Biologically Effective Management of Grazing

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Grazing is biologically beneficial for grass plants and for grassland ecosystems when grazing periods are coordinated with grass phenological growth stages (Whitman 1974).

The four primary physiological growth mechanisms within grass plants that perform the herbage replacement processes are activated with partial defoliation by grazing animals when 25% to 33% of leaf weight is removed from 60% to 80% of lead tillers during vegetative phenological growth stages between the three and a half new leaf stage and the flower stage when a threshold quantity of 100 lbs/ac (112 kg/ha) of mineral nitrogen is available (Manske 1999a). Unavailable soil organic nitrogen must be mineralized by soil microbes in order for nitrogen to be usable by grass plants. A large biomass of rhizosphere microorganisms is required to mineralize a large quantity of nitrogen yielding 100 lbs/ac. Grassland microbes are achlorophyllous and cannot fix their own carbon energy. Large quantities of surplus short chain carbon energy are produced by healthy vegetative lead tillers that can be exudated into the microbial rhizosphere when 25% to 33% of the leaf weight is removed with partial defoliation by grazing animals while lead tillers are between the three and a half new leaf stage and the flower stage (Manske 2018a). This treatment is applicable for crested wheatgrass and native grasses. Smooth bromegrass common varieties with southern parentage do not form symbiotic associations with rhizosphere microorganisms. On the other hand, the uncommon varieties with northern parentage readily form symbiotic associations with rhizosphere microorganisms (Manske 2017d). The four primary physiological growth mechanisms are not functional when less than 100 lbs/ac of mineral nitrogen is available and are not activated when zero % or greater than 33% of the leaf weight of lead tillers is removed during vegetative growth stages between the three and a half new leaf stage and the flower stage (Manske 2018a).

The three and a half new leaf stage is the phenological growth stage when grass lead tillers become physiologically capable of being grazed if only 25% to 33% of the tiller leaf weight is removed. Removal of 50% leaf weight is detrimental until after the flower stage (Manske 2010, 2014a, b, 2018c). The three and a half new leaf growth stage is the definitive signal showing when grasslands are ready for grazing to start. Perennial grass leaf growth stages of second year lead tillers is a simple, accurate, and dependable method to determine grazing readiness because development of the number of leaves is determined by the length of daylight resulting in a maximum year to year variance in grass species leaf growth stage of only 3 days with many common grasses having a variance of 1 day. Correct determination of grazing readiness by counting grass leaf stages requires a rudimentary understanding of how grasses grow.

The number of true seedlings is very low in a grassland and are negligible to the ecosystem. The grass in a grassland is almost always comprised of tillers produced vegetatively from axillary buds. Each tiller lives for two growing seasons. During the first growing season, grass tillers remain vegetative and can produce 6 to 8 leaves. During the second growing season, grass lead tillers produce a second set of 6 to 8 leaves plus development of flowers and seeds. At the end of each growing season, all tillers deactivate the chlorophyll and turn a tan color. Lead tillers that had produced flowers are terminal. Vegetative tillers that had produced only leaves remain alive through the winter by burning carbohydrates that were stored during the winter hardening period that occurs from mid August to around mid October. As a result of winter respiration by the carryover tillers, these carbohydrate reserves are nearly depleted and not adequate to support both root and new leaf growth the following growing season (Manske 2011).

Chlorophyll is reactivated during early spring in parts of old previous years leaves where the cells did not rupture. Usually, each carryover tiller has 2 or 3 previous years leaves that are half tan with ruptured cells and half green with complete intact cells. These green chlorophyll portions photosynthesize the material that will be used to produce the new current years leaves. New leaves of these second year lead tillers grow straight up from the apical meristem, located at the tiller base, through the old leaf sheaths until it reaches full size, then it tips to one side of the tiller. The next new leaf will tip to the other side of the tiller when it reaches full size and so on. When lead tillers are between the third new leaf stage and the three and a half new leaf stage, the apical meristem ceases production of leaf primordia and begins to produce flower primordia (Frank 1996, Frank et al, 1997). After three new full size leaves and a fourth new leaf, about half size and still growing straight up, have been produced, that lead tiller has sufficient leaf area to provide all of the photosynthetic assimilates required for additional new growth. The previously formed leaf buds will continue to grow and produce new full size leaves and later that growing season sexual reproductive floral structures will develop. The old carryover leaves are no longer required after the three and a half new leaf stage (Manske 2011).

These old carryover leaves will completely dry in a short time with portions of the leaves usually remaining attached towards the bottom of the lead tiller. Although the carryover leaves had activated chlorophyll and had photosynthesized assimilates during the current growing season, these leaves were produced during the previous growing season and should never be included in the count of new current years leaves. Including previous years leaves when counting the leaf growth stages of lead tillers causes a major problem by attributing that these tillers have reached the three and a half leaf stage at an earlier date than the biological date that they actually do reach grazing readiness, as would have been indicated by counting only the current years leaves to determine the three and a half new leaf stage. Starting grazing at an earlier leaf growth stage other than that at which the grass tillers are physiologically ready for grazing will undoubtedly cause noticeable degradation to that grassland and will subvert the intended purpose for using this technique.

Grass phenological stages of growth and development are triggered primarily by day length (Roberts 1939, Dahl 1995). In the northern hemisphere daylight hours increase during the growing season between mid April and 21 June and then decrease at the same rate of change each year. The leaf length and weight can be slightly modified by temperature and precipitation and will be variable from year to year (McMillan 1957, Dahl and Hyder 1977). The critical three and a half new leaf stage is not developed by all grass species at the same time or length of daylight. However, this leaf growth stage does occur during three seasonality time periods for similar grass types. The domesticated cool season grasses (crested wheatgrass and smooth bromegrass) are the first grass type to develop three and a half new leaves slightly before or near 1 May. The recommended grazing start date for domesticated cool season grass complementary spring pastures is 1 May (Manske 2017c, d). The native cool season grasses develop three and a half new leaves just before, on, or near 1 June. The native warm season grasses develop three and a half new leaves during mid June. The recommended grazing start date for native rangeland is 1 June (Manske 2018b). The wildryes (Altai and Russian) develop three and a half new leaves during early June. Wildryes are very different than other grasses biologically, they act as if they were types of perennial winter cereal with stimulation of the growth mechanisms during the fall, and they are negatively affected by traditional grass management practices. The recommended grazing start date for wildryes is mid October (Manske 2017a, b).

Crested wheatgrass starts early leaf greenup of vegetative carryover tillers in mid April. The crested wheatgrass lead tillers have three and a half new leaves around 22 April which is four to five weeks earlier than native cool season grasses. These early new leaves are highly nutritious with 16.3% crude protein, however, the available herbage weight is insufficient during April. Grazing can start 1 May. The nutritional quality of ungrazed lead tillers of crested wheatgrass changes with the tillers' phenological development. Early season growth stages are high in crude protein and water. Early vegetative leaf stages contain levels of crude protein above 15% during early to mid May. Early boot stage occurs in mid May. As seed stalks begin to develop, crude protein levels decrease. The first stalks with flowers occurs around 28 May. At the flower stage, lead tillers contain 13.5% crude protein. Most of the lead tillers reach the flower stage during a 10 to 14 day period. The late flowering lead tillers should flower by 10 June. During the flower stage period, crested wheatgrass herbage has the greatest weight of crude protein per acre available. After the flower stage, seed development occurs with crude protein levels remaining above 9.6% until late June. Native rangeland grasses contain greater crude protein levels at 15.5% to 12.0% during June. Crested wheatgrass seeds fill and reach maturity during the 5 to 8 weeks following flowering. As lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility (TDN) decrease. By early July, crude protein levels drop below 7.8% and below 6.2% in early August. Phosphorus levels drop below 0.18% in late July (Whitman et al. 1951, Manske 1999b, 2017c, 2018f).

The optimum period to graze domesticated crested wheatgrass complementary spring pastures is during the month of May.

Smooth bromegrass starts early leaf greenup of vegetative carryover tillers in mid April. Leaf development occurs slowly. The smooth bromegrass lead tillers have three and a half new leaves around early May, which is four or so weeks earlier than native cool season grasses. These early new leaves are highly nutritious with 17.6% crude protein. Grazing can start 1 May. The nutritional quality of ungrazed lead tillers of smooth bromegrass changes with the tillers' phenological development. Early season growth stages are high in crude protein above 18% during early to mid May. Smooth bromegrass is sensitive to early season heavy grazing. Early boot stage starts to occur in mid May developing slowly while crude protein levels decrease. Flower stalk emergence occurs in early June and first flowers appear around 13 June. At the flower stage, lead tillers contain 14.4% crude protein. Most of the lead tillers reach the flower stage by late June. During the flower stage period, smooth bromegrass herbage has the greatest weight of crude protein per acre available. After the flower stage, seed development occurs with crude protein levels remaining above 9.8% until late June. Native rangeland grasses contain greater crude protein levels at 15.5% to 12.0% during June. Smooth bromegrass seeds fill and reach maturity during the first week of July. As lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility (TDN) decrease. By early July, crude protein level drops below 9.5% and below 8.0% in early August. Phosphorus levels drop below 0.18% during early July (Whitman et al. 1951, Manske 1999b, 2017d). The optimum period to graze domesticated smooth bromegrass complementary spring pastures is during the month of May.

Native cool season grasses start early leaf greenup of vegetative carryover tillers in mid April and grow slowly until early May, reaching 59% of the leaf growth in height by mid May with crude protein levels above 16%. Most cool season grasses reach the three and a half new leaf stage around early June at 73% of the leaf growth in height, contain levels of crude protein above 15% during early to mid June, reach 94% of the leaf growth in height by late June, and 100% of the leaf growth height by late July. Cool season grasses start the flower stage period before 21 June. After the flower stage, crude protein levels begin to decrease below 15%. During the seed development stage, flower stalks reach 94% of the growth in height by late June and crude protein levels remain above 9.6% until mid July. The growth in height reaches 100% by late July when seeds are maturing and being shed. As the lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility (TDN) decrease. During late July, crude protein levels drop below 8.0% and below 6.5% in late August (Whitman et al. 1951, Goetz 1963, Manske 2000, 2008b, 2018c, f). Partial defoliation managed by the twice-over rotation system activates secondary vegetative tillers. Crude protein levels of cool season secondary tillers increase above 9.6% during July and August to 13.2% in early September, decrease during September, and drop below 9.6% in early to mid October (Sedivec 1999, Manske 2008b). Phosphorus levels of lead tillers drop below 0.18% in late July, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

Native warm season grasses start early leaf greenup of vegetative carryover tillers in mid May, have crude protein levels above 15%, reach 44% of the leaf growth in height by early June, containing crude protein above 13% during early to mid June. Most warm season grasses reach the three and a half new leaf stage around mid June, reaching 85% of the leaf growth in height by late June and reach 100% of height by late July. Seed stalks begin to develop in mid June and reach the flower stage after 21 June with 12.2% crude protein. During the seed development stage, crude protein levels remain above 9.6% until late July when the flower stalks reach 91% of the growth in height. As the lead tillers mature, the fiber content increases and percent crude protein, water, and digestibility (TDN) decrease. During mid August, crude protein levels drop below 7.0%, seed stalks reach 100% of the growth in height by late August when the seeds are mature and being shed, and drop below 6.0% in crude protein by early September (Whitman et al. 1951, Goetz 1963, Manske 2000, 2008b, 2018c, f). Partial defoliation managed by the twice-over rotation system activates secondary vegetative tillers. Crude protein levels of warm season secondary tillers increase above 9.0% during August to 10.0% in early September, decreases during September, and drop below 9.6% in late September (Sedivec 1999, Manske 2008b). Phosphorus levels of lead tillers drop below 0.18% in late August, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

Crude protein levels of upland sedges do not follow the same relationship with phenological growth stages as in cool and warm season grasses. Crude protein levels in upland sedges remain high through the flower and seed mature stages. Upland sedges grow very early and produce seed heads in late April to early May and crude protein remains above 9.6% until mid July. Crude protein levels decrease with increases in senescence and drop below 7.8% in early August but do not fall below 6.2% for the remainder of the growing season (Whitman et al. 1951, Manske 2008b, 2018f). Phosphorus levels drop below 0.18% in mid May when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008a).

Wildryes, Altai and Russian, start early leaf greenup of vegetative carryover tillers in mid April. Leaf development occurs slowly. The lead tillers of wildryes develop three and a half new leaves during early June. Flower stalks develop during mid May to mid June, before the 21st, and are stiff, mostly leafless, and unpalatable to livestock. The leaves of lead tillers contain crude protein at levels above 12% during most of the growing season. However, lightly grazing wildryes prior to the flower stage does not activate vegetative tillers as in other grasses. Early season grazing actually decreases tiller basal cover. Fall grazing during mid October to mid November that removes less than 50% of the standing leaf biomass greatly increases vegetative secondary tiller and fall tiller development during the following summer and early fall. Removal of greater than 50% of the herbage biomass during the fall grazing periods greatly reduces active lead tiller growth followed by critical reductions in herbage biomass and nutritional quality during subsequent growing seasons eventually causing termination of a major portion of the living crown tillers that results in stand depletion within 20 to 25 years.

Leaving 50% of the herbage biomass in mid November is absolutely necessary for proper development of the vegetative and fall tillers during the following season. The basal leaves and flower stalks of the current lead tillers compose most of the standing herbage biomass during June. After the flower stage, the crude protein content of the basal leaves starts to decrease slowly. The vegetative tillers, that had been activated by the previous fall grazing period, begin visible growth shortly after the lead tiller stalks reach the flower stage. The herbage biomass during July and August consist of both the slowly aging lead tiller leaves and the rapidly growing vegetative tillers. The fall tillers develop after mid August producing substantial herbage biomass during September and October. By mid October, the fall tillers contain around 10% to 12% crude protein, the vegetative tillers contain around 8% to 10% crude protein, and the lead tillers contain around 6% to 8% crude protein. The ratio of the three tiller types affects the mean available crude protein level. Ungrazed wildrye plants produce very low quantities of vegetative and fall tillers showing low quantities of crude protein during fall. Annually grazed wildryes are the only perennial grass type that can provide adequate nutritional quality after mid October to meet a lactating cows requirements during a fall grazing period from mid October to mid November that leaves 50% of the herbage biomass at the end of the grazing period (Manske 2017a, b; 2018e, f).

The four primary physiological grass growth mechanisms are: compensatory physiological mechanisms, vegetative reproduction by tillering, nutrient resource uptake competitiveness, and water use efficiency (Manske 2018a, c).

The compensatory physiological mechanisms give grass plants the capability to replace lost leaf and shoot biomass following grazing by increasing meristematic tissue activity, increasing photosynthetic capacity, and increasing allocation of carbon and nitrogen (McNaughton 1979, 1983; Briske 1991). Fully activated mechanisms can produce replacement foliage at 140% of the weight that was removed during grazing (Manske 2009).

Vegetative secondary tillers are shoots that develop on lead tillers from growth of axillary buds and the subsequent development of vegetative tillers is regulated by auxin, a growth-inhibiting hormone produced in the apical meristem and young leaves. Partial defoliation of young leaf material at vegetative growth stages temporarily reduces the quantity of auxin which then allows cytokinin, a growth hormone, to stimulate the meristematic tissue of multiple axillary buds to develop into vegetative secondary tillers (Mueller and Richards 1986, Richards et al. 1988, Murphy and Briske 1992, Briske and Richards 1994, 1995).

Nutrient resource uptake competitiveness determines the level of grass plant dominance within a grassland community. Removal of aboveground leaf material from grass plants affects root functions. Removal of 50% or more leaf material greatly reduces root growth, root respiration, and root nutrient and water absorption resulting in severe degradation of the functionality of grass plants (Crider 1955). Reduction of active root biomass causes diminishment of grass plant health and vigor (Whitman 1974) that result in a loss of resource uptake efficiency and a suppression of the competitiveness of grass plants to take up mineral nitrogen, essential elements, and soil water.

Reduction of grass plant nutrient uptake competitiveness allows successful establishment of undesirable grasses, weedy forbs, and shrub seedlings and rhizomes into grassland communities (Li and Wilson 1998, Kochy 1999, Kochy and Wilson 2000, Peltzer and Kochy 2001).

Water use efficiency in grass plants is not at a single constant rate. Precipitation (water) use efficiency of grass plants improves when soil mineral nitrogen is available at threshold quantities of 100 lbs/ac (112 kg/ha) and greater. The inhibitory deficiencies of mineral nitrogen on grasslands that have less than 100 lbs/ac of available soil mineral nitrogen cause the weight of herbage production per inch of precipitation received to be reduced an average of 49.6% below the weight of herbage produced per inch of precipitation on the grassland ecosystems that have greater than 100 lbs/ac of mineral nitrogen (Wight and Black 1972, 1979).

The vegetative reproduction by tillering and the compensatory physiological mechanisms function at remarkably high rates on grasslands that have greater than 100 lbs/ac of available mineral nitrogen and these mechanisms do not function or function at extremely low rates on grasslands that have mineral nitrogen deficiencies at less than 100 lbs/ac (Manske 2009, 2014c, 2018d).

Continuous functionality at high production rates of the four primary physiological grass growth mechanisms requires partial defoliation by grazing that removes 25% to 33% of leaf weight from 60% to 80% of the lead tillers between the three and a half new leaf stage and the flower stage annually with mineral nitrogen available at 100 lbs/ac or greater (Manske 1999a, 2014c, 2018a). This requirement is applicable to all perennial grasses except the wildryes. For the wildryes, the vegetative reproduction by tillering and the compensatory physiological mechanisms are activated by partial defoliation during a mid October to mid November annual grazing period (Manske 2017a, 2018f).

Rhizosphere microbes with a high biomass from 214 to 406 kg/m^3 (363 to 689 lbs/yd^3) can mineralize 111.3 to 176.3 kg/ha (99.4 to 157.4 lbs/ac) of mineral nitrogen (Manske 2018d). A large biomass of rhizosphere microorganisms can perform all of the grassland ecosystem biogeochemical processes that renew nutrient flow activities in the intact grassland soil. Biogeochemical processes transform stored essential elements from organic forms into plant-usable inorganic forms. Biogeochemical processes also capture replacement quantities of lost or removed major essential elements of carbon, hydrogen, nitrogen, and oxygen, with assistance from active live plants, and transform the captured major essential elements into storage as organic forms for later use. And the biogeochemical processes also decompose complex unusable organic material into compounds and then into reusable essential elements (Manske 2018a).

Management of grazing has traditionally been designed to provide forage for livestock with sensible stewardship for the aboveground portions of grass plants and with provisions for wildlife. Grassland ecosystems are much more complex than the traditional concept and consist of three principal interactive biotic components that have specific biological requirements.

The indispensable biotic components of a functional grassland ecosystem are grass vegetation, rhizosphere organisms, and domesticated cattle. Grazing livestock depend on grass plants for nutritious forage. Grass plants depend on rhizosphere organisms for mineralization of essential elements from the soil organic matter. Rhizosphere organisms, which are achlorophyllous, depend on grass plants for short carbon chain energy that is exudated through the roots of lead tillers at vegetative growth stages following partial defoliation by grazing livestock. Grass plants produce double the leaf biomass than is needed for photosynthesis in order to attract the vital partial defoliation by grazing livestock on which they depend.

Biologically Effective Management

The perennial forage grasses that grow in the Northern Mixed Grass Prairie region with similar phenological growth characteristics can be categorized into three seasonality time periods (grazing periods) in which the herbage production curves and the nutrient quality curves of the forage grasses match the biological and physiological requirements of each grazing cow with a calf. The spring seasonality period forage grasses support grazing during early to late May and include the introduced domesticated cool season grasses, such as crested wheatgrass and smooth bromegrass. The summer seasonality period forage grasses support grazing during early June to mid October and include the cool season and warm season native grasses. The fall seasonality period forage grasses support grazing during mid October to mid November and include the wildryes, such as Altai and Russian.

The forage grasses from the three seasonality time periods can be combined to form a biologically effective strategy that has spring and fall complementary pastures with summer native rangeland pastures designed to coordinate partial defoliation events with grass phenological growth stages, to meet the nutrient requirements of the grazing livestock, the biological requirements of the grass plants and the rhizosphere microorganisms, to enhance the ecosystem biogeochemical processes, and to activate the four primary internal grass plant physiological growth mechanisms in order for grassland ecosystems to function at the greatest achievable levels.

The Spring Seasonality Period

A domesticated cool season grass complementary spring pasture of crested wheatgrass or smooth bromegrass has been traditionally grazed from 1 to 31 May on one pasture. Productivity can be greatly increased by splitting that pasture in half with each half pasture grazed for two periods of 7 days for a total of 28 days called a two pasture switchback system. With this simplified version, the pasture switch can always be made during the same day each week i.e. on four May Monday mornings at 8:00 am. A more complicated version can add 4 grazing days by making the pasture switch on 8 day periods. This will add one weekday to each rotation and these days should probably be marked on a calendar.

Using the two pasture switchback system on crested wheatgrass with two 7 or 8 day grazing periods on each pasture activated functioning of the vegetative reproduction by tillering and the compensatory physiological mechanisms at much higher rates during May than the performing rates on a traditional single pasture strategy. On the two pasture switchback system herbage biomass was produced at 2183 lbs/ac, supporting a stocking rate at 1.30 ac/AUM, and calf weight gain at 66.6 lbs/ac. On the traditional single pasture strategy herbage biomass was produced at 1261 lbs/ac, supporting a stocking rate at 2.33 ac/AUM, and calf weight gain at 32.9 lbs/ac. The grass growth mechanisms functioning at higher rates on the two pasture switchback system increased herbage biomass production 73.1% greater, increased the stocking rate 79.2% greater, and increased calf weight gain 102.5% greater per acre than the productivity on the traditional strategy (Manske 2018f).

Livestock are moved to native rangeland pastures during early June. Native grasses have greater crude protein content during June than either crested wheatgrass or smooth bromegrass and activation of the important secondary vegetative tillers requires partial defoliation by grazing native grasses during 7 to 17 days on each pasture during the first grazing period of 45 days from 1 June to 15 July.

The Summer Seasonality Period

The twice-over rotation grazing management strategy uses three to six native grassland pastures. Each pasture is grazed for two periods per growing season. The number of grazing periods is determined by the number of sets of tillers: one set of lead tillers and one set of vegetative secondary tillers per growing season. The first grazing period is 45 days long, ideally, from 1 June to 15 July, with each pasture grazed for 7 to 17 days (never less or more). The number of days of the first grazing period on each pasture is the same percentage of 45 days as the percentage of the total season's grazeable forage contributed by each pasture to the complete system. The forage is measured as animal unit months (AUM's). The average grazing season month is 30.5 days long (Manske 2012). The number of days grazed are not counted by calendar dates but by the number of 24-hr periods grazed from the date and time the livestock are turned out to pasture. The second grazing period is 90 days long, ideally from 15 July to 14 October, each pasture is grazed for twice the number of days as in the first period. The length of the total grazing period is best at 135 days; 45 days during the first period plus 90 days during the second period. There is some flexibility in the grazing period dates. The starting date has a variance of plus or minus 3 days with a range of start dates from 29 May to 4 June. This gives an extreme early option to start on 29 May with the first period to 12 July and with the second period to 11 October. The extreme late alternative option can start on 4 June with the first period to 18 July and with the second period to 17 October. There is also the option to add a total of 2 days to the total length of the grazing period. These 2 days can be used when a scheduled rotation date occurs on an inconvenient date by adding one day to each of two rotation dates. The limit of additional days is two per year resulting in a total length of 137 days. If inconvenient rotation dates occur during 3 or more times, an equal number of days greater than two must be subtracted from the grazing season, so total number of days grazed per year does not exceed 137 days. If the start date is later than 4 June, the scheduled rotation dates must remain as if the start date were on 4 June, in order to maintain the coordinated match of the partial defoliation events with the grass phenological growth stages. The total number of days grazed will be 135 days minus the number of days from 4 June to the actual start date. However, it is best to start on 1 June each year.

During the first period, partial defoliation that removes 25% to 33% of the leaf biomass from grass lead tillers between the three and a half new leaf stage and the flower stage increases the rhizosphere microbe biomass and activity, enhances the ecosystem biogeochemical processes, and activates the internal grass plant growth mechanisms. Manipulation of these processes and mechanisms does not occur at any other time during a growing season. During the second grazing period, the lead tillers are maturing and declining in nutritional quality and defoliation by grazing is only moderately beneficial to grass development. Adequate forage nutritional quality during the second period depends on the activation of sufficient quantities of vegetative secondary tillers from axillary buds during the first period. Livestock are removed from intact grassland pastures in mid October, towards the end of the perennial grass growing season, in order to allow the carryover tillers to store the carbohydrates and nutrients which will maintain plant mechanisms over the winter. Most of the upright vegetative tillers on grassland ecosystems during the autumn will be carryover tillers which will resume growth as lead tillers during the next growing season. Almost all grass tillers live for two growing seasons, the first season as vegetative secondary tillers and the second season as lead tillers. Grazing carryover tillers after mid October causes the termination of a large proportion of the population, resulting in greatly reduced herbage biomass production in subsequent growing seasons. The pasture grazed first in the rotation sequence is the last pasture grazed during the previous year. The last pasture grazed has the greatest live herbage weight on 1 June of the following season (Manske 2018a).

Stocking rates are based on peak herbage biomass on seasonlong grazing practices. The starting stocking rate on the "new" twice-over grazing practice is usually 80% to 100% of the seasonlong stocking rate. It usually requires three grazing seasons with the twice-over strategy stocked at 100% to increase the rhizosphere microbe biomass to be great enough to mineralize 100 lbs/ac of mineral nitrogen (nitrate NO_3 and ammonium NH_4). After the increased rhizosphere microbe biomass can mineralize 100 lbs/ac of mineral nitrogen, the stocking rate can be increased at 10% per year until the system is stocked at 140% of the seasonlong stocking rate. This has been the maximum biological potential reached on North American grasslands from the twice-over rotation strategy.

Once a rotation date scheduled has been determined, do not change that schedule greater than one day for any worldly reason. If you do not like your neighbors bull, build a fence that the bull cannot jump. If you have water sources that sometimes go dry, put in a water tank system on a pipeline. Fix the problems that develop with solutions that do not change the rotation schedule.

Using a three pasture twice-over rotation system activated functioning of the four primary grass physiological growth mechanisms at much higher rates during the summer grazing period of 1 June to 14 October than the performing rates on a traditional seasonlong native rangeland pasture strategy. On the twice-over rotation system, the higher functioning rates of the grass growth mechanisms increased growing season native grass herbage biomass 31.2% greater, cool season lead tiller biomass was 25.5% greater during July and secondary vegetative tiller biomass was 50.7% greater during September, warm season lead tiller biomass was 16.1% greater during August and secondary vegetative tiller biomass was 29.9% greater during September and October, stocking rate was 14.2% greater, calf weight gain per acre was 23.0% greater, and cow weight gain per acre was 46.9% greater than the productivity on the traditional seasonlong strategy (Manske 2018f).

The Fall Seasonality Period

A domesticated wildrye complementary fall pasture of Russian or Altai wildrye has not been a widely accepted practice. Wildrye are biologically different than other grasses and plant density decreases when managed with standard practices typically used with native grasses. Vegetative secondary tiller and fall tiller development of wildryes are activated by partial defoliation grazing during the fall from mid October to mid November and leaving 50% of the standing herbage biomass. Removing greater than 50% of the herbage results in harsh reductions in productivity. However, by leaving 50% residual vegetation annually, the potential herbage production can be greater than 3000 lbs/ac. Annually grazed wildryes are the only perennial grass type that provides adequate nutritional quality to meet a lactating cows requirements during fall grazing from mid October to mid November.

Using an Altai wildrye pasture during mid October to mid November and leaving 50% residual herbage biomass provided 3141 lbs/ac herbage with a mean content of 10.2% crude protein. A reserved late season native rangeland pasture provided 891 lbs/ac herbage with a mean content of 4.8% crude protein. On the Altai wildrye pasture, the vegetative reproduction by tillering and the compensatory physiological mechanisms were activated during the fall grazing period producing 252.5% greater herbage biomass, supporting a stocking rate at 191.5% greater, with calf weight gains per acre at 747.5% greater, and cow weight gains per acre at 349.8% greater than the productivity on the reserved native rangeland pasture (Manske 2018f).

Providing forage for livestock is not the only purpose for grazing grasslands. Grass plants have biological requirements and have four primary physiological growth mechanisms that must be activated by partial defoliation by grazing. Rhizosphere microorganisms are needed in large quantities to perform all of the ecosystem biogeochemical processes, but are unable to fix carbon energy and require exudated short chain carbon energy that can be provided by partial defoliation by grazing. The three indispensable biotic components of grasslands; grass vegetation, rhizosphere organisms, and domesticated livestock; must have their biological requirements provided with partial defoliation by grazing in order for grassland ecosystems to function at achievable levels.

Biologically effective management of grazing has been developed for modern high-performance beef livestock and is able to provide the biological and physiological requirements to the forage grass plants, soil microorganisms, and grazing livestock, able to activate and maintain the grass plant growth mechanisms and the ecosystem biogeochemical processes, able to revitalize soil structure, aggregation, and functionality, able to increase forage quantity and nutritional quality, and able to improve livestock growth and performance along with the capture of greater wealth per acre from renewable grassland natural resources.

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