Changes in the Physiology and Feed Quality of Prairie Grass during Regrowth

L. R. Turner,* D. J. Donaghy, P. A. Lane, and R. P. Rawnsley

ABSTRACT
Species-specific grazing management is required to maximize the potential of perennial grass species, and it follows that the optimal performance of prairie grass (Bromus willdenowii Kunth.) as a dairy pasture species is reliant on a customized optimal grazing interval. The aim of the present study was to investigate morphological and physiological changes in prairie grass during regrowth to establish a basis for optimum defoliation management of prairie grass pastures. Greenhouse treatments consisted of one preliminary harvest followed by six sequential harvests at each leaf regrowth stage from one to six fully expanded leaves per tiller. Leaf tissue, stubble tissue below 50 mm and roots were collected at each harvest event. Root and stubble samples were analyzed for water-soluble carbohydrates (WSC). Leaf samples were analyzed for P, K, Na, Mg, Ca, and N concentrations and metabolizable energy (ME) was predicted by near-infrared spectrometry (NIRS). This study confirmed that the tiller base in prairie grass is the primary storage organ for WSC and that leaf growth has the highest priority for available energy following defoliation, followed by root growth and tiller initiation. A defoliation interval based on the 4-leaf stage of regrowth enabled adequate time for prairie grass to replenish WSC reserves, resume root growth and initiate new tillers, before the onset of significant leaf senescence and consequent reduction in feed quality. At the 4-leaf stage, feed quality was relatively high (ME > 11.80 MJ kg⁻¹ DM), with concentrations of P, K and Na adequate to meet the needs of a high-producing dairy cow. Concentrations of Ca and Mg were insufficient to meet these requirements throughout the regrowth cycle.

Perennial ryegrass (Lolium perenne L.) is the dominant grass of Tasmanian dairy pastures and of the wider cool temperate region of Australia. However, the dryland dairy areas of southern Australia may benefit from the introduction of alternative grass species such as prairie grass, to be used in combination with perennial legumes such as white clover (Trifolium repens L.). In New Zealand, recent studies have shown that alternative grass species outperformed perennial ryegrass in terms of milk production, largely as a result of greater summer herbage production (Thom et al., 1998, 2001). Under dryland conditions prairie grass remains active, responding well to limited summer rainfall and maintaining a longer growing season than ryegrass (Belton, 1992).

Although several studies have clearly shown prairie grass is capable of greater herbage production than perennial ryegrass (Vartha, 1977; Fraser, 1982; DeLacy, 1987; Fulkerson et al., 2000), when grazed in the same manner as ryegrass-based pastures (as is common practice), prairie grass is disadvantaged, particularly from late spring to early autumn when the leaf appearance rate of prairie grass is more rapid than for ryegrass (Turner et al., 2006).

For example, in a Tasmanian study, prairie grass was initially shown to be unproductive with poor persistence (Department of Primary Industry, 1987) because existing best management practice for ryegrass-based pastures was applied to both pasture types. In a subsequent study, prairie grass was grazed to leave longer postgrazing residuals and allowed to set seed in spring. Utilization from the prairie grass pasture rose to 2, then 4 Mg DM greater than utilization of ryegrass in successive years (Department of Primary Industry, 1987). Grazing management based on the physiological status of the prairie grass plant is more efficient than grazing management based on herbage accumulation or on set day rotations (Thom et al., 1990; Fulkerson and Donaghy, 2001). A useful plant-related indicator of optimal defoliation timing is the full expansion of a particular number of leaves per tiller. For perennial ryegrass, the 2- to 3-leaf stage of regrowth has been accepted as the optimal defoliation interval (Fulkerson and Donaghy, 2001).

When perennial ryegrass plants are defoliated before the 2-stage, there is insufficient time for replenishment of WSC reserves, which are depleted immediately following defoliation. Repeated defoliations before plants are physiologically “ready” therefore results in reduced leaf regrowth, tillering, and root growth (Donaghy and Fulkerson, 1997, 1998; Rawnsley et al., 2002). In addition to the changes in stubble WSC concentration during regrowth, Fulkerson et al., (1998) suggest that there may also be an imbalance in herbage mineral levels and the ratio of carbohydrates to protein when perennial ryegrass is grazed before the 2-stage.

When perennial ryegrass plants are defoliated after the 3-stage, leaf senescence and an increase in fiber concentration leads to increased rejection of herbage by grazing stock and therefore lower levels of DM utilization. The optimal grazing intervals defined for perennial ryegrass pastures are the key to grazing management for the maintenance of a balance between pasture growth, persistence, quality and utilization (Fulkerson and Donaghy, 2001). As species-specific grazing management is required to maximize the potential of perennial grass species, it follows that the optimal performance of prairie grass as a dairy pasture species would be similarly reliant on a customized optimal grazing interval.

Fulkerson et al. (2000) found that a grazing rotation based on the 3.5- to 4-stage of regrowth favored...
prairie grass growth, persistence and herbage feed quality throughout the year. The aim of the present study was to further investigate morphological and physiological changes in prairie grass during regrowth and hence the mechanisms underpinning the existing defoliation management recommendations for prairie grass pastures.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Tasmanian Institute of Agricultural Research, Burnie, Australia (41°04’ S, 145°53’ E, elevation 206 m), between May and November 2004. Three seeds of ‘Matua’ prairie grass were planted in each of 385 polyvinyl bags (100-mm diam. by 280-mm depth), on May 5th. The bags had perforated bases and contained a potting mixture composed of 50% pine (Pinus radiata D.) bark, 30% sand, and 20% Spagnum sp. moss. Once established, the weakest seedlings were removed to contain a potting mixture composed of 50% pine (Pinus radiata D.) bark, 30% sand, and 20% Spagnum sp. moss. Once established, the weakest seedlings were removed to allow a single healthy seedling to reach maturity in each bag. The plants were arranged in the greenhouse at a density of 100 plants m⁻². Plants were watered daily via an underlying geotextile membrane capillary mat, to replace evapotranspiration losses. Greenhouse conditions were controlled to maintain day/night temperatures of 20/10°C. At 56 d from germination and again before treatments being imposed, plants were fertilized with Osmocote (Scotts Australia Pty Ltd., New South Wales, Australia) at a rate equivalent to 40 kg N ha⁻¹.

Determination of Leaf Stage

Each leaf regrowth stage was defined as the presence of a particular number of fully expanded leaves per tiller. Prairie grass maintains 4 to 5 live leaves per tiller, with a new leaf commencing growth when the previous leaf has reached approximately 75% of its full length. Thus, at any given time two prairie grass leaves are expanding, and measurement of “leaf stage” is estimated by the amount of growth of the current expanding leaves.

Experimental Design

Plants were arranged in a randomized complete block design, with five blocks each containing seven randomly allocated treatments. Each treatment consisted of a row of nine plants per block, resulting in 45 plants in total per treatment. Treatments consisted of one preliminary harvest (0) and six sequential harvests at each leaf regrowth stage from one to six fully expanded leaves per tiller (1–6L). Buffer plants were placed around the minisward to minimize boundary effects. These plants were harvested but otherwise not included in analyses. On 30 June (55 d following sowing), all plants were defoliated to a stubble height of 50 mm to promote tillering. At the 5-leaf and 6-leaf stages, two subsamples from the harvested leaf material within each block were taken and one was separated into live and dead material, while the other was sorted into leaf and stem material, with stem determined as elongated internode.

Destructive Harvest Regime and Determination of Dry Matter Yield

The second defoliation to 50 mm constituted the first pretreatment destructive harvest (0). Sequential harvests then followed at each leaf regrowth stage, up to the 6-leaf stage. Nonsheath leaf tissue (≥50 mm) was removed at each harvest event, and leaf DM yield plant⁻¹ determined after drying samples for at least 24 h at 100°C in a forced draft oven. Stubble tissue below 50 mm and roots were collected at each harvest event. Stubble and washed roots were dried for at least 24 h at 80°C in a forced draft oven then weighed. Tiller DM and number per plant were also determined at each harvest interval. Harvests were consistently performed at 3 h after sunrise, to negate the confounding effect of diurnal fluctuations in WSC (Fulkerson and Slack, 1994). Dried leaf, root and stubble samples were ground through a 1-mm sieve before chemical analyses.

Differentiation in Leaf Material

Leaf and tiller senescence as well as reproductive development proceeded as plants matured, and measures were taken to define differentiation in leaf material with plant growth. At the 5-leaf and 6-leaf stages, two subsamples from the harvested leaf material within each block were taken and one was separated into live and dead material, while the other was sorted into leaf and stem material, with stem determined as elongated internode.

Water-Soluble Carbohydrate Analysis

Root, stubble and leaf samples were analyzed for WSC. The concentration of WSC was determined by cold extraction of plant material in a reciprocal shaker for 1 h using 0.2% benzoic acid C₆H₅CO₂H–water solution, and the hydrolyzation of the cold water carbohydrates to invert sugar by 1 mol L⁻¹ HCl. This was heated at 90°C, and the sugar was dialyzed into an alkaline stream of potassium ferrocyanide [K₄Fe(CN)₃H₂O], again heated at 90°C, and then measured at 420 nm using an autoanalyzer (Technicon Industrial Method no. 302-73A, derived from the method outlined by Smith, 1969).

Herbage Quality Analysis

Metabolizable Energy

Leaf samples were analyzed for ME concentration using NIRS at Hamilton FeedTEST Laboratories (Victoria Department of Primary Industries).

Minerals

Phosphorus, K, Na, Mg, and Ca concentrations of leaf samples were determined by digestion of finely ground plant material in nitric acid (HNO₃) using a Milestone microwave (Milestone, Connecticut, USA) and measurement by ICP-AES (McQuaker et al., 1979).

Nitrogen

Finely ground leaf material was combusted at 950°C in O₂, using a Leco FP-428 Nitrogen Analyzer (LECO Instruments, St. Joseph, MI, USA). The released N from the sample was measured as it passed through a thermal conductivity cell (Sweeney and Rexroad, 1987). The CP content was calculated as N concentration (g kg⁻¹ DM) × 6.25.

Statistical Analyses

Pretreatment DM values from defoliation Event 0 were used as a covariate. Differences between treatment (leaf regrowth stage) means were tested for the following variables: leaf DM, root DM, individual tiller DM, WSC, ME, CP, Ca, P, Ca/P, K, Na and Mg. Means were compared by ANOVA using the statistical package SPSS, and least significant difference (LSD) when F tests were significant at P = 0.05, as defined by Steel and Torrie (1960), Regression (r²) between WSC level and plant regrowth was tested using the statistical functions of EXCEL.
RESULTS

Changes in Stubble and Root Water-Soluble Carbohydrate with Leaf Regrowth

At defoliation (leaf regrowth Stage 0) and throughout the subsequent regrowth cycle, the mean WSC concentration (g kg\(^{-1}\) DM) in the stubble was greater (\(P < 0.001\)) than in the roots. Following defoliation, there was a decline (\(P < 0.001\)) in the stubble and root WSC concentrations. There was an increase (\(P < 0.05\)) in stubble WSC concentration between and 1-leaf and 5-leaf stages of regrowth, while root WSC concentration initially increased (\(P < 0.001\)) between the 1-leaf and 2-leaf stages, but then decreased (\(P < 0.05\)) between the 4-leaf and 5-leaf stages of regrowth (Fig. 1).

Total stubble WSC content (mg plant\(^{-1}\) and mg tiller\(^{-1}\)) decreased at the 1-leaf stage, and then returned to prededefoliation levels by the 2-leaf stage of regrowth. Stubble WSC content was higher (\(P < 0.05\)) at the 5-leaf and 6-leaf stages than at any previous regrowth stage (Table 1).

Table 1. Stubble WSC content (mg plant\(^{-1}\) and mg tiller\(^{-1}\)) in relation to regrowth stage.

<table>
<thead>
<tr>
<th>Leaf regrowth stage</th>
<th>Stubble WSC</th>
<th>Stubble WSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>leaves tiller(^{-1})</td>
<td>mg tiller(^{-1})</td>
<td>mg plant(^{-1})</td>
</tr>
<tr>
<td>0</td>
<td>8.41b</td>
<td>63.07b</td>
</tr>
<tr>
<td>1L</td>
<td>1.15a</td>
<td>19.71a</td>
</tr>
<tr>
<td>2L</td>
<td>8.34b</td>
<td>66.38b</td>
</tr>
<tr>
<td>3L</td>
<td>17.46b</td>
<td>138.91b</td>
</tr>
<tr>
<td>4L</td>
<td>20.33b</td>
<td>139.35b</td>
</tr>
<tr>
<td>5L</td>
<td>36.53c</td>
<td>256.46c</td>
</tr>
<tr>
<td>6L</td>
<td>49.05c</td>
<td>370.45d</td>
</tr>
<tr>
<td>LSD ((P = 0.05))</td>
<td>13.20</td>
<td>89.17</td>
</tr>
</tbody>
</table>

* Letters that differ within columns indicate values that are significantly different at \(P = 0.05\).

Changes in Tiller per Plant with Regrowth

Before defoliation, there were 6.7 ± 0.4 tillers plant\(^{-1}\) and this remained relatively constant (\(P > 0.05\)) until the 3-leaf stage, after which tiller numbers increased (\(P < 0.05\)) to 8.0 ± 0.4 at the 4-leaf and 5-leaf stages, and 9.4 ± 0.4 at the 6-leaf stage of regrowth.

Changes in Dry Matter Yield with Regrowth

Stubble DM (mg tiller\(^{-1}\)) decreased (\(P < 0.05\)) following defoliation and increased (\(P < 0.05\)) at a constant rate until the 3-leaf stage of regrowth. Stubble DM was higher (\(P < 0.05\)) at the 5-leaf and 6-leaf stages than at any previous regrowth stage (Table 2). There was no difference (\(P > 0.05\)) in root DM (mg plant\(^{-1}\)) from defoliation until the 3-leaf stage, followed by an increase (\(P < 0.001\)) from the 4-leaf to the 6-leaf stage of regrowth (Table 2). Following defoliation, there was a steady increase (\(P < 0.05\)) in leaf DM (mg plant\(^{-1}\)) with regrowth (Table 2). Leaf senescence was first measured at the 5-leaf stage, with 0.05 of leaf DM senescent, increasing to 0.09 at the 6-leaf stage of regrowth (Fig. 2).

Changes in Herbage Quality with Regrowth

The ME concentration of the leaf decreased (\(P < 0.05\)) with regrowth between the 4-leaf to the 6-leaf stage, with no difference (\(P > 0.05\)) between the 1-leaf, 3-leaf and 4-leaf stages (Fig. 2). The stem material proportion of DM at the 5-leaf and 6-leaf stages of regrowth was 0.14 and 0.16 respectively (Fig. 2).

There was a general decline in leaf CP, Ca, Mg, P, and K concentrations with regrowth following defoliation.

Relationship between Plant Water-Soluble Carbohydrate Levels and Regrowth

There was a strong positive linear relationship between leaf, tiller and root DM yield at each leaf regrowth stage and stubble WSC concentration and content (g kg\(^{-1}\) DM and mg tiller\(^{-1}\)), as follows:

Leaf DM plant\(^{-1}\) (g) = 0.1404 stubble WSC (g kg\(^{-1}\) DM) – 0.3226 (\(r^2 = 0.83\)) = 0.0831 stubble WSC (mg tiller\(^{-1}\)) + 0.9138 (\(r^2 = 0.81\))

Stubble DM (mg tiller\(^{-1}\)) = 2.7171 stubble WSC (g kg\(^{-1}\) DM) + 24.751 (\(r^2 = 0.85\)) = 1.7186 stubble WSC (mg tiller\(^{-1}\)) + 46.461 (\(r^2 = 0.95\))

Root DM plant\(^{-1}\) (g) = 0.0702 stubble WSC (g kg\(^{-1}\) DM) – 0.5019 (\(r^2 = 0.75\)) = 0.0465 stubble WSC (mg tiller\(^{-1}\)) + 0.0173 (\(r^2 = 0.92\))

A positive correlation was found between stubble DM and root WSC concentration (g kg\(^{-1}\) DM), although the proportion of experimental variation (\(r^2\)) was only 0.40. No such relationship was found between root DM, leaf DM or tiller number and root WSC concentration, or between tiller number and stubble WSC concentration or content.

Fig. 1. Changes in stubble (▲) and root (■) WSC (g kg\(^{-1}\) DM) concentration with regrowth of prairie grass after defoliation. LSD \((P = 0.05)\) shown as vertical bars.
However, the decline was not constant, with a plateau effect evident between the 2-leaf or 3-leaf and 5-leaf stages (Table 3). The concentration of Na in the leaf decreased (P < 0.05) between the 1-leaf and 2-leaf stages, and increased (P < 0.05) between the 3-leaf and 5-leaf stages of regrowth (Table 3).

**DISCUSSION**

The current study presents quantitative evidence to indicate that the optimal time of defoliation for growth, persistence and forage quality of prairie grass is the 4-leaf stage of regrowth. At this stage of plant development, increased WSC reserve levels coincide with a resumption of tillering and root growth. Feed quality is also relatively high (ME > 11.80 MJ kg\(^{-1}\) DM), with concentrations of P, K and Na adequate to meet the needs of a high-producing dairy cow (National Research Council, 1989). However, concentrations of Ca and Mg were insufficient to meet these requirements throughout the regrowth cycle.

Both the concentration of WSC and the level of replenishment following defoliation were greater in the stubble than in the root system, confirming that, as in ryegrass (Danckwerts and Gordon, 1987; Fulkerson and Slack, 1994) and orchardgrass (Dactylis glomerata L.) (Davidson and Milthorpe, 1966a; Rawnsley et al., 2002), the stubble is the major storage site for WSC in prairie grass. Immediately following defoliation, WSC replenishment commenced, resulting in significantly higher WSC levels at the 5-leaf and 6-leaf stages than at any previous regrowth stage. In contrast to orchardgrass plants, in which WSC reserves are replenished to predefoliation levels by the 4-leaf stage (Rawnsley et al., 2002), prairie grass WSC reserves in this study were replenished to predefoliation levels by the 2-leaf stage of regrowth.

The strong positive linear relationship between stubble WSC levels and the regrowth capacity of prairie grass confirms that WSC reserves play an important role in the entire plant regrowth cycle following defoliation. The importance of WSC reserves in the regrowth of orchardgrass (Davidson and Milthorpe, 1966a; Rawnsley et al., 2002), perennial ryegrass (Davies, 1965; Fulkerson and Slack, 1994; 1995; Donaghy and Fulkerson, 1997, 1998), tall fescue (Festuca arundinacea Schreb.) (Booysen and Nelson, 1975; Volene, 1986) and timothy (Phleum pratense L.) (Smith, 1974) has been previously reported. However, the extent of reliance of ryegrass (Danckwerts and Gordon, 1987; Fulkerson and Slack, 1994; Donaghy and Fulkerson, 1997) and orchardgrass (Davidson and Milthorpe, 1966a,b) plants on reserves in such studies has often been shown to be limited to several days postdefoliation.

While there was little difference in the strength of linear relationships between regrowth of leaves and stubble WSC content (mg tiller\(^{-1}\)) compared with WSC concentration (g kg\(^{-1}\) DM), there were closer relationships between stubble DM and regrowth of roots with stubble WSC content compared with concentration. With prairie grass tillers weighing up to three times that of perennial ryegrass tillers (Turner et al., 2006), the regenerative capacity of prairie grass is not only correlated

![Fig. 2. Changes in ME concentration (MJ kg\(^{-1}\) DM) (▲) and the accumulation of senescent (□) and stem (■) (proportion of DM) material with regrowth of prairie grass after defoliation. LSD (P = 0.05) shown as vertical bars.](image-url)
to WSC content but also the size of the storage organ. Based on the figures from the current study, for any given WSC concentration, there is a significantly higher WSC content (mg tiller\(^{-1}\)) in prairie grass compared with perennial ryegrass.

Leaf growth had a higher priority for available energy than root growth and tiller initiation in the current study. This was evidenced by immediate leaf regrowth following defoliation, compared with significant root regrowth not until the 3-leaf stage, and significant increases in tiller number not until the 4-leaf stage of regrowth. This time sequence and overall priority for allocation of WSC reserves is almost identical to that found for perennial ryegrass (root regrowth occurring at the 1-leaf and tillering at the 2-leaf stage; Donaghy and Fullkerson, 1998) and orchardgrass (root regrowth occurring at the 4-leaf and tillering at the 5-leaf stage; Rawnsley et al., 2002). Thus it appears evident that for a range of pasture grasses, a similar priority for energy reserve allocation exists, and this has ramifications for grazing management.

Despite the capability of prairie grass to immediately resume replenishment of energy reserves following defoliation, it is likely that defoliation before the 4-leaf stage of regrowth will not allow tiller initiation to occur. As perenniality of grasses depends on their capacity to replace dying tillers (Colvill and Marshall, 1984; Marshall, 1987), defoliation before the 4-leaf stage of regrowth may result in reduced persistence of prairie grass plants. The detrimental effect of frequent defoliation on the persistence of prairie grass is further exacerbated by the relatively low tiller density of this species compared with perennial ryegrass (Turner et al., 2006). It is also important to note that the plants in the current study were defoliated at the 4-leaf stage of regrowth before treatments commencing—had they been defoliated at an earlier leaf stage, the pattern of WSC replenishment during the subsequent regrowth cycle may have differed considerably.

A reduction in root growth following defoliation has been previously reported for orchardgrass (Jacques and Edmond, 1952; Davidson and Milthorpe, 1966b; Evans, 1973; Rawnsley et al., 2002) and perennial ryegrass (Jacques and Edmond, 1952; Evans, 1971, 1972, 1973; Fullkerson et al., 1993; Donaghy et al., 1997, Donaghy and Fullkerson, 1997, 1998). In the current study, defoliation almost halved the root DM of prairie grass during the time it took to regrow one new leaf, supporting the findings of Evans (1972) and Donaghy and Fullkerson (1998) that root regrowth is highly sensitive to changes in WSC concentrations. Prairie grass resumed significant root growth at the 3-leaf stage of regrowth. Management that restricts root growth affects plant growth in general, due to the limitation placed on water and nutrient uptake (Davidson and Milthorpe, 1966b; Clement et al., 1978), and therefore plant survival. From a root system perspective, defoliation of prairie grass before the 3-leaf stage of regrowth would therefore have a detrimental effect on plant survival.

The ME value of prairie grass remained above 11.80 MJ kg\(^{-1}\) DM until (and including) the 4-leaf stage, after which increased stem and senescent material combined to reduce the ME concentration with regrowth. Given the increased leaf DM at the 5-leaf and 6-leaf stages, total ME yield (MJ ha\(^{-1}\)) would be substantially greater at the longer regrowth interval, but may not result in increased pasture utilization in a grazing situation due to increased rejection by stock because of the increased stem and senescent material.

The decrease in CP concentration with regrowth was expected; Minson (1990) investigated the CP levels of a range of grass species and reported an average rate of decline of 0.22% per day. The CP concentration of prairie grass met the requirements of a high-producing dairy cow until (and including) the 4-leaf stage, after which point CP concentrations fell below the requirements, possibly due to the increased stem/leaf ratio and increased levels of WSC (Beever et al., 2000).

A decrease in the concentration of Ca in the leaf with increasing maturity is unusual and in contrast to that reported for perennial ryegrass (Wilman et al., 1994; Fullkerson et al., 1998), white clover (Wilman et al., 1994) and orchardgrass (Rawnsley et al., 2002). Combined with the more rapid decline in the concentration of P in the leaf, there was a 1.5-fold increase in the ratio of Ca/P concentration in the leaf from the 1-leaf to the 6-leaf stage of regrowth. At no stage of regrowth did the Ca/P approach the ratio of 1.6 recommended by National Research Council (1989) for a high-producing dairy cow. The concentration of Ca in the leaf only met these requirements at the 1-leaf stage of regrowth, while the concentration of P in the leaf was in excess of these requirements throughout the regrowth cycle. The low Ca concentrations observed in this study may not translate to Ca deficiencies for grazing animals in the field, as prairie grass would be sown with a companion legume (legumes generally contain more Ca than grasses; Whitehead, 1972) and regular applications of superphosphate and lime to the pasture should maintain Ca levels (Grace, 1989).

The decline in the concentration of Mg in the leaf was in contrast to the pattern of Mg accumulation reported for perennial ryegrass (Wilman et al., 1994; Fullkerson et al., 1998; Fullkerson and Donaghy, 2001) but in agreement with that reported for orchardgrass (Rawnsley et al., 2002). The concentration of Mg in the leaf of prairie grass did not approach the recommended 2.0 g kg\(^{-1}\) DM (National Research Council, 1989) at any stage of the regrowth cycle. A low Mg concentration is one of the previously reported nutritional limitations of prairie grass (Thom et al., 1990; Fullkerson et al., 2000), however the effect of low herbage Mg on milk production has been shown to be insignificant (Wilson and Grace, 1978).

Leaf K concentrations were adequate until (and including) the 4-leaf stage of regrowth, after which point the continuing decline in K concentrations with regrowth failed to meet the National Research Council (1989) recommendation of 54.0 g kg\(^{-1}\) DM. The pattern of Na accumulation in the leaf was somewhat unpredictable, but significantly increased between the 1-leaf and 6-leaf stages and remained in excess of the requirements of a high-producing dairy cow for the duration of
the regrowth cycle. The high concentrations of P and Na in the current study contrast with a previous study (Crush et al., 1989), in which these minerals were identified as potential nutritional limitations for prairie grass compared with perennial ryegrass.

In conclusion, a defoliation interval based on the 4-leaf stage of regrowth enables adequate time for prairie grass to replenish WSC reserves, resume root growth and initiate new tillers, before the onset of significant leaf senescence, stem production and consequent reduction in feed quality. These results confirmed that the tiller base is the primary storage organ for WSC (Fulkerson and Slack, 1994) and that leaf growth has the highest priority for available energy after defoliation, followed by root growth and tiller initiation, as is the case for perennial ryegrass (Donaghy and Fulkerson, 1998) and orchardgrass (Rawnsley et al., 2002).

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