (RMSD = 14% of mean) when a seasonal pattern of root maintenance respiration (R_m) was assumed (Bouma *et al.*, 2000) (figure 3). A model inversion exercise suggested that R_m at 20?C varied from 0.5%/day in winter to 3%/day in mid-summer. This change in the paradigm of a constant R_m for roots has major implications in the overall balance and allocation of carbon within the plant.

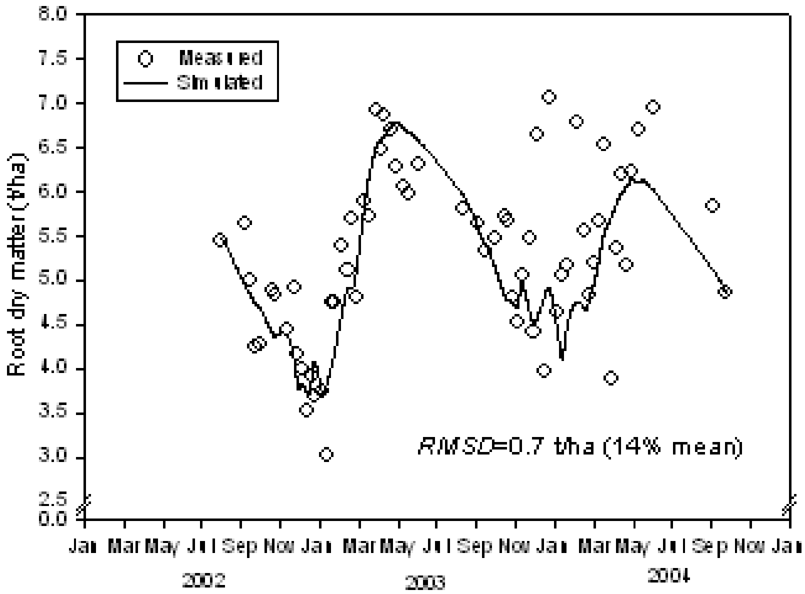

Figure 3. Adjusted fit of root dry matter simulation for lucerne crops grazed at 42-days regrowth cycles at Lincoln University, Canterbury, New Zealand. RMSD is the root mean squared deviation.

Conclusion

These findings increase our understanding of the physiological processes of lucerne growth and development and add management flexibility to lucerne stands. It is important to allow crops to accumulate sufficient root reserves after mid-summer to boost growth rates during the following early-spring and in the start of regrowth cycles when carbon allocation to shoots via photosynthesis is impaired by low temperatures and reduced leaf area. Our findings suggest that frequent defoliations can be used strategically during spring to early-summer without compromising long term productivity of the stand because the allocation of reserves to roots is minimal during this period. The modelling exercise unveiled the possible existence of a seasonal pattern of root maintenance respiration that may be further confirmed by experimentation and incorporated in current simulation models.

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