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Effect of Varying Temperature Regime on Phyllochron in Four Warm-Season Pasture Grasses

Paul W. Bartholomew

USDA-ARS Grazinglands Research Laboratory, El Reno, OK, USA
Email: paul.bartholomew@ars.usda.gov

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Abstract

Using accumulated temperature measures to predict plant development may provide guidance on timing of management practices to minimize competition between warm and cool-season components of mixed pastures. However, temperature and plant development relationships for warm-season pasture grasses common in the southern Great Plains of the USA have not been extensively studied. Under controlled environment conditions, base temperature (T_{base}) values were determined for Big bluestem (*Andropogon gerardii* Vitman), Indiangrass (*Sorghastrum nutans*, (L.) Nash), Little bluestem (*Schizachyrium scoparium* (Michx) Nash) and, Sideoats grama (*Bouteloua curtipendula* (Michx) Torr). Measures of the accumulated temperature requirement for the phyllochron (leaf appearance interval) were made under a range of temperature regimes for these same species. Mean T_{base} was 8.1˚C and differences among species were not significant ($P > 0.05$). Within temperature regimes mainstem leaf appearance was closely and linearly related to accumulated temperature above T_{base}. Increase of 7.5˚C in night temperature increased phyllochron by a mean of 43%, but similar increase in day temperature only increased phyllochron by 16%. Phyllochron increased by 6.4˚C leaf^{-1} for each 1˚C increase in daily mean temperature within the range of 15.0˚C to 22.5˚C. If accumulated temperature measures are to monitor reliably the development of warm-season grasses, allowance must be made for changes in phyllochron as the growing season progresses.

Keywords

Phyllochron, Base Temperature, Warm-Season Grass

1. Introduction

In the southern USA, cool- and warm-season grasses may be grown in mixtures of perennial species [1] or as a

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sequence of annual species overseeded into a perennial base [2] [3], in order to extend the productive growing season. The expectation of increased annual production arising from a longer growing season is, however, frequently not fully realized because of competition between cool- and warm-season components of pasture that results in lower than expected aggregate productivity [4] or in reduced persistence of one or both components of the mixture [5].

Problems arising from competition in mixed pastures might be alleviated by adoption of management practices, such as timing of harvests or N fertilizer application, that reduce interference between warm and cool-season grasses, especially at times of year when conditions are suitable for active growth of both warm and cool-season species. Appropriate timing of field operations depends on knowledge of the growth and development status of the components of the mixed pasture, but this information may not be readily available because it requires frequent field observation of plant growth stage. An indirect method of monitoring the progress of pasture development that eliminates the need for time-consuming direct observation might be of value in support of pasture management decisions by farmers.

Other work has shown a close relation between accumulated temperature, or growing degree days [GDD] and plant phenological stage and this is commonly expressed as leaf appearance interval (phyllochron) [6]-[8]. Since data needs for calculation of accumulated temperature are limited to daily maximum and minimum temperatures that can be readily interpolated to provide site-specific information [9], an accumulated temperature approach might provide a readily-accessible method for assessing crop development stage. In the specific instance of cool- and warm-season mixed pastures however, although phenological responses of cool-season species have been relatively well studied [6], there is little information on corresponding responses in warm-season grasses, especially those native species that provide the basis of perennial warm-season pasture in the southern Great Plains. For these species, base temperatures and phyllochron are not well defined.

The objectives of the work described here were to determine base temperature (T_{base}) values for four common native pasture species and to examine the effect of a range of temperature regimes on the relation of accumulated temperature and leaf appearance, through measure of phyllochron of these same species.

2. Materials and Methods

Three sets of experiments were undertaken in controlled environment to characterize development responses to different temperature regimes of four perennial warm-season pasture grass species: Big bluestem (*Andropogon gerardii* Vitman [cv Rountree]) [BB], Indiangrass (*Sorghastrum nutans*, (L.) Nash [cv Holt]) [IG], Little bluestem (*Schizachyrium scoparium* (Michx) Nash [cv Blaze]) [LB] and, Sideoats grama (*Bouteloua curtipendula* (Michx) Torr [cv Butte]) [SOG].

2.1. Plant Management

In all experiments single plants of each species were grown in 155 mL individual pots (conetainers®, Stuewe & Co., Corvallis, OR) in potting soil, either as Miracle-Gro, (Miracle-Gro lawn products Inc., Marysville, OH) consisting 600 $g \cdot kg^{-1}$ forest products compost + 400 $g \cdot kg^{-1}$ sphagnum peat moss and perlite or as Baccto (Michigan Peat Co., Houston, TX) consisting 840 $g \cdot kg^{-1}$ reed sedge peat + 160 $g \cdot kg^{-1}$ sand and perlite. Plants were grown from seed in controlled environment chambers (Percival Scientific Inc., Perry, IA) and thinned to a single seedling per container within 3 days of emergence. Watering was made through uniform applications of 10 ml of deionized water to each plant, at a frequency sufficient to keep the surface soil moist. Throughout the experiments plants were subject to a 13 h light and 11 h dark regime. Light input was maintained at an average photosynthetic photon flux density (PPFD) of 265 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ at the top of the canopy and was maintained by adjustment of shelving height as plant size increased. The temperature regimes used are noted below for each set of experiments. Day and night temperature settings were programmed in each growth chamber and were periodically monitored for consistency using HOBO temperature dataloggers (Onset Computer Corporation, Pocasset, MA). No anomaly in set and monitored temperature was observed during the experiments. Measurement of seedling development was made by counts of leaf and tiller number that were made twice-weekly on 5 seedlings of each species within each temperature treatment, and in each repetition of the experiment, up to 5 weeks after emergence.

2.2. Determination of Base Temperature (Set 1)

In an initial set of experiments the base temperature for growth (T_{base}) was determined for each species following techniques described by Gramig and Stoltenberg [10]. Plants were grown in constant temperatures of 12.5˚C, 17.5˚C or 22.5˚C and mainstem leaf appearance rate at each temperature was estimated. A relation between temperature and leaf appearance rate was established and the temperature corresponding to a zero rate of leaf appearance was estimated for each species, assuming a linear response of leaf appearance rate to temperature [10].

2.3. Effect of Temperature Regime on Phyllochron (Set 2)

Mainstem leaf appearance response of each grass species was measured under day/night temperature regimes of 17.5/12.5, 22.5/7.5, 25.0/20.0 or 30.0/15.0˚C, that provided mean daily temperatures of 15.0˚C or 22.5˚C, at diurnal temperature ranges of 5.0˚C or 15.0˚C. Accumulated temperature (˚C above T_{base}) was calculated as the accumulation of mean daily temperature $[\{(T_{max} - T_{min})/2\} - T_{base}]$ where base temperature T_{base} = 8.1˚C determined as the mean over grass species tested in Set 1. Rate of leaf appearance per unit of accumulated temperature was determined and the leaf appearance interval (phyllochron) was calculated as the reciprocal of leaf appearance rate.

2.4. Effect of Day, Night and Daily Mean Temperatures on Phyllochron (Set 3)

Leaf appearance rate and phyllochron were estimated, as described above, for plants exposed to day temperatures of 22.5˚C or 30.0˚C, in combination with night temperatures of 7.5˚C or 15.0˚C, providing mean temperatures of 15.0˚C, 18.75˚C or 22.5˚C.

2.5. Statistical Procedures

A single mean value of mainstem leaf count was derived from each group of 5 seedlings under the same temperature treatment within each experiment. The progression of mean leaf count with increasing accumulated temperature was analyzed by linear regression to provide a mean rate of leaf appearance for each treatment. Replication was provided by repeating each experiment in time in different growth chambers, four times in the case of measures of base temperature (Set 1) and five times for measures of the effects of temperature regime (Set 2) or day and night temperature combinations on phyllochron (Set 3). Phyllochron (˚C [above 8.1˚C] $leaf^{-1}$) was calculated as the reciprocal of the linear regression coefficient of leaf appearance rate (leaves $˚C^{-1}$ [above 8.1˚C]). Comparison of treatment effects (fixed effects were grass species, mean daily and diurnal temperature range in Set 2 and grass species, day temperature and night temperature in Set 3) was made by ANOVA of these phyllochron values. The change in phyllochron response to change in mean daily temperature was assessed by linear regression in Set 3. Genstat 11 procedures [11] were used for linear regression and for ANOVA calculations.

3. Results

3.1. Base Temperatures

Over the range of temperatures used (12.5˚C - 22.5˚C) there was a strong linear relation between leaf appearance rate and temperature, with an overall R^2 of 0.96. Over four experiments averages for T_{base} were estimated at 7.6, 7.0, 8.7 and 9.1 for Big bluestem, Little bluestem, Indiangrass and Sideoats grama, respectively. The difference among species was not significant ($P > 0.05$) and the overall mean was 8.1 (±0.69 s.e.) ˚C.

3.2. Temperature Regime and Phyllochron

There was no significant interaction ($P < 0.05$) between species and mean temperature or temperature range treatments. Mean phyllochron differed significantly among species (**Figure 1(a)**). Increase in mean temperature from 15.0˚C to 22.5˚C and decrease in diurnal temperature change from 15.0˚C to 5.0˚C increased phyllochron (**Figure 1(b)**). There was a significant interaction of mean temperature and temperature range and this was evident mainly through reduced phyllochron in the 22.5/7.5 treatment (**Figure 1(c)**).

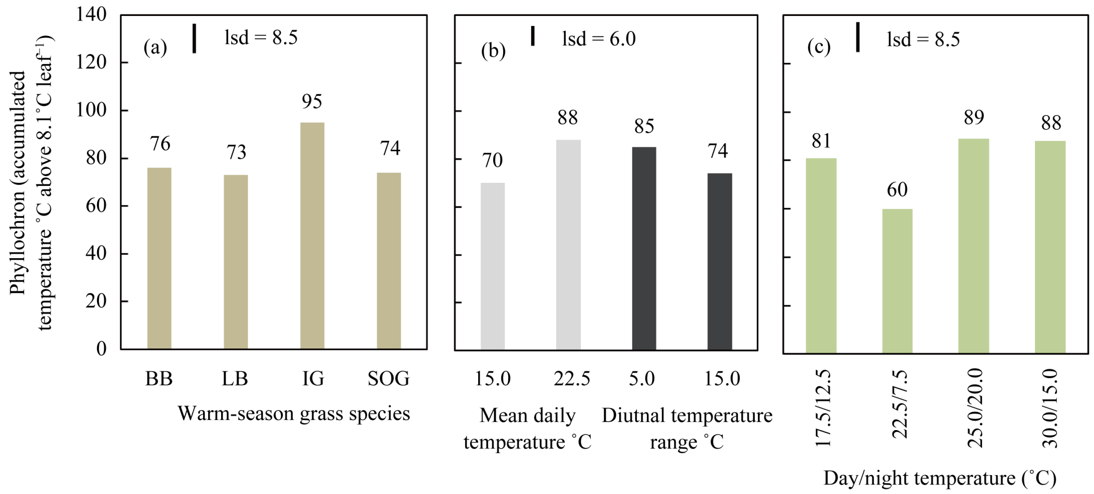

Figure 1. (a) Mean phyllochron for Big bluestem (BB), Little bluestem (LB), Indiangrass (IG) and Sideoats grama (SOG). (b) Effect of daily mean temperature and diurnal temperature range (˚C) on phyllochron (mean of 4 species above and, (c) Effect of day/night temperature regime on phyllochron (mean of 4 species). In each graph, bar indicates least significant difference (lsd) P = 0.05 between or among means.

3.3. Day, Night and Daily Mean Temperatures

There was no significant ($P < 0.05$) interaction of species with temperature treatment, and results are presented as means of main treatment effects. Significant differences among species showed phyllochron rankings (**Figure 2(a)**) similar to those observed in the temperature regime experiments. Phyllochron increased with increase in daily mean temperature (**Figure 2(b)**). Over a temperature range of 15.0˚C to 22.5˚C, phyllochron showed a linear increase of 6.4 (±0.81 s.e.) ˚C for each 1˚C increase in mean daily temperature. There was no significant difference ($P > 0.05$) among species in rate of change in phyllochron with changing temperature. Increase in both day (22.5˚C to 30.0˚C) and night (7.5˚C to 15.0˚C) temperatures increased phyllochron (**Figure 2(c)**) but the increase in night temperature increased phyllochron by 43%, compared with only 16% with a similar, 7.5˚C, increase in day temperature.

4. Discussion

Other authors have emphasized the need for accurate determination of base temperature as a prerequisite for effective use of accumulated temperature based models of crop development [12] [13]. However, values for base temperature in warm season grasses are not widely reported in literature. Published estimates vary among species and among cultivars within species and are susceptible to uncertainty arising from method of estimation [12]-[14]. The estimates reported here showed little variation among species, and offer some refinement of generic values for warm-season grasses cited in literature that range from 0˚C [15] [16] to 12˚C [17] [18]. Direct comparison of IG cultivar Holt indicates a higher value for T_{base} in the work reported here than in Madakadze *et al.* [14]. Some of the difference may be attributed to use here of a linear, rather than curvilinear, model for estimation of T_{base}. A smaller daily temperature amplitude also increases T_{base} [19] and estimates here were based on constant day/night temperatures.

The temperature regimes used here were intended to represent average temperatures observed between early-April and end-May in the central Southern Plains [20] and thus to represent the period of greatest interference between cool- and warm-season grasses in mixed pastures in this region. Diurnal temperature variation in this zone averages 12.4˚C, so the 22.5/7.5˚C and 30/15˚C regimes match actual temperature conditions more closely than the 25/20˚C, 17.5/12.5˚C, 22.5/15˚C or 30/7.5˚C treatments. Phyllochron responses to variable temperature regimes reflected results reported with cool-season pasture grasses [21] [22] and with wheat or barley [8] [23] that have shown increase in phyllochron as mean daily temperature increased. The response to changing temperature was similar in all species tested, with no significant interaction between species and temperature treatment. The relatively large effect of increase in night temperature on phyllochron may be of significance in future

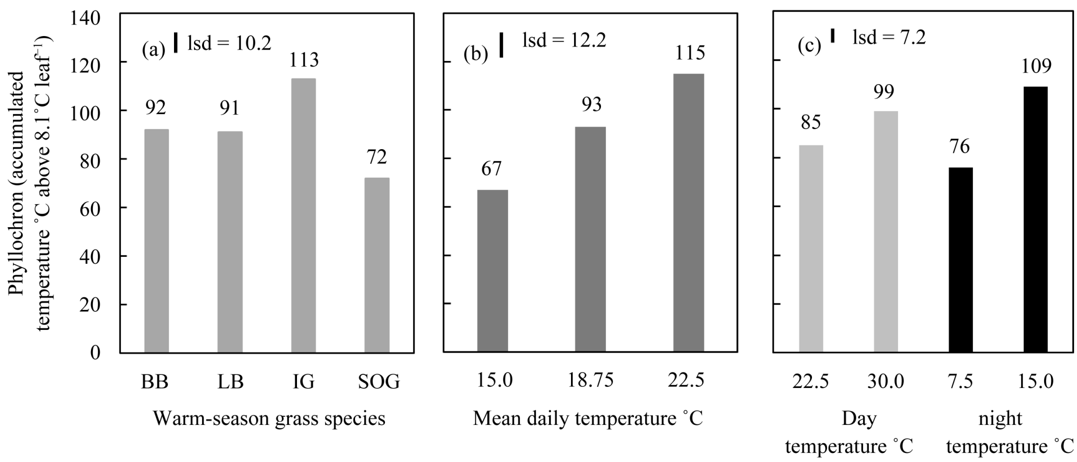

Figure 2. (a) Mean phyllochron for Big bluestem (BB), Little bluestem (LB), Indiangrass (IG) and Sideoats grama (SOG) grown under day temperatures of 22.5˚C or 30.0˚C and night temperatures of 7.5˚C or 15˚C. (b) Phyllochron response to different mean daily temperature (mean of 4 species). (c) Effect of day and night temperatures on phyllochron (mean of 4 species). In each graph, bar indicates least significant difference (lsd) P = 0.05 between or among means.

modeling of grass development responses to a changing temperature environment if reported trends [24] that show greater increase in night than in day temperatures over recent decades continue.

Other work has shown that, in addition to variable temperature effects, soil moisture [25], nutrient status [26] and bulk density [27] [28] may all impact phyllochron in small-grain cereals or pasture grasses. Controlled environment studies may therefore not be immediately applicable to field-grown crops [15] [29]. The objective here was to determine how variable temperatures might affect phyllochron, and the usefulness of this measure as a predictor of grass development stage, rather than to identify definitive values applicable to a field situation. Clearly, a single value for phyllochron is not valid over a broad range of average temperature, or throughout a growing season. However, the results reported here suggest that, over the spring growing season, changes in phyllochron can be readily estimated as a linear function of mean daily temperature and adjustment for changes in development rate with changing temperature made accordingly. Accumulated temperature observations may therefore provide a viable basis for predicting development stage in warm-season pasture grasses.

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References

[1] Belesky, D.P. and Fedders, J.M. (1995) Comparative Growth Analysis of Cool- and Warm-Season Grasses in a Cool-Temperate Environment. *Agronomy Journal*, **87**, 974-980. http://dx.doi.org/10.2134/agronj1995.00021962008700050034xdup

[2] Bartholomew, P.W. and Williams, R.D. (2008) Seeding Cool-Season Grasses into Unimproved Warm-Season Pasture in the Southern Great Plains of the United States. *Grass and Forage Science*, **63**, 94-106. http://dx.doi.org/10.1111/j.1365-2494.2007.00617.x

[3] Evers, G.W. (2005) A Guide to Overseeding Warm-Season Perennial Grasses with Cool-Season Annuals. *Forage and Grazinglands*, **3**. http://dx.doi.org/10.1094/fg-2004-0614-01-mg

[4] Bartholomew, P.W., Burner, D.M. and West, C.P. (2013) Productivity and Persistence of Summer-Active and Summer-Dormant Tall Fescue Cultivars in the Southern Great Plains. *Forage and Grazinglands*, **11**. http://dx.doi.org/10.1094/fg-2013-0430-01-rs

[5] Bouton, J.H., Gates, R.N. and Hoveland, C.S. (2001) Selection for Persistence in Endophyte-Free Kentucky 31 Tall

Fescue. *Crop Science*, **41**, 1026-1028. http://dx.doi.org/10.2135/cropsci2001.4141026x

[6] Frank, A.B. and Bauer, A. (1995) Phyllochron Differences in Wheat, Barley, and Forage Grasses. *Crop Science*, **35**, 19-23. http://dx.doi.org/10.2135/cropsci1995.0011183X003500010004x

[7] Kirby, E.J.M. (1995) Factors Affecting Rate of Leaf Emergence in Barley and Wheat. *Crop Science*, **35**, 11-19. http://dx.doi.org/10.2135/cropsci1995.0011183X003500010003x

[8] Cao, W. and Moss, D.N. (1989) Temperature Effect on Leaf Emergence and Phyllochron in Wheat and Barley. *Crop Science*, **29**, 1018-1021. http://dx.doi.org/10.2135/cropsci1989.0011183X002900040038x

[9] DeGaetano, A.T. and Belcher, B.N. (2007) Spatial Interpolation of Daily Maximum and Minimum Air Temperatures Based on Meteorological Analyses and Independent Observations. *Journal of Applied Meteorology and Climatology*, **46**, 1981-1992. http://dx.doi.org/10.1175/2007JAMC1536.1

[10] Gramig, G.G. and Stoltenberg, D.E. (2007) Leaf Appearance Base Temperature and Phyllochron for Common Grass and Broadleaf Weed Species. *Weed Technology*, **21**, 249-254. http://dx.doi.org/10.1614/WT-06-039.1

[11] Genstat (2008) Genstat for Windows, Release 11.1.0.1575. 11th Edition, VSN International Ltd., Oxford.

[12] Moreno, L.S.B., Pedreira, C.S.G., Boote, K.J. and Alves, R.R. (2014) Base Temperature Determination of Tropical *Panicum* spp. Grasses and Its Effects on Degree-Day-Based Models. *Agricultural and Forest Meteorology*, **186**, 26-33. http://dx.doi.org/10.1016/j.agrformet.2013.09.013

[13] Unruh, J.B., Gaussoin, R.E. and Wiest, S.C. (1996) Basal Growth Temperature and Growth Rate Constants of Warm-Season Turfgrass Species. *Crop Science*, **39**, 997-999. http://dx.doi.org/10.2135/cropsci1996.0011183X0036000400030x

[14] Madakadze, I.C., Stewart, K.A., Madakadze, R.M. and Smith, D.L. (2003) Base Temperature for Seedling Growth and Their Correlation with Chilling Sensitivity for Warm-Season Grasses. *Crop Science*, **43**, 874-878. http://dx.doi.org/10.2135/cropsci2003.8740

[15] Gillen, R.L. and Ewing, A.L. (1992) Leaf Development of Native Bluestem Grasses in Relation to Degree-Day Accumulation. *Journal of Range Management*, **45**, 200-204. http://dx.doi.org/10.2307/4002784

[16] Frank, A.B. and Hofmann, L. (1989) Relationship among Grazing Management, Growing Degree-Days, and Morphological Development for Native Grasses on the Northern Great Plains. *Journal of Range Management*, **42**, 199-202. http://dx.doi.org/10.2307/3899472

[17] Fidanza, M.A., Dernoeden, P.H. and Zhang, M. (1996) Degree-Days for Predicting Smooth Crabgrass Emergence in Cool-Season Turfgrasses. *Crop Science*, **36**, 990-996. http://dx.doi.org/10.2135/cropsci1996.0011183X0036000400029x

[18] Mitchell, R.B., Moore, K.J., Moser, L.E., Fritz, J.O. and Redfearn, D.D. (1997) Predicting Developmental Morphology in Switchgrass and Big Bluestem. *Agronomy Journal*, **89**, 827-832. http://dx.doi.org/10.2134/agronj1997.00021962008900050018x

[19] Bonhomme, R. (2000) Bases and Limits to Using "Degree Day" Units. *European Journal of Agronomy*, **13**, 1-10. http://dx.doi.org/10.1016/S1161-0301(00)00058-7

[20] OCS (2012) Oklahoma Climatological Survey. http://www.mesonet.org/index.php/weather/category/past_data_files

[21] Bartholomew, P.W. and Williams, R.D. (2005) Cool-Season Grass Development Response to Accumulated Temperature under a Range of Temperature Regimes. *Crop Science*, **45**, 529-534. http://dx.doi.org/10.2135/cropsci2005.0529

[22] Durand, J.L., Schaufele, R. and Gastal, F. (1999) Grass Leaf Elongation Rate as a Function of Developmental Stage and Temperature: Morphological Analysis and Modelling. *Annals of Botany*, **83**, 577-588. http://dx.doi.org/10.1006/anbo.1999.0864

[23] Frank, A.B. and Bauer, A. (1996) Temperature, Nitrogen, and Carbon Dioxide Effects on Spring Wheat Development and Spikelet Numbers. *Crop Science*, **36**, 659-665. http://dx.doi.org/10.2135/cropsci1996.0011183X003600030024x

[24] Tebaldi, C., Hayhoe, K., Arblaster, J.M. and Meehl, G.A. (2006) Going to the Extremes. *Climatic Change*, **79**, 185-211. http://dx.doi.org/10.1007/s10584-006-9051-4

[25] Krenzer, E.G.J., Nipp, T.L. and McNew, R.W. (1991) Winter Wheat Mainstem Leaf Appearance and Tiller Formation vs. Moisture Treatment. *Agronomy Journal*, **83**, 663-667. http://dx.doi.org/10.2134/agronj1991.00021962008300040003x

[26] Longnecker, N. and Robson, A. (1994) Leaf Emergence of Spring Wheat Receiving Varying Nitrogen Supply at Different Stages of Development. *Annals of Botany*, **74**, 1-7. http://dx.doi.org/10.1006/anbo.1994.1087

[27] Masle, J. and Passioura, J.B. (1987) The Effect of Soil Strength on the Growth of Young Wheat Plants. *Australian Journal of Plant Physiology*, **14**, 643-656. http://dx.doi.org/10.1071/PP9870643

[28] Bartholomew, P.W. and Williams, R.D. (2010) Effects of Soil Bulk Density and Strength on Seedling Growth of An-

nual Ryegrass and Tall Fescue in Controlled Environment. *Grass and Forage Science*, **65**, 348-357.

[29] Bartholomew, P.W. and Williams, R.D. (2006) Effects of Exposure to Below-Freezing Temperatures, Soil Moisture Content and Nitrogen Application on Phyllochron in Cool-Season Grasses. *Grass and Forage Science*, **61**, 146-153. http://dx.doi.org/10.1111/j.1365-2494.2006.00518.x