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ABSTRACT

Stage of morphological development during spring growth of perennial forage grasses can be predicted reliably from accumulated growing degree-days (GDD), but information is lacking on the relationship between morphological development and GDD accumulated following grazing. A study was conducted in a rainout shelter at Mandan, ND during 1987 and 1988 to determine the GDD required for morphological development of initial and regrowth forage of crested wheatgrass [*Agropyron desertorum* (Fisch. ex. Link) Schult.] and western wheatgrass [*Pascopyrum smithii* Rydb, (Löve)]. Crested wheatgrass was grazed twice each year and western wheatgrass three times each year by sheep (*Ovis aries* L.). Water was applied weekly to provide treatments receiving 50, 100, and 150% of the long term 1 April to 1 November rainfall received at Mandan, ND. Plant development following the first grazing for both species was linearly related to GDD but plant development following subsequent grazing for both species was curvilinear. The deviation from linearity became greater after the first regrowth phase for both species and occurred during periods of decreasing photoperiods. Plant development for both species was similar at all three water treatments. This information should be useful for predicting stage of plant development and, when considered with other management information, would have utility in managing grazing systems utilizing several grazing cycles.

MORPHOLOGICAL development of crop and forage plants has been related to growing degree-days (GDD) accumulated from emergence or planting of annual crops or from spring growth initiation of perennial crops to harvest with much success (1,5,6,7,15). In related studies different rates of applied water and fertilizer N had no effect on the GDD required for development of crested and western wheatgrass to seed soft dough stage and fall regrowth (8). However, data are lacking on similar relationships for the regrowth of perennial forages defoliated by grazing in contrast to forages grown for hay production. The increased use of grazing systems that rapidly defoliates forage plants followed by periods of regrowth requires close monitoring of the forage to prevent overuse. Further refinement of the GDD-morphological development relationship for grazed forage should be beneficial in monitoring forage development in intensive grazing systems.

The objective of this research was to determine the relationship between accumulated GDD and plant morphological development for grazed forage of crested wheatgrass and western wheatgrass.

METHODS AND MATERIALS

Plantings of 'Rodan' western wheatgrass and 'Nordan' crested wheatgrass were established in a rainout shelter in 1983 and managed as a hay crop from 1984 through 1986 at Mandan, ND. The experimental design was a randomized complete block with three replications on a Parshall fine sandy loam (coarse-loamy mixed Pachic Haploborolls). A water variable was established by applying water at 50, 100, and 150% of the long term 1 April to 1 November rainfall (336 mm) received at Mandan. Water was applied weekly to all plots with an overhead sprinkler located in the rainout shelter to provide monthly rainfall totals to each plot (3.1 by 4.6 m). Starting in 1987 the plots were grazed with eight 1-yr-old ewes placed simultaneously on all plots of one species and herded to obtain uniform grazing. Grazing was conducted during daylight periods and was completed within 2 d for each species. The plots received the same treatments in 1987 and 1988. Grazing of crested wheatgrass was started on 6 May and 16 June 1987, and 18 May and 22 June 1988. Grazing of western wheatgrass was started on 8 May, 17 June, and 20 July 1987, and 23 May, 23 June, and 21 July 1988. Forage dry matter was measured before and after grazing by clipping samples at a 5-cm stubble height and drying at 70 °C to determine percent of forage biomass remaining after grazing.

Plant morphological development was determined as the average development stage of five stems from three randomly selected locations within each plot three times per week from 1 April to 1 November based on the Haun scale (10). Morphological development of ungrazed plants was followed through Haun Stage 6, which is the flag leaf on reproductive stems of both crested and western wheatgrass (6). Following each grazing event, plant development was determined on plants that had not been grazed during the prior grazing period and on new tillers initiated following grazing. The tillers scored for development following grazing events were not separated by type or origin. However, the selected tillers were initiated within a 2-d period and were of uniform size. The Haun scores for the three locations in each plot were averaged for statistical analyses. The Haun scale is a numerical designation, subdivided into decimal fractions, of the number of leaves formed on a stem. The decimal fractions are determined by comparing the newly developing leaf to the previously developed leaf. The Haun scale is reported to be more definitive and sensitive to changes in plant development than other scales (2).

Growing degree-days were calculated from daily minimum and maximum air temperature measured hourly at 1 m above an adjacent clipped (5 cm) grass area with a base temperature of 0 °C. Accumulation of GDD was started on 2 April for both years, which was the first day after March 15 that the average daily air temperature exceeded 0 °C for five consecutive days at Mandan. The data were subjected to regression analysis among water treatments to determine the relationship between accumulated GDD and Haun stage for initial spring growth forage and following each grazing event. Differences among regression lines for water treatments within years and grazing periods were determined by testing the continuous by discrete interaction using SAS GLM procedures (14).

RESULTS AND DISCUSSION

Air temperature extremes were common during the 1988 growing season. The accumulated GDD curve (Fig. 1) showed that fewer GDD were accumulated in 1988 compared to 1987 until 18 June. After 18 June, daytime air temperatures were higher in 1988 compared to 1987. In 1988 there were 43 d compared to the long-term average of 17 d between 29 May and 25 August when the maximum daily air temperature ex-

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Abbreviation: GDD; growing degree-days.

Table 1. Regression equations for crested wheatgrass and western wheatgrass data presented in Fig. 2 and 3, respectively.

Species equation	Coefficient of determination
Crested wheatgrass	
Initial growth 1987: Haun stage = −0.0667 + 0.0096GDD	$r^2 = 0.98$
First regrowth 1987: Haun stage = −3.3029 + 0.0074GDD	$r^2 = 0.98$
Second regrowth 1987: Haun stage = −5.5667 + 0.0064GDD − 0.000001GDD²	$R^2 = 0.95$
Initial growth 1988: Haun stage = −2.1573 + 0.0134GDD	$r^2 = 0.97$
First regrowth 1988: Haun stage = −2.6815 + 0.0046GDD	$r^2 = 0.99$
Second regrowth 1988: Haun stage = −7.7432 + 0.0081GDD − 0.000001GDD²	$R^2 = 0.86$
Western wheatgrass	
Initial growth 1987: Haun stage = −0.0618 + 0.0085GDD	$r^2 = 0.97$
First regrowth 1987: Haun stage = −3.0679+ 0.0063GDD	$r^2 = 0.97$
Second regrowth 1987: Haun stage = −8.2877 + 0.0082GDD − 0.000001GDD²	$R^2 = 0.99$
Third regrowth 1987: Haun stage = −2.6658 + 0.0189GDD − 0.000003GDD²	$R^3 = 0.93$
Initial growth stage 1988: Haun stage = −1.3645 + 0.0091GDD	$r^2 = 0.93$
First regrowth 1988: Haun stage = −3.5778 + 0.0052GDD	$r^2 = 0.97$
Second regrowth 1988: Haun stage = −7.9642 + 0.0078GDD − 0.000001GDD²	$R^2 = 0.95$
Third regrowth 1988: Haun stage = −3.5727 + 0.0021GDD	$r^2 = 0.97$

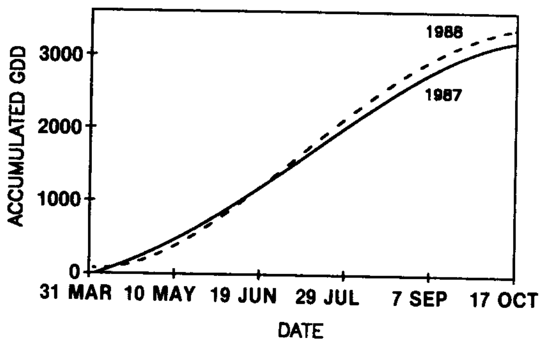

Fig. 1. Accumulated growing degree-days (GDD) at Mandan, ND in 1987 and 1988.

ceeded 32 °C, whereas, in 1987 air temperature exceeded 32 °C on only 13 d during the same period.

There were no significant differences among the three water treatments or water × GDD interactions within years for the initial growth, first regrowth, or second regrowth forage Haun stage for crested wheatgrass. There were no differences among regression lines for each water treatment. Thus a combined regression between accumulated GDD and Haun stage across the three water treatments for crested wheatgrass was developed. This relationship was linear for the initial growth and regrowth forage following the first grazing period (Fig. 2 and Table 1). Regression of accumulated GDD and Haun stage for the second regrowth forage after the second grazing was curvilinear. Plant development following the second grazing did not exceed Haun stage 4 either year. Haun stage was similar at the beginning of the first grazing period during both years, 4.3 in 1987 and 4.8 in 1988, but for the second grazing period, the Haun stage was 5.0 in 1987 compared to 3.2 in 1988 (Table 2). The lower Haun at the beginning of the second grazing in 1988 compared to 1987 was probably due to the higher air temperature received in 1988. During the first regrowth period the average maximum air temperature was 24.3 and 30.1 °C in 1987 and 1988, respectively. There were 14 d in 1988 when the maximum air temperature exceeded 32 °C compared to 6 d in 1987 during the first regrowth period. Forage biomass remaining after grazing of crested wheatgrass during both years averages 929 (SE = 271) and 796 (SE = 200) kg ha⁻¹ dry matter for the first and second grazing, respectively.

Table 2. Grazing date, Haun stage, and growing degree-days (GDD) accumulated from initiation of spring growth to grazing date for crested and western wheatgrass in 1987 and 1988.

Species	Date grazed	Haun stage	Accumulated GDD
	1987		
Crested wheatgrass	6 May	4.3	426
	16 June	5.0	1127
Western wheatgrass	8 May	3.9	457
	17 June	4.3	1150
	20 July	2.4	1805
	1988		
Crested wheatgrass	18 May	4.8	517
	22 June	3.2	1294
Western wheatgrass	23 May	4.4	592
	23 June	3.2	1323
	21 July	2.8	1953

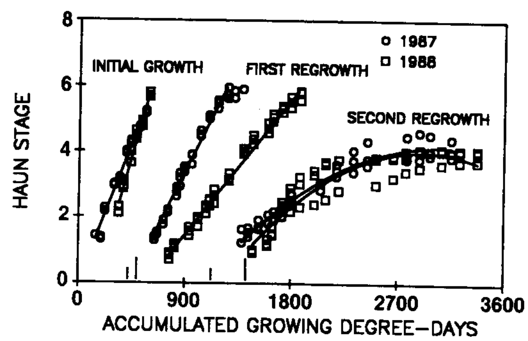

Fig. 2. Regression analysis (see Table 1 for equations) of Haun stage vs. growing degree-days (GDD) accumulated for crested wheatgrass initial growth and two regrowth cycles following grazing with sheep. The short vertical lines on the x-axis indicates grazing in 1987 and the long line in 1988. Symbols for water levels are the same within each year.

No significant differences were detected among the three water treatments or water × GDD interactions within years for the initial growth and all regrowth cycles Haun stage for western wheatgrass except during the later stages of the second regrowth in 1988. Regressions between accumulated GDD and Haun stage were developed across all three water treatments. The relationships were linear during the initial growth and

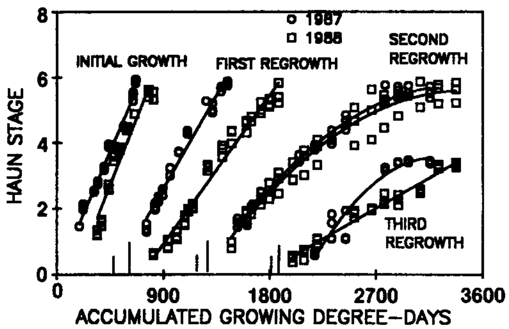

Fig. 3. Regression analysis (see Table 1 for equations) of Haun stage vs. growing degree-days (GDD) accumulated for western wheatgrass initial growth and three regrowth cycles following grazing with sheep. The short vertical line on the x-axis indicates grazing in 1987 and the long line in 1988. Symbols for water levels are the same within each year.

the first regrowth periods, but curvilinear during the second regrowth period (Fig. 3 and Table 1). During the third regrowth period, the relationship was curvilinear in 1987, but not in 1988. Haun stages were similar at each grazing in 1987 and 1988 differing by only 0.5 or less at the first and third grazing and by 1.1 at the second grazing (Table 2). Also regressions between Haun stage and accumulated GDD were similar for each year and grazing date, except in 1988 when development of regrowth forage following the first grazing was delayed. The first regrowth of western wheatgrass in 1988 may have been affected by the higher air temperatures received in 1988 compared to 1987. Maximum air temperatures during the first regrowth period were 24.3 and 31.5 °C in 1987 and 1988, respectively, with 7 d in 1987 and 15 d in 1988 having maximum air temperatures greater than 32 °C. Development of plants following the third grazing did not exceed Haun Stage 4. Western wheatgrass forage remaining after grazing averaged 510 (SE = 226), 509 (SE = 164), and 391 (SE = 3) kg ha^{-1} dry matter for the first, second, and third regrowth, respectively.

The results of this study showed that development of regrowth crested and western wheatgrass forage are strongly correlated to air temperature expressed as GDD and are similar to reports on the relationship between GDD and morphological development of these species managed for hay production (8). This concept for plant development is compatible with the small soluble carbon pool and the lack of any significant correlation between carbohydrates and regrowth of crested wheatgrass and blue bunch wheatgrass [*A. spicatum* (Pursch) Scribn. & Smith] (3,13).

The higher temperatures recorded in 1988 compared to 1987 appeared to slow plant development during the first regrowth stage for both species which suggests the need to consider imposing a high temperature constraint in accumulation of GDD. Corn (*Zea maize* L.) researchers restricted maximum temperatures to 30 °C or less when calculating accumulated GDD (9). If one considers that maximum above ground dry matter yield was obtained at 18.8 and 23.3 °C soil and crown temperatures for western wheatgrass and crested wheatgrass (12), respectively, then a high temperature constraint for accumulation of GDD near 32 °C would seem realistic.

A linear relationship did not exist for all regrowth cycles, suggesting that factors other than effects of air temperature are involved. Because the curvilinear responses occurred primarily late in the growing season (after mid-August), decreasing photoperiods (15.9 h on 22 June to 11.7 h on 1 October) may be a contributing factor. The phyllochron in spring wheat (*Triticum aestivum* L.) has been shown to change as day length changes during development of the crop (4). Also, the rate of leaf initiation in [Oryzopsis miliacea (L.) Asch et Schw.] was greatly reduced, but continued for a longer period when grown under noninductive short day photoperiods compared to inductive long photoperiods (11). The curvilinear response observed for crested and western wheatgrass also occurred during noninductive photoperiods.

The results indicating that applied water had no effect on morphological development of grazed forage were similar to the data for simulated hay management (8). Also, these data are in agreement with the concept that forage (8) and spring wheat (1) production is primarily a function of water and soil fertility, whereas plant development is primarily a function of air temperature.

This information should be useful for predicting development stage of regrowth forage in grazing systems involving several grazing cycles. Also, using GDD to predict plant development stage has utility in making management decisions for grazing readiness and in development of growth models.

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