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BERMUDAGRASS (C*YNODON DACTYLON*) RESPONSE TO SUMMER PRESCRIBED BURNING

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Abstract.–*B*ermudagrass (C*ynodon dactylon* (L.) Pers.) is one of the principle hay and forage crops throughout Texas. However, maintaining the productivity of those pastures can be challenging due to high input costs such as fertilizer and herbicide. To offset fertilizer costs and increase vegetative reproduction of bermudagrass stands, a summer prescribed burn was implemented on an irrigated bermudagrass pasture in west-central Texas. Summer fires took place on 30 July 2015 near San Angelo, Texas. Soil response to burning was measured using plant root simulator probes (PRS Western Technologies) to determine the belowground effects of a hot summer prescribed burn. Vegetative reproduction of bermudagrass was assessed by determining active, dormant, and dead vegetative buds on bermudagrass tillers. Forage quality of bermudagrass hay samples were also assessed to determine prescribed burn effects. Prescribed burning was beneficial to bermudagrass irrigated pasture. Bioavailable nitrogen (N), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), iron (Fe), manganese (Mn), zinc (Zn), and sulphur (S) increased following the prescribed burn compared to the non-burned control. Burned bermudagrass had increased bud bank activity and density compared to non-burned controls. Forage analysis also showed positive responses to prescribed burning with increases in crude protein (cp), total digestive nutrients (TDN), K, and Ca in hay forage samples compared to samples taken from non-burned controls. Prescribed burning presents a positive, inexpensive alternative to fertilizer on irrigated bermudagrass pastures. Prescribed burning offers both below-and aboveground positive effects through increased forage quality, soil fertility, and vegetative reproductive buds of bermudagrass.

Keywords: bud banks, tiller, vegetative reproduction

Bermudagrass (*Cynodon dactyon* (L.) Pers.) is one of the principle hay and forage grass crops in Texas, contributing to approximately $1,014,813,000 hay value in Texas alone (Corriher et al. 2010). Bermudagrass is an introduced warm-season perennial forage grass. It has many characteristics that make it a desirable grass for variable climates across the southeast US. Bermudagrass responds well to

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fertilizer, thrives in numerous soil conditions, tolerates heavy grazing pressure, and persists through adverse climatic conditions making it an excellent forage base for grazing or haying.

Bermudagrass, however, tends not to be productive without nutrient inputs. Usually, the most limiting nutrient in bermudagrass production is Nitrogen (N), which is vital to plants for optimum growth. Deficiencies of N appear as pale green color in the plants, very poor growth and yield, and low protein. A low-cost alternative to N fertilizer application is prescribed burning. Prescribed burning has shown to be very beneficial to both below-and aboveground properties on native rangeland specifically for perennial grasses and other research has shown positive effects on bermudagrass. For example, prescribed burning removes litter buildup and most of the nutrients are deposited on the soil surface in a form readily available for uptake by the bermudagrass (Bade 1999). Following fire, the soil surface is blackened which allows more radiant heat to be absorbed and increases soil temperatures that increase bermudagrass growth. Prescribed burning can also decrease fire-sensitive broadleaf weeds and annual grasses and clean up pastures that will later be hayed for horse producers (Bade 1999). Patterns of belowground bud development, dormancy, and mortality are important because new buds, longevity of maintained buds, and overall bud dynamics determine the size of the bud bank during the growing and dormant seasons (Ott & Hartnett 2011). The size and demography of the bud bank are considered ecological drivers in response to typical grassland disturbance processes, such as fire and grazing (Dalgleish & Hartnett 2006; Russell et al. 2013). In addition, a reserve population of dormant buds may buffer population dynamics in the face of unpredictable environmental change, such as drought or prolonged growing seasons (Ott & Hartnett 2011). By recruiting tillers from a reserve bud bank, bermudagrass can respond rapidly to environmental changes and is highly resilient following grazing, drought, fire, or other stresses.

The objective of this study is to assess below- and aboveground effects from a summer prescribed burn on overall bermudagrass dynamics. This objective will be operationalized through two hypotheses by analyzing the following variables: 1) soil nutrients, 2) bermudagrass belowground bud bank dynamics, 3) biomass production, and 4) forage quality compared to non-burned controls.

Hypothesis 1: Summer prescribed burns will increase nutrient availability and will result in an immediate flush of belowground bud bank production of bermudagrass compared to non-burned controls.

Hypothesis 2: Enhanced bud bank production from increased soil nutrients will lead to increased biomass production and forage quality compared to non-burned controls.

These hypotheses will determine the relationship between belowground dynamics of soil nutrient and bud bank pulses and aboveground forage quality and quantity following summer prescribed fire. A greater understanding of these dynamics will provide more insight into the utility of implementing prescribed fire as a tool in an intensively managed bermudagrass hay operation.

MATERIALS & METHODS

Research was conducted in irrigated bermudagrass pasture near San Angelo, Texas, USA (31.28361°N, 100.550278°W) from July 2015 through July 2016. Average annual precipitation for the area is 51 cm (20 in.), with a majority occurring from May-June and August-October. Average high temperature consists of 32°C in July and 1°C as the average low temperature in January. The frost-free growing season ranges from 228 to 237 d.

The study site is dominated by Angelo clay loams, including a complex of RioDiablo silty clay loam, and Texon-Ozona complex. Vegetation is dominated by bermudagrass, but other species present include perennial, native C_4 species including, sideoats grama

(*Bouteloua curtipendula* (Michx.) Torr.), buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus), purple threeawn (*Aristida purpurea* Nutt.), and to a lesser extent blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths). Forbs included Mexican sagewort (*Artemisia ludoviciana* Nutt.) and croton (*Croton spp.*), bundleflower (*Desmanthus* Willd.), and Engelmann's daisy (*Engelmannia* A. Gray ex Nutt.). Plant nomenclature follows the USDA PLANTS database.

Fire treatments (no fire and summer fire) were assigned to plots with three replications for 6 total, 20 × 20 m plots in a completely randomized experimental design. Summer prescribed fires were implemented on 30 July 2015. Summer burn conditions consisted of 35-37°C, 10-12% RH, with winds approximately 8-16 km/h (5-10 mph) SSW (gusts to 19-24 km/h (12-15 mph) SSW) on a 51 ha (125 acre) irrigated bermudagrass pasture. Thermocouples were also utilized during the prescribed burns to quantify actual burn conditions (Table 1). Average temperature across plots during the burn was 287 ± 12°C. Soil nutrient availability was measured 2-wks prior to the fire treatments and 24-wks following the fire treatments using Plant Root Simulator (PRS) probes (Western Ag Innovations, Saskatoon, Saskatchewan) during the 2015 and 2016 growing seasons. Four sets of probes were placed in both the burned and non-burned plots for 24-wks following fire. These probes were used in pairs to measure bioavailability of N, Ca, Mg, P, K, Fe, Mn, Zn, S, aluminum (Al), copper (Cu), boron (B), lead (Pb), and cadmium (Cd). Probes were randomly placed inside the burned plots and non-burned plots immediately following the fire treatments on 30 July 2015. Probes were inserted approximately 15-cm into the soil at random sites within plots in both treatments at 4-wk intervals.

Bud assessments were conducted monthly during the 2015 and 2016 growing seasons and early autumn. Belowground bud assessments were made from tillers that were destructively sampled, so different plants were sampled at each harvest interval. Plants visibly damaged by herbivores, insects, or pathogens were excluded

Table 1. Thermocouple measurements averaged across plots at soil surface level for summer fire treatments on bermudagrass pasture near San Angelo, Texas. Heat duration and dosage were assessed using 60°C as a base temperature. Heat duration was calculated as time (seconds) of heat greater than 60°C and heat dosage was the sum of the degrees > 60°C for each second (degree-seconds).

Summer fire	Rx Burn Characteristics
Maximum temperature (°C)	287±12
Heat duration (s)	1623±55
Heat dosage (°C · s)	27,774±621

from further measurements. Amount of active buds, dormant buds, and dead buds were classified using a dissecting microscope and confirmed using Tetrazolium and Evans Blue staining procedures as described by Busso et al. (1989).

Forage quality samples were analyzed by the Soil, Water and Forage Testing Laboratory at Texas A&M University. Samples were analyzed for crude protein, acid detergent fiber (ADF), TDN, P, K, Ca, Mg, Na, Zn, Fe, Cu, Mn, S, and B. Samples were harvested, dried, and analyzed at the end of each growing season in 2015 and 2016. Biomass was estimated by clipping all vegetation to ground level in five, randomly placed 1-m^2 quadrats within each fire treatment plot and sorted by bermudagrass. Harvested vegetation was dried at 60°C for 48-h and weighed to the nearest 0.01-g.

Data were collected prior to fire treatments and throughout 2015 and 2016 growing seasons to determine bermudagrass and nutrient supply response to fire. Analysis of variance using the statistical analysis system (general linear model procedure, SAS, Littell et al. 2006) was done within and across years for the nutrient supply data. The mean data reported are averages of years and are separated by LSD at the 0.05 level. Soil nutrient supply indices were used as response variables and the experimental unit was plot. Bud bank data were analyzed using analysis of variance (MIXED procedure of SAS, Littell et al. 2006) with tiller harvest date as a repeated measure. This model included tiller harvest date and fire as fixed effects for bud bank dynamics. Aboveground biomass was collected one and two growing seasons post-fire. Data were analyzed using generalized least squares (MIXED procedure of SAS, Littell et al. 2006) with year as a repeated measure. The model included year, fire, and all interactions as fixed effects. Biomass and forage quality indices were response variables and the experimental unit was plot. If necessary, data were log(n+1) transformed and tested for normality and equivalence of variance. Statistical significance was determined at $P < 0.05$ all sets of models.

RESULTS & DISCUSSION

The data support both hypotheses that summer prescribed burns increase soil nutrient availability, bermudagrass bud bank production, contributing to increased biomass production and enhanced forage quality. Burned bermudagrass sites had higher plant-available nutrients than the surrounding non-burned sites two growing seasons after burning (Tables 2 & 3).

Soil nutrient responses following summer prescribed fire produced a neutral or positive effect following fire. However, by the second growing season, most of the nutrients increased their availability significantly more than the non-burned control plots. Ammonium was approximately six times higher in the burned bermudagrass pasture than in the non-burned bermudagrass sites by the second growing season. Nitrate was almost 22 times higher by the second growing season on burned sites than on non-burned sites.

Bud banks belonging to the burned sites of the bermudagrass pasture were more productive throughout the first and second growing seasons post-fire (Figure 1A). Active bud production was consistently higher from the burned plots immediately following fire and continued through the second growing season. However, dormant buds were inconsistent varying their response more to phenology stage rather than a fire response (Figure 1B). Dormant bermudagrass

Table 2. Mean (± 1 *SE*) soil nutrient supply values following summer fire compared to non-burned control plots in bermudagrass pasture near San Angelo, Texas in 2015. All values are significantly different between treatments, $P < 0.05$. Multiplication factor indicates the difference (ratio) in nutrient supply values (burned sites: non-burned sites).

Bioavailable Nutrient	Non-burned plots mg/10 cm^3	Burned plots mg/10 cm^3	Multiplication factor
NO_3^--N	295.07 (114.03)	491.87 (62.34)	1.6
NH_4^+-N	0.40 (0.20)	0.47 (0.24)	1.2
Ca^{2+}	2710.97 (71.38)	2929.03 (160.47)	1.1
Mg^{2+}	179.33 (8.46)	210.30 (0.07)	1.2
K^+	41.63 (1.79)	53.93 (4.36)	1.3
$H_2PO_4^-$-P	3.70 (0.44)	8.34 (1.22)	2.3
Fe^{3+}	6.87 (0.47)	7.13 (0.26)	1.0
Mn^{2}	2.09 (0.15)	2.11 (0.07)	1.0
Cu^{2+}	0.44 (0.04)	0.69 (0.13)	1.6
Zn^{2+}	0.45 (0.05)	0.85 (0.28)	1.9
$B(OH)_4^-$-B	0.34 (0.02)	0.59 (0.08)	1.7
SO_4^--S	111.90 (15.89)	119.71 (5.39)	1.1
Pb^{2+}	1.26 (0.19)	1.34 (0.26)	1.1
Al^{3+}	9.25 (0.71)	12.75 (1.24)	1.4
Cd^{2+}	0.10 (0.02)	0.17 (0.04)	1.8

buds tended to increase dormancy of their belowground reserves during the early fall of both 2015 and 2016.

Forage quality and biomass were significantly greater on burned sites of the bermudagrass pasture (Table 4). Crude protein increased by 51% or more following summer fires compared to the non-burned control samples. Aboveground biomass increased approximately 37% the first growing season and continued to increase by 60% in production after the second growing season following fire. Every indicator of forage quality tested, produced an overall positive or neutral response to fire by the end of the first growing season following a summer prescribed burn.

Table 3. Mean (±1 *SE*) soil nutrient supply values following summer fire compared to non-burned control plots in bermudagrass pasture near San Angelo, Texas in 2016. All values are significantly different between treatments, $P < 0.05$. Multiplication factor indicates the difference (ratio) in nutrient supply values (burned sites: non-burned sites).

Bioavailable Nutrient	Non-burned plots mg/10 cm^3	Burned plots mg/10 cm^3	Multiplication factor
NO_3^--N	18.02 (0.44)	395.07 (64.03)	21.9
NH_4^+-N	0.20 (0.20)	1.26 (0.04)	6.3
Ca^{2+}	1110.97 (71.33)	3176.90 (26.38)	2.9
Mg^{2+}	119.33 (8.46)	214.84 (2.24)	1.8
K^+	19.63 (1.79)	53.70 (2.35)	2.7
$H_2PO_4^-$-P	1.17 (0.42)	10.17 (0.89)	8.7
Fe^{3+}	1.61 (0.37)	9.27 (0.47)	5.8
Mn^2	1.09 (0.15)	4.92 (0.64)	4.5
Cu^{2+}	0.14 (0.03)	0.87 (0.02)	6.2
Zn^{2+}	0.25 (0.05)	1.36 (0.07)	5.4
$B(OH)_4^-$-B	0.16 (0.02)	0.20 (0.02)	1.3
SO_4^--S	41.90 (15.99)	122.16 (12.26)	2.9
Pb^{2+}	0.46 (0.19)	1.60 (0.14)	3.5
Al^{3+}	2.25 (0.71)	11.35 (0.98)	5.0
Cd^{2+}	0.06 (0.02)	0.09 (0.01)	1.5

Summer prescribed fire on coastal bermudagrass pasture near San Angelo, Texas provided neutral or positive belowground and aboveground effects after the first growing season following fire. By the second growing season post-fire, most belowground and aboveground effects were still significantly greater on burned sites compared to non-burned sites.

Many grass species are protected against intense heat from fire by storing resources in belowground meristems that are well-protected and insulated by soil (Wright & Bailey 1982). Belowground reserves of meristematic tissue, or axillary buds, allow for vegetative reproduction to replace older or dead tillers. This process of vegetative reproduction is self-reinforcing, where growth responses determine future plant community composition and the intensity and

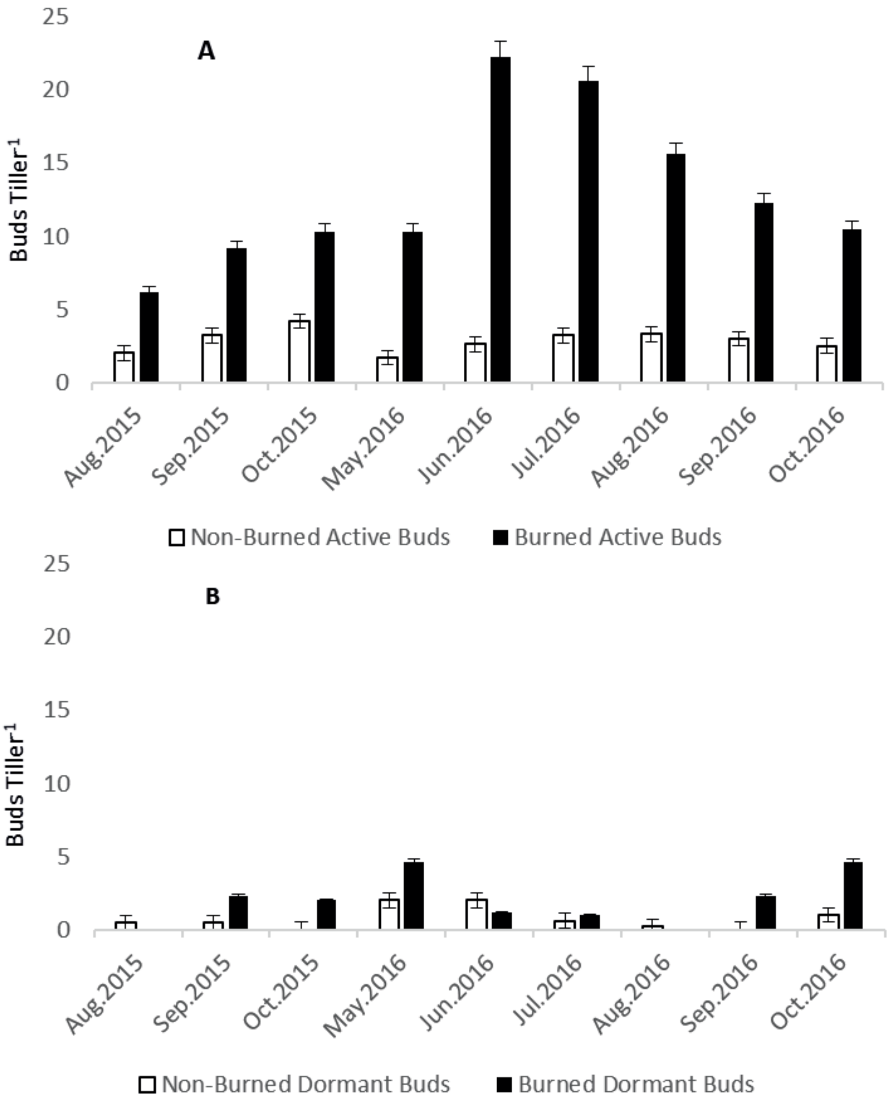

Figure 1. A comparison of A) active bermudagrass buds from non-burned and summer burned plots and B) dormant bermudagrass buds from non-burned and summer burned plots for two growing seasons near San Angelo, Texas. Error bars represent one standard error.

Table 4. Forage quality and biomass estimates comparing non-burned to summer fire on bermudagrass at the end of 2015 and 2016 growing seasons near San Angelo, Texas. All values are significantly different between treatments, $P < 0.05$. Multiplication factor indicates the difference (ratio) in nutrient supply values (burned sites: non-burned sites).

	2015			2016		
	Non-burned	Burned	Multiplication Factor	Non-burned	Burned	Multiplication Factor
Biomass (lb/acre)	1312	3502	2.9	2221	3703	3.4
CP (%)	7.8	10.2	1.3	6.4	12.6	2.0
ADF (%)	31.8	30.2	1.0	30.3	34.3	1.1
TDN (%)	59.7	61.8	1.0	50.2	78.3	1.6
P (%)	0.1	0.2	1.3	0.1	0.2	1.6
K (%)	1.4	1.5	1.1	1.0	2.0	2.0
Ca (%)	0.3	0.4	1.4	0.1	0.6	5.6
Mg (%)	0.1	0.1	1.5	0.2	0.5	2.1
Na (ppm)	117	160	1.4	140	169	1.2
Zn (ppm)	14	20	1.4	16	22	1.4
Fe (ppm)	101	167	1.7	85	148	1.7
Cu (ppm)	18	21	1.2	12	20	1.7
Mn (ppm)	50	67	1.3	40	55	1.4
S (ppm)	3614	3763	1.0	3154	3162	1.0
B (ppm)	2	4	2.2	3	3	1.1

frequency of future fires (Pyne 1982). Coastal bermudagrass is highly sterile (Burton 1947), therefore, vegetative regeneration is the driver of aboveground production and growth. Results indicate buds of Coastal bermudagrass will survive a summer prescribed burn and regenerate growth. Therefore, the belowground bud bank is the primary source of recruitment for new tillers. By recruiting tillers from a bud bank, perennial grasses are able to respond rapidly to their environment and are highly resilient following grazing, drought, fire, or other stresses (Russell et al. 2015). The immediate positive bermudagrass bud bank response reveal buds are the mechanism responsible for rapid, future growth. Research has shown that bud banks play an important role in aboveground vegetation dynamics in grassland systems. For example, patterns of plant abundance and productivity associated with fire, grazing and climatic variability are mediated through the bud bank (Benson & Hartnett 2006; Russell et al. 2017). Furthermore, decreased bud bank densities lead to decreased aboveground productivity of perennial native grasses allowing invasions by exotic species (Dalgleish & Hartnett 2006).

Although no previous studies have looked at fire effects in bermudagrass from a belowground perspective, previous research using the same PRS soil nutrient probes showed that fire on Northern Great Plains rangelands increased soil N, P, and Zn but had no effect on eight other soil nutrients (Reinhart et al. 2016). Fire effects on soil chemistry are also likely to depend on fire intensity (Raison 1979). Fires often increase short-term availability of residual soil N (Wan et al. 2001) and P (Raison 1979; Cui et al. 2010; Schaller et al. 2014). Yet intense fires will more fully combust biomass and volatilize nutrients (Certini 2005), especially N (Raison 1979). Thus, varying fire intensities may produce a spectrum of effects on soil chemistry.

An additional Texas study conducted in 1987 in Falls County on a 60-ha pasture of coastal bermudagrass found similar positive and/or neutral effects to winter burning (Bade 1999). Their results showed that winter burns increased grass production by 143%, while decreasing weed production by 96%. A 4% increase in crude protein, a 2% increase in TDN, and a slight increase in the mineral content (Ca, P, K, Mg) of the forage was observed in the burned portion of the pasture.

CONCLUSIONS

Prescribed burning will remove excess dead forage and allow the soil to warm earlier promoting faster green-up in the spring, destroy some insects, winter weeds, and weedy grasses. The disadvantages of burning include fire hazards, removing stubble which protects the grass from late freezes, and potentially allowing more soil erosion. However, prescribed burning represents a management strategy that promotes both belowground and aboveground renovation and production of coastal bermudagrass systems in West-Central Texas. This research study shows that prescribed burning ecological effects are numerous and complex. Fire can manipulate soil nutrient dynamics, forage quality, and biomass production, which potentially may benefit grazing animal performance and production. However, given the variability associated with fire intensity, it can be extremely challenging to interpret or predict soil nutrient pulses on both direct and indirect effects on plant biomass. Prescribed burning in mid-summer is shown to provide production benefits to bermudagrass at this site, but further research is needed to understand the consequences of prescribed burn timing, frequency, and intensity on bermudagrass.

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