Growth Pattern and Phenological Development of Major Graminoids on the Northern Plains

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Growth Pattern and Phenological Development of Crested Wheatgrass on the Northern Plains

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Intact grassland ecosystems are complex; exceedingly more complex than the most complicated machines ever built by humans. Knowledge and understanding of the growth pattern and phenological development of the major forage grasses are fundamentally essential for generation of biologically effective management strategies with inclusivity of all biotic and abiotic components of grassland ecosystems in the Northern Plains.

The inspirational goals of this study were developed by Dr. Warren C. Whitman (c. 1950) and Dr. Harold Goetz (1963) which were to gain quantitative knowledge of each component species and to provide a pathway essential for the understanding of relationships of ecosystem components that would result in the development and establishment of scientific standards for proper management of grazinglands in the Northern Plains.

This growth pattern and phenological development study of the major forage graminoids was conducted during the growing seasons of 1983-1986 and 1987-1989 with data collected biweekly June-August. The study included 3 cool season, 2 warm season, 1 upland sedge, 1 naturalized, and 2 domesticated grasses. The study sites were located at the NDSU Dickinson Research Extension Center ranch near Manning in western North Dakota and consisted of 143 acres (58 ha) of two seeded domesticated grasslands and 720 acres (291 ha) of native rangeland pastures separated into three management treatments, each with two replications, with data collection sites established on sandy, shallow, and silty ecological sites. Each ecological site of the grazed treatments had matching paired plots, one grazed and the other with an ungrazed exclosure.

Study Area

The physiography of the study area consists of the Unglaciated section of the Missouri Plateau (Fenneman 1931, 1946; Hunt 1974). The landscape surface is highly eroded fluvial sedimentary deposits of material removed from the uplifted Rocky Mountains. Most of the deposition occurred from slow meandering streams during the Laramide Orogeny and during the 20 to 30 million years of the late Cretaceous and early Tertiary Periods following the uplift. Intense widespread erosion of these sediments occurred from about 5 to 3 million years ago during the late Pliocene Epoch (Bluemle 2000). The extensive erosion during this period removed about 500 to 1000 feet of sediments (Fenneman 1931) forming a landscape with well developed integrated drainage systems of broad mature valleys and gently rolling uplands containing widely spaced large hills and buttes with erosion resistant caps raising 500 to 650 feet above the plain (Bluemle 2000).

The soils of western North Dakota developed from eroded Tertiary fluvial sedimentary deposits in the Ustic-Frigid soil moisture-temperature regime. The Ustic soil moisture regime is typical of semi arid climates. The Frigid soil temperature regime has mean annual soil temperatures of less than 47° F (8° C) (Soil Survey Staff 1975). These soils are primarily Typic Borolls (semi arid cool Mollisols) and support vegetation of mid and short grasses of the Mixed Grass Prairie (Manske 2008b).

The current "native" plant species in the Northern Plains did not originate here. All of the plant species have migrated into the region by different mechanisms and at different times and rates. The present plant species have flora affinities to northern, eastern, western, Rocky Mountain, and Great Basin plant communities (Zaczkowski 1972). This wide mix of plant species was formed from remnants of previously existing plant communities. The climate changed about 5,000 years ago to conditions like those of the present, with cycles of wet and dry periods (Bluemle 1977, 1991; Manske 1994). The large diversity of plant species that make up the current mixed grass prairie permits dynamic responses to changes in climatic conditions by increasing the combination of plant species favored by any set of climatic conditions (Manske 2008a).

Long-Term Weather

The NDSU Dickinson Research Extension Center ranch is located in Dunn County in western North Dakota, at 47° 14' north latitude, 102° 50' west longitude. Mean annual temperature is 42.3° F (5.7° C). January is the coldest month, with mean temperature of 14.6° F (-9.7° C). July and August are the warmest months with mean temperatures of 69.7° F (20.9° C) and 68.6° F (20.3° C), respectively. Long-term (1982-2012) mean annual precipitation is 16.91 inches (429.61 mm). The perennial plant growing season precipitation (April to October) is 14.13 inches (358.97 mm) and is 83.6% of annual precipitation. June has the greatest monthly precipitation at 3.27 inches (83.08 mm). The precipitation received during the 3-month period of May, June, and July (8.26 inches, 209.80 mm) accounts for 48.8% of the annual precipitation.

Growing season months with water deficiency disrupt plant growth rates and are identified from monthly temperature and precipitation data by the Emberger ombrothermic diagram technique. Long-term (1983-2012) 30 year reoccurrence rates (table 1) show relatively low rates of water deficiency reoccurring during April (16.7%), May and June (10.0%), moderate rates during July and October (36.7%), and high rates during August (56.7%) and September (60.0%). Long-term occurrence of water deficiency conditions was 33.3% of the growing season months, for a mean of 2.0 water deficient months per each 6.0 month growing season (15 Apr-15 Oct).

Growing Season Precipitation

The growing season precipitation information collected during the grass leaf height study has been grouped into two periods with the first period occurring during 1983 to 1986 and the second period occurring during 1987 to 1989.

Mean growing season precipitation of 1983-1986 (table 2) was 14.11 inches (99.9% of LTM). None of the four 6 month growing seasons received precipitation at less than 80% of LTM. One growing season, 1986, received precipitation at near 130% of LTM. The rate of water deficiency occurrence during the four growing seasons was 29.2%, for a mean of 1.75 water deficient months per growing season (table 3). The growing season of 1984 had 3.0 months in water deficiency. The growing seasons of 1983 and 1986 had 1.5 months in water deficiency each. The growing season of 1985 had 1.0 month in water deficiency.

Mean growing season precipitation of 1987-1989 (table 4) was low at 9.14 inches (64.7% of LTM). The growing season of 1987 received 11.53 inches (81.6% of LTM) precipitation. The growing season of 1989 received 10.60 inches (75.0% of LTM) precipitation. The growing season of 1988 received only 5.30 inches (37.5% of LTM) precipitation and was dry. The rate of water deficiency occurrence during the three growing seasons was 61.1%, for a mean of 3.7 water deficient months per growing season (table 5). The growing seasons of 1987 and 1989 had 3.0 months in water deficiency each. The growing season of 1988 had 5.0 months of its 6 month growing season in water deficiency conditions. That is comparable to 2 other growing seasons with high water deficiency conditions. The growing season of 1934 had 4.5 months in water deficiency and the growing season of 1936 had 5.5 months in water deficiency.

Table 1. Growing season months with water deficiency, DREC ranch, 1983-2012.

	Apr	May	Jun	Jul	Aug	Sep	Oct	# Months	% 6 Months 15 Apr-15 Oct
Total	5	3	3	11	17	18	11	60.0	33.3
% of 30 Years	16.7	10.0	10.0	36.7	56.7	60.0	36.7		

Table 2. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1983-1986.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59	15.55
% of LTM	14.58	59.77	99.69	105.35	261.76	60.56	54.96	96.18	91.96
1984	2.87	0.00	5.30	0.11	1.92	0.53	0.96	11.69	12.88
% of LTM	199.31	0.00	162.08	4.53	112.94	37.32	73.28	82.73	76.17
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80	15.13
% of LTM	86.11	126.95	48.32	44.03	108.24	119.01	162.60	90.59	89.47
1986	3.13	3.68	2.58	3.04	0.46	5.29	0.18	18.36	22.96
% of LTM	217.36	143.75	78.90	125.10	27.06	372.54	13.74	129.94	135.78
1983-1986	1.86	2.12	3.18	1.70	2.17	2.09	1.00	14.11	16.63
% of LTM	129.34	82.62	97.25	69.75	127.50	147.36	76.15	99.86	98.34

Table 3. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1983-1986.

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1983	■					■		1.5	25.0
1984		■		■		■		3.0	50.0
1985				■				1.0	16.7
1986					■		■	1.5	25.0
#	**1**	**1**	**0**	**2**	**1**	**2**	**1**	**7.0**	**29.2**
%	**25.0**	**25.0**	**0.0**	**50.0**	**25.0**	**50.0**	**25.0**		

Table 4. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1987-1989.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1987	0.10	1.38	1.15	5.39	2.65	0.78	0.08	11.53	14.13
% of LTM	6.94	53.91	35.17	221.81	155.88	54.93	6.11	81.60	83.56
1988	0.00	1.85	1.70	0.88	0.03	0.73	0.11	5.30	9.03
% of LTM	0.00	72.27	51.99	36.21	1.76	51.41	8.40	37.51	53.40
1989	2.92	1.73	1.63	1.30	1.36	0.70	0.96	10.60	13.07
% of LTM	202.78	67.58	49.85	53.50	80.00	49.30	73.28	75.02	77.29
1987-1989	1.01	1.65	1.49	2.52	1.35	0.74	0.38	9.14	12.08
% of LTM	69.91	64.58	45.67	103.84	79.22	51.88	29.26	64.71	71.42

Table 5. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1987-1989.

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1987	■		■			■	■	3.0	50.0
1988	■		■	■	■	■	■	5.0	83.3
1989				■	■	■		3.0	50.0
#	**2**	**0**	**2**	**2**	**2**	**3**	**2**	**11.0**	**61.1**
%	**66.7**	**0.0**	**66.7**	**66.7**	**66.7**	**100.0**	**66.7**		

Procedures

The 1983-1989 Study

Grass tiller leaf heights were determined for reproductive lead tillers, vegetative tillers, robust vegetative tillers, and secondary tillers on a biweekly sampling period from June through August. Each leaf of ten ungrazed tillers of each study species was measured with a meter stick to the nearest 0.1 cm from ground level to the tips of the extended leaves. Basal leaf heights were measured for grass species in which the leaves and stalks were distinctly separate. Stalk leaf heights were measured for grass species where leaves are attached to the culm during vegetative stages and fruiting stages.

Degree of leaf senescence was estimated as percent dryness for each leaf. Percent dryness for basal leaves was considered from the apex to ground level. Percent dryness for stalk leaves was considered for the blade only. The categories of dryness were: 0%, 2%, 25%, 50%, 75%, 98% and 100% dry. Start of senescence was considered to be dryness greater than 2%. Leaves with less than 50% senescent tissue were designated to be photosynthetically active.

Grass flower stalk heights were determined by measurements from ground level to the tip of the stalk or the apex of the top floret. The awns, if present, were not included in the height measurements. The phenological stages of flower stalk development were recorded as: flower stalk developing (FSD), head emergence (HE), anthesis (Ant), seeds developing (SD), and seeds being shed (SBS). Recording the flower stalk development stages started when stalk enlargement or swelling was outwardly noticeable; prior development is not detectable without destruction of the tiller. The swelling of the stalk, traditionally called the boot stage, was categorized as the flower stalk developing stage. Head emergence is a short duration stage but easily defined when the flower head emerges from the sheath and rapidly elongates to near full height. Anthesis (flowering) is also a short duration stage but easily defined by the exposure of the anthers and stigmas. Needle and thread is usually cleistogamous that self-fertilizes without opening and exposing the anthers and stigmas. Following fertilization, the seeds develop through milk, dough, and mature stages which are difficult to differentiate on small grass seeds. These seed progression stages have been separated into more easily defined categories of seeds developing for the early seed stages and seeds being shed for the mature seed stages when seeds could be easily removed from the inflorescence by wind, by gentle rubbing, or when it could be observed that some seeds had already been dropped. Sometimes a floret will abort the seed production process resulting in failure of viable seeds to materialize. This condition could be revealed in the data set as earlier than normal recordings of seeds being shed.

During 1983 to 1986 and during 1987 to 1989, the paired plot sample sites were managed by ungrazed and May grazed treatments of the spring complementary pastures strategy.

Designation of Tiller Types

Reproductive lead tillers are second year tillers derived from carryover tillers that were vegetative tillers during the previous growing season. The portions of the carryover leaves that have intact cell walls will regreen with active chlorophyll early in the growing season and provide photosynthate for rapid growth of new current years leaves. Two and three new leaves are produced during April and the fourth full leaf is produced before early May. The anthesis (flowering) period can occur between late May to mid June. No new leaves are produced after the anthesis stage, during the seed development stages. Tillers that flower usually produce 5 to 8 leaves. Reproductive lead tillers are terminal at the end of the growing season; their apical meristem was used up producing a flower head.

Vegetative tillers are first year tillers derived from previous growing season initiated fall tillers and from early spring initiated secondary tillers and have escaped hormonal control by a lead tiller. These tillers are the primary forage tillers with rapid growth rates, usually producing 5 to 8 leaves during the growing season. The apical meristem remains vegetative, permitting these tillers to overwinter as carryover tillers and becoming reproductive lead tillers during the successive growing season.

Robust vegetative tillers are uncommon first year tillers that grow amongst normal vegetative tillers, but that atypically can produce more leaves than the conventional 8 leaves, usually 9 leaves in one growing season. The unconventional leaves greater than 8 are vulnerable to short periods of water stress subject to senescence which can result in robust tillers with unaffected leaves 6, 7, and 8 remaining green and affected leaf 9 completely senescent.

Secondary tillers are young current growing season tillers usually initiated from axillary buds during May to July that remain hormonally controlled by a dominant lead tiller that has proprietary access to all resources slowing rates of growth. Reproductive lead tillers have a high nutrient demand during the period of anthesis through early seed development stages causing withholding of essential nutrient flow to the secondary tillers which results in nearly stopping growth and leaf development. Some secondary tillers can remain at the 2 or 3 leaf stage for longer than a month or two. The high nutrient demand periods of lead tillers coincides with the period of high secondary tiller terminations. The secondary tillers that survive and produce 4 leaves become independent from the hormone control of the lead tiller and transform into vegetative tillers with rapid growth rates. The secondary tillers that are initiated during August to early September are traditionally called fall tillers.

Results

Crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., is a member of the grass family, Poaceae, tribe, Triticeae, and is a long lived perennial, monocot, cool-season, mid grass, that is highly drought tolerant and winter hardy. Crested wheatgrass was introduced into the United States in 1906 and into Canada in 1915 from Eurasia and was naturalized in the Northern Plains. Numerous accessions of plant material originating from Turkey, Iran, Kazakhstan, central Asia, western and southwestern Siberia, and the steppe region of European Russia have been brought to North America. A total of three recognized species were introduced: Crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., (Fairway type); Desert wheatgrass, *Agropyron desertorum* (Fisch. Ex Link) Schultes, (Nordan type and MT Standard type); and Siberian wheatgrass, *Agropyron fragile* (Roth) Candargy, (Siberian type). Even though each species maintained as isolated plant material has distinct characteristics, specific identification of nonsecluded individual plants is difficult because the morphological variation has developed into a continuum as a result of the extensive intercrossing that has occurred since the 1930's. The separation of this resultant mixture of plants into more than one taxon has proven to be impractical. A taxonomic description of most of this material would be more similar to *Agropyron cristatum*. The first North Dakota record is Stevens 1961. Early aerial growth consists of basal leaves from crown and rhizome tiller buds. Basal leaf blades are 10-20 cm (4-8 in) long, 5-10 mm wide, tapering to a point. Leaves roll inward when dry. The split sheath has overlapping margins that open towards the top. The distinct collar is divided. The membranous ligule is 1-2 mm long with a cut like fringed edge. The small auricles are slender, clasping, and clawlike. The rhizomes are traditionally described as short and the plants are categorized as bunches (caespitose), however, the number and length of the rhizomes and the relative quantities of crown tillers and the rhizomes tillers is determined by the timing of the partial defoliation management and having sufficient quantities of viable green leaf area remaining at end of the treatment. Partial defoliation prior to flowering stimulates the number and length of the rhizomes and increases the quantity of rhizome tillers. Partial defoliation following flowering inhibits rhizome development and decreases the quantity of rhizome tillers. The extensive root system has tough main roots arising from stem crowns and rhizome nodes growing vertically downward producing numerous fine branches forming a dense mass in the top 1 m (3.3 ft) of soil. Several long main roots descend to depths of 2.4 m (8 ft) in loose soil. Regeneration is primarily asexual propagation by crown and rhizome tiller buds. Viable seed production is high and seedlings are vigorous, however, seedlings are successful only when competition from established plants is nonexistent. The numerous flower stalks are erect, slender, 30-80 cm (12-32 in) tall, and hairless. Inflorescence is a flattened dense spike, 5-10 cm (2-4 in) long, that has closely spaced overlapping, laterally compressed spikelets of 3 to 8 florets in two opposite rows with one spikelet per node. Flower period is from late May to mid June. Aerial parts are palatable and nutritious during May. Stocking rates greater than proper for native rangeland can be used during early to late May. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reduction in biomass production and tiller density. This summary information on growth development and regeneration of Crested wheatgrass was based on works of Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Zlatnik 1999a and b, Ogle 2006 a and b, Larson and Johnson 2007, Stubbendieck et al. 2011, and Ogle et al. 2013.

During the seven years of this study, the number of crested wheatgrass tillers measured was 5031 with 2972 during 1983-1986 and 2059 during 1987-1989 (table 6). The collection protocol required measurement on all available flower stalks and ten vegetative tillers on each sample site each collection period, amounting to 360 tillers per year on the spring complementary strategy. During the 3 growing seasons with low precipitation amounts, less than ten tillers were measured each collection period. The reductions in sample numbers would indicate the degree of negative affect from reduced precipitation. This affect is designated as collection efficiency on table 6.

Table 6. Number of tillers measured from May grazed and ungrazed management treatments on spring complementary strategy.

Tiller Type	Spring Complementary 1983-1986		Spring Complementary 1987-1989	
	Ungrazed	May Grazed	Ungrazed	May Grazed
Flower Stalk	262	211	215	200
Vegetative	920	1048	485	413
Robust	234	83	35	0
Secondary	24	190	297	414
Subtotal	1440	1532	1032	1027
Total	2972		2059	
Sum total	5031			
Collection Efficiency	100%	106%	96%	95%

Reproductive Lead Tillers

The second year reproductive lead tillers had the fastest rate of growth and development until mid to late July. Lead tillers can produce 3.5 new leaves around 22 April. These early new leaves are highly nutritious forage, however the available herbage weight is insufficient for grazing until 1 May. Lead tillers reached the boot stage (FSD) around early to mid May. Flower stalk development occurred very rapidly with the lead tillers progressing through head emergence (HE) during mid to late May. Mean flower date is 28 May. Most lead tillers reached anthesis (Ant) during late May to mid June. Flowering tillers usually produced 5 to 8 leaves. No new leaves were produced after the anthesis stage. Seeds developed (SD) through the milk and dough stages during late May to late June with most seeds reaching maturity (SBS) from late June to late July (table 7). The apical meristem of reproductive lead tillers can no longer produce leaf buds after it had produced flower buds and these tillers were terminated at the end of the growing season.

Lead tiller new leaf growth begins very early in the spring. By early April, around 92% of the tillers have 2 new leaves and around 8% of the tillers are developing the third leaf. However, the tallest leaf is only 8.8 cm (3.5 in) tall (table 8). By early May, around 98% of the tillers have 3 or 4 new leaves with the leaf height from 13.1 cm (5.2 in) to 18.0 cm (7.1 in) (table 8). During May, available forage weight will range between 1261 lbs/ac and 2143 lbs/ac that will contain around 20% to 13% crude protein.

Growth and development data of crested wheatgrass reproductive lead tillers managed with the May grazed and the ungrazed treatments during 1983 to 1986 and 1987 to 1989 are on tables 9 and 10, respectively.

Reproductive lead tillers with 5 to 8 leaves on the spring complementary strategy during 1983 to 1986 composed 13.8% of the total population with 211 tillers (table 6) that had a mean flower stalk height of 26.4 cm, during the growing season a mean of 20.8% were photosynthetically active with a mean leaf height of 16.7 cm and the tallest leaf averaged 18.8 cm tall (table 9).

Reproductive lead tillers with 5 to 8 leaves on the ungrazed treatment during 1983 to 1986 composed 18.2% of the total population with 262 tillers (table 6) that had a mean flower stalk height of 35.4 cm, during the growing season a mean of 23.6% were photosynthetically active with a mean leaf height of 28.6 cm and the tallest leaf averaged 31.8 cm tall (table 9).

Reproductive lead tillers with 5 to 8 leaves on the spring complementary strategy during 1987 to 1989 composed 19.5% of the total population with 200 tillers (table 6) that had a mean flower stalk height of 25.4 cm, during the growing season a mean of 27.8% were photosynthetically active with a mean leaf height of 19.5 cm and the tallest leaf averaged 21.6 cm tall (table 10).

Reproductive lead tillers with 5 to 8 leaves on the ungrazed treatment during 1987 to 1989 composed 20.8% of the total population with 215 tillers (table 6) that had a mean flower stalk height of 34.1 cm, during the growing season a mean of 28.4% were photosynthetically active with a mean leaf height of 29.0 cm and the tallest leaf averaged 31.1 cm tall (table 10).

All of the reproductive lead tillers measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments on the spring complementary strategy during the 1983-1986 and 1987-1989 periods (tables 9 and 10). It is not believed that grazed treatments cause reproductive lead tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the May grazed treatment tended to have slightly lower photosynthetically active leaves than the tillers growing on the ungrazed treatment. Reproductive lead tillers located on the ungrazed treatment had 1.7 more (7.0%) photosynthetically active leaves than the tillers located on the May grazed treatment (tables 9 and 10). The lead tiller flowers dried rapidly from mid June to late July and many dried flower stalks remained standing to the end of the growing season.

Reproductive lead tillers composed a low percentage of the total measured tiller population. Reproductive lead tillers located on the May grazed treatment composed 13.8% and 19.5% and the tillers located on the ungrazed treatment composed 18.2% and 20.8% of the total tiller population during the 1983 to 1986 and 1987 to 1989 periods, respectively.

Table 7. Phenological stages of flower stalk development for crested wheatgrass, 1983-1986.

6 May	22 May	6 Jun	22 Jun	6 Jul	22 Jul
FSD	FSD				
HE	HE				
	Ant	Ant			
	SD	SD	SD		
			SBS	SBS	SBS

FSD flower stalk developing
HE head emergence
Ant anthesis (flowering)
SD seeds developing
SBS seeds being shed

Table 8. Growth and development of crested wheatgrass lead tillers during April and May on the May grazed treatment, 1983-1986.

May Grazed	6 Apr	6 May
2 Leaves		
% Population	91.7	2.1
% Active Leaf	100.0	100.0
Leaf Height cm	6.0	10.4
Tallest Leaf cm	6.7	12.7
3 Leaves		
% Population	8.3	25.5
% Active Leaf	100.0	100.0
Leaf Height cm	7.3	11.1
Tallest Leaf cm	8.8	13.1
4 Leaves		
% Population	0.0	72.3
% Active Leaf	-	100.0
Leaf Height cm	-	13.2
Tallest Leaf cm	-	18.0
% Population	100.0	99.9

Table 9. Growth and development of crested wheatgrass reproductive lead tillers on May grazed and ungrazed treatments, 1983-1986.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1983-1986						
Stalk Height cm	17.2	33.7	27.7	21.1	25.0	33.7
% Active Leaf	57.6	46.8	10.0	2.5	8.0	0.0
Leaf Height cm	11.7	25.8	22.9	17.8	5.1	-
Tallest Leaf cm	16.3	30.2	22.9	17.8	7.0	-
Ungrazed 1983-1986						
Stalk Height cm	29.4	31.5	39.0	37.5	37.8	37.4
% Active Leaf	64.3	45.5	13.6	11.7	6.7	0.0
Leaf Height cm	27.7	27.0	37.8	44.0	6.7	-
Tallest Leaf cm	32.7	32.3	38.0	48.5	7.5	-

Table 10. Growth and development of crested wheatgrass reproductive lead tillers on May grazed and ungrazed treatments, 1987-1989.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1987-1989						
Stalk Height cm	23.1	21.8	28.5	22.8	31.3	25.1
% Active Leaf	60.0	24.0	53.3	21.4	0.0	8.0
Leaf Height cm	15.5	17.8	20.0	16.5	-	27.7
Tallest Leaf cm	20.0	18.0	24.6	17.0	-	28.2
Ungrazed 1987-1989						
Stalk Height cm	31.4	29.2	41.2	31.6	40.6	30.4
% Active Leaf	54.5	36.0	46.7	25.9	0.0	7.4
Leaf Height cm	23.1	28.6	28.2	33.2	-	32.0
Tallest Leaf cm	26.7	31.0	31.4	34.3	-	32.0

Vegetative Tillers

The vegetative tillers had the second fastest rate of active growth and development continuing until mid to late July. Early new leaf development was rapid with production of 3 and 4 new leaves by early May. Vegetative tillers with 5 or 6 leaves decreased from 64% of the tiller population in early June to 52% in late July, to 29% in late August. Vegetative tillers with 7 or 8 leaves increased from 36% of the tiller population in early June, to 48% in late July, to 71% in late August. The percentage of vegetative tillers with 5 leaves started decreasing during mid June and the tillers with 6 leaves started decreasing by late July. The vegetative tillers with 7 or 8 leaves increased slowly during June and July and then rapidly increased during late July through mid August (figure 1).

Growth and development data of crested wheatgrass vegetative tillers managed with the spring complementary strategy during 1983 to 1986 are on table 11.

Vegetative tillers with 5 leaves composed 27.6% of the population with 289 tillers (table 6), during the growing season a mean of 2.8 leaves (55.0%) were photosynthetically active with a mean leaf height of 10.7 cm and the tallest leaf averaged 12.2 cm tall (table 11).

Vegetative tillers with 6 leaves composed 33.0% of the population with 346 tillers (table 6), during the growing season a mean of 3.4 leaves (57.0%) were photosynthetically active with a mean leaf height of 12.3 cm and the tallest leaf averaged 14.1 cm tall (table 11).

Vegetative tillers with 7 leaves composed 25.9% of the population with 271 tillers (table 6), during the growing season a mean of 3.8 leaves (54.8%) were photosynthetically active with a mean leaf height of 15.8 cm and the tallest leaf averaged 18.1 cm tall (table 11).

Vegetative tillers with 8 leaves composed 13.5% of the population with 142 tillers (table 6), during the growing season a mean of 4.4 leaves (55.2%) were photosynthetically active with a mean leaf height of 19.4 cm and the tallest leaf averaged 22.8 cm tall (table 11).

Growth and development data of crested wheatgrass vegetative tillers managed with the ungrazed treatment during 1983 to 1986 are on table 12.

Vegetative tillers with 5 leaves composed 9.8% of the population with 90 tillers (table 6), during the growing season a mean of 2.1 leaves (41.7%) were photosynthetically active with a mean leaf height of 18.4 cm and the tallest leaf averaged 20.5 cm tall (table 12).

Vegetative tillers with 6 leaves composed 27.0% of the population with 248 tillers (table 6), during the growing season a mean of 2.7 leaves (45.8%) were photosynthetically active with a mean leaf height of 21.8 cm and the tallest leaf averaged 23.6 cm tall (table 12).

Vegetative tillers with 7 leaves composed 34.5% of the population with 317 tillers (table 6), during the growing season a mean of 3.3 leaves (47.6%) were photosynthetically active with a mean leaf height of 23.7 cm and the tallest leaf averaged 25.7 cm tall (table 12).

Vegetative tillers with 8 leaves composed 28.8% of the population with 265 tillers (table 6), during the growing season a mean of 3.8 leaves (47.9%) were photosynthetically active with a mean leaf height of 28.4 cm and the tallest leaf averaged 31.3 cm tall (table 12).

Growth and development data of crested wheatgrass vegetative tillers managed with the spring complementary strategy during 1987 to 1989 are on table 13.

Vegetative tillers with 5 leaves composed 61.3% of the population with 253 tillers (table 6), during the growing season a mean of 2.7 leaves (53.3%) were photosynthetically active with a mean leaf height of 12.6 cm and the tallest leaf averaged 14.4cm tall (table 13).

Vegetative tillers with 6 leaves composed 27.1% of the population with 112 tillers (table 6), during the growing season a mean of 2.7 leaves (44.5%) were photosynthetically active with a mean leaf height of 12.3 cm and the tallest leaf averaged 16.1 cm tall (table 13).

Vegetative tillers with 7 leaves composed 8.5% of the population with 35 tillers (table 6), during the growing season a mean of 2.5 leaves (35.7%) were photosynthetically active with a mean leaf height of 13.6 cm and the tallest leaf averaged 15.6 cm tall (table 13).

Vegetative tillers with 8 leaves composed 3.1% of the population with 13 tillers (table 6), during the growing season a mean of 2.7 leaves (33.3%) were photosynthetically active with a mean leaf height of 15.7 cm and the tallest leaf averaged 17.6 cm tall (table 13).

Growth and development data of crested wheatgrass vegetative tillers managed with the ungrazed treatment during 1987 to 1989 are on table 14.

Vegetative tillers with 5 leaves composed 39.6% of the population with 192 tillers (table 6), during the growing season a mean of 2.2 leaves (43.3%) were photosynthetically active with a mean leaf height of 18.2 cm and the tallest leaf averaged 19.9 cm tall (table 14).

Vegetative tillers with 6 leaves composed 29.3% of the population with 142 tillers (table 6), during the growing season a mean of 2.5 leaves (41.7%) were photosynthetically active with a mean leaf height of 20.2 cm and the tallest leaf averaged 22.4 cm tall (table 14).

Vegetative tillers with 7 leaves composed 20.8% of the population with 101 tillers (table 6), during the growing season a mean of 3.5 leaves (50.0%) were photosynthetically active with a mean leaf height of 19.7 cm and the tallest leaf averaged 22.3 cm tall (table 14).

Vegetative tillers with 8 leaves composed 10.3% of the population with 50 tillers (table 6), during the growing season a mean of 2.8 leaves (35.4%) were photosynthetically active with a mean leaf height of 24.0 cm and the tallest leaf averaged 26.3 cm tall (table 14).

Not all the leaves on a grass tiller are photosynthetic during the entire growing season. Leaves grow and senesce in the order they appear. The first and second leaves are usually dry by early June. The rate of leaf senescence can be rapid during water deficiency periods and slow during periods with adequate precipitation. During senescence, leaves translocate cell components to other plant parts. The senesced leaf has less weight and has very low nutritional quality. The greater the number of leaves not senescent, the greater the tiller nutritional quality.

The growing conditions on the ungrazed treatment tended to have slightly greater rates of tiller leaf senescence than the growing conditions on the May grazed treatment. The decrease in the number of photosynthetically active leaves occurs for tiller from the ungrazed treatment during the growing season of 1983-1986 resulting in a mean of 3.0 active leaves per tiller. The decrease in the number of photosynthetically active leaves occurs for tillers from the May grazed treatment during the growing season resulting in a mean of 3.6 active leaves per tiller. Tillers on the May grazed treatment have 0.6 more photosynthetically active leaves than the tillers on the ungrazed treatment (tables 11 and 12).

All of the vegetative tillers with 5 to 8 leaves measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments during the 1983-1986 and 1987-1989 periods (tables 11 to 14). It is not believed that grazed treatments cause vegetative tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the May grazed treatment tended to have greater photosynthetically active leaves than the tillers growing on the ungrazed treatment. Vegetative tillers with 5 to 8 leaves located on the May grazed treatment had 55.5% photosynthetically active leaves and the tillers on the ungrazed treatment had 45.8% photosynthetically active leaves. Vegetative tillers with 5 to 8 leaves located on May grazed treatment 21.2% more photosynthetically active leaves than the tillers located on the ungrazed treatment during 1983 to 1986.

Vegetative tillers with 5 to 8 leaves composed a high percentage of the total measured tiller population during the 1983 to 1986 period and composed a lower percentage of the population during the 1987-1989 period. Vegetative tillers located on the May grazed treatment composed 68.4% and tillers located on the ungrazed treatment composed 63.9% during the 1983 to 1986 period. During the 1987 to 1989 period, vegetative tillers located on the May grazed treatment composed 40.2% and tillers located on the ungrazed treatment composed 47.0% of the total tiller population.

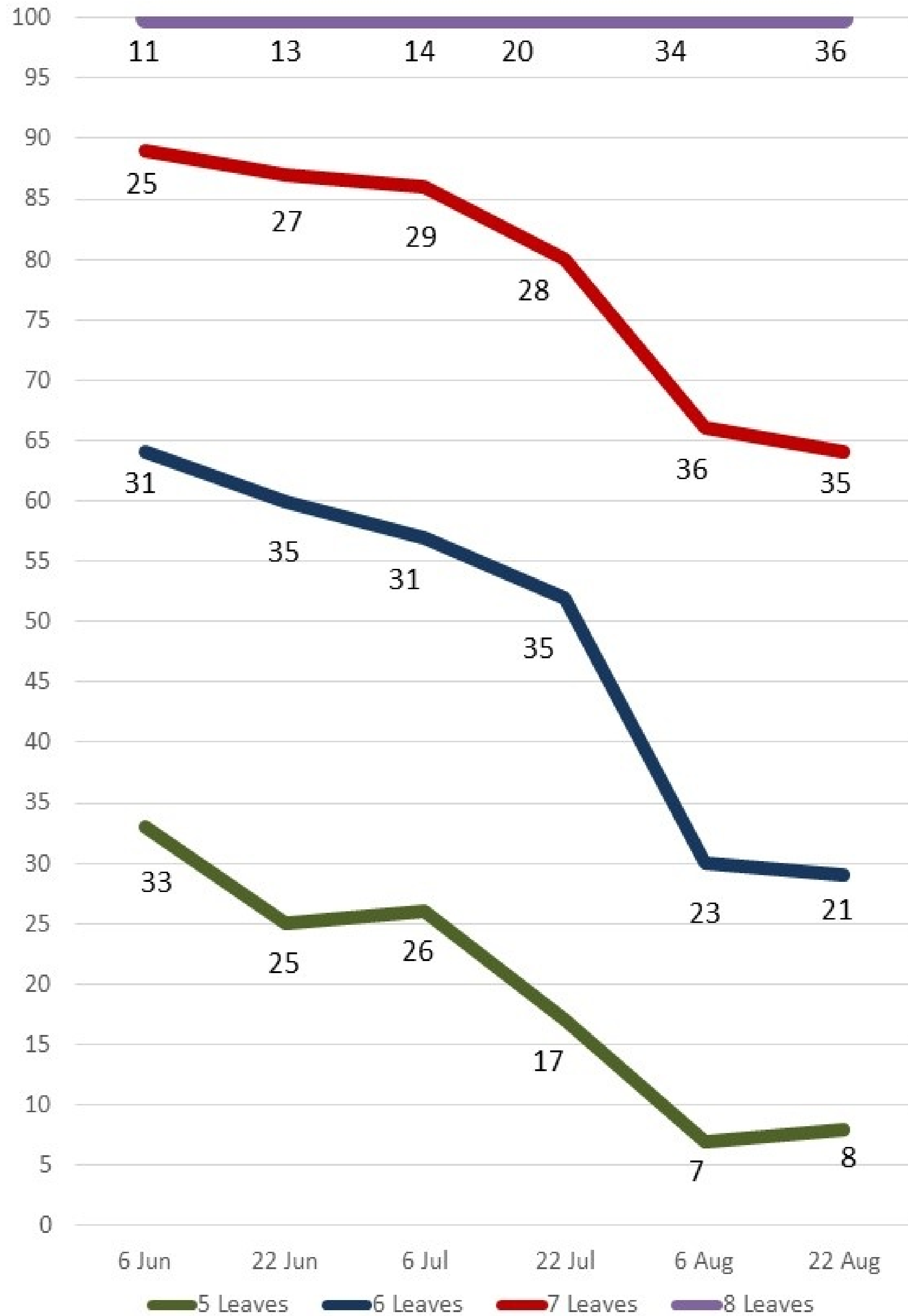

Figure 1. Percent of vegetative tiller population with 5, 6, 7, and 8 leaves.

Table 11. Growth and development of crested wheatgrass vegetative tillers with 5 to 8 leaves on May grazed treatment, 1983-1986.

May Grazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	44.7	40.0	37.2	26.7	12.7	12.3
% Active Leaf	60.0	70.0	60.0	40.0	60.0	40.0
Leaf Height cm	9.0	11.6	9.5	11.9	9.7	12.7
Tallest Leaf cm	10.1	14.8	10.5	13.2	10.9	13.5
6 Leaves						
% Population	33.0	31.9	38.6	38.9	30.2	26.7
% Active Leaf	66.7	66.7	66.7	41.7	50.0	50.0
Leaf Height cm	9.4	13.2	11.8	13.8	11.6	13.7
Tallest Leaf cm	12.5	16.0	13.8	15.6	12.2	14.7
7 Leaves						
% Population	18.4	21.0	23.4	20.8	33.3	35.4
% Active Leaf	71.4	64.3	57.1	50.0	42.9	42.9
Leaf Height cm	14.1	19.0	15.5	16.5	14.1	15.5
Tallest Leaf cm	18.5	22.6	17.3	18.6	15.2	16.6
8 Leaves						
% Population	3.9	7.1	0.7	13.6	23.8	25.5
% Active Leaf	62.5	68.8	50.0	50.0	50.0	50.0
Leaf Height cm	15.2	23.6	21.6	19.3	18.1	18.4
Tallest Leaf cm	21.7	28.3	25.6	22.3	19.4	19.6
% Population	100.0	100.0	99.9	100.0	100.0	99.9

Table 12. Growth and development of crested wheatgrass vegetative tillers with 5 to 8 leaves on ungrazed treatment, 1983-1986.

Ungrazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	21.2	9.7	13.8	8.2	1.0	4.9
% Active Leaf	80.0	70.0	40.0	30.0	0.0	30.0
Leaf Height cm	17.6	21.0	17.7	17.6	-	18.3
Tallest Leaf cm	20.5	23.5	18.6	19.0	-	20.9
6 Leaves						
% Population	30.3	38.2	23.1	31.7	15.4	15.2
% Active Leaf	66.7	58.3	50.0	33.3	33.3	33.3
Leaf Height cm	21.4	22.4	21.1	21.3	22.3	22.5
Tallest Leaf cm	24.7	24.8	22.5	22.6	23.2	23.5
7 Leaves						
% Population	31.1	33.3	35.4	34.4	40.4	34.1
% Active Leaf	57.1	64.3	57.1	42.9	28.6	35.7
Leaf Height cm	23.1	24.7	24.1	23.5	23.9	22.8
Tallest Leaf cm	27.4	27.9	26.2	24.4	24.5	23.7
8 Leaves						
% Population	17.4	18.8	27.7	25.7	43.3	45.7
% Active Leaf	62.5	62.5	50.0	37.5	37.5	37.5
Leaf Height cm	26.9	29.3	32.4	26.1	27.9	27.5
Tallest Leaf cm	32.6	34.9	34.2	28.9	28.5	28.4
% Population	100.0	100.0	100.0	100.0	100.1	99.9

Table 13. Growth and development of crested wheatgrass vegetative tillers with 5 to 8 leaves on May grazed treatment, 1987-1989.

May Grazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	60.4	42.2	92.2	67.6	100.0	51.6
% Active Leaf	60.0	60.0	80.0	60.0	60.0	0.0
Leaf Height cm	9.6	7.6	15.4	10.6	19.6	-
Tallest Leaf cm	10.8	8.9	18.6	12.2	21.7	-
6 Leaves						
% Population	27.5	48.4	7.8	21.1	0.0	29.8
% Active Leaf	66.7	50.0	83.3	66.7	-	0.0
Leaf Height cm	12.3	9.8	19.1	8.1	-	-
Tallest Leaf cm	15.9	11.2	25.6	11.7	-	-
7 Leaves						
% Population	8.8	6.3	0.0	9.9	0.0	12.9
% Active Leaf	57.1	57.1	-	57.1	-	42.9
Leaf Height cm	10.4	11.8	-	15.9	-	15.8
Tallest Leaf cm	13.5	14.0	-	17.2	-	17.7
8 Leaves						
% Population	3.3	3.1	0.0	1.4	0.0	5.6
% Active Leaf	62.5	37.5	-	50.0	-	50.0
Leaf Height cm	12.1	16.2	-	18.5	-	16.1
Tallest Leaf cm	15.1	16.7	-	20.0	-	18.7
% Population	100.0	100.0	100.0	100.0	100.0	99.9

Table 14. Growth and development of crested wheatgrass vegetative tillers with 5 to 8 leaves on ungrazed treatment, 1987-1989.

Ungrazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	39.0	26.0	85.0	20.6	100.0	35.5
% Active Leaf	40.0	40.0	80.0	60.0	40.0	0.0
Leaf Height cm	15.3	19.1	21.0	15.0	20.8	-
Tallest Leaf cm	16.6	19.8	25.3	15.4	22.3	-
6 Leaves						
% Population	38.2	30.1	13.3	37.1	0.0	24.0
% Active Leaf	66.7	50.0	83.3	50.0	-	0.0
Leaf Height cm	17.2	21.9	18.3	23.2	-	-
Tallest Leaf cm	20.5	23.2	21.3	24.5	-	-
7 Leaves						
% Population	16.3	28.8	1.7	24.7	0.0	28.9
% Active Leaf	57.1	57.1	85.7	57.1	-	42.9
Leaf Height cm	21.3	23.2	16.2	22.3	-	15.4
Tallest Leaf cm	23.2	26.2	21.2	23.5	-	17.2
8 Leaves						
% Population	6.5	15.1	0.0	17.5	0.0	11.6
% Active Leaf	62.5	50.0	-	50.0	-	50.0
Leaf Height cm	23.8	25.2	-	22.5	-	24.3
Tallest Leaf cm	28.0	27.4	-	23.6	-	26.3
% Population	100.0	100.0	100.0	99.9	100.0	100.0

Robust Vegetative Tillers

The robust vegetative tillers are uncommon vegetative tillers that produce 9 or more leaves during the same period that common vegetative tillers produce 5 to 8 leaves. Robust tillers grow amongst normal tillers and there is no obvious differences in habitat characteristics. During growing seasons with normal precipitation conditions, robust tillers make up about 10.7% of the total tiller population, and makeup about 5.4% of the vegetative tiller population on the May grazed treatment and make up about 16.3% of the vegetative tiller population on the ungrazed treatment. During growing seasons with below normal precipitation conditions, robust tillers are not present on the May grazed treatment and make up about 3.4% of the vegetative tiller population on the ungrazed treatment.

Growth and development data of crested wheatgrass robust tillers managed with the spring complementary strategy and the ungrazed treatment during 1983 to 1986 are on table 15.

Robust vegetative tillers with 9 leaves on the May grazed strategy composed 5.4% of the total population with 83 tillers (table 6), during the growing season a mean of 4.5 leaves (49.8%) were photosynthetically active with a mean leaf height of 21.2 cm and the tallest leaf averaged 23.9 cm tall (table 15).

Robust vegetative tillers with 9 leaves on the ungrazed treatment composed 16.3% of the total population with 234 tillers (table 6), during the growing season a mean of 4.7 leaves (52.5%) were photosynthetically active with a mean leaf height of 31.9 cm and the tallest leaf averaged 35.9 cm tall (table 15).

Growth and development data of crested wheatgrass robust tillers managed with the spring complementary strategy and the ungrazed treatment during 1987 to 1989 are on table 16.

Robust vegetative tillers with 9 leaves on the May grazed strategy composed 0.0% of the total population with 0 tillers (table 16).

Robust vegetative tillers with 9 leaves on the ungrazed treatment composed 3.4% of the total population with 35 tillers (table 6), during the growing season a mean of 5.0 leaves (55.4%) were photosynthetically active with a mean leaf height of 27.2 cm and the tallest leaf averaged 30.3 cm tall (table 16).

All of the robust vegetative tillers with 9 leaves measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments during the 1983 to1986 and the 1987 to 1989 periods (tables 15 and 16). It is not believed that grazed treatments cause robust vegetative tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the May grazed treatment tended to have lower photosynthetically active leaves than the tillers growing on the ungrazed treatment. Robust vegetative tillers with 9 leaves located on the May grazed treatment had 49.8% photosynthetically active leaves and the tillers located on the ungrazed treatment had 52.5% photosynthetically active leaves.

Robust vegetative tillers with 9 leaves composed a low percentage of the total measured tiller population during the 1983 to 1986 period and were extremely low during the 1987 to 1989 period. Robust vegetative tillers located on the May grazed treatment composed 5.4% and tillers located on the ungrazed treatment composed 16.3% during 1983 to 1986. During the 1987 to 1989 period, robust vegetative tillers located on the May grazed treatment composed 0.0% and tillers located on the ungrazed treatment composed 3.4%.

Table 15. Growth and development of crested wheatgrass robust tillers managed with May grazed and ungrazed treatments, 1983-1986.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1983-1986						
% Population	0.0	1.4	0.0	5.2	19.4	12.8
% Active Leaf	-	57.9	-	46.4	52.6	42.1
Leaf Height cm	-	19.4	-	18.7	20.4	26.4
Tallest Leaf cm	-	25.1	-	21.1	22.0	27.4
Ungrazed 1983-1986						
% Population	5.5	5.6	11.8	23.9	35.0	33.1
% Active Leaf	66.7	66.7	57.9	39.5	52.6	31.6
Leaf Height cm	27.1	31.7	34.7	32.7	33.5	31.8
Tallest Leaf cm	36.2	39.3	38.1	34.4	34.6	32.6

Table 16. Growth and development of crested wheatgrass robust tillers managed with May grazed and ungrazed treatments, 1987-1989.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1987-1989						
% Population	0.0	0.0	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-	-	-
Leaf Height cm	-	-	-	-	-	-
Tallest Leaf cm	-	-	-	-	-	-
Ungrazed 1987-1989						
% Population	2.0	0.0	0.0	2.0	0.0	17.6
% Active Leaf	55.6	-	-	63.2	-	47.4
Leaf Height cm	23.7	-	-	30.0	-	28.0
Tallest Leaf cm	27.2	-	-	33.6	-	30.1

Secondary Tillers

The secondary tillers had very slow rates of growth and development because these subordinate tillers were hormonally controlled by a dominant lead tiller that regulated the flow of essential nutrients. During growing seasons with normal precipitation conditions, secondary tillers made up about 12.4% of the total tiller population on the May grazed treatment and made up about 1.7% of the ungrazed treatment. During growing seasons with below normal precipitation conditions, secondary tillers made up about 40.3% of the total tiller population on the May grazed treatment and made up about 28.8% on the ungrazed treatment. During growing seasons with below normal precipitation, about 59.7% of the total tiller population were able to produce more than 4 leaves on the May grazed treatment and about 71.2% of the tillers were able to produce more than 4 leaves on the ungrazed treatment.

Growth and development data of crested wheatgrass secondary tillers managed with the spring complementary strategy and the ungrazed treatment during 1983 to 1986 and 1987 to 1989 are on tables 17 and 18, respectively.

Secondary tillers with 2 to 4 leaves on the May grazed strategy during 1983 to 1986 composed 12.4% of the total population with 190 tillers (table 6), during the growing season a mean of 2.0 leaves (56.2%) were photosynthetically active with a mean leaf height of 9.4 cm and the tallest leaf averaged 10.7 cm tall (table 17).

Secondary tillers with 2 to 4 leaves on the ungrazed treatment during 1983 to 1986 composed 1.7% of the total population with 24 tillers (table 6), during the growing season a mean of 1.8 leaves (51.1%) were photosynthetically active with a mean leaf height of 17.7 cm and the tallest leaf averaged 18.6 cm tall (table 17).

Secondary tillers with 2 to 4 leaves on the May grazed strategy during 1987 to 1989 composed 40.3% of the total population with 414 tillers (table 6), during the growing season a mean of 2.0 leaves (55.8%) were photosynthetically active with a mean leaf height of 10.8 cm and the tallest leaf averaged 11.8 cm tall (table 18).

Secondary tillers with 2 to 4 leaves on the ungrazed treatment during 1987 to 1989 composed 28.8% of the total population with 297 tillers (table 6), during the growing season a mean of 2.0 leaves (57.4%) were photosynthetically active with a mean leaf height of 16.0 cm and the tallest leaf averaged 17.4 cm tall (table 18).

All of the secondary tillers measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments during the 1983-1986 and 1987-1989 periods (tables 17 and 18). It is not believed that grazed treatments cause secondary tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the May grazed treatment tended to have greater photosynthetically active leaves than the tillers growing on the ungrazed treatment during 1983 to 1986. Secondary tillers located on the May grazed treatment had 56.2% photosynthetically active leaves and the tillers located on the ungrazed treatment had 51.1% photosynthetically active leaves.

Secondary tillers composed a low percentage of the total measured tiller population during the 1983 to 1986 period with normal precipitation conditions. The quantity of secondary tillers greatly increased during the 1987 to 1989 period with below normal precipitation conditions and composed a moderate percentage of the total population. During the 1983 to 1986 period, secondary tillers located on the May grazed treatment composed 12.4% and tillers located on the ungrazed treatment composed 1.7% of the total tiller population. During the 1987 to 1989 period, secondary tillers located on the May grazed treatment composed 40.3% and tillers located on the ungrazed treatment composed 28.8% of the total tiller population. During the growing season with below normal precipitation conditions greater than 35% of the total tiller population that should have been producing 5 to 8 leaves were inhibited to the production of 4 or less leaves.

Table 17. Growth and development of crested wheatgrass secondary tillers managed with the May grazed and ungrazed treatments, 1983-1986.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1983-1986						
% Population	41.1	35.6	11.6	6.0	1.9	1.1
% Active Leaf	55.6	68.8	50.0	37.5	75.0	50.0
Leaf Height cm	6.2	8.8	9.1	10.1	9.4	13.0
Tallest Leaf cm	7.7	9.9	9.5	10.9	10.6	15.7
Ungrazed 1983-1986						
% Population	4.1	4.8	3.3	0.8	0.0	0.0
% Active Leaf	75.0	54.5	50.0	25.0	-	-
Leaf Height cm	20.0	16.2	18.9	15.5	-	-
Tallest Leaf cm	21.2	17.6	19.9	15.5	-	-

Table 18. Growth and development of crested wheatgrass secondary tillers managed with the May grazed and ungrazed treatments, 1987-1989.

Spring	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
May Grazed 1987-1989						
% Population	56.7	61.4	29.2	53.0	83.3	20.5
% Active Leaf	33.3	44.4	71.4	85.7	71.4	28.6
Leaf Height cm	8.2	10.0	15.6	8.1	14.0	8.7
Tallest Leaf cm	8.4	10.2	17.7	9.7	15.4	9.4
Ungrazed 1987-1989						
% Population	35.5	55.8	17.8	34.2	84.5	6.3
% Active Leaf	71.4	44.4	71.4	71.4	71.4	14.3
Leaf Height cm	14.0	14.7	18.5	11.7	15.7	21.6
Tallest Leaf cm	15.5	15.2	20.7	12.0	19.1	21.6

Discussion

Crested wheatgrass, *Agropyron cristatum,* is an introduced, long-lived perennial, cool season, mid grass, monocot, of the grass family that is abundant on the Northern Plains. Crested wheatgrass can grow on most ecological sites. Crested wheatgrass is highly tolerant of drought and is winter hardy. Crested wheatgrass tillers live for two growing seasons; the first growing season as a vegetative tiller and the second season as a reproductive lead tiller. Early season activity starts by regreening with active chlorophyll the portions of the carryover leaves that have intact cell walls from the previous growing season vegetative tillers. The green portion of the carryover leaves provides large quantities of carbohydrates and energy for the production of new leaves.

New leaf growth of crested wheatgrass started in early April, leaf growth rate increased during May and June, and then become much slower during July. The tillers derived from carryover tillers that developed into reproductive lead tillers produced four new leaves by early May and produced 5 to 8 leaves by early June. Early flower stalk growth and development (FSD) began to swell around early to mid May. Lead tillers progressed rapidly through head emergence (HE) during mid to late May. Mean flower date is 28 May. Most lead tillers reached anthesis (Ant) during late May to mid June. Flowering tillers usually produced 5 to 8 leaves. No new leaves were produced after the anthesis stage. Seeds developed (SD) through the milk and dough stages during late May to late June with most seeds reaching maturity (SBS) from late June to late July.

The vegetative tillers derived from the previous seasons fall tillers and the current seasons early spring initiated tillers were not inhibited by lead tiller hormones and produced 3 and 4 new leaves by early May. Vegetative tillers produced 5 to 8 new leaves during early June to August. The percentage of vegetative tillers with 5 leaves decreased after mid June. Vegetative tillers with 6 leaves decreased after late July. Vegetative tillers with 7 and 8 leaves increased slowly during June and July and increased rapidly during late July through mid August as the new leaves were added to the tillers with 5 or 6 leaves.

About 5.4% of the tiller population on the May grazed treatment and about 16.3% of the tiller population on the ungrazed treatment develop robust growth and produced 9 new leaves during growing seasons with normal precipitation conditions. However, the robust tillers grow amongst normal tillers with 5 to 8 leaves and have no obvious differences in habitat characteristics. The mean leaf heights of the robust tillers were a little taller than those of the normal tillers. The main noticeable difference was the uncommonly greater number of leaves.

Secondary tillers are derived from vegetative growth of crown or rhizome axillary buds. The tillers that were initiated during the growing season were hormonally controlled by a dominated lead tiller that has proprietary access to all essential nutrients available to the secondary tillers. This arrangement had positive and negative affects. Most of the time, the secondary tillers have access to greater quantities of essential nutrients than a seedling would have, which ensures secondary tillers with superior survivability. Thus, a high percentage of secondary tillers live and grow for two growing seasons, and almost no grass seedlings develop into mature plants. However, during periods of water stress or other problematic conditions, lead tillers restrict nutrient flow to secondary tillers resulting in very slow rates of growth or sometimes tiller termination. During growing season months with water deficiency, secondary tillers can remain at the 2 or 3 leaf stage for a month or two. When secondary tillers produce their fourth leaf, they have adequate leaf area to photosynthesize their own carbon energy and develop a large enough root system for self sustaining nutrient resource uptake.

An increase in the quantity of secondary tillers initiated from axillary buds requires specialized grazing management, like the two pasture switchback strategy, designed to manipulate the hormones that regulate axillary bud meristematic tissue. With an increase in secondary tiller production, greater quantities of forage vegetative tillers provide greater quantities of nutrients, mainly crude protein, that help lactating cows produce at biological potential. Traditional grazing practices do not stimulate vegetative and secondary tillers production, thus provide forage at lower weights and tiller densities.

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Growth Pattern and Phenological Development of Altai Wildrye on the Northern Plains

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Intact grassland ecosystems are complex; exceedingly more complex than the most complicated machines ever built by humans. Knowledge and understanding of the growth pattern and phenological development of the major forage grasses are fundamentally essential for generation of biologically effective management strategies with inclusivity of all biotic and abiotic components of grassland ecosystems in the Northern Plains.

The inspirational goals of this study were developed by Dr. Warren C. Whitman ©. 1950) and Dr. Harold Goetz (1963) which were to gain quantitative knowledge of each component species and to provide a pathway essential for the understanding of relationships of ecosystem components that would result in the development and establishment of scientific standards for proper management of grazinglands in the Northern Plains.

This growth pattern and phenological development study of the major forage graminoids was conducted during the growing seasons of 1983-1986 and 1987-1989 with data collected biweekly June-August. The study included 3 cool season, 2 warm season, 1 upland sedge, 1 naturalized, and 2 domesticated grasses. The study sites were located at the NDSU Dickinson Research Extension Center ranch near Manning in western North Dakota and consisted of 143 acres (58 ha) of two seeded domesticated grasslands and 720 acres (291 ha) of native rangeland pastures separated into three management treatments, each with two replications, with data collection sites established on sandy, shallow, and silty ecological sites. Each ecological site of the grazed treatments had matching paired plots, one grazed and the other with an ungrazed exclosure.

Study Area

The physiography of the study area consists of the Unglaciated section of the Missouri Plateau (Fenneman 1931, 1946; Hunt 1974). The landscape surface is highly eroded fluvial sedimentary deposits of material removed from the uplifted Rocky Mountains. Most of the deposition occurred from slow meandering streams during the Laramide Orogeny and during the 20 to 30 million years of the late Cretaceous and early Tertiary Periods following the uplift. Intense widespread erosion of these sediments occurred from about 5 to 3 million years ago during the late Pliocene Epoch (Bluemle 2000). The extensive erosion during this period removed about 500 to 1000 feet of sediments (Fenneman 1931) forming a landscape with well developed integrated drainage systems of broad mature valleys and gently rolling uplands containing widely spaced large hills and buttes with erosion resistant caps raising 500 to 650 feet above the plain (Bluemle 2000).

The soils of western North Dakota developed from eroded Tertiary fluvial sedimentary deposits in the Ustic-Frigid soil moisture-temperature regime. The Ustic soil moisture regime is typical of semi arid climates. The Frigid soil temperature regime has mean annual soil temperatures of less than 47° F (8° C) (Soil Survey Staff 1975). These soils are primarily Typic Borolls (semi arid cool Mollisols) and support vegetation of mid and short grasses of the Mixed Grass Prairie (Manske 2008b).

The current "native" plant species in the Northern Plains did not originate here. All of the plant species have migrated into the region by different mechanisms and at different times and rates. The present plant species have flora affinities to northern, eastern, western, Rocky Mountain, and Great Basin plant communities (Zaczkowski 1972). This wide mix of plant species was formed from remnants of previously existing plant communities. The climate changed about 5,000 years ago to conditions like those of the present, with cycles of wet and dry periods (Bluemle 1977, 1991; Manske 1994). The large diversity of plant species that make up the current mixed grass prairie permits dynamic responses to changes in climatic conditions by increasing the combination of plant species favored by any set of climatic conditions (Manske 2008a).

Long-Term Weather

The NDSU Dickinson Research Extension Center ranch is located in Dunn County in western North Dakota, at 47° 14' north latitude, 102° 50' west longitude. Mean annual temperature is 42.3° F (5.7° C). January is the coldest month, with mean temperature of 14.6° F (-9.7° C). July and August are the warmest months with mean temperatures of 69.7° F (20.9° C) and 68.6° F (20.3° C), respectively. Long-term (1982-2012) mean annual precipitation is 16.91 inches (429.61 mm). The perennial plant growing season precipitation (April to October) is 14.13 inches (358.97 mm) and is 83.6% of annual precipitation. June has the greatest monthly precipitation at 3.27 inches (83.08 mm). The precipitation received during the 3-month period of May, June, and July (8.26 inches, 209.80 mm) accounts for 48.8% of the annual precipitation.

Growing season months with water deficiency disrupt plant growth rates and are identified from monthly temperature and precipitation data by the Emberger ombrothermic diagram technique. Long-term (1983-2012) 30 year reoccurrence rates (table 1) show relatively low rates of water deficiency reoccurring during April (16.7%), May and June (10.0%), moderate rates during July and October (36.7%), and high rates during August (56.7%) and September (60.0%). Long-term occurrence of water deficiency conditions was 33.3% of the growing season months, for a mean of 2.0 water deficient months per each 6.0 month growing season (15 Apr-15 Oct).

Growing Season Precipitation

The growing season precipitation information collected during the grass leaf height study has been grouped into two periods with the first period occurring during 1983 to 1986 and the second period occurring during 1987 to 1989.

Mean growing season precipitation of 1983-1986 (table 2) was 14.11 inches (99.9% of LTM). None of the four 6 month growing seasons received precipitation at less than 80% of LTM. One growing season, 1986, received precipitation at near 130% of LTM. The rate of water deficiency occurrence during the four growing seasons was 29.2%, for a mean of 1.75 water deficient months per growing season (table 3). The growing season of 1984 had 3.0 months in water deficiency. The growing seasons of 1983 and 1986 had 1.5 months in water deficiency each. The growing season of 1985 had 1.0 month in water deficiency.

Mean growing season precipitation of 1987-1989 (table 4) was low at 9.14 inches (64.7% of LTM). The growing season of 1987 received 11.53 inches (81.6% of LTM) precipitation. The growing season of 1989 received 10.60 inches (75.0% of LTM) precipitation. The growing season of 1988 received only 5.30 inches (37.5% of LTM) precipitation and was dry. The rate of water deficiency occurrence during the three growing seasons was 61.1%, for a mean of 3.7 water deficient months per growing season (table 5). The growing seasons of 1987 and 1989 had 3.0 months in water deficiency each. The growing season of 1988 had 5.0 months of its 6 month growing season in water deficiency conditions. That is comparable to 2 other growing seasons with high water deficiency conditions. The growing season of 1934 had 4.5 months in water deficiency and the growing season of 1936 had 5.5 months in water deficiency.

Table 1. Growing season months with water deficiency, DREC ranch, 1983-2012.

	Apr	May	Jun	Jul	Aug	Sep	Oct	# Months	% 6 Months 15 Apr-15 Oct
Total	5	3	3	11	17	18	11	60.0	33.3
% of 30 Years	16.7	10.0	10.0	36.7	56.7	60.0	36.7		

Table 2. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1983-1986.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59	15.55
% of LTM	14.58	59.77	99.69	105.35	261.76	60.56	54.96	96.18	91.96
1984	2.87	0.00	5.30	0.11	1.92	0.53	0.96	11.69	12.88
% of LTM	199.31	0.00	162.08	4.53	112.94	37.32	73.28	82.73	76.17
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80	15.13
% of LTM	86.11	126.95	48.32	44.03	108.24	119.01	162.60	90.59	89.47
1986	3.13	3.68	2.58	3.04	0.46	5.29	0.18	18.36	22.96
% of LTM	217.36	143.75	78.90	125.10	27.06	372.54	13.74	129.94	135.78
1983-1986	1.86	2.12	3.18	1.70	2.17	2.09	1.00	14.11	16.63
% of LTM	129.34	82.62	97.25	69.75	127.50	147.36	76.15	99.86	98.34

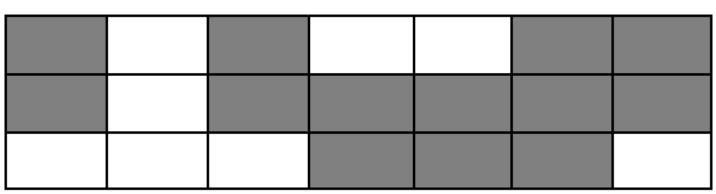
Table 3. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1983-1986.

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1983	■					■		1.5	25.0
1984		■		■		■		3.0	50.0
1985				■				1.0	16.7
1986					■		■	1.5	25.0
#	**1**	**1**	**0**	**2**	**1**	**2**	**1**	**7.0**	**29.2**
%	**25.0**	**25.0**	**0.0**	**50.0**	**25.0**	**50.0**	**25.0**		

Table 4. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1987-1989.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1987	0.10	1.38	1.15	5.39	2.65	0.78	0.08	11.53	14.13
% of LTM	6.94	53.91	35.17	221.81	155.88	54.93	6.11	81.60	83.56
1988	0.00	1.85	1.70	0.88	0.03	0.73	0.11	5.30	9.03
% of LTM	0.00	72.27	51.99	36.21	1.76	51.41	8.40	37.51	53.40
1989	2.92	1.73	1.63	1.30	1.36	0.70	0.96	10.60	13.07
% of LTM	202.78	67.58	49.85	53.50	80.00	49.30	73.28	75.02	77.29
1987-1989	1.01	1.65	1.49	2.52	1.35	0.74	0.38	9.14	12.08
% of LTM	69.91	64.58	45.67	103.84	79.22	51.88	29.26	64.71	71.42

Table 5. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1987-1989.



	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1987								3.0	50.0
1988								5.0	83.3
1989								3.0	50.0
#	**2**	**0**	**2**	**2**	**2**	**3**	**2**	**11.0**	**61.1**
%	**66.7**	**0.0**	**66.7**	**66.7**	**66.7**	**100.0**	**66.7**		

Procedures

The 1983-1989 Study

Grass tiller leaf heights were determined for reproductive lead tillers, vegetative tillers, and secondary tillers on a biweekly sampling period from June through August. Each leaf of ten ungrazed tillers of each study species was measured with a meter stick to the nearest 0.1 cm from ground level to the tips of the extended leaves. Basal leaf heights were measured for grass species in which the leaves and stalks were distinctly separate. Stalk leaf heights were measured for grass species where leaves are attached to the culm during vegetative stages and fruiting stages.

Degree of leaf senescence was estimated as percent dryness for each leaf. Percent dryness for basal leaves was considered from the apex to ground level. Percent dryness for stalk leaves was considered for the blade only. The categories of dryness were: 0%, 2%, 25%, 50%, 75%, 98% and 100% dry. Start of senescence was considered to be dryness greater than 2%. Leaves with less than 50% senescent tissue were designated to be photosynthetically active.

Grass flower stalk heights were determined by measurements from ground level to the tip of the stalk or the apex of the top floret. The awns, if present, were not included in the height measurements. The phenological stages of flower stalk development were recorded as: flower stalk developing (FSD), head emergence (HE), anthesis (Ant), seeds developing (SD), and seeds being shed (SBS). Recording the flower stalk development stages started when stalk enlargement or swelling was outwardly noticeable; prior development is not detectable without destruction of the tiller. The swelling of the stalk, traditionally called the boot stage, was categorized as the flower stalk developing stage. Head emergence is a short duration stage but easily defined when the flower head emerges from the sheath and rapidly elongates to near full height. Anthesis (flowering) is also a short duration stage but easily defined by the exposure of the anthers and stigmas. Needle and thread is usually cleistogamous that self-fertilizes without opening and exposing the anthers and stigmas. Following fertilization, the seeds develop through milk, dough, and mature stages which are difficult to differentiate on small grass seeds. These seed progression stages have been separated into more easily defined categories of seeds developing for the early seed stages and seeds being shed for the mature seed stages when seeds could be easily removed from the inflorescence by wind, by gentle rubbing, or when it could be observed that some seeds had already been dropped. Sometimes a floret will abort the seed production process resulting in failure of viable seeds to materialize. This condition could be revealed in the data set as earlier than normal recordings of seeds being shed.

During 1983 to 1986 and during 1987 to 1989, the paired plot sample sites were managed by fall grazed treatments of the Altai wildrye complementary strategy.

Designation of Tiller Types

Reproductive lead tillers are second year tillers derived from carryover tillers that were vegetative tillers during the previous growing season. The portions of the carryover leaves that have intact cell walls will regreen with active chlorophyll early in the growing season and provide photosynthate for rapid growth of new current years leaves. Two and maybe three new leaves are produced during early April, with 3 to 6 basal leaves produced before early June. The anthesis (flowering) period occurs during mid to late June with some early first flowers occurring before 21 June. New leaf 7 completes growth in height during July after the anthesis stage and during the seed development stages. Tillers with flower stalks usually produce 5 to 7 basal leaves. Lead tiller basal leaves produce most of the herbage weight during June and July. Flower stalks are mostly leafless, are unpalatable, and are completely dry by mid July. Lead tiller basal leaves are completely dry by late August but remain palatable to livestock. Reproductive lead tillers are terminal at the end of the growing season; their apical meristem was used up producing a flower head.

Vegetative tillers are first year tillers derived from previous growing season initiated fall tillers and from early spring initiated secondary tillers and have escaped hormonal control by a lead tiller. These tillers are the primary forage tillers with rapid growth rates. Most vegetative tillers have 5 and 6 leaves during June and early July. During mid July and August one to three new leaves are added usually producing 5 to 9 basal leaves during the growing season and adding considerable herbage weight during July and August. The apical meristem remains vegetative, permitting these tillers to overwinter as carryover tillers and becoming reproductive lead tillers during the successive growing season.

Secondary tillers are young current growing season tillers usually initiated from crown axillary buds during May to July that remain hormonally controlled by a dominant lead tiller that has proprietary access to all resources slowing rates of growth until after the lead tillers have reached the flower stage. The secondary crown tillers produce 4 leaves and become independent from the hormone control of the lead tiller and transform into vegetative tillers with rapid growth rates producing additional herbage weight during July and August. A large quantity of fall secondary tillers develop during late July and August that continue producing herbage weight during September and October.

Results

Altai wildrye, *Leymus angustus* (Trin.) Pilg., is a member of the grass family, Poaceae, tribe, Triticeae, syn.: *Elymus angustus* Trin., and is a long lived perennial, monocot, cool-season, mid grass, that is drought tolerant, very winter hardy, highly tolerant of saline soils nearly at the level of tall wheatgrass, and fairly tolerant of alkaline soils. Altai wildrye was introduced into Canada as two seed lots. The first seed lot arrived in 1934 from Voronezh, USSR, located in the far western European Russian Steppe. The second seed lot arrived in 1939 from the Steppe of Kustanay located in the northern region of Kazakhstan. Three synthetic strains were developed from seed increase plots started in 1950 at the Swift Current Research Station followed by more sites at seven research stations in Alberta, Manitoba, and Saskatchewan, which produced the first released cultivar, Prairieland, in 1976. Seed from the increase fields at Swift Current was used to establish 60 acres of Altai wildrye monoculture at the NDSU Dickinson Research Extension Center for a replicated study of late season grazing during mid October to mid November conducted from 1983 to 2005 for 23 years. Early aerial growth consists of basal leaves from crown tiller buds. Basal leaf blades are 15-25 cm (6-10 in) long, 0.5-0.7 cm wide, erect, coarse, light green to bluegreen to blue, and can remain upright under deep wet snow. The leaf sheath is usually shorter than the internodes and grayish green. The membrane ligule is 0.5-1.0 mm long with an obtuse apex. Some early specimens of introduced strains showed vigorous rhizome charateristics and aggressive spreading which was considered to be undesirable. The available released plant material are generally weakly rhizomatous with short rhizomes. Unfortunately, fields seeded with plant material that has nonaggressive short rhizomes is limited by around a 20 to 25 year life expectancy when managed with traditional practices. However, the uniquely deep extensive fibrous root system that can penetrate to depths of 3-4 m (9.8-13.1 ft) and efficiently absorb available soil water was retained. Regeneration is primarily asexual propagation by crown and short rhizome tiller buds. Seedlings have slow, weak growth and are successful only when competition from established plants is nonexistant. Flower stalks are erect, 60-100 cm (24-39 in) tall, mostly leafless and few in numbers. Inflorescence is a terminal spike 15-20 cm (6-8 in) long, 1 cm in diameter, that has closely spread overlapping spikelets of 2 or 3 florets, with 2 or 3 spikelets per node. Basal leaves are palatable to livestock and seed stalks are not. Wildryes maintain slightly higher levels of protein and digestibility with advancing maturity better than other species of perennial grasses. Wildryes are best used for late season grazing from mid October to mid November. Fire top kills aerial parts and kills deeply into the crown when soil is dry. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reduction in biomass production and tiller density. This summary information on growth development and regeneration of Altai wildrye was based on works of Lawrence 1976 and St. John et al. 2010.

During the seven years of this study, the number of Altai wildrye tillers measured were 2768 with 1484 during 1983 to 1986 and 1284 during 1987 to 1989 (table 6). The collection protocol required measurement on all available flower stalks and ten vegetative tillers on each sample site each collection period, amounting to 360 tillers per year on the fall complementary strategy. During the 3 growing seasons with low precipitation amounts, more lead tillers and less than ten vegetative tillers were measured each collection period. The reductions in sample numbers would indicate the degree of negative affect from reduced precipitation. This affect is designated as collection efficiency on table 6.

Table 6. Number of tillers measured from fall grazed management treatment on the Altai wildrye complementary strategy.

Tiller Type	Fall Complementary 1983-1986 Fall Grazed	Fall Complementary 1987-1989 Fall Grazed
Flower Stalk	259	395
Vegetative	1014	390
Secondary	211	499
Total	1484	1284
Sum total	2768	
Collection Efficiency	103%	119%

Reproductive Lead Tillers

The second year reproductive lead tillers had the fastest rate of growth and development until mid to late July. The flower stalk developing (FSD) stage with the swelling of the sheath was not observed and probably took place low in the crown. However, the flower stalk growth occurred very rapidly during mid May to late June. Head emergence (HE) with elongation of the flower stalk occurred during early to late June. Lead tillers reached anthesis (Ant) during mid to late June. Tillers with flower stalks usually produced 5 to 7 leaves. New leaf 7 completed growth in height after the anthesis stage. Seeds developed (SD) through the milk and dough stages during late June to mid July with most seeds reaching maturity (SBS) during mid July with some seeds remaining on dry stalks during the summer (table 7). The apical meristem of reproductive lead tillers can no longer produce leaf buds after it had produced flower buds and these tillers were terminated at the end of the growing season.

Lead tiller new leaf growth started very early in the spring. Leaves 1 and 2 had started to develop by early April. These leaves developed slowly and were still at about half their height during late April (table 8). Leaf 3 was not visible in late April. By early June, leaf 1 and 2 had finished growth in height and then completely dried and leaves 3 to 6 had rapidly developed to near full height.

Growth and development data of Altai wildrye reproductive lead tillers managed with the fall grazed and the ungrazed treatments during 1983 to 1986 and 1987 to 1989 are on table 9.

Reproductive lead tillers with 3 to 7 basal leaves on the fall grazed strategy during 1983 to 1986 composed 17.5% of the total population with 259 tillers (table 6) that had a mean flower stalk height of 83.3 cm, during the growing season a mean of 42.3% of the leaves were photosynthetically active with a mean leaf height of 58.5 cm and the tallest leaf averaged 71.7 cm tall (table 9).

Reproductive lead tillers with 3 to 7 basal leaves on the fall grazed strategy during 1987 to 1989 composed 30.8% of the total population with 395 tillers (table 6) that had a mean flower stalk height of 63.7 cm, during the growing season a mean of 32.9% of the leaves were photosynthetically active with a mean leaf height of 38.3 cm and the tallest leaf averaged 49.0 cm tall (table 9).

The growing season months during 1983 to 1986 received 99.9% of the regional long-term mean precipitation and only 29.2% of the months had water deficiency conditions (tables 2 and 3). The growing season months during 1987 to 1989 received only 64.7% of the regional long-term mean precipitation resulting in a 35.3% precipitation deficit causing 61.1% of the months to have water deficiency conditions (tables 4 and 5). These differences in levels of precipitation received during the growing season caused some differences in reproductive lead tiller growth. All of the reproductive lead tillers measured during this study were not grazed during the growing season. The flower stalk height was 30.8% taller during the growing seasons with 99.9% normal precipitation than during that with a 35.3% deficit but not significantly different. The basal leaves with less than 50% senescent tissue were designated to be photosynthetically active. The percent of the basal leaves that were photosynthetically active was 31.6% greater during the growing season with 99.9% normal precipitation but not significantly different. The mean basal leaf height was 52.7% taller during the growing seasons with 99.9% normal precipitation and was significantly different. The height of the tallest basal leaf of the lead tillers was 46.3% taller during the growing seasons with 99.9% normal precipitation and was significantly different.

Table 7. Phenological stages of flower stalk development for Altai wildrye, 1983-1986.

6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
HE	HE				
	Ant				
	SD	SD			
			SBS	SBS	SBS

FSD flower stalk developing
HE head emergence
Ant anthesis (flowering)
SD seeds developing
SBS seeds being shed

Table 8. Growth and development of Altai wildrye lead tillers during April on the fall grazed treatment, 1983-1986.

Fall Grazed	6 Apr	22 Apr
1 Leaf		
% Population	20.8	0.0
% Active Leaf	100.0	-
Leaf Height cm	12.6	-
Tallest Leaf cm	12.6	-
2 Leaves		
% Population	79.2	100.0
% Active Leaf	100.0	100.0
Leaf Height cm	11.9	15.7
Tallest Leaf cm	15.0	19.3
% Population	100.0	100.0

Table 9. Growth and development of Altai wildrye reproductive lead tillers on the fall grazed treatment, 1983-1986 and 1987-1989.

Oct-Nov	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Fall Grazed 1983-1986						
Stalk Height cm	61.9	80.3	98.9	92.2	116.7	101.9
% Active Leaf	65.0	48.5	27.8	28.0	0.0	0.0
Leaf Height cm	49.7	58.8	66.7	58.9	-	-
Tallest Leaf cm	66.0	72.9	75.6	72.4	-	-
Fall Grazed 1987-1989						
Stalk Height cm	50.9	56.4	86.5	52.2	78.5	57.8
% Active Leaf	55.4	42.4	53.3	21.7	16.7	8.0
Leaf Height cm	35.0	37.1	51.2	44.0	27.1	35.5
Tallest Leaf cm	48.3	47.3	67.6	44.4	40.7	45.7

Vegetative Tillers

The vegetative tillers had the second fastest rate of active growth and development continuing until mid to late July. Early new leaf development was rapid in the 30% of the tillers with 3 to 4 leaves and in the 70% of vegetative tillers with 5 or 7 basal leaves before early June. Between early June and early July, vegetative tillers with 5 or 6 leaves remained around 92% to 94% of the population. The percentage of vegetative tillers with 7 leaves increased during early to late July and the tillers with 8 leaves increased during late July. The older vegetative tillers with 5 or 6 leaves were moving up to become tillers with 7 or 8 leaves, while the subordinate secondary tillers had received greater quantities of essential nutrients after the lead tillers had completed the anthesis and early seed development stages, permitting the secondary tillers to produce their 4^{th} leaf and obtain their independence, followed by rapid production of leaf 5. As a result, the percent vegetative tiller population with 5 leaves stayed around 25% during the remainder of the growing season (figure 1).

Growth and development data of Altai wildrye vegetative tillers managed with the fall grazed strategy during 1983 to 1986 are on table 10.

Vegetative tillers with 5 leaves composed 39.1% of the population with 396 tillers (table 6), during the growing season a mean of 3.1 leaves (61.7%) were photosynthetically active with a mean leaf height of 38.4 cm and the tallest leaf averaged 46.0 cm tall (table 10).

Vegetative tillers with 6 leaves composed 40.8% of the population with 414 tillers (table 6), during the growing season a mean of 3.3 leaves (54.2%) were photosynthetically active with a mean leaf height of 42.4 cm and the tallest leaf averaged 51.1 cm tall (table 10).

Vegetative tillers with 7 leaves composed 17.9% of the population with 182 tillers (table 6), during the growing season a mean of 3.9 leaves (55.9%) were photosynthetically active with a mean leaf height of 41.7 cm and the tallest leaf averaged 51.5 cm tall (table 10).

Vegetative tillers with 8 leaves composed 2.1% of the population with 21 tillers (table 6), during the growing season a mean of 4.2 leaves (52.1%) were photosynthetically active with a mean leaf height of 43.3 cm and the tallest leaf averaged 53.8 cm tall (table 10).

Vegetative tillers with 9 leaves composed 0.1% of the population with 1 tiller (table 6), during the growing season a mean of 4.0 leaves (44.4%) were photosynthetically active with a mean leaf height of 30.7 cm and the tallest leaf averaged 43.5 cm tall (table 10).

Growth and development data of Altai wildrye vegetative tillers managed with the fall grazed strategy during 1987 to 1989 are on table 11.

Vegetative tillers with 5 leaves composed 59.2% of the population with 231 tillers (table 6), during the growing season a mean of 3.0 leaves (60.0%) were photosynthetically active with a mean leaf height of 30.7 cm and the tallest leaf averaged 38.4 cm tall (table 11).

Vegetative tillers with 6 leaves composed 29.7% of the population with 116 tillers (table 6), during the growing season a mean of 2.8 leaves (47.2%) were photosynthetically active with a mean leaf height of 33.6 cm and the tallest leaf averaged 41.8 cm tall (table 11).

Vegetative tillers with 7 leaves composed 9.2% of the population with 36 tillers (table 6), during the growing season a mean of 3.1 leaves (44.9%) were photosynthetically active with a mean leaf height of 34.0 cm and the tallest leaf averaged 43.1 cm tall (table 11).

Vegetative tillers with 8 leaves composed 1.3% of the population with 5 tillers (table 6), during the growing season a mean of 3.0 leaves (37.5%) were photosynthetically active with a mean leaf height of 35.9 cm and the tallest leaf averaged 41.3 cm tall (table 11).

Vegetative tillers with 9 leaves composed 0.5% of the population with 2 tillers (table 6), during the growing season a mean of 4.0 leaves (44.4%) were photosynthetically active with a mean leaf height of 36.2 cm and the tallest leaf averaged 45.9 cm tall (table 11).

Not all the leaves on a grass tiller are photosynthetic during the entire growing season. Leaves grow and senesce in the order they appear. The first and second leaves are usually dry by early June. The rate of leaf senescence can be rapid during water deficiency periods and slow during periods with adequate precipitation. During senescence, leaves translocate cell components to other plant parts. The senesced leaf has less weight and has very low nutritional quality. The greater the number of leaves not senescent, the greater the tiller nutritional quality.

The growing season months during 1983 to 1986 received 99.9% of normal precipitation (tables 2 and 3) and the growing season months during 1987 to 1989 received a 35.3% deficit in precipitation (tables 4 and 5). These differences in levels of precipitation received during the growing season caused some differences in vegetative tiller growth. The basal leaves with less than 50% senescent tissue were designated to be photosynthetically active. The mean percent of the basal leaves that were photosynthetically active during the growing season was 57.3% during 1983 to 1986 and 48.2% during 1987 to 1989 but not significantly different. All of the vegetative tillers measured during this study were not grazed during the growing season. The mean basal leaf height was 25.1%, 26.2%, and 22.6% taller for vegetative tillers with 5, 6, and 7 leaves, respectively, during the growing seasons with 99.9% normal precipitation and were significantly taller than those during the growing seasons with a 35.3% deficit. The tallest basal leaf height was 19.8%, 22.2%, and 19.5% taller for vegetative tillers with 5, 6, and 7 leaves, respectively, during the growing seasons with 99.9% normal precipitation and were significantly taller than those during the growing seasons with a 35.3% deficit.

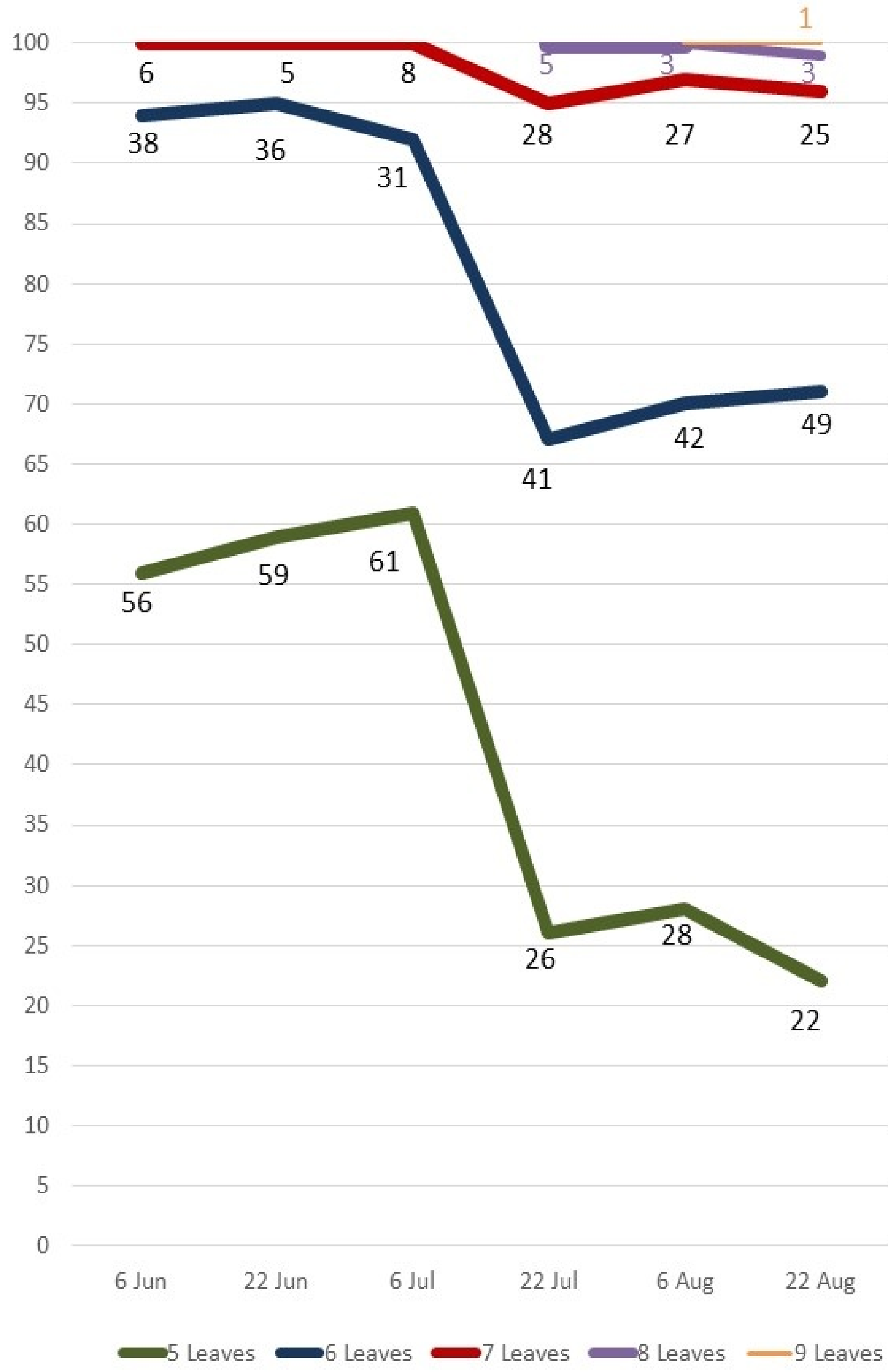


Figure 1. Percent of vegetative tiller population with 5 to 9 leaves.

Table 10. Growth and development of Altai wildrye vegetative tillers with 5 to 9 leaves on the fall grazed treatment, 1983-1986.

Fall Grazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	56.3	58.8	61.2	26.2	29.1	22.3
% Active Leaf	60.0	70.0	60.0	70.0	60.0	50.0
Leaf Height cm	38.7	35.9	40.8	34.0	42.3	38.8
Tallest Leaf cm	45.9	45.1	50.4	43.7	45.9	44.9
6 Leaves						
% Population	37.9	35.7	31.1	40.9	41.8	49.1
% Active Leaf	50.0	66.7	50.0	58.3	50.0	50.0
Leaf Height cm	43.4	39.4	45.9	42.3	43.8	39.3
Tallest Leaf cm	51.1	49.9	58.4	51.0	50.1	45.8
7 Leaves						
% Population	5.8	5.4	7.8	28.4	26.6	25.1
% Active Leaf	57.1	64.3	57.1	50.0	57.1	50.0
Leaf Height cm	42.0	35.9	41.3	44.4	45.4	41.0
Tallest Leaf cm	55.0	48.2	53.4	53.0	51.9	47.7
8 Leaves						
% Population	0.0	0.0	0.0	4.4	2.5	3.2
% Active Leaf	-	-	-	50.0	62.5	43.8
Leaf Height cm	-	-	-	48.8	43.9	37.3
Tallest Leaf cm	-	-	-	56.6	55.3	49.6
9 Leaves						
% Population	0.0	0.0	0.0	0.0	0.0	0.4
% Active Leaf	-	-	-	-	-	44.4
Leaf Height cm	-	-	-	-	-	30.7
Tallest Leaf cm	-	-	-	-	-	43.5
% Population	100.0	99.9	100.1	99.9	100.0	100.1

Table 11. Growth and development of Altai wildrye vegetative tillers with 5 to 9 leaves on the fall grazed treatment, 1987-1989.

Fall Grazed	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	51.5	67.8	97.1	52.9	100.0	47.2
% Active Leaf	60.0	40.0	80.0	60.0	60.0	60.0
Leaf Height cm	30.3	30.0	31.1	29.5	32.1	31.1
Tallest Leaf cm	38.0	34.6	43.3	34.4	41.5	38.4
6 Leaves						
% Population	33.8	25.4	2.9	36.8	0.0	36.6
% Active Leaf	50.0	50.0	83.3	50.0	-	50.0
Leaf Height cm	31.9	31.2	36.5	33.3	-	35.3
Tallest Leaf cm	37.6	36.9	51.3	40.2	-	43.0
7 Leaves						
% Population	14.7	6.8	0.0	5.7	0.0	13.8
% Active Leaf	53.3	57.1	-	57.1	-	57.1
Leaf Height cm	37.1	27.3	-	37.1	-	34.4
Tallest Leaf cm	45.6	39.4	-	45.8	-	41.5
8 Leaves						
% Population	0.0	0.0	0.0	3.4	0.0	1.6
% Active Leaf	-	-	-	37.5	-	37.5
Leaf Height cm	-	-	-	36.4	-	35.4
Tallest Leaf cm	-	-	-	44.8	-	37.8
9 Leaves						
% Population	0.0	0.0	0.0	1.1	0.0	0.8
% Active Leaf	-	-	-	44.4	-	44.4
Leaf Height cm	-	-	-	37.0	-	35.3
Tallest Leaf cm	-	-	-	45.3	-	46.5
% Population	100.0	100.0	100.0	99.9	100.0	100.0

Secondary Tillers

The secondary tillers had very slow rates of growth and development because these subordinate tillers were hormonally controlled by a dominant lead tiller that regulated the flow of essential nutrients. During growing seasons with normal precipitation conditions, secondary tillers made up about 14.2% of the total tiller population on the fall grazed treatment. During growing seasons with below normal precipitation conditions, secondary tillers made up about 38.9% of the total tiller population on the fall grazed treatment. During growing seasons with below normal precipitation, about 61.1% of the total tiller population were able to produce more than 4 leaves and about 85.8% of the tillers were able to produce more than 4 leaves during the growing seasons with normal precipitation.

Growth and development data of Altai wildrye secondary tillers managed with the fall grazed treatment during 1983 to 1986 and 1987 to 1989 are on table 12.

Secondary tillers with 2 to 4 leaves on the fall grazed strategy during 1983 to 1986 composed 14.2% of the total population with 211 tillers (table 6), during the growing season a mean of 2.3 leaves (65.6%) were photosynthetically active with a mean leaf height of 31.5 cm and the tallest leaf averaged 35.1 cm tall (table 12).

Secondary tillers with 2 to 4 leaves on the fall grazed strategy during 1987 to 1989 composed 38.9% of the total population with 499 tillers (table 6), during the growing season a mean of 2.5 leaves (70.1%) were photosynthetically active with a mean leaf height of 29.4 cm and the tallest leaf averaged 33.3 cm tall (table 12).

The growing season months during 1983 to 1986 received 99.9% of normal precipitation (tables 2 and 3) and the growing season months during 1987 to 1989 received a 35.3% deficit in precipitation (tables 4 and 5). These differences in levels of precipitation received during the growing seasons did not cause significant differences in secondary tiller growth. The basal leaves with less than 50% senescent tissue were designated to be photosynthetically active. The mean percent of the secondary tiller basal leaves that were photosynthetically active was 7.0% greater but not significantly different. All of the secondary tillers measured during this study were not grazed during the growing season. The mean basal leaf height was 7.1% taller and the tallest basal leaf was 16.8% taller during the growing seasons with 99.9% normal precipitation, respectively, but not significantly different than those during the growing seasons with a 35.3% deficit.

Table 12. Growth and development of Altai wildrye secondary tillers managed with the fall grazed treatment, 1983-1986 and 1987-1989.

Oct-Nov	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Fall Grazed 1983-1986						
% Population	29.5	20.8	8.8	10.4	1.3	3.1
% Active Leaf	85.7	81.8	50.0	71.4	50.0	54.5
Leaf Height cm	32.3	35.0	33.7	38.7	16.0	33.1
Tallest Leaf cm	39.6	41.7	35.3	42.4	16.2	35.3
Fall Grazed 1987-1989						
% Population	64.0	59.6	68.8	43.1	86.8	16.9
% Active Leaf	71.4	77.8	71.4	71.4	71.4	57.1
Leaf Height cm	27.6	28.9	28.8	25.4	31.6	34.3
Tallest Leaf cm	30.5	33.0	33.5	28.6	36.0	38.1

Synopsis of tiller growth and development

Altai wildrye tillers, as all perennial grass tillers, live for two growing seasons, the first growing season as a vegetative tiller, a secondary tiller, or a fall tiller and the second season as a reproductive lead tiller. The difference between vegetative, secondary, and fall tillers is the time of the growing season that they initiate growth. Cool season vegetative tillers are first year tillers that initiate growth very early in the spring and are derived from previous growing season initiated fall tillers and from early spring initiated secondary tillers that have escaped hormonal control by a dominant lead tiller. Secondary tillers are young current growing season tillers usually initiated from crown or rhizome axillary buds during the early portion of the growing season primarily from May to mid July. Their rate of growth is slow at first because it is hormonally controlled by a dominant lead tiller that continues until the lead tiller reaches the flower stage; at that time the secondary tiller has access to greater quantities of nutrient resources. After the fourth new leaf has been produced, the secondary tiller has adequate leaf area to photosynthesize their own carbon energy and develop a large enough root system for self sustaining nutrient resource uptake. The four leaf secondary tillers transforms into vegetative tillers.

Fall tillers are cool season grass tillers that are initiated from crown or rhizome axillary buds usually during the winter hardening period from mid August to hard frost. Some Altai wildrye fall tillers are initiated during mid to late July. Fall tillers overwinter and usually become next growing seasons vegetative tillers. Rarely, during some growing seasons, a few of the well developed fall tillers become next growing seasons reproductive lead tillers.

Reproductive lead tillers are second year tillers almost always derived from carryover tillers which were previous growing season vegetative tillers that have successfully overwintered with portions of last seasons leaves that have unruptured/intact cell walls that regreen with active chlorophyll and provide photosynthate for growth of new current leaves. Even though the carryover leaves perform photosynthesis during the current season, the leaf material was produced during the previous growing season and should not be included in the new leaf count to determine the physiologic status of lead tillers.

Growth of Altai wildrye lead tiller new leaves begins very early in the spring. New leaves 1 and 2 develop during early April and reach about half size during late April. New leaf 3 is still not visible in late April. During May, leaf 1 and 2 develop rapidly; they finish their growth in height and rapidly senesce and are completely dry before early June. Also, during May, new basal leaves 3 to 6 develop rapidly, reaching near full height by early June.

The flower stalk develops very early during May. The early stages are not detected and assumed to occur low in the crown. The mostly leafless flower stalk emerges and elongate rapidly to near maximum height during early to late June and continue to slowly increase in height until mid July. The flower period (anthesis) occurs during mid to late June. Seeds develop through the milk and dough stage during late June to mid July. Seeds reach maturity by mid July and the flower stalk is completely dry by mid July but still contains some of the ripe seeds. The flower stalks are unpalatable to livestock and are never eaten. New basal leaf 7 completes growth in height during July, after the anthesis stage. Lead tiller basal leaves, usually are 3 to 7, produce most of the herbage biomass during June and July (table 13 and figure 2). The lead tiller leaves rapidly senesce during August and are completely dry by late August. Even though the lead tiller leaves are dry, they remain palatable to livestock and are readily consumed during the fall grazing period.

About 95% of the vegetative tillers consists of 5 to 6 basal leaves with about 60% of the leaf material photosynthetically active during June and early July, with at least 50% of the leaf material remain photosynthetically active at the end of August. Vegetative tillers continue to add leaves 7, 8, and 9 during July and August that slowly increase in weight until the end of the growing season. The vegetative tillers contribute a considerable quantity of the total herbage biomass during late summer and early fall (table 13 and figure 2) that also adds nutritional quality to the forage during the fall grazing period.

Secondary tillers develop slowly until after the lead tiller reaches the flower stage and no longer inhibits secondary tiller growth and development. Secondary tillers produce their fourth new leaf, become independent from the hormone control of the lead tiller, and transform into vegetative tillers. By late July, the newly formed vegetative tillers have produced their fifth leaf and makeup about 25% of the vegetative tiller population. These new vegetative tillers continue growth and development producing herbage biomass until hard frost (table 13 and figure 2). They will overwinter and some will become next growing season lead tillers and most will remain as vegetative tillers during the successive season.

Fall tillers initiate growth during the winter hardening period occurring from late July to hard frost and produce 2 to 4 leaves depending on their age. These late season produced secondary tillers continue to grow and develop until hard frost and contribute substantial quantities of herbage biomass during September and October (table 13 and figure 2). The fall tillers overwinter and became next season vegetative tillers.

The combination of the lead tillers, primary vegetative tillers, secondary vegetative tillers, and fall secondary tillers produce a mean annual herbage biomass at greater than 3000 lbs/ac with adequate levels of crude protein to meet the requirements of a modern high performance lactating beef cow during a grazing period from mid October to mid November that removes only 50% of the standing leaf biomass. The wildryes are the only perennial grass that is grown in the Northern Plains that can provide adequate crude protein to beef cows after mid October.

Cows and calves grazing Altai wildrye complementary pastures for 30 days from mid October to mid November had positive weight gain performance. Cows gained 0.55 lbs/day, 11.9 lbs/ac, and accumulated weight gain was 16.5 lbs. Calves gained 1.73 lbs/day, 38.0 lbs/ac, and accumulated weight gain was 52.8 lbs.

The wildryes do not grow and behave like native grasses of the Northern Plains and cannot be managed with regional traditional management practices. The native grasses plus crested wheatgrass and smooth bromegrass grow and behave as if they were types of perennial spring cereals. Their vegetative tillers are stimulated by partial defoliation in the spring between the 3.5 new leaf stage and the flower stage. The wildryes, Altai and Russian, grow and behave as if they were types of perennial winter cereals. Their vegetative tillers are stimulated by partial defoliation in the fall between mid October and mid November with 50% of leaf biomass remaining standing after mid November. Partial defoliation of Altai wildrye during the spring before the flower stage does not activate vegetative tiller development. Early season grazing actually decreased tiller basal cover. However, fall grazing during mid October to mid November that removed only 50% of the standing leaf biomass greatly increased vegetative tiller, secondary tiller, and fall tiller development during the following growing season and provided greater quantities of crude protein during the fall grazing period (table 13 and figure 2).

Table 13. Conjectural contributions of weight/acre in pounds (lbs) and percentage (%) by the tiller types to total herbage biomass during monthly periods and percent (%) and pounds (lbs) of crude protein from tiller types during the mid October to mid November grazing period.

						Grazing Period	
Tiller Type	Jun	Jul	Aug	Sep	Oct	% CP	lbs CP
Lead Tillers							
lbs/ac	1669	1335	1068	855	684	8%	54.7
%	100.0	60.4	46.6	28.3	21.8		
Vegetative Tillers							
lbs/ac		876	1224	1591	1432	10%	143.2
%		39.6	53.4	52.6	45.6		
Fall Tillers							
lbs/ac				576	1025	12%	123.0
%				19.1	32.6		
Total Herbage							
lbs/ac	1669	2211	2292	3022	3141	10.2%	320.9

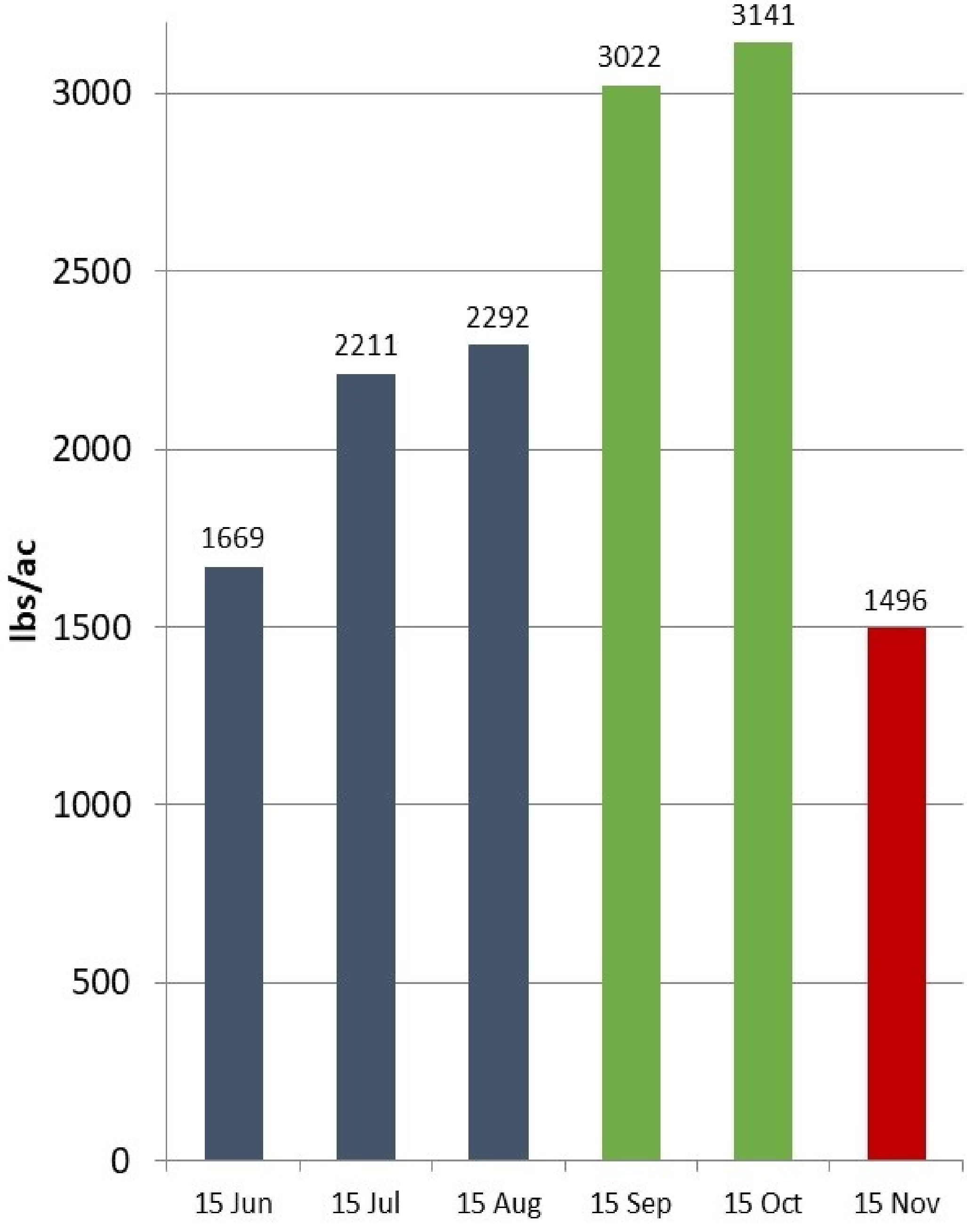


Figure 2. Altai wildrye mean monthly herbage biomass (lbs/ac) on two pastures fall grazed during mid October to mid November, 1984-2002.

Discussion

Altai wildrye, *Leymus angustus,* is an introduced, long-lived perennial, cool season, mid grass, monocot, of the grass family. Altai wildrye grows well on loam and clay loam soils and has a wide tolerance for other soil types. Russian wildrye does not grow well on sandy soils. Altai wildrye is tolerant of cold, drought, and has a high tolerance to alkali and saline soils. Altai wildrye tillers live for two growing seasons; the first growing season as a vegetative tiller and the second season as a reproductive lead tiller. Early season activity starts by regreening with active chlorophyll the portions of the carryover leaves that have intact cell walls from the previous growing season vegetative tillers. The green portion of the carryover leaves provides large quantities of carbohydrates and energy for the production of new leaves.

New leaf growth of Altai wildrye started in early April, leaf growth rate increased during May and June, and then become much slower during July. The tillers derived from carryover tillers that developed into reproductive lead tillers produced two new leaves during April and four additional new leaves during May. Early flower stalk growth and development (FSD) occurred low in the crown. Flower stalk elongation progressed rapidly through head emergence (HE) during early to late June. Lead tillers reached anthesis (Ant) during mid to late June. Tillers with flower stalks usually produced 5 or 6 basal leaves before the flower stage. New basal leaf 7 completed growth in height after the anthesis stage. Seeds developed (SD) through the milk and dough stages during late June to mid July with most seeds reaching maturity (SBS) during mid July.

The vegetative tillers derived from the previous seasons fall tillers and the current seasons early spring initiated tillers were not inhibited by lead tiller hormones. The vegetative tillers produced 5 or 6 new leaves during early June and early July. Some vegetative tillers with 5 and 6 leaves continue to produce an additional leaf or two. The quantity of vegetative tillers with 7 leaves increased during early to late July and the tillers with 8 leaves increased during late July.

Secondary tillers are derived from vegetative growth of crown axillary buds. The tillers that were initiated during the growing season were hormonally controlled by a dominated lead tiller that has proprietary access to all essential nutrients available to the secondary tillers. This arrangement had positive and negative affects. Most of the time, the secondary tillers have access to greater quantities of essential nutrients than a seedling would have, which ensures secondary tillers with superior survivability. Thus, a high percentage of secondary tillers live and grow for two growing seasons, and almost no grass seedlings develop into mature plants. However, during periods of water stress or other problematic conditions, lead tillers restrict nutrient flow to secondary tillers resulting in very slow rates of growth or tiller termination. During some growing seasons, secondary tillers can remain at the 2 or 3 leaf stage for a month or two. When secondary tillers produce their fourth leaf, they have adequate leaf area to photosynthesize their own carbon energy and develop a large enough root system for self sustaining nutrient resource uptake.

Differences in the quantity of precipitation received during the growing season affect some growth characteristics of Altai wildrye tillers. The amount of basal leaves that were photosynthetically active during growing seasons that received 99.9% normal precipitation was 31.6% greater for lead tillers, 18.9% greater for vegetative tillers, and 7.0% greater for secondary tillers than that during growing seasons that received 35.3% deficit in precipitation but were not significantly different. Flower stalk height during growing seasons with 99.9% normal precipitation was 30.8% greater than during growing seasons that received 35.3% deficit but not significantly different. The mean basal leaf height during growing seasons with 99.9% normal precipitation was 52.7% taller for lead tillers and 24.6% taller for vegetative tillers than during growing seasons that received 35.3% deficit and were significantly greater. The mean basal leaf height of secondary tillers was 7.1% taller during growing seasons with 99.9% normal precipitation than during growing seasons with 35.3% deficit but was not significantly different. The tallest basal leaf height was 46.3% taller for lead tillers and 20.5% taller for vegetative tillers during growing seasons with 99.9% normal precipitation were significantly greater than that during growing seasons with 35.3% deficit. The tallest basal leaf height was 16.8% taller for secondary tillers during growing seasons with 99.9% normal precipitation but were not significantly different than that during growing seasons with 35.3% deficit.

Early season aerial growth of Altai wildrye basal leaves arise from crown tiller buds. Carryover leaves provide the carbohydrates and energy for early season new leaf growth. Tillers from short rhizomes are rare. Vegetative growth of crown tillers form large tussocks. Basal leaves and flower stalks of lead tillers have the fastest growth rates. Vegetative crown tillers have the second fastest growth rates. The lead tiller basal leaves produce most of the herbage biomass during June and July. Vegetative crown tiller basal leaves produce considerable additional herbage biomass during July, August, and September. Secondary vegetative tillers contribute new herbage biomass during August, September, and October. Fall secondary tillers produce additional herbage biomass after mid August during September and October. The combined annual tiller biomass averages greater than 3,000 lbs/ac. The increase in vegetative tiller and fall tiller biomass was stimulated to develop during the previous growing seasons fall grazing period during mid October to mid November and this stimulated new biomass contains an increased quantity of crude protein. However, if the grazing removes greater than 50% of the standing leaf biomass during the fall grazing period or any grazing after mid November, a large portion of the current seasons vegetative tillers and fall tillers do not survive until the following spring to transform into the next growing season lead tillers and primary vegetative tillers along with the loss of the stimulated tiller buds that would develop into the next growing seasons secondary tillers and fall tillers. Thus the key to successful management of wildrye fall pastures is to leave 50% leaf biomass at the end of the fall grazing period.

Wildrye tussocks have shallow roots that extend out past the drip line of the foliage which are extremely sensitive to compaction that is expressed as complete or partial death of the tussock. Do not drive tractors or pickups in wildrye pastures except on trails needed for maintenance or management of the pasture. Do not cut Altai wildrye for hay. The equipment traffic causes great reductions in tiller production with decreased basal cover and herbage biomass production. Furthermore, cattle reject dried Altai wildrye hay as winter feed.

Altai wildrye is best used as fall complementary pastures grazed from mid October to mid November with 50% leaf biomass left standing. The wildryes, Altai and Russian, are the only perennial grass type that retains adequate nutritional quality to meet a modern high performance lactating beef cow’s requirements later than mid October.

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Growth Pattern and Phenological Development of Kentucky Bluegrass on the Northern Plains

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Intact grassland ecosystems are complex; exceedingly more complex than the most complicated machines ever built by humans. Knowledge and understanding of the growth pattern and phenological development of the major forage grasses are fundamentally essential for generation of biologically effective management strategies with inclusivity of all biotic and abiotic components of grassland ecosystems in the Northern Plains.

The inspirational goals of this study were developed by Dr. Warren C. Whitman (c. 1950) and Dr. Harold Goetz (1963) which were to gain quantitative knowledge of each component species and to provide a pathway essential for the understanding of relationships of ecosystem components that would result in the development and establishment of scientific standards for proper management of grazinglands in the Northern Plains.

This growth pattern and phenological development study of the major forage graminoids was conducted during the growing seasons of 1983-1986 and 1987-1989 with data collected biweekly June-August. The study included 3 cool season, 2 warm season, 1 upland sedge, 1 naturalized, and 2 domesticated grasses. The study sites were located at the NDSU Dickinson Research Extension Center ranch near Manning in western North Dakota and consisted of 143 acres (58 ha) of two seeded domesticated grasslands and 720 acres (291 ha) of native rangeland pastures separated into three management treatments, each with two replications, with data collection sites established on sandy, shallow, and silty ecological sites. Each ecological site of the grazed treatments had matching paired plots, one grazed and the other with an ungrazed exclosure.

Study Area

The physiography of the study area consists of the Unglaciated section of the Missouri Plateau (Fenneman 1931, 1946; Hunt 1974). The landscape surface is highly eroded fluvial sedimentary deposits of material removed from the uplifted Rocky Mountains. Most of the deposition occurred from slow meandering streams during the Laramide Orogeny and during the 20 to 30 million years of the late Cretaceous and early Tertiary Periods following the uplift. Intense widespread erosion of these sediments occurred from about 5 to 3 million years ago during the late Pliocene Epoch (Bluemle 2000). The extensive erosion during this period removed about 500 to 1000 feet of sediments (Fenneman 1931) forming a landscape with well developed integrated drainage systems of broad mature valleys and gently rolling uplands containing widely spaced large hills and buttes with erosion resistant caps raising 500 to 650 feet above the plain (Bluemle 2000).

The soils of western North Dakota developed from eroded Tertiary fluvial sedimentary deposits in the Ustic-Frigid soil moisture-temperature regime. The Ustic soil moisture regime is typical of semi arid climates. The Frigid soil temperature regime has mean annual soil temperatures of less than 47° F (8° C) (Soil Survey Staff 1975). These soils are primarily Typic Borolls (semi arid cool Mollisols) and support vegetation of mid and short grasses of the Mixed Grass Prairie (Manske 2008b).

The current "native" plant species in the Northern Plains did not originate here. All of the plant species have migrated into the region by different mechanisms and at different times and rates. The present plant species have flora affinities to northern, eastern, western, Rocky Mountain, and Great Basin plant communities (Zaczkowski 1972). This wide mix of plant species was formed from remnants of previously existing plant communities. The climate changed about 5,000 years ago to conditions like those of the present, with cycles of wet and dry periods (Bluemle 1977, 1991; Manske 1994). The large diversity of plant species that make up the current mixed grass prairie permits dynamic responses to changes in climatic conditions by increasing the combination of plant species favored by any set of climatic conditions (Manske 2008a).

Long-Term Weather

The NDSU Dickinson Research Extension Center ranch is located in Dunn County in western North Dakota, at 47° 14' north latitude, 102° 50' west longitude. Mean annual temperature is 42.3° F (5.7° C). January is the coldest month, with mean temperature of 14.6° F (-9.7° C). July and August are the warmest months with mean temperatures of 69.7° F (20.9° C) and 68.6° F (20.3° C), respectively. Long-term (1982-2012) mean annual precipitation is 16.91 inches (429.61 mm). The perennial plant growing season precipitation (April to October) is 14.13 inches (358.97 mm) and is 83.6% of annual precipitation. June has the greatest monthly precipitation at 3.27 inches (83.08 mm). The precipitation received during the 3-month period of May, June, and July (8.26 inches, 209.80 mm) accounts for 48.8% of the annual precipitation.

Growing season months with water deficiency disrupt plant growth rates and are identified from monthly temperature and precipitation data by the Emberger ombrothermic diagram technique. Long-term (1983-2012) 30 year reoccurrence rates (table 1) show relatively low rates of water deficiency reoccurring during April (16.7%), May and June (10.0%), moderate rates during July and October (36.7%), and high rates during August (56.7%) and September (60.0%). Long-term occurrence of water deficiency conditions was 33.3% of the growing season months, for a mean of 2.0 water deficient months per each 6.0 month growing season (15 Apr-15 Oct).

Growing Season Precipitation

The growing season precipitation information collected during the grass leaf height study has been grouped into two periods with the first period occurring during 1983 to 1986 and the second period occurring during 1987 to 1989.

Mean growing season precipitation of 1983-1986 (table 2) was 14.11 inches (99.9% of LTM). None of the four 6 month growing seasons received precipitation at less than 80% of LTM. One growing season, 1986, received precipitation at near 130% of LTM. The rate of water deficiency occurrence during the four growing seasons was 29.2%, for a mean of 1.75 water deficient months per growing season (table 3). The growing season of 1984 had 3.0 months in water deficiency. The growing seasons of 1983 and 1986 had 1.5 months in water deficiency each. The growing season of 1985 had 1.0 month in water deficiency.

Mean growing season precipitation of 1987-1989 (table 4) was low at 9.14 inches (64.7% of LTM). The growing season of 1987 received 11.53 inches (81.6% of LTM) precipitation. The growing season of 1989 received 10.60 inches (75.0% of LTM) precipitation. The growing season of 1988 received only 5.30 inches (37.5% of LTM) precipitation and was dry. The rate of water deficiency occurrence during the three growing seasons was 61.1%, for a mean of 3.7 water deficient months per growing season (table 5). The growing seasons of 1987 and 1989 had 3.0 months in water deficiency each. The growing season of 1988 had 5.0 months of its 6 month growing season in water deficiency conditions. That is comparable to 2 other growing seasons with high water deficiency conditions. The growing season of 1934 had 4.5 months in water deficiency and the growing season of 1936 had 5.5 months in water deficiency.

Table 1. Growing season months with water deficiency, DREC ranch, 1983-2012.

	Apr	May	Jun	Jul	Aug	Sep	Oct	# Months	% 6 Months 15 Apr-15 Oct
Total	5	3	3	11	17	18	11	60.0	33.3
% of 30 Years	16.7	10.0	10.0	36.7	56.7	60.0	36.7		

Table 2. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1983-1986.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59	15.55
% of LTM	14.58	59.77	99.69	105.35	261.76	60.56	54.96	96.18	91.96
1984	2.87	0.00	5.30	0.11	1.92	0.53	0.96	11.69	12.88
% of LTM	199.31	0.00	162.08	4.53	112.94	37.32	73.28	82.73	76.17
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80	15.13
% of LTM	86.11	126.95	48.32	44.03	108.24	119.01	162.60	90.59	89.47
1986	3.13	3.68	2.58	3.04	0.46	5.29	0.18	18.36	22.96
% of LTM	217.36	143.75	78.90	125.10	27.06	372.54	13.74	129.94	135.78
1983-1986	1.86	2.12	3.18	1.70	2.17	2.09	1.00	14.11	16.63
% of LTM	129.34	82.62	97.25	69.75	127.50	147.36	76.15	99.86	98.34

Table 3. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1983-1986.

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1983	■					■		1.5	25.0
1984		■		■		■		3.0	50.0
1985				■				1.0	16.7
1986					■		■	1.5	25.0
#	**1**	**1**	**0**	**2**	**1**	**2**	**1**	**7.0**	**29.2**
%	**25.0**	**25.0**	**0.0**	**50.0**	**25.0**	**50.0**	**25.0**		

Table 4. Precipitation in inches and percent of long-term mean for perennial plant growing season months, DREC ranch, 1987-1989.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2012	1.44	2.56	3.27	2.43	1.70	1.42	1.31	14.13	16.91
1987	0.10	1.38	1.15	5.39	2.65	0.78	0.08	11.53	14.13
% of LTM	6.94	53.91	35.17	221.81	155.88	54.93	6.11	81.60	83.56
1988	0.00	1.85	1.70	0.88	0.03	0.73	0.11	5.30	9.03
% of LTM	0.00	72.27	51.99	36.21	1.76	51.41	8.40	37.51	53.40
1989	2.92	1.73	1.63	1.30	1.36	0.70	0.96	10.60	13.07
% of LTM	202.78	67.58	49.85	53.50	80.00	49.30	73.28	75.02	77.29
1987-1989	1.01	1.65	1.49	2.52	1.35	0.74	0.38	9.14	12.08
% of LTM	69.91	64.58	45.67	103.84	79.22	51.88	29.26	64.71	71.42

Table 5. Growing season months with water deficiency conditions that caused water stress in perennial plants, DREC ranch, 1987-1989.

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1987	■		■			■	■	3.0	50.0
1988	■		■	■	■	■	■	5.0	83.3
1989				■	■	■		3.0	50.0
#	**2**	**0**	**2**	**2**	**2**	**3**	**2**	**11.0**	**61.1**
%	**66.7**	**0.0**	**66.7**	**66.7**	**66.7**	**100.0**	**66.7**		

Viking Vexation

Poa pratensis L. was named by Carolus Linnaeus (1707-1778) in the 1753 edition of Species Plantarum without including a common name. Linnaeus made no distinction between European and North America source plant material. The common name used in Europe is smooth meadowgrass or smoothstalk meadowgrass. The common name used in North America is Kentucky bluegrass which was started between 1833 and 1859 as a promotion of thoroughbreds, bourbon, and bluegrass for the state of Kentucky.

Poa pratensis was most likely introduced into North America during the third expedition that Greenland Vikings, led by Thorfinn Karlsefni, attempted to establish a settlement in Newfoundland at Straumfjord Vinland on the north shore along the Strait of Belle Isle in the St. Lawrence Seaway and at a second site to the south at Straumsoy and hop near Gander Lake on the Atlantic east side during 1009 to 1012 (Chapman n.d., Linden 2004, Short 2017).

The great Viking period of expansion, called landnam (land talking or first settlement), occurred during 800 to 1050 A.D. when vast numbers of people emigrated from Scandinavia to the North Atlantic lands of Scotland, Ireland, and the north Britain islands, then advancing to Iceland in 874 and to Greenland in 986.

The vegetation of Northen Norway, Northern Britain, subarctic Iceland, and low arctic Greenland was very similar with common plants of birch, willow, sedge, and Poa pratensis. The Nordic colonists were familiar with this type landscape and had long-developed management skills specific to these conditions. They raised cattle, sheep, goats, pigs, and a hardy small horse that needed pasture and harvested forage to be productive.

When the Greenlandic people attempted for the third time, to establish a settlement in Newfoundland, they brought milk cows and a bull and sheep for wool. These animals would have required harvested forage for the voyage which presumably contained Poa pratensis. Soon after those animals were unloaded from the 3 knarr ships, Poa pratensis seeds would have been deposited on North American soil in 1009. With early establishment, this grass would have had time to spread through the Appalachian Mountains and Great Lakes region before the second set of European immigrants settled in eastern North America (Manske 2017).

Procedures

The 1983-1989 Study

Grass tiller leaf heights were determined for reproductive tillers, vegetative tillers, and secondary tillers on a biweekly sampling period from June through August. Each leaf of ten ungrazed tillers of each study species was measured with a meter stick to the nearest 0.1 cm from ground level to the tips of the extended leaves. Basal leaf heights were measured for grass species in which the leaves and stalks were distinctly separate. Stalk leaf heights were measured for grass species where leaves are attached to the culm during vegetative stages and fruiting stages.

Degree of leaf senescence was estimated as percent dryness for each leaf. Percent dryness for basal leaves was considered from the apex to ground level. Percent dryness for stalk leaves was considered for the blade only. The categories of dryness were: 0%, 2%, 25%, 50%, 75%, 98% and 100% dry. Start of senescence was considered to be dryness greater than 2%. Leaves with less than 50% senescent tissue were designated to be photosynthetically active.

Grass flower stalk heights were determined by measurements from ground level to the tip of the stalk or the apex of the top floret. The awns, if present, were not included in the height measurements. The phenological stages of flower stalk development were recorded as: flower stalk developing (FSD), head emergence (HE), anthesis (Ant), seeds developing (SD), and seeds being shed (SBS). Recording the flower stalk development stages started when stalk enlargement or swelling was outwardly noticeable; prior development is not detectable without destruction of the tiller. The swelling of the stalk, traditionally called the boot stage, was categorized as the flower stalk developing stage. Head emergence is a short duration stage but easily defined when the flower head emerges from the sheath and rapidly elongates to near full height. Anthesis (flowering) is also a short duration stage but easily defined by the exposure of the anthers and stigmas. Needle and thread is usually cleistogamous that self-fertilizes without opening and exposing the anthers and stigmas. Following fertilization, the seeds develop through milk, dough, and mature stages which are difficult to differentiate on small grass seeds. These seed progression stages have been separated into more easily defined categories of seeds developing for the early seed stages and seeds being shed for the mature seed stages when seeds could be easily removed from the inflorescence by wind, by gentle rubbing, or when it could be observed that some seeds had already been dropped. Sometimes a floret will abort the seed production process resulting in failure of viable seeds to materialize. This condition could be revealed in the data set as earlier than normal recordings of seeds being shed.

During 1983 to 1986, the paired plot sample sites with sandy, silty, and clay soil types were managed by ungrazed and grazed treatments of the twice-over rotation strategy. During 1987 to 1989, the paired plot sample sites with sandy, and silty soil types were managed by long-term nongrazed treatments, and by ungrazed and grazed treatments of the traditional seasonlong practice and the twice-over rotation strategy. Poa pratensis can grow on shallow soils but none were measured during this study, thus not included in this report.

Designation of Tiller Types

Reproductive tillers are second year tillers derived from carryover tillers that were vegetative tillers during the previous growing season. The portions of the carryover leaves that have intact cell walls will regreen with active chlorophyll early in the growing season and provide photosynthate for rapid growth of new current years leaves. New leaf development resumed early spring in early April but growth progressed during early and mid May. The anthesis (flowering) period occurred between mid May and late June with first flowers usually occurring before 21 June. No new leaves are produced after the anthesis stage, during the seed development stages. Flower stalks, have 1 or 2 small stalk leaves and usually produce 2 to 7 basal leaves. Seeds developed during early June to early July and were being shed during mid June to mid July. Reproductive tillers are terminal at the end of the growing season; their apical meristem was used up producing a flower head.

Vegetative tillers are first year tillers derived from previous growing season initiated fall tillers and from early spring initiated secondary tillers that have escaped hormonal control by a lead tiller. Vegetative tillers produced 4 to 6 new leaves before early June. These tillers are the primary forage tillers with rapid growth rates, usually producing 5 to 7 leaves during the growing season. The apical meristem remains vegetative, permitting these tillers to overwinter as carryover tillers and becoming reproductive tillers during the successive growing season.

Secondary tillers are young current growing season tillers usually with 2 to 4 leaves that initiated from axillary buds during April to July. The secondary tillers become independent and transform into vegetative tillers with rapid growth rates during June to August. A large quantity of secondary fall tillers develop from crown and rhizome buds during August.

Results

Kentucky bluegrass, *Poa pratensis* L., is a member of the grass family, Poaceae, tribe, Poeae, and is a naturalized (introduced from Europe by early colonists probably around the early 1000's), long lived perennial, monocot, cool-season, mid grass, that is intolerant of drought, intolerant of waterlogged soil, intolerant of dense shade but tolerant of slight partial shade, and is a high water user and a high nitrogen user. The first North Dakota record is Bergman 1910. Early aerial growth consists of basal leaves arising from rhizome tiller buds. Basal leaf blades are generally short 1-15 cm (0.4-6.0 in) long, 0.9-3.6 mm wide, keeled, with tip boat prow shaped. The split sheath has thin, translucent margins that overlap for the lower ½. The collar is narrow and continuous. The membranous ligule is 0.51 mm long, continuous with sheath margins, and has a squared off edge. The auricles are absent. The dense rhizome system forms thick mats. The long creeping rhizomes frequently branch producing several tillers at each node at progressive intervals. The dense shallow root system has very fine branching roots arising from stem crowns and rhizome nodes thickly occupying the top 46 to 61 cm (1.5-2.0 ft) of soil with a few long main roots reaching 91 cm (3.0 ft) deep. Most of the roots and rhizomes are in the top 7.6 cm (3 in) of soil that dries out easily. Regeneration is primarily asexual propagation by crown and rhizome tiller buds. Seedlings are somewhat successful where competition from established plants is nonexistent because viable seed production is frequently high. Flower stalks are erect, slender, wiry, 30-60 cm (12-24 in) tall and round in cross section. Inflorescence is a moderately open, somewhat contracted pyramidal panicle, 5-10 cm (2-4 in) long, with 3-5 branches in whorls at each node. Spikelets are laterally compressed with 3 to 6 florets. Flower period is from mid May to late June. Aerial parts are nutritious only before flowering. Forage biomass production is lower than for native grasses because of the high water use and long summer dormancy period. Fire top kills aerial parts and can consume entire crown when soil is dry with a temperature great enough to kill some of the shallow rhizomes and roots. Fire halts the processes of the four major defoliation resistance mechanisms and causes great reductions in biomass production and tiller density. This summary information on growth development and regeneration of Kentucy bluegrass was based on works of Weaver

1954, Stevens 1963, Zaczkowski 1972, Dodds 1979, Great Plains Flora Association 1986, Uchytil 1993, Wennerberg 2004, Johnson and Larson 2007, and Stubbendieck et al. 2011.

During the seven years of this study, the number of Kentucky bluegrass tillers measured was 3445 with 437 tillers on sandy soils, 2029 tillers on silty soils, and 979 tillers on clay soils (tables 6, 7, and 8). The collection protocol required measurement on all available flower stalks and ten vegetative tillers on each sample site each collection period, amounting to 360 tillers per year on the twice-over treatment and 120 tillers per year on the seasonlong and nongrazed treatments. The protocol numbers were not obtained because Kentucky bluegrass was not abundant on any of the ecological sites. During the 3 growing seasons with low precipitation amounts, less than ten tillers were measured each collection period. The reductions in sample numbers would indicate the degree of negative affect from reduced precipitation. This affect is designated as collection efficiency on tables 6, 7, and 8.

Table 6. Number of tillers measured from management treatments on sandy soils.

Tiller Type	Twice-over 1983-1986		Twice-over 1987-1989		Seasonlong 1987-1989	Nongrazed 1987-1989
	Ungrazed	Grazed	Ungrazed	Grazed	Grazed	Ungrazed
Flower Stalk	68	0	10	0	7	31
Vegetative	73	34	15	0	14	15
Secondary	95	8	17	0	15	35
Subtotal	236	42	42	0	36	81
Total	278		42		117	
Sum total			437			
Collection Efficiency	16.4%	2.9%	3.9%	0.0%	5.0%	22.5%

Table 7. Number of tillers measured from management treatments on silty soils.

Tiller Type	Twice-over 1983-1986		Twice-over 1987-1989		Seasonlong 1987-1989	Nongrazed 1987-1989
	Ungrazed	Grazed	Ungrazed	Grazed	Grazed	Ungrazed
Flower Stalk	283	107	70	23	15	25
Vegetative	357	268	125	56	28	35
Secondary	310	144	97	41	17	28
Subtotal	950	519	292	120	60	88
Total	1469		412		148	
Sum total			2029			
Collection Efficiency	66.0%	36.0%	27.0%	11.1%	8.3%	24.4%

Table 8. Number of tillers measured from management treatments on clay soils.

Tiller Type	Twice-over 1983-1986		Twice-over 1987-1989		Seasonlong 1987-1989	Nongrazed 1987-1989
	Ungrazed	Grazed	Ungrazed	Grazed	Grazed	Ungrazed
Flower Stalk	173	68				
Vegetative	281	138				
Secondary	179	140				
Subtotal	633	346				
Total	979					
Sum total						
Collection Efficiency	44.0%	24.0%				

Reproductive Tillers

The second year reproductive tillers had the fastest rate of growth and development until mid to late July. Reproductive tillers reach the boot stage (FSD) during mid to late April. Flower stalk development occurred very rapidly with the reproductive tillers progressing through head emergence (HE) during late April to early May and reaching the flower stage during mid May to late June. No new leaves were produced after the anthesis stage. Seeds developed (SD) through the milk and dough stages during early June to early July with most seeds reaching maturity (SBS) during mid June to mid July, and some seeds are held through late summer (table 9). The apical meristem of reproductive tillers can no longer produce leaf buds after it had produced flower buds and these tillers were terminated at the end of the growing season.

Growth and development data of Kentucky bluegrass reproductive tillers on sandy soils managed with the twice-over strategy and the ungrazed treatment during 1983 to 1986 are on table 10.

Reproductive tillers with 2 to 7 basal leaves on the twice-over strategy during 1983 to 1986 composed 0.0% of the total population with 0 tillers (tables 6 and 10).

Reproductive tillers with 2 to 7 basal leaves on the ungrazed treatment during 1983 to 1986 composed 28.8% of the total population with 68 tillers (table 6) that had a mean flower stalk height of 40.4 cm, during the growing season a mean of 13.7% leaves were photosynthetically active with a mean basal leaf height of 19.1 cm and the tallest leaf averaged 28.5 cm tall (table 10).

Growth and development data of Kentucky bluegrass reproductive tillers on silty soils managed with the twice-over strategy and the ungrazed treatment during 1983 to 1986 are on table 11.

Reproductive tillers with 2 to 7 basal leaves on the twice-over strategy during 1983 to 1986 composed 20.6% of the total population with 107 tillers (table 7) that had a mean flower stalk height of 34.7 cm, during the growing season a mean of 16.3% leaves were photosynthetically active with a mean basal leaf height of 13.6 cm and the tallest leaf averaged 19.2 cm tall (table 11).

Reproductive tillers with 2 to 7 basal leaves on the ungrazed treatment during 1983 to 1986 composed 29.8% of the total population with 283 tillers (table 7) that had a mean flower stalk height of 36.8 cm, during the growing season a mean of 18.1% leaves were photosynthetically active with a mean basal leaf height of 17.9 cm and the tallest leaf averaged 21.7 cm tall (table 11).

Growth and development data of Kentucky bluegrass reproductive tillers on clay soils managed with the twice-over strategy and the ungrazed treatment during 1983 to 1986 are on table 12.

Reproductive tillers with 2 to 7 basal leaves on the twice-over strategy during 1983 to 1986 composed 19.7% of the total population with 68 tillers (table 8) that had a mean flower stalk height of 40.6 cm, during the growing season a mean of 15.6% leaves were photosynthetically active with a mean basal leaf height of 15.4 cm and the tallest leaf averaged 20.2 cm tall (table 12).

Reproductive tillers with 2 to 7 basal leaves on the ungrazed treatment during 1983 to 1986 composed 27.3% of the total population with 173 tillers (table 8) that had a mean flower stalk height of 45.1 cm, during the growing season a mean of 17.3% leaves were photosynthetically active with a mean basal leaf height of 13.1 cm and the tallest leaf averaged 17.6 cm tall (table 12).

Growth and development data of Kentucky bluegrass reproductive tillers on sandy soils managed with the twice-over strategy and the ungrazed treatment and the seasonlong and nongrazed treatments during 1987 to 1989 are on tables 13 and 14.

Reproductive tillers with 2 to 7 basal leaves on the twice-over strategy during 1987 to 1989 composed 0.0% of the total population with 0 tillers (tables 6 and 13).

Reproductive tillers with 2 to 7 basal leaves on the ungrazed treatment during 1987 to 1989 composed 23.8% of the total population with 10 tillers (table 6) that had a mean flower stalk height of 27.3 cm, during the growing season a mean of 0.0% leaves were photosynthetically active (table 13).

Reproductive tillers with 2 to 7 basal leaves on the seasonlong treatment during 1987 to 1989 composed 19.4% of the total population with 7 tillers (table 6) that had a mean flower stalk height of 37.0 cm, during the growing season a mean of 15.0% leaves were photosynthetically active with a mean basal leaf height of 17.1 cm and the tallest leaf averaged 23.1 cm tall (table 14).

Reproductive tillers with 2 to 7 basal leaves on the nongrazed treatment during 1987 to 1989 composed 38.3% of the total population with 31 tillers (table 6) that had a mean flower stalk height of 35.3 cm, during the growing season a mean of 19.8% leaves were photosynthetically active with a mean basal leaf height of 16.2 cm and the tallest leaf averaged 19.5 cm tall (table 14).

Growth and development data of Kentucky bluegrass reproductive tillers on silty soils managed with the twice-over strategy and the ungrazed treatment and the seasonlong and nongrazed treatments during 1987 to 1989 are on tables 15 and 16.

Reproductive tillers with 2 to 7 basal leaves on the twice-over strategy during 1987 to 1989 composed 19.2% of the total population with 23 tillers (table 7) that had a mean flower stalk height of 29.7 cm, during the growing season a mean of 2.1% leaves were photosynthetically active with a mean basal leaf height of 13.5 cm and the tallest leaf averaged 13.5 cm tall (table 15).

Reproductive tillers with 2 to 7 basal leaves on the ungrazed treatment during 1987 to 1989 composed 24.0% of the total population with 70 tillers (table 7) that had a mean flower stalk height of 32.6 cm, during the growing season a mean of 15.0% leaves were photosynthetically active with a mean basal leaf height of 13.6 cm and the tallest leaf averaged 19.4 cm tall (table 15).

Reproductive tillers with 2 to 7 basal leaves on the seasonlong treatment during 1987 to 1989 composed 25.0% of the total population with 15 tillers (table 7) that had a mean flower stalk height of 26.8 cm, during the growing season a mean of 13.5% leaves were photosynthetically active with a mean basal leaf height of 11.4 cm and the tallest leaf averaged 12.9 cm tall (table 16).

Reproductive tillers with 2 to 7 basal leaves on the nongrazed treatment during 1987 to 1989 composed 28.4% of the total population with 25 tillers (table 7) that had a mean flower stalk height of 37.6 cm, during the growing season a mean of 13.6% leaves were photosynthetically active with a mean basal leaf height of 19.8 cm and the tallest leaf averaged 21.6 cm tall (table 16).

All of the reproductive tillers measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean flower stalk heights, mean basal leaf heights, and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments on the sandy, silty, and clay soils during the 1983-1986 period. The mean flower stalk heights were slightly lower on the grazed treatments than on the ungrazed treatments on the sandy, and silty soils during the 1987-1989 period. It is not believed that grazed treatments cause reproductive tillers to produce slightly shorter flower stalk and stalk leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the twice-over treatment tended to have similar low quantity of photosynthetically active leaves (35.0%) as the tillers growing on the ungrazed treatment (36.4%). Flower stalk leaves senesce rapidly following the anthesis stage.

Reproductive tillers composed a relatively low percentage of the total measured tiller population. Reproductive tillers located on the twice-over treatment composed 13.4% (175 tillers) and 9.6% (23 tillers) and the reproductive tillers located on the ungrazed treatment composed 28.6% (524 tillers) and 23.9% (80 tillers) of the total tiller population during the 1983-1986 period and the 1987-1989 period, respectively. There were no reproductive tillers on the sandy soils grazed by the twice-over strategy. Reproductive tillers located on the seasonlong and nongrazed treatments composed 22.2% (22 tillers) and 33.4% (56 tillers) of the total population during the 1987-1989 period, respectively.

Table 9. Phenological stages of flower stalk development for Kentucky bluegrass, 1983-1986.

22 Apr	6 May	22 May	6 Jun	22 Jun	6 Jul
FSD					
HE	HE				
		Ant	Ant	Ant	
			SD	SD	SD
				SBS	SBS

FSD flower stalk developing
HE head emergence
Ant anthesis (flowering)
SD seeds developing
SBS seeds being shed

Table 10. Growth and development of Kentucky bluegrass reproductive tillers on sandy soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Sandy	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
Stalk Height cm	-	-	-	-	-	-
% Active Leaf	0.0	0.0	0.0	0.0	0.0	0.0
Leaf Height cm	-	-	-	-	-	-
Tallest Leaf cm	-	-	-	-	-	-
Ungrazed 1983-1986						
Stalk Height cm	43.7	39.3	36.1	34.9	45.6	42.7
% Active Leaf	50.0	8.1	0.0	23.8	0.0	0.0
Leaf Height cm	20.0	21.2	-	16.0	-	-
Tallest Leaf cm	30.0	29.4	-	26.0	-	-

Table 11. Growth and development of Kentucky bluegrass reproductive tillers on silty soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Silty	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
Stalk Height cm	28.3	35.1	36.4	28.5	37.2	42.9
% Active Leaf	64.3	33.3	0.0	0.0	0.0	0.0
Leaf Height cm	11.3	15.9	-	-	-	-
Tallest Leaf cm	17.1	21.2	-	-	-	-
Ungrazed 1983-1986						
Stalk Height cm	29.2	35.0	37.9	39.5	37.1	41.9
% Active Leaf	63.0	40.0	5.6	0.0	0.0	0.0
Leaf Height cm	15.0	17.2	21.6	-	-	-
Tallest Leaf cm	21.5	21.9	21.6	-	-	-

Table 12. Growth and development of Kentucky bluegrass reproductive tillers on clay soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Clay	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
Stalk Height cm	31.5	36.0	53.6	40.9	39.1	42.2
% Active Leaf	70.0	23.8	0.0	0.0	0.0	0.0
Leaf Height cm	11.6	19.2	-	-	-	-
Tallest Leaf cm	17.4	23.0	-	-	-	-
Ungrazed 1983-1986						
Stalk Height cm	37.4	42.5	52.5	34.8	58.4	44.9
% Active Leaf	65.0	36.8	0.0	2.2	0.0	0.0
Leaf Height cm	14.8	17.0	-	7.6	-	-
Tallest Leaf cm	22.7	22.9	-	7.6	-	-

Table 13. Growth and development of Kentucky bluegrass reproductive tillers on sandy soil managed with the grazed and ungrazed treatments of the twice-over grazing strategy, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
Stalk Height cm	-	-	-	-
% Active Leaf	0.0	0.0	0.0	0.0
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
Ungrazed 1987-1989				
Stalk Height cm	-	-	24.8	29.7
% Active Leaf	0.0	0.0	0.0	0.0
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-

Table 14. Growth and development of Kentucky bluegrass reproductive tillers on sandy soil managed with the grazed seasonlong and nongrazed treatments, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
Seasonlong 1987-1989				
Stalk Height cm	35.0	39.6	-	36.4
% Active Leaf	60.0	0.0	0.0	0.0
Leaf Height cm	17.1	-	-	-
Tallest Leaf cm	23.1	-	-	-
Nongrazed 1987-1989				
Stalk Height cm	38.5	41.0	31.5	30.0
% Active Leaf	57.9	21.4	0.0	0.0
Leaf Height cm	17.5	14.9	-	-
Tallest Leaf cm	24.0	14.9	-	-

Table 15. Growth and development of Kentucky bluegrass reproductive tillers on silty soil managed with the grazed and ungrazed treatments of the twice-over grazing strategy, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
Stalk Height cm	-	28.1	31.4	29.7
% Active Leaf	0.0	8.3	0.0	0.0
Leaf Height cm	-	13.5	-	-
Tallest Leaf cm	-	13.5	-	-
Ungrazed 1987-1989				
Stalk Height cm	32.0	29.6	39.1	29.8
% Active Leaf	60.0	0.0	0.0	0.0
Leaf Height cm	13.6	-	-	-
Tallest Leaf cm	19.4	-	-	-

Table 16. Growth and development of Kentucky bluegrass reproductive tillers on silty soil managed with the grazed seasonlong and nongrazed treatments, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
Seasonlong 1987-1989				
Stalk Height cm	23.6	22.1	34.7	-
% Active Leaf	42.9	11.1	0.0	0.0
Leaf Height cm	12.1	10.6	-	-
Tallest Leaf cm	13.6	12.1	-	-
Nongrazed 1987-1989				
Stalk Height cm	37.9	42.8	45.6	23.9
% Active Leaf	40.0	14.3	0.0	0.0
Leaf Height cm	20.8	18.8	-	-
Tallest Leaf cm	23.0	20.2	-	-

Vegetative Tillers

The vegetative tillers had the second fastest rate of growth and development continuing until mid to late July. Early new leaf development for vegetative tillers arise from fall tillers produced from crown or rhizome tiller buds during August of the previous growing season. The rate of growth greatly increased during early and mid May resulting in tillers with 4 to 6 leaves during late May. During mid to late July the rate of growth decreased resulting in tillers with 5 to 7 leaves (figure 1). Vegetative tillers with 5 leaves composed 68%, with 6 leaves composed 28%, and with 7 leaves composed 4% of the population.

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the twice-over strategy during 1983 to 1986 are on table 17.

Vegetative tillers with 5 leaves composed 52.9% of the population with 18 tillers, during the growing season a mean of 2.0 leaves (40.0%) were photosynthetically active with a mean leaf height of 9.0 cm and the tallest leaf averaged 9.9 cm tall (table 17).

Vegetative tillers with 6 leaves composed 38.2% of the population with 13 tillers, during the growing season a mean of 3.0 leaves (50.%) were photosynthetically active with a mean leaf height of 8.9 cm and the tallest leaf averaged 11.1 cm tall (table 17).

Vegetative tillers with 7 leaves composed 8.8% of the population with 3 tillers, during the growing season a mean of 3.0 leaves (42.9%) were photosynthetically active with a mean leaf height of 9.4 cm and the tallest leaf averaged 12.5 cm tall (table 17).

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the ungrazed treatment during 1983 to 1986 are on table 18.

Vegetative tillers with 5 leaves composed 56.2% of the population with 41 tillers, during the growing season a mean of 3.0 leaves (60.0%) were photosynthetically active with a mean leaf height of 15.8 cm and the tallest leaf averaged 20.6 cm tall (table 18).

Vegetative tillers with 6 leaves composed 39.7% of the population with 29 tillers, during the growing season a mean of 3.0 leaves (50.0%) were photosynthetically active with a mean leaf height of 16.1 cm and the tallest leaf averaged 19.7 cm tall (table 18).

Vegetative tillers with 7 leaves composed 4.1% of the population with 3 tillers, during the growing season a mean of 3.8 leaves (53.6%) were photosynthetically active with a mean leaf height of 17.0 cm and the tallest leaf averaged 20.0 cm tall (table 18).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the twice-over strategy during 1983 to 1986 are on table 19.

Vegetative tillers with 5 leaves composed 61.2% of the population with 164 tillers, during the growing season a mean of 2.8 leaves (56.7%) were photosynthetically active with a mean leaf height of 9.8 cm and the tallest leaf averaged 11.7 cm tall (table 19).

Vegetative tillers with 6 leaves composed 33.2% of the population with 89 tillers, during the growing season a mean of 3.0 leaves (50.0%) were photosynthetically active with a mean leaf height of 10.7 cm and the tallest leaf averaged 14.1 cm tall (table 19).

Vegetative tillers with 7 leaves composed 5.6% of the population with 15 tillers, during the growing season a mean of 3.0 leaves (43.1%) were photosynthetically active with a mean leaf height of 17.5 cm and the tallest leaf averaged 21.3 cm tall (table 19).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the ungrazed treatment during 1983 to 1986 are on table 23.

Vegetative tillers with 5 leaves composed 70.3% of the population with 251 tillers, during the growing season a mean of 2.9 leaves (58.3%) were photosynthetically active with a mean leaf height of 14.6 cm and the tallest leaf averaged 18.3 cm tall (table 20).

Vegetative tillers with 6 leaves composed 26.1% of the population with 93 tillers, during the growing season a mean of 3.1 leaves (51.4%) were photosynthetically active with a mean leaf height of 14.6 cm and the tallest leaf averaged 18.3 cm tall (table 20).

Vegetative tillers with 7 leaves composed 3.6% of the population with 13 tillers, during the growing season a mean of 3.8 leaves (53.6%) were photosynthetically active with a mean leaf height of 16.9 cm and the tallest leaf averaged 22.9 cm tall (table 20).

Growth and development data of Kentucky bluegrass vegetative tillers on clay soils managed with the twice-over strategy during 1983 to 1986 are on table 21.

Vegetative tillers with 5 leaves composed 65.9% of the population with 91 tillers, during the growing season a mean of 2.6 leaves (51.7%) were photosynthetically active with a mean leaf height of 10.7 cm and the tallest leaf averaged 13.1 cm tall (table 21).

Vegetative tillers with 6 leaves composed 27.5% of the population with 38 tillers, during the growing season a mean of 3.3 leaves (54.2%) were photosynthetically active with a mean leaf height of 12.6 cm and the tallest leaf averaged 17.1 cm tall (table 21).

Vegetative tillers with 7 leaves composed 6.5% of the population with 9 tillers, during the growing season a mean of 3.6 leaves (51.2%) were photosynthetically active with a mean leaf height of 11.8 cm and the tallest leaf averaged 14.4 cm tall (table 21).

Growth and development data of Kentucky bluegrass vegetative tillers on clay soils managed with the ungrazed treatment during 1983 to 1986 are on table 22.

Vegetative tillers with 5 leaves composed 61.6% of the population with 173 tillers, during the growing season a mean of 2.5 leaves (50.0%) were photosynthetically active with a mean leaf height of 15.9 cm and the tallest leaf averaged 19.7 cm tall (table 22).

Vegetative tillers with 6 leaves composed 32.7% of the population with 92 tillers, during the growing season a mean of 3.1 leaves (51.4%) were photosynthetically active with a mean leaf height of 16.5 cm and the tallest leaf averaged 21.6 cm tall (table 22).

Vegetative tillers with 7 leaves composed 5.7% of the population with 16 tillers, during the growing season a mean of 2.5 leaves (35.7%) were photosynthetically active with a mean leaf height of 16.2 cm and the tallest leaf averaged 19.4 cm tall (table 22).

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the twice-over strategy during 1987 to 1989 are on table 23.

Vegetative tillers with 5, 6, and 7 leaves composed 0.0% of the population with 0 tillers (table 23).

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the ungrazed treatment during 1987 to 1989 are on table 24.

Vegetative tillers with 5 leaves composed 100.0% of the population with 15 tillers, during the growing season a mean of 2.5 leaves (50.0%) were photosynthetically active with a mean leaf height of 14.0 cm and the tallest leaf averaged 18.0 cm tall (table 24).

Vegetative tillers with 6 and 7 leaves composed 0.0% of the population with 0 tillers (table 24).

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the traditional seasonlong practice during 1987 to 1989 are on table 25.

Vegetative tillers with 5 leaves composed 78.6% of the population with 11 tillers, during the growing season a mean of 2.3 leaves (46.7%) were photosynthetically active with a mean leaf height of 14.3 cm and the tallest leaf averaged 16.1 cm tall (table 25).

Vegetative tillers with 6 leaves composed 21.4% of the population with 3 tillers, during the growing season a mean of 3.2 leaves (53.6%) were photosynthetically active with a mean leaf height of 13.2 cm and the tallest leaf averaged 19.2 cm tall (table 25).

Vegetative tillers with 7 leaves composed 0.0% of the population with 0 tillers (table 25).

Growth and development data of Kentucky bluegrass vegetative tillers on sandy soils managed with the long-term nongrazed treatment during 1987 to 1989 are on table 26.

Vegetative tillers with 5 leaves composed 100.0% of the population with 15 tillers, during the growing season a mean of 3.0 leaves (60.0%) were photosynthetically active with a mean leaf height of 15.8 cm and the tallest leaf averaged 20.2 cm tall (table 26).

Vegetative tillers with 6 and 7 leaves composed 0.0% of the population with 0 tillers (table 26).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the twice-over strategy during 1987 to 1989 are on table 27.

Vegetative tillers with 5 leaves composed 75.0% of the population with 42 tillers, during the growing season a mean of 2.8 leaves (55.0%) were photosynthetically active with a mean leaf height of 8.5 cm and the tallest leaf averaged 10.8 cm tall (table 27).

Vegetative tillers with 6 leaves composed 23.2% of the population with 13 tillers, during the growing season a mean of 3.8 leaves (62.5%) were photosynthetically active with a mean leaf height of 7.5 cm and the tallest leaf averaged 9.8 cm tall (table 27).

Vegetative tillers with 7 leaves composed 1.8% of the population with 1 tiller, during the growing season a mean of 4.0 leaves (57.2%) were photosynthetically active with a mean leaf height of 15.2 cm and the tallest leaf averaged 23.7 cm tall (table 27).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the ungrazed treatment during 1987 to 1989 are on table 28.

Vegetative tillers with 5 leaves composed 73.6% of the population with 92 tillers, during the growing season a mean of 3.0 leaves (60.0%) were photosynthetically active with a mean leaf height of 14.1 cm and the tallest leaf averaged 17.5 cm tall (table 28).

Vegetative tillers with 6 leaves composed 23.2% of the population with 29 tillers, during the growing season a mean of 3.8 leaves (62.5%) were photosynthetically active with a mean leaf height of 12.6 cm and the tallest leaf averaged 16.4 cm tall (table 28).

Vegetative tillers with 7 leaves composed 3.2% of the population with 4 tillers, during the growing season a mean of 4.3 leaves (61.9%) were photosynthetically active with a mean leaf height of 13.5 cm and the tallest leaf averaged 17.9 cm tall (table 28).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the traditional seasonlong practice during 1987 to 1989 are on table 29.

Vegetative tillers with 5 leaves composed 78.6% of the population with 22 tillers, during the growing season a mean of 3.2 leaves (63.3%) were photosynthetically active with a mean leaf height of 9.0 cm and the tallest leaf averaged 12.5 cm tall (table 29).

Vegetative tillers with 6 leaves composed 17.9% of the population with 5 tillers, during the growing season a mean of 2.0 leaves (33.3%) were photosynthetically active with a mean leaf height of 7.6 cm and the tallest leaf averaged 11.6 cm tall (table 29).

Vegetative tillers with 7 leaves composed 3.6% of the population with 1 tiller, during the growing season a mean of 5.0 leaves (71.4%) were photosynthetically active with a mean leaf height of 7.2 cm and the tallest leaf averaged 12.3 cm tall (table 29).

Growth and development data of Kentucky bluegrass vegetative tillers on silty soils managed with the long-term nongrazed treatment during 1987 to 1989 are on table 30.

Vegetative tillers with 5 leaves composed 80.0% the population with 28 tillers, during the growing season a mean of 2.8 leaves (55.0%) were photosynthetically active with a mean leaf height of 17.0 cm and the tallest leaf averaged 22.9 cm tall (table 30).

Vegetative tillers with 6 leaves composed 11.4% of the population with 4 tillers, during the growing season a mean of 2.5 leaves (41.7%) were photosynthetically active with a mean leaf height of 20.3 cm and the tallest leaf averaged 26.5 cm tall (table 30).

Vegetative tillers with 7 leaves composed 8.6% of the population with 3 tillers, during the growing season a mean of 3.5 leaves (50.0%) were photosynthetically active with a mean leaf height of

15.6 cm and the tallest leaf averaged 20.0 cm tall (table 30).

Not all the leaves on a grass tiller are photosynthetically active during the entire growing season. Leaves grow and senesce in the order they appear. The first leaves are usually dry by early June and the second leaves are usually dry by late June. The rate of leaf senescence can be rapid during water deficiency periods and slow during periods with adequate precipitation. During senescence, leaves translocate cell components to other plant parts. The senesced leaf has less weight and has very low nutritional quality. The greater number of leaves not senescent, the greater the tiller nutritional quality. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active.

The rate of leaf senescence of Kentucky bluegrass vegetative tillers on sandy, silty and clay soils managed with the ungrazed and twice-over treatments during 1983 to 1986 that received adequate precipitation was very similar with the first and second leaves drying during June. Vegetative tillers with 5 to 7 leaves maintained 2.9 and 3.1 photosynthetically active leaves on the twice-over and ungrazed treatments through the growing season, respectively.

The rate of leaf senescence of Kentucky bluegrass vegetative tillers on sandy, and silty soils managed with the nongrazed, seasonlong, ungrazed, and twice-over treatments during 1987 to 1989 that had water deficiency during most of the growing season months was more severe than during the 1983 to 1986 period. Tillers on the nongrazed and seasonlong treatments maintained a mean of 2.0 and 2.6 photosynthetically active leaves during the growing season, respectively. Tillers on the twice-over and ungrazed treatment maintained a mean of 3.5 and 3.6 photosynthetically active leaves, respectively.

All of the vegetative tillers of Kentucky bluegrass with 5 to 7 leaves measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed and nongrazed treatments on the sandy, silty, and clay soils during the 1983-1986 period and on the sandy, and silty soils during the 1987-1989 period. It is not believed that grazed treatments cause vegetative tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

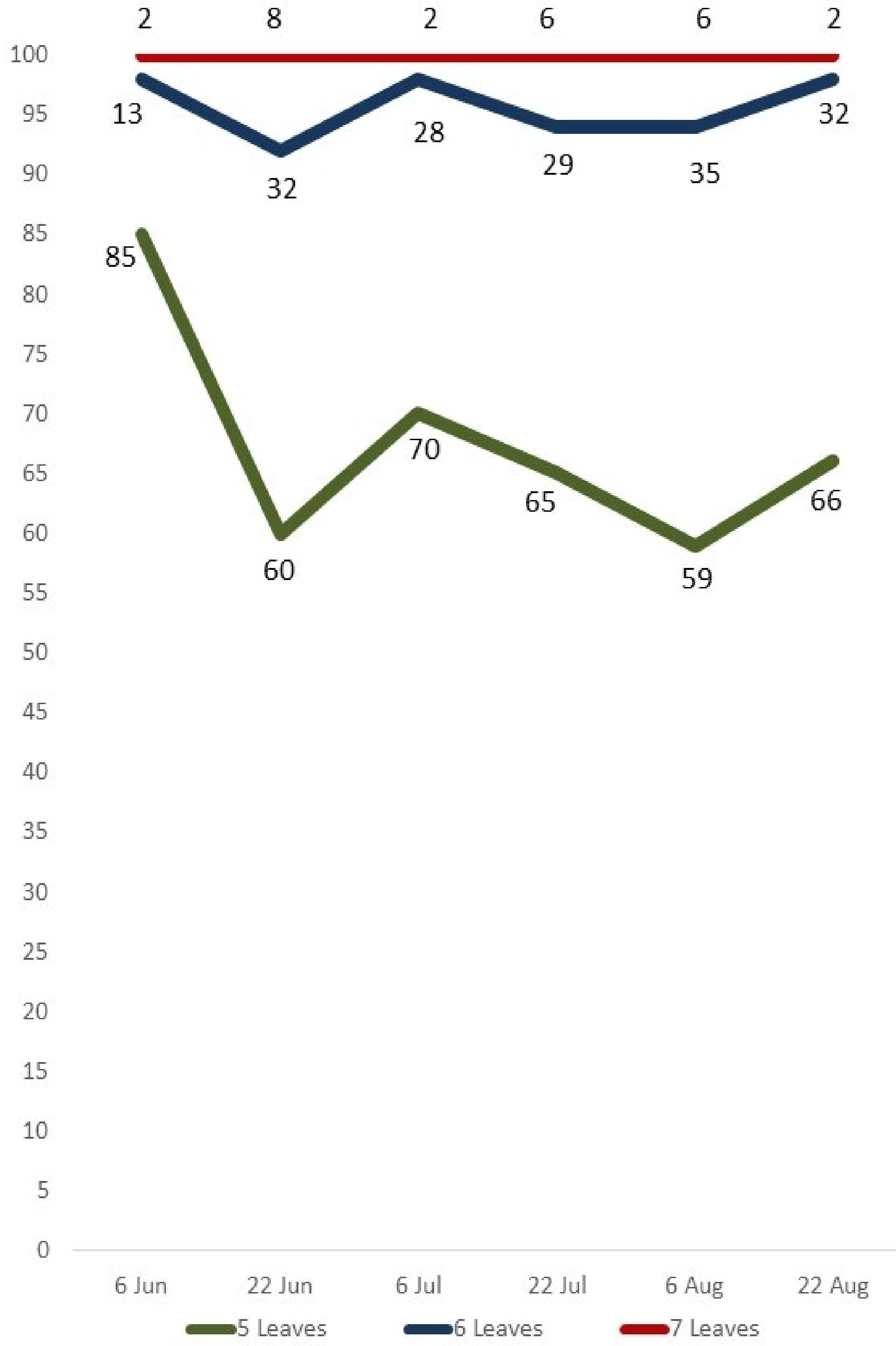

Figure 1. Percent of vegetative tiller population with 5 to 7 leaves.

Table 17. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the grazed treatment of the twice-over strategy, 1983-1986.

Sandy	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	0.0	52.9	0.0	0.0	0.0	0.0
% Active Leaf	-	40.0	-	-	-	-
Leaf Height cm	-	9.0	-	-	-	-
Tallest Leaf cm	-	9.9	-	-	-	-
6 Leaves						
% Population	0.0	38.2	0.0	0.0	0.0	0.0
% Active Leaf	-	50.0	-	-	-	-
Leaf Height cm	-	8.9	-	-	-	-
Tallest Leaf cm	-	11.1	-	-	-	-
7 Leaves						
% Population	0.0	8.8	0.0	0.0	0.0	0.0
% Active Leaf	-	42.9	-	-	-	-
Leaf Height cm	-	9.4	-	-	-	-
Tallest Leaf cm	-	12.5	-	-	-	-
% Population	0.0	99.9	0.0	0.0	0.0	0.0

Table 18. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the ungrazed treatment of the twice-over strategy, 1983-1986.

Sandy	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	20.0	80.0	100.0	54.5	60.0	60.0
% Active Leaf	60.0	40.0	80.0	60.0	60.0	60.0
Leaf Height cm	16.2	10.7	18.6	15.1	20.7	13.6
Tallest Leaf cm	19.2	15.5	24.2	19.2	27.4	17.8
6 Leaves						
% Population	70.0	20.0	0.0	45.5	40.0	30.0
% Active Leaf	50.0	33.3	-	66.7	50.0	50.0
Leaf Height cm	14.8	12.0	-	14.2	22.9	16.7
Tallest Leaf cm	17.3	12.3	-	17.7	29.4	21.9
7 Leaves						
% Population	10.0	0.0	0.0	0.0	0.0	10.0
% Active Leaf	42.9	-	-	-	-	64.3
Leaf Height cm	18.5	-	-	-	-	15.4
Tallest Leaf cm	21.0	-	-	-	-	18.9
% Population	100.0	100.0	100.0	100.0	100.0	100.0

Table 19. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the grazed treatment of the twice-over strategy, 1983-1986.

Silty	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	94.4	66.0	89.3	41.5	38.2	60.0
% Active Leaf	60.0	50.0	60.0	50.0	60.0	60.0
Leaf Height cm	9.7	10.1	10.6	11.6	8.5	8.5
Tallest Leaf cm	11.9	11.8	13.4	12.7	11.5	8.9
6 Leaves						
% Population	5.6	26.0	10.7	56.6	44.1	40.0
% Active Leaf	50.0	50.0	50.0	50.0	50.0	50.0
Leaf Height cm	11.5	10.0	12.6	13.7	7.2	9.4
Tallest Leaf cm	14.8	13.8	17.9	18.3	8.5	11.1
7 Leaves						
% Population	0.0	8.0	0.0	1.9	17.6	0.0
% Active Leaf	-	42.9	-	57.1	29.2	-
Leaf Height cm	-	11.1	-	12.1	29.3	-
Tallest Leaf cm	-	13.9	-	19.9	30.1	-
% Population	100.0	100.0	100.0	100.0	99.9	100.0

Table 20. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the ungrazed treatment of the twice-over strategy, 1983-1986.

Silty	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	92.5	56.8	75.0	70.6	72.1	72.1
% Active Leaf	60.0	60.0	60.0	60.0	60.0	50.0
Leaf Height cm	13.5	12.5	15.9	12.8	16.2	16.5
Tallest Leaf cm	17.0	16.4	20.7	16.6	20.4	18.4
6 Leaves						
% Population	7.5	35.8	25.0	23.5	25.6	26.0
% Active Leaf	50.0	50.0	50.0	41.7	66.7	50.0
Leaf Height cm	11.2	13.8	18.2	14.7	16.9	13.0
Tallest Leaf cm	13.2	17.9	23.6	17.0	22.0	16.1
7 Leaves						
% Population	0.0	7.4	0.0	5.9	2.3	1.9
% Active Leaf	-	50.0	-	57.1	57.1	50.0
Leaf Height cm	-	16.7	-	16.9	16.6	17.2
Tallest Leaf cm	-	21.8	-	24.4	22.3	22.9
% Population	100.0	100.0	100.0	100.0	100.0	100.0

Table 21. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on clay soils managed with the grazed treatment of the twice-over strategy, 1983-1986.

Clay	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	73.7	38.3	80.0	86.4	78.9	80.8
% Active Leaf	60.0	50.0	40.0	60.0	60.0	40.0
Leaf Height cm	7.7	8.1	10.1	15.4	10.4	12.3
Tallest Leaf cm	8.5	9.6	10.8	19.4	14.0	16.2
6 Leaves						
% Population	26.3	46.8	20.0	4.5	21.1	19.2
% Active Leaf	66.7	58.3	66.7	33.3	50.0	50.0
Leaf Height cm	9.3	10.3	9.0	11.4	22.8	12.9
Tallest Leaf cm	10.4	12.7	18.6	17.0	26.4	17.4
7 Leaves						
% Population	0.0	14.9	0.0	9.1	0.0	0.0
% Active Leaf	-	52.4	-	50.0	-	-
Leaf Height cm	-	7.9	-	15.6	-	-
Tallest Leaf cm	-	9.2	-	19.5	-	-
% Population	100.0	100.0	100.0	100.0	100.0	100.0

Table 22. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on clay soils managed with the ungrazed treatment of the twice-over strategy, 1983-1986.

Clay	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
5 Leaves						
% Population	82.4	59.0	57.7	61.9	48.4	66.1
% Active Leaf	60.0	50.0	40.0	40.0	60.0	50.0
Leaf Height cm	10.6	14.2	17.7	19.5	18.6	14.9
Tallest Leaf cm	13.8	18.8	20.4	22.8	22.6	19.6
6 Leaves						
% Population	11.8	32.8	38.5	31.0	48.4	30.6
% Active Leaf	50.0	50.0	50.0	50.0	50.0	58.3
Leaf Height cm	10.8	15.1	18.0	18.5	22.3	14.0
Tallest Leaf cm	18.1	18.8	25.0	23.1	25.6	18.7
7 Leaves						
% Population	5.9	8.2	3.8	7.1	3.2	3.2
% Active Leaf	28.6	28.6	28.6	42.9	57.1	28.6
Leaf Height cm	15.0	17.7	12.6	18.4	21.6	12.1
Tallest Leaf cm	18.1	19.1	13.0	21.9	29.9	14.9
% Population	100.1	100.0	100.0	100.0	100.0	99.9

Table 23. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the grazed treatment of the twice-over strategy, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
6 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
7 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
% Population	0.0	0.0	0.0	0.0

Table 24. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the ungrazed treatment of the twice-over strategy, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	0.0	0.0	100.0	100.0
% Active Leaf	-	-	60.0	40.0
Leaf Height cm	-	-	15.9	12.1
Tallest Leaf cm	-	-	22.7	13.2
6 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
7 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
% Population	0.0	0.0	100.0	100.0

Table 25. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the grazed seasonlong treatment, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	71.4	80.0	0.0	100.0
% Active Leaf	60.0	20.0	-	60.0
Leaf Height cm	17.4	16.5	-	8.9
Tallest Leaf cm	21.5	16.5	-	10.3
6 Leaves				
% Population	28.6	20.0	0.0	0.0
% Active Leaf	57.1	50.0	-	-
Leaf Height cm	15.7	10.7	-	-
Tallest Leaf cm	24.7	13.6	-	-
7 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
% Population	100.0	100.0	0.0	100.0

Table 26. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on sandy soils managed with the nongrazed treatment, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	0.0	100.0	100.0	100.0
% Active Leaf	-	40.0	80.0	0.0
Leaf Height cm	-	14.3	17.2	-
Tallest Leaf cm	-	16.5	23.9	-
6 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
7 Leaves				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
% Population	0.0	100.0	100.0	100.0

Table 27. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the grazed treatment of the twice-over strategy, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	80.8	76.5	87.5	65.2
% Active Leaf	60.0	40.0	60.0	60.0
Leaf Height cm	8.4	8.4	7.8	9.5
Tallest Leaf cm	10.3	10.3	10.1	12.6
6 Leaves				
% Population	15.4	23.5	12.5	30.4
% Active Leaf	66.7	50.0	66.7	66.7
Leaf Height cm	6.6	6.0	8.1	9.3
Tallest Leaf cm	10.1	7.1	9.8	12.1
7 Leaves				
% Population	3.8	0.0	0.0	4.3
% Active Leaf	71.4	-	-	42.9
Leaf Height cm	9.9	-	-	20.5
Tallest Leaf cm	16.1	-	-	31.3
% Population	100.0	100.0	100.0	99.9

Table 28. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the ungrazed treatment of the twice-over strategy, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	80.8	67.3	78.6	73.7
% Active Leaf	60.0	60.0	60.0	60.0
Leaf Height cm	8.4	15.4	13.5	19.0
Tallest Leaf cm	10.3	18.7	18.7	22.4
6 Leaves				
% Population	15.4	30.8	21.4	15.8
% Active Leaf	66.7	50.0	66.7	66.7
Leaf Height cm	6.6	18.1	13.2	12.5
Tallest Leaf cm	10.1	19.9	20.5	15.2
7 Leaves				
% Population	3.8	1.9	0.0	10.5
% Active Leaf	71.4	42.9	-	71.4
Leaf Height cm	9.9	14.8	-	15.8
Tallest Leaf cm	16.1	19.0	-	18.6
% Population	100.0	100.0	100.0	100.0

Table 29. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the grazed seasonlong treatment, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	66.7	88.9	75.0	0.0
% Active Leaf	60.0	70.0	60.0	-
Leaf Height cm	9.9	6.7	10.5	-
Tallest Leaf cm	12.5	9.8	15.3	-
6 Leaves				
% Population	0.0	11.1	25.0	0.0
% Active Leaf	-	33.3	33.3	-
Leaf Height cm	-	6.6	8.5	-
Tallest Leaf cm	-	10.5	12.6	-
7 Leaves				
% Population	33.3	0.0	0.0	0.0
% Active Leaf	71.4	-	-	-
Leaf Height cm	7.2	-	-	-
Tallest Leaf cm	12.3	-	-	-
% Population	100.0	100.0	100.0	0.0

Table 30. Growth and development of Kentucky bluegrass vegetative tillers with 5 to 7 leaves on silty soils managed with the nongrazed treatment, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
5 Leaves				
% Population	100.0	66.7	90.0	54.5
% Active Leaf	60.0	60.0	60.0	40.0
Leaf Height cm	15.4	20.2	21.0	11.3
Tallest Leaf cm	18.9	26.1	30.9	15.7
6 Leaves				
% Population	0.0	0.0	10.0	27.3
% Active Leaf	-	-	50.0	33.3
Leaf Height cm	-	-	27.9	15.6
Tallest Leaf cm	-	-	33.7	19.3
7 Leaves				
% Population	0.0	33.3	0.0	18.2
% Active Leaf	-	57.1	-	42.9
Leaf Height cm	-	15.8	-	15.3
Tallest Leaf cm	-	21.2	-	18.8
% Population	100.0	100.0	100.0	100.0

Secondary Tillers

The secondary tillers had very slow rates of growth and development until they produce their fourth leaf. During growing seasons with normal precipitation conditions (1983-1986), secondary tillers made up about 29.1% of the total tiller population on the grazed twice-over treatment and made up about 33.7% of the ungrazed treatment. During growing seasons with below normal precipitation conditions (1987-1989), secondary tillers made up a slightly greater proportion of the total tiller population, with 34.2% on the grazed twice-over strategy, 36.9% on the ungrazed treatment, 35.0% on the seasonlong, and 37.5% on the nongrazed treatments. The grazed treatments had lower proportions of secondary tillers than the ungrazed and nongrazed treatments.

Growth and development data of Kentucky bluegrass secondary tillers on sandy, silty, and clay soils managed with the twice-over strategy and the ungrazed treatment during 1983 to 1986 are on tables 31, 32, and 33, respectively.

Secondary tillers with 2 to 4 leaves on sandy soils of the twice-over strategy composed 19.0% of the total population with 8 tillers (table 6), during the growing season 53.6% of the leaves were photosynthetically active with a mean leaf height of 9.6 cm and the tallest leaf averaged 9.9 cm tall (table 31).

Secondary tillers with 2 to 4 leaves on sandy soils of the ungrazed treatment composed 40.3% of the total tiller population with 95 tillers (table 6), during the growing season 57.0% of the leaves were photosynthetically active with a mean leaf height of 14.2 cm and the tallest leaf averaged 15.9 cm tall (table 31).

Secondary tillers with 2 to 4 leaves on silty soils of the twice-over strategy composed 27.7% of the total tiller population with 144 tillers (table 7), during the growing season 62.1% of the leaves were photosynthetically active with a mean leaf height of 10.6 cm and the tallest leaf averaged 12.1 cm tall (table 32).

Secondary tillers with 2 to 4 leaves on silty soils of the ungrazed treatment composed 32.6% of the total tiller population with 310 tillers (table 7), during the growing season 61.3% of the leaves were photosynthetically active with a mean leaf height of 12.9 cm and the tallest leaf averaged 14.6 cm tall (table 32).

Secondary tillers with 2 to 4 leaves on clay soils of the twice-over strategy composed 40.5% of the total tiller population with 140 tillers (table 8), during the growing season 63.6% of the leaves were photosynthetically active with a mean leaf height of 11.2 cm and the tallest leaf averaged 13.1 cm tall (table 33).

Secondary tillers with 2 to 4 leaves on clay soils of the ungrazed treatment composed 28.3% of the total tiller population with 179 tillers (table 8), during the growing season 59.0% of the leaves were photosynthetically active with a mean leaf height of 13.5 cm and the tallest leaf averaged 15.6 cm tall (table 33).

Growth and development data of Kentucky bluegrass secondary tillers on sandy and silty soils managed with the twice-over strategy and the ungrazed treatment and with the seasonlong and nongrazed treatments during 1987 to 1989 are on tables 34, 35, 36, and 37, respectively.

Secondary tillers with 2 to 4 leaves on sandy soils of the twice-over strategy composed 0.0% of the total tiller population with 0 tillers (tables 6 and 34).

Secondary tillers with 2 to 4 leaves on sandy soils of the ungrazed treatment composed 40.5% of the total tiller population with 17 tillers (table 6), during the growing season 57.1% of the leaves were photosynthetically active with a mean leaf height of 13.6 cm and the tallest leaf averaged 16.8 cm tall (table 34).

Secondary tillers with 2 to 4 leaves on sandy soils of the seasonlong treatment composed 41.7% of the total tiller population with 15 tillers (table 6), during the growing season 41.7% of the leaves were photosynthetically active with a mean leaf height of 14.2 cm and the tallest leaf averaged 15.6 cm tall (table 35).

Secondary tillers with 2 to 4 leaves on sandy soils of the nongrazed treatment composed 43.2% of the total tiller population with 35 tillers (table 6), during the growing season 62.3% of the leaves were photosynthetically active with a mean leaf height of 18.2 cm and the tallest leaf averaged 21.7 cm tall (table 35).

Secondary tillers with 2 to 4 leaves on silty soils of the twice-over strategy composed 34.2% of the total tiller population with 41 tillers (table 7), during the growing season 60.7% of the leaves were photosynthetically active with a mean leaf height of

6.8 cm and the tallest leaf averaged 8.1 cm tall (table 36).

Secondary tillers with 2 to 4 leaves on silty soils of the ungrazed treatment composed 33.2% of the total tiller population with 97 tillers (table 7), during the growing season 53.6% of the leaves were photosynthetically active with a mean leaf height of 12.2 cm and the tallest leaf averaged 14.1 cm tall (table 36).

Secondary tillers with 2 to 4 leaves on silty soils of the seasonlong treatment composed 28.3% of the total tiller population with 17 tillers (table 7), during the growing season 62.2% of the leaves were photosynthetically active with a mean leaf height of 7.7 cm and the tallest leaf averaged 10.5 cm tall (table 37).

Secondary tillers with 2 to 4 leaves on silty soils of the nongrazed treatment composed 31.8% of the total tiller population with 28 tillers (table 7), during the growing season 50.0% of the leaves were photosynthetically active with a mean leaf height of 16.8 cm and the tallest leaf averaged 20.0 cm tall (table 37).

All of the secondary tillers measured during this study were not grazed including the tillers located on grazed treatments. The not grazed tillers remaining on the grazed treatments tended to have slightly shorter mean leaf heights and mean tallest leaf heights which were not significantly different than the not grazed tillers on the ungrazed treatments on sandy, silty, and clay soils during the 1983-1986 period (tables 31, 32, and 33) and on the sandy and silty soils during the 1987-1989 period (tables 34, 35, 36, and 37). It is not believed that grazed treatments cause secondary tillers to produce slightly shorter leaf heights. It is surmised that grazing cattle have a disproportional rate of selection for taller tillers than for shorter tillers leaving a distorted sample population of not grazed tillers with slightly shorter leaf heights.

Leaves grow and senesce in about the same order of their appearance. This study has designated that leaves with less than 50% senescent tissue to be photosynthetically active. Tillers growing on the twice-over treatment tended to have slightly greater photosynthetically active leaves (59.8%) than the tillers growing on the ungrazed treatment (59.1%), during the growing seasons with normal precipitation conditions (1983 to 1986). During the growing seasons with below normal precipitation conditions (1987 to 1989), secondary tillers growing on the twice-over treatment had greater photosynthetically active leaves (60.7%) than secondary tillers growing on the ungrazed treatment (55.4%), the traditional seasonlong practice (52.0%), and the long-term nongrazed treatment (56.2%).

Secondary tillers composed a high percentage of the total measured tiller population during the 1983 to 1986 period with normal precipitation conditions with 29.1% on the grazed twice-over strategy and 33.7% on the ungrazed treatment. The quantity of secondary tillers increased during the 1987 to 1989 period with below normal precipitation conditions and composed 34.2% on the grazed twice-over strategy, 36.9% on the ungrazed treatment, 35.0% on the traditional seasonlong practice, and 37.5% on the long-term nongrazed treatment.

Table 31. Growth and development of Kentucky bluegrass secondary tillers on sandy soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Sandy	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
% Population	47.4	19.0	0.0	0.0	0.0	0.0
% Active Leaf	57.1	50.0	-	-	-	-
Leaf Height cm	11.3	7.9	-	-	-	-
Tallest Leaf cm	11.7	8.1	-	-	-	-
Ungrazed 1983-1986						
% Population	47.4	78.3	90.0	42.1	0.0	55.6
% Active Leaf	57.1	53.8	71.4	45.5	-	57.1
Leaf Height cm	11.3	13.9	19.3	12.3	-	14.0
Tallest Leaf cm	11.7	15.5	22.4	14.7	-	15.3

Table 32. Growth and development of Kentucky bluegrass secondary tillers on silty soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Silty	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
% Population	67.3	21.9	54.1	31.2	15.0	31.4
% Active Leaf	77.8	54.5	71.4	54.5	57.1	57.1
Leaf Height cm	8.4	10.8	10.5	12.0	8.1	13.8
Tallest Leaf cm	10.0	12.0	12.5	13.1	9.1	15.6
Ungrazed 1983-1986						
% Population	50.6	46.9	63.1	54.1	38.6	35.4
% Active Leaf	77.8	62.5	57.1	56.3	57.1	57.1
Leaf Height cm	11.2	11.3	14.5	13.6	12.1	14.8
Tallest Leaf cm	12.6	12.4	16.6	14.7	15.2	15.8

Table 33. Growth and development of Kentucky bluegrass secondary tillers on clay soils managed with the grazed and ungrazed treatments of the twice-over strategy, 1983-1986.

Clay	6 Jun	22 Jun	6 Jul	22 Jul	6 Aug	22 Aug
Grazed 1983-1986						
% Population	61.2	36.5	75.0	45.0	62.7	40.9
% Active Leaf	71.4	57.1	57.1	63.6	57.1	75.0
Leaf Height cm	8.8	9.4	14.3	12.8	12.3	9.4
Tallest Leaf cm	11.3	11.5	16.1	14.1	13.3	12.5
Ungrazed 1983-1986						
% Population	63.0	40.8	31.6	38.7	22.5	35.4
% Active Leaf	57.1	61.5	57.1	57.1	57.1	64.3
Leaf Height cm	12.8	11.1	11.1	17.5	17.6	10.6
Tallest Leaf cm	14.6	12.4	12.1	20.0	20.8	13.5

Table 34. Growth and development of Kentucky bluegrass secondary tillers on sandy soil managed with the grazed and ungrazed treatments of the twice-over strategy, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
% Population	0.0	0.0	0.0	0.0
% Active Leaf	-	-	-	-
Leaf Height cm	-	-	-	-
Tallest Leaf cm	-	-	-	-
Ungrazed 1987-1989				
% Population	0.0	0.0	48.1	80.0
% Active Leaf	-	-	57.1	57.1
Leaf Height cm	-	-	16.6	10.5
Tallest Leaf cm	-	-	19.6	14.0

Table 35. Growth and development of Kentucky bluegrass secondary tillers on sandy soil managed with the grazed seasonlong and nongrazed treatments, 1987-1989.

Sandy	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
% Population	36.4	44.4	0.0	77.8
% Active Leaf	50.0	25.0	-	50.0
Leaf Height cm	18.4	10.4	-	13.8
Tallest Leaf cm	19.9	10.4	-	16.4
Nongrazed 1987-1989				
% Population	0.0	64.7	75.0	70.6
% Active Leaf	-	57.1	72.7	57.1
Leaf Height cm	-	18.8	20.0	15.9
Tallest Leaf cm	-	19.8	26.3	18.9

Table 36. Growth and development of Kentucky bluegrass secondary tillers on silty soil managed with the grazed and ungrazed treatments of the twice-over strategy, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
% Population	33.3	56.4	42.9	23.3
% Active Leaf	57.1	57.1	71.4	57.1
Leaf Height cm	9.1	6.6	7.4	3.9
Tallest Leaf cm	10.5	8.2	9.4	4.3
Ungrazed 1987-1989				
% Population	33.3	44.1	37.8	57.8
% Active Leaf	57.1	57.1	57.1	42.9
Leaf Height cm	9.1	11.6	12.4	15.5
Tallest Leaf cm	10.5	12.4	17.4	15.9

Table 37. Growth and development of Kentucky bluegrass secondary tillers on silty soil managed with the grazed seasonlong and nongrazed treatments, 1987-1989.

Silty	6 Jun	22 Jun	22 Jul	22 Aug
Grazed 1987-1989				
% Population	66.7	47.1	15.8	0.0
% Active Leaf	57.1	54.5	75.0	-
Leaf Height cm	8.3	7.5	7.4	-
Tallest Leaf cm	10.8	9.3	11.4	-
Nongrazed 1987-1989				
% Population	38.9	66.7	44.4	38.9
% Active Leaf	57.1	42.9	57.1	42.9
Leaf Height cm	15.3	18.9	18.6	14.3
Tallest Leaf cm	18.4	21.8	21.4	18.3

Discussion

Kentucky bluegrass*, Poa pratensis,* is a naturalized (introduced from Europe by early Norse colonists around the early 1000's), long-lived perennial, cool season, mid grass, monocot, of the grass family that has invaded much of the grasslands on the Northern Plains. Kentucky bluegrass can grow on sandy, shallow, silty, overflow, and clay ecological sites. Poa pratensis does not grow and develop well in western North Dakota except during growing seasons that receive precipitation at 112% or greater (15.8 in.) of the long-term mean (14.1 in.). Kentucky bluegrass tillers live for two growing seasons; the first growing season as a vegetative tiller and the second season as a reproductive tiller. Early season activity starts by regreening with active chlorophyll the portions of the carryover leaves that have intact cell walls from the previous growing season vegetative tillers. The green portion of the carryover leaves provides large quantities of carbohydrates and energy for the production of new leaves.

New leaf growth of Kentucky bluegrass started in early April, leaf growth rate increased during May and June, and then become much slower during July. The tillers derived from carryover tillers that developed into reproductive tillers produced 4 to 6 new basal leaves by late May. The first and second leaves may be missing. Early flower stalk growth and development (FSD) began to swell around mid to late April. Early tillers progressed rapidly through head emergence (HE) during late April to early May. Most reproductive tillers reached anthesis (Ant) during mid May to late June. Flowering tillers have one or two small stalk leaves and usually produced 2 to 7 basal leaves. No new leaves were produced after the anthesis stage. Seeds developed (SD) through the milk and dough stages during early June to early July with most seeds reaching maturity (SBS) during mid June with some seeds held on the stalk during late summer.

The vegetative tillers derived from the previous seasons fall tillers and the current seasons early spring initiated tillers produced 4 to 6 new basal leaves by late May. During the growing season 68.0% of the vegetative tillers produced 5 leaves, 28.0% produced 6 leaves, and 4.0% produced 7 leaves.

Secondary tillers are derived from vegetative growth of axillary buds. The tillers that were initiated during the growing season have a slow rate of growth and receive at least a portion of their nutrients from older tillers. This arrangement had positive and negative affects. Most of the time, the secondary tillers have access to greater quantities of essential nutrients than a seedling would have, which ensures secondary tillers with superior survivability. Thus, a high percentage of secondary tillers live and grow for two growing seasons, and almost no grass seedlings develop into mature plants. However, during periods of water stress or other problematic conditions, secondary tillers develop at very slow rates of growth and sometimes are terminated. During high water deficiency conditions growing seasons, secondary tillers can remain at the 2 or 3 leaf stage for a month or two. When secondary tillers produce their fourth leaf, they have adequate leaf area to photosynthesize their own carbon energy and develop a large enough root system for self sustaining nutrient resource uptake.

Restoration of Invaded Grasslands

Kentucky bluegrass is one of two introduced grasses that have weak lead tillers that do not hormonally inhibit vegetative reproduction from crown or rhizome axillary buds which permits abundant quantities of vegetative tillers to develop without partial defoliation management. This seemingly unlimited forage producing feature has a huge cost of double the water use per pound of herbage produced. Unfortunately, Kentucky bluegrass plants have extensively invaded native grasslands that have been poorly managed. Kentucky bluegrass begins growth and development during early spring before native grass species, permitting Kentucky bluegrass early use of the stored soil water resulting in production of considerable quantities of forage during late May that native grasses do not provide. However, this early season high use of the available stored water depletes these water resources from the soil at the time of initiation of native grass plant growth which devastates their herbage biomass productivity.

The flower stalk basal leaves of Kentucky bluegrass senesce during June and then transition into a quiescent state deficient of nutrients during July and August. A small quantity of fall tillers produce a relatively small amount of new green herbage biomass during mid August and early September that develop into vegetation tillers during the successive season.

Kentucky bluegrass is not a desirable grass to have in Northern Plains grassland pastures. The earlier initiation of spring growth of Kentucky bluegrass and the depletion of the available stored soil water causes great reductions in native grass density and herbage production. Because Kentucky bluegrass has weak lead tillers and does not inhibit vegetative tillering hormonally, the water use efficiency mechanisms are negatively affected causing the use of double the quantity of water per pound of herbage biomass produced. At any amount of growing season precipitation, Kentucky bluegrass would produce half the herbage biomass that the strong lead tiller native grasses could.

Repeated prescribed burning does not and cannot remove Kentucky bluegrass from grassland ecosystems because removal of all or most of the aboveground herbage biomass with fire does not stop vegetative reproduction by tillering. Kentucky bluegrass also cannot be removed from a grassland by repeated heavy grazing. However, heavy grazing causes lethal damage to desirable native grasses creating additional open spaces in which Kentucky bluegrass rhizomes can move into and increase (Manske 2017).

Healthy grassland ecosystems can prevent the invasion of Kentucky bluegrass and only after poor management practices or heavy grazing reduce the native grass plant nutrient resource uptake competitiveness mechanisms and creates open spaces in the plant community can Kentucky bluegrass move in and expand. This evidence indicates that the biological process to remove Kentucky bluegrass from a grassland would be to restore the ecosystems biogeochemical processes and the four major internal grass growth mechanisms in order to renew the functionality of the native species permitting them to out compete and reduce the invading Kentucky bluegrass. All of this can be accomplished through implementation of the twice-over rotation grazing strategy, which has been described in Manske 2019 and in a few earlier reports.

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