

Grazing induced changes in light interception and radiation-use efficiency of winter wheat

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Abstract

During winter, dual-purpose wheat provides an alternate source of livestock fodder to pastures. Whilst there has been much research on the agronomic effects of grazing on wheat, information on light relations after grazing and its consequences for growth is limited. Three grazing treatments were compared to an ungrazed control (C): low or high intensity for a short period (33.7 or 67.3 dry sheep equivalents (DSE) ha⁻¹ for 31 days, LS or HS respectively) or low intensity for a long period (33.7 DSE ha⁻¹ for 62 days, LL). The HS post-grazing-anthesis growth rate was significantly less than that of the control (9.0 cf. 10.3 g m⁻² d⁻¹), but was significantly greater than that of the LL treatment (7.4 g m⁻² d⁻¹). The rate of change of light intercepted with time (dI/dt) was greatest for crops that had the lowest LAI after grazing, irrespective of the time of sheep removal. There were no significant differences in RUE in the post-grazing-anthesis period, with values estimated at 1.09, 1.16, 0.98 and 1.11 g MJ⁻¹ for the LS, HS, LL and C treatments respectively. This study has shown that crop growth rates and LAI recovery were greater after early, intense grazing and produced greater biomass than after longer, more lenient grazing.

Key Words

Dual-purpose wheat, defoliation, green biomass

Introduction

During its vegetative stages, winter wheat can be grazed for a moderate length of time by livestock. This practice supplies a valuable source of green fodder when the availability of other pastures is lacking, particularly during colder months when growth rates are low. Provided grazing is carried out at moderate intensities, the effect of removing some of the biomass from vegetative winter wheat may have a negligible, or even beneficial effect on grain yield (e.g. Dove et al. 2002, Davidson et al. 1990). The purpose of many previous experiments has been to evaluate the suitability of one or more cultivars to a particular climate, grazing regime, or as an alternative to pastures. Studies generally do not supply information on crop radiation-use efficiency (RUE). RUE estimation would allow useful comparisons across grazing regimens or study climates, and an assessment of the relative suitability of a given cultivar to grazing.

Removal of any green biomass can be expected to affect light interception by leaves. Some of the studies listed above have demonstrated that a reduction of biomass will not necessarily have a significant effect on final grain yield. This implies that under certain circumstances, winter wheat can either (i) produce biomass in quantities that are superfluous for maximum grain yield requirements, or (ii) compensate for lost biomass by increasing growth rates when it is defoliated in its vegetative stages. Information detailing the extent to which wheat can be grazed so that leaf area index (LAI) becomes sufficiently small to limit radiation interception, and thus carbon gain, is scarce. In an attempt to bridge this information gap, we conducted a grazing experiment of winter wheat with two primary objectives in mind. The first was to examine the changes in LAI and the fraction of incident light intercepted (f) caused by grazing, and the second was to determine the effect of these grazing regimens on the resulting growth rates and RUE.

Methods

The experiment was conducted from March to December 2007 on the CSIRO Ginninderra Experiment Station near Canberra. On March 21st 2007, winter wheat (*Triticum aestivum*) cv. MacKellar was sown at 100 kg ha⁻¹ with 110 kg ha⁻¹ of diammonium phosphate fertiliser. Average seedling density was 170 ± 5 plants m⁻² at emergence on April 1st. The rainfall recorded on site during 2007 was 547 mm, below the annual average of 619 mm. There was a long dry spell between July 9th and October 26th, with only 36 mm of rainfall, compared to the 203 mm long-term average over the July – October period.

Grazing treatments were based on representative farming systems, including a 'light' grazing intensity (33.7 DSE ha⁻¹) for a short or long period (LS: 31 d or LL: 62 d, respectively) and a heavy grazing intensity for a short period (HS: 67.3 DSE ha⁻¹ for 31 d). The experiment was a completely randomised block design, with three replicates of each treatment. On June 18th, Merino hoggets began grazing the crop. The LL treatment was conducted for twice as long as the LS treatment, which meant that the LL and HS treatments had identical numbers of DSE days. Grazing was terminated on July 19th or August 19th for the short and long treatments respectively. No apical meristems were removed by grazing.

On each sampling date, 1.44 m² of shoot biomass was cut per plot. Subsamples were separated into leaf lamina, stem and senescent biomass. The total area of laminae in each subsample was measured using a leaf area meter. Leaf dry mass per unit leaf area (LMA) was calculated as the laminae area divided by the dry mass of the subsample. LAI was calculated from the LMA, the proportion of leaf to shoot in the subsample and total shoot mass per unit area.

The fraction of incident light intercepted by the crop canopy (f) in the photosynthetically-active radiation (PAR) spectrum was measured using a ceptometer. Measurements were made from April 17th to anthesis of each treatment (October 18th C, 20th LS, 22nd HS and 24th LL). All measurements of f were made orthogonally to crop rows and were taken between 10:00 and 14:00 on clear sunny days. Incident PAR was assumed to be 50% of daily global short-wave radiation (MJ m⁻² d⁻¹). The fraction of PAR intercepted per day was estimated by linearly interpolating f measurements. RUE (g shoot dry matter MJ⁻¹ IPAR) was calculated as the increment in shoot dry matter divided by the cumulative IPAR (Σ IPAR) in the post-grazing-anthesis period. The typical method of using the slope of the linear relationship between shoot biomass and Σ IPAR (Sinclair and Muchow 1999) was not adopted since there was evidence that water stress confounded the relationship at different developmental stages of each treatment.

Differences between treatments in the post-grazing-anthesis period were tested by ANOVA followed by unplanned comparisons, using GENSTAT Version 10.1.0.72 (VSN International Ltd) with block as a random factor. Changes in biomass or LAI (Δ LAI) between the start and end of grazing were analysed as repeated measures with a residual maximum likelihood (REML) model. The REML analyses assumed that the least significant difference at the 0.05 level (LSD_{0.05}) between two means of the same treatment on separate dates was twice the standard error of the difference between the two means. Nominal variables (e.g. f) having heterogeneous residual variance were logit transformed (e.g. $\ln[f/(1 - f)]$) before analysis.

Results and discussion

The average reduction in shoot dry matter for the LS, HS and LL treatments was 34, 235 and 119 g m⁻² respectively. In the first month of grazing (June 18th to July 19th), the control plots grew by an average of 45 g m⁻². In the following month (July 19th to August 20th), the increase in shoot dry matter was 192 g m⁻² (Fig. 1). Growth rates (estimated as the linear slope of shoot biomass against time) from the end of grazing to anthesis were 9.5, 9.0 and 7.4 g m⁻² d⁻¹ for the LS, HS and LL treatments respectively, and that of the control was 10.3 g m⁻² d⁻¹ from July 19th to anthesis (LSD_{0.05} = 0.8 g m⁻² d⁻¹). Over the grazing period, growth rates during the second month were much higher, presumably due to warmer temperatures. Differences in soil moisture between the two months were almost certainly not the factor responsible for the increased growth rates, with 88 mm of rain falling in the first month compared to only 13 mm in the second month.

To assess the rate of canopy closure after grazing, the rate of change of f over time (df/dt) was calculated for approximately 46 days after each grazing treatment (the length of time over which changes in f were

relatively linear, Fig. 2). These periods were from July 19th to September 3rd for the LS and HS treatments, and from August 20th to October 4th for the LL treatment. The df/dt of the LS, HS and LL treatments were 0.0089, 0.014 and 0.014 d^{-1} ($LSD_{0.05} = 0.003$). From July 19th to September 3rd, the df/dt of the control was 0.004 d^{-1} . The greater the reduction in f during grazing, the greater the df/dt after sheep were removed. This phenomenon can be explained by the Beer-Lambert equation, which states that $f = e^{-kLAI}$ where k is a light extinction coefficient. When LAI is small, the relationship between f and LAI is approximately linear.

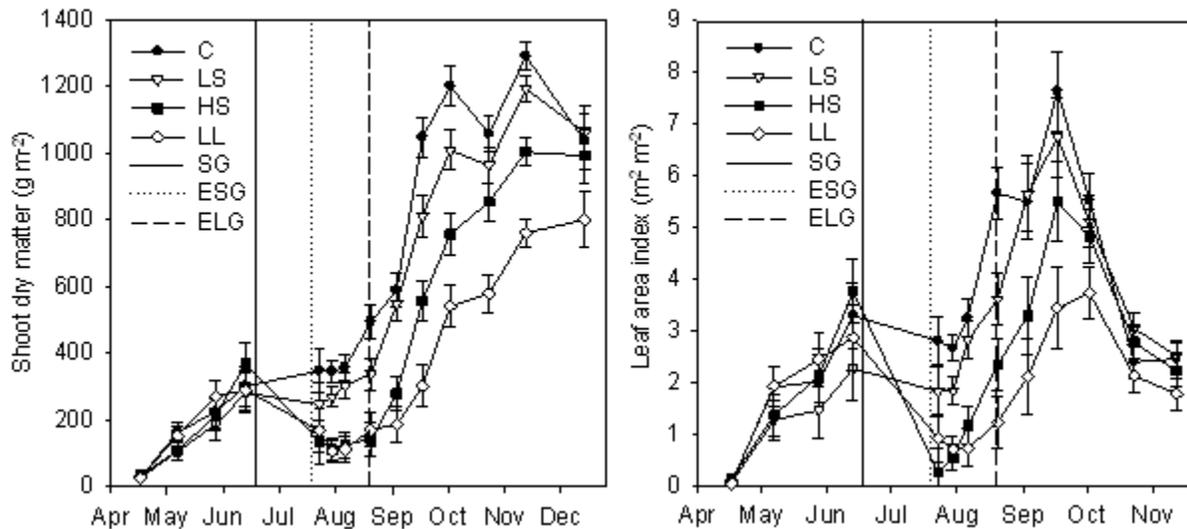


Figure 1 . Total shoot dry matter (left) and corresponding leaf area indices (right) measured for the ungrazed control (C), light short (LS), heavy short (HS) and light long (LL) grazing treatments in 2007. Vertical lines SG, ESG and ELG represent the start of grazing and end of short or long grazing, respectively

However, when LAI is high, the f -LAI curve approaches an upper bound of unity, so that increases in LAI no longer produce linear increases in f .

The effect of biomass removal in general was to reduce LAI and f , but it had varying effects on growth rates. The mean change in LAI (ΔLAI) between the start and end of grazing was -0.5, -3.5 and -1.6 $m^2 m^{-2}$ for the LS, HS and LL treatments (Fig. 1). For the control, ΔLAI was relatively static in the first month, and then underwent a large increase over the second grazing month (the $LSD_{0.05}$ for the short and long grazing treatments was 1.5 $m^2 m^{-2}$ and 1.7 $m^2 m^{-2}$ respectively). Whilst the HS treatment finished a month earlier than the LL treatment, the shoot biomass remaining on the two treatments was not significantly different on August 20th. This demonstrates that grazing the crop for the same number of DSE days left about the same amount of biomass, irrespective of the grazing periods. After August 20th, however, there were significant differences in crop recoveries. The growth rate of the LS treatment was not significantly affected by grazing, and although that of the HS treatment was less than the control, it was markedly greater than that of the LL treatment in the same period. Clearly, shoot growth rates of grazed crops did not increase to compensate for lost biomass.

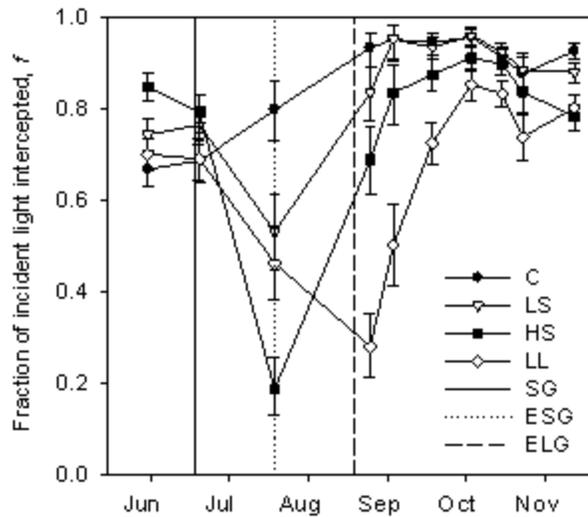


Figure 2. Fraction of incident light intercepted (f) by wheat shoots for each grazing treatment in 2007. Symbol definitions as per Fig. 1

The differences in growth rates may be explained by the peak LAI attained. The C, LS and HS treatments reached maximum LAI values of 7.6 ± 0.7 , 6.7 ± 0.6 and $5.5 \pm 0.6 \text{ m}^2 \text{ m}^{-2}$, whereas the LL LAI peaked at only $3.7 \pm 0.8 \text{ m}^2 \text{ m}^{-2}$. The prolonged water shortage in spring probably limited the leaf area expansion of the LL crop, resulting in reduced growth rates. Allowing dual-purpose wheat sufficient time to re-establish LAI before anthesis will prevent restriction of post-grazing growth rates, particularly in years of limited rainfall.

To determine whether the differences observed in growth rates were due to the conversion efficiency of light into dry matter, RUE was computed in the post-grazing-anthesis period. Only the LL treatment had significantly reduced biomass accumulation and cumulative light interception in this period (Table 1). The RUE of the ungrazed crop, 1.11 g MJ^{-1} , was at the lower end of the range of values reported for wheat by Sinclair and Muchow (1999). However, this RUE was estimated for only part of the season. If RUE was recalculated over the emergence-anthesis period, a value of $1.51 \pm 0.05 \text{ g MJ}^{-1} \text{ IPAR}$ was obtained. This value compares reasonably well with other RUE values estimated from shoot biomass per unit IPAR in previous experiments on rainfed wheat in Australia (1.43 , Gregory and Eastham (1996), 1.42 , Sadras et al. (2005)). Observed differences in growth rates in this study were therefore unlikely to be due to RUE effects.

Table 1 Changes in shoot biomass, cumulative light intercepted (ΣIPAR) and radiation-use efficiency of the shoots (RUE) in the post grazing-anthesis period for each grazing treatment. C = control, LS = light short, HS = heavy short and LL = light long

Grazing treatment	Biomass accumulation [†] (g m^{-2})	ΣIPAR (MJ m^{-2})	RUE after grazing [‡] ($\text{g MJ}^{-1} \text{ IPAR}$)
C	750 (2.88a)	676a	1.11a
LS	720 (2.86a)	662a	1.09a

HS	691 (2.84a)	599a	1.16a
LL	416 (2.62b)	443b	0.98a
LSD _{0.05}	0.07	83	0.25

† ANOVA conducted on log-transformed values shown in brackets. LSD_{0.05} is with respect to transformed values.

‡ RUE was computed as the ratio of shoot biomass to ΣIPAR at the end of the post-grazing-anthesis period

^{a, b} Means followed by the same letter within a column are not significantly different

Conclusions

All grazing treatments reduced *f* and LAI, but no significant differences were detected in post-grazing-anthesis RUE. Greater removal of shoot biomass and LAI was typically followed by greater rates of canopy closure. Growth rates after grazing were primarily limited by soil moisture availability, a factor that influenced leaf area expansion and peak LAI. This study has shown that heavy grazing of dual-purpose wheat can be conducted under years of limited spring rainfall, provided that grazing takes place relatively early in the season.

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