GRAZING EFFECTS ON FORBS FOR WHITE-TAILED DEER AND PLANT SPECIES RICHNESS

A Thesis

by

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ABSTRACT

Grazing Effects on Forb for White-tailed Deer and Plant Species Richness

(AUGUST 2020)

Dillan Joseph Drabek, B.S., Texas A&M University-Kingsville

Chairman of Committee: J. Alfonso Ortega-S., Ph.D.

Cattle (Bos spp.) grazing has been recommended as a tool to improve wildlife habitat, but available results are inconclusive and sometimes contradictory. Forbs are an important part of a white-tailed deer (*Odocoileus virginianus*) diet. Consumption of grass by cattle can potentially confer a competitive advantage to forbs resulting in increased forb standing crop. Forb standing crop is also strongly influenced by rainfall and soil properties. My objectives were to: 1) determine the relationship between grass disappearance resulting from herbivory and forb standing crop on the East Foundation ranches located in the Jim Hogg, Kenedy, Starr, and Willacy counties; and 2) determine how large ungulate grazing affected plant species richness. To evaluate cattle grazing effects on grass and forb standing crop and composition, I selected six 2,500 ha study sites located on the East Foundation ranches in south Texas. Fifty 1.5-m^2 grazing exclosures were randomly placed in each of the six study sites. During the autumn growing season, I sampled vegetation within exclosures and at an outside paired point. I then stored the collected samples in a portable drying room trailer maintaining a temperature of 45^{o} C, to obtain the dry mass (kg). Under the conditions this study was conducted grazing had little effect on forbs for deer. Forb standing crop was optimized (666 kg/ha) with no August rainfall and abundant September rainfall in areas with high sand percentages (90%). I found that grazing herbivores avoided low productive sites (<562 kg/ha) and models showed that grazing use was an influence in forb production, but rainfall and sand were more important. Plant species richness was affected by grazing use more than abiotic factors in the reduced data set. My results were strongly influenced by the legacy effect of decades of overgrazing and severe drought during 2011 to 2013. Within the time frame of my study, precipitation and sand percentage were more important drivers of forb dynamics than herbivores.

DEDICATION

I would like to dedicate this thesis and all academic achievements I have had throughout my career to my family. Without there continued support and love I do not know where I would be without them. Thank you Ronald Drabek, Carlette Drabek and Charlie Kubesch for being there for me through the hard times, your faith, and helping me to achieve my goals. To my sisters, Jennifer and Abegayle Drabek, your encouragement, guidance, and support has been forever grateful in this journey. Your success Jennifer has helped myself keep fighting until I pursue my goal. Abegayle keep excelling to fulfill your dreams and I am deeply proud of you of all your accomplishments. Thank you Amber Novosad for pushing me to my limits, being supportive, loving, and being a big part of my heart throughout my college career. Uncles, aunts, and cousins thank you for always giving me praise and encouragement in finishing and continuing to pursue my dreams.

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Grazing Effects on Forbs for White-tailed Deer and Plant Species Richness

Background

In past observations from 1855, the South Texas Plains where my study was conducted was described as an open grassy plain with low, stunted brush (Inglis 1964). This area is now dominated by dense brush. The grazing history is to understand how past herbicide treatments, grazing strategies, or plants in that area had been affected (Milchunas et al.1988, Cohen et al. 1989, Gofu 2001). Past grazing could affect the vegetation community, and the above ground net primary production (ANPP) in an area (Milchunas 1988). Studies should be conducted for several years to get valid information on the effects of herbivory.

Grazing utilization is the proportion of forage that is consumed or removed by grazing animals during the growing cycle of the plant (Green and Brazee 2012). The goal in grazing management is to leave sufficient forage to preserve the soil and maximize plant vigor (Lyons and Machen 2001). In some cases, cattle grazing may compete with other animals such as white-tailed deer (*Odocoileus virginianus*). Grazing intensity may be consistently increased, leading to competition between cattle and white-tailed deer for forbs, browse, and graminoids (Armstrong 1997, Fulbright and Ortega 2013. Ortega et al. 1997). Other researchers have found that grazing herbivores can influence abundance of forbs by reducing the amount of graminoids.

This chapter follows the formatting for Rangeland Ecology and Management

Ortega et al. (1997) reported on the Welder Wildlife Refuge that if you maintain the rangeland at moderate stocking density (1 AU/4.9 ha/yr.), it can positively influence plants consumed by the white-tailed deer. The East Foundation, where this study takes place, uses regional grazing paradigms of high stocking rate (1 animal unit [AU]/14 ha) and moderate (1 AU/20 ha) (Montalvo et al. 2020). Fulbright and Ortega (2013) mentioned that at intermediate levels of grazing, (moderate level of disturbance) plant species richness increased. Understanding grazing utilization may assist in gaining knowledge of range conditions for optimum wildlife habitat.

The grazing optimization hypothesis (Figure 1) indicates that annual net primary productivity (ANPP) is maximized at some optimum grazing level (Hilbert et al. 1981). This relationship is described by a bell-shaped curve where maximum net primary productivity (NPP) occurs with intermediate levels of grazing, but the gradient declines rapidly beyond the peak moderate grazing level.

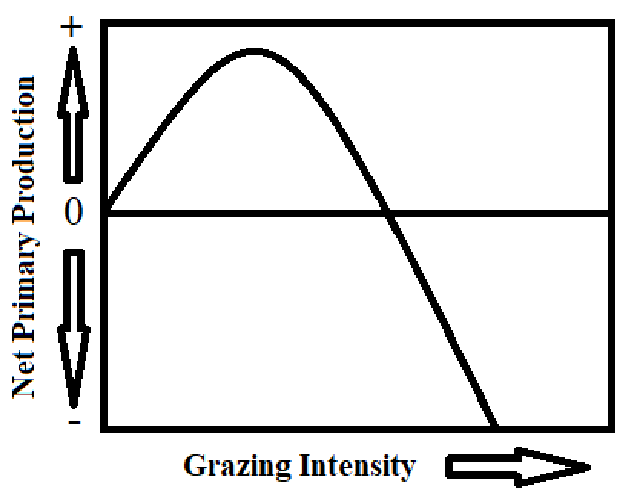

Figure 1. Potential response of net primary production of plants with increasing grazing intensity by herbivores (Hilbert et al. 1981).

The intermediate disturbance hypothesis predicts a bell-shaped response of species' richness goes along a grazing intensity gradient (Milchunas et al.1988**).** This model displays how intermediate grazing intensity can increase plant production during the right conditions. Competition among other plants and animals does not necessarily mean that this intermediate disturbance can be beneficial all of the time (Milchunas et al.1988). Competition among plants is one of the most important mechanisms in vegetation succession stages, and the dominant community phylogeny present in that area then began to emerge (Bestelmeyer et al. 2003, Weigelt et al. 2000). Grazing as a disturbance could set back succession and prevent progression to a stage further (Bestelmeyer et al. 2003, Leopold et al. 1986). Overgrazing and drought could be potential factors for transitioning a plant community throughout time.

Important abiotic and biotic factors that affect plant production include grazing, precipitation, and soil. Legacy effect on rangelands through the history of grazing herbivores may influence plant community aspects present today. Dominance of a certain plant species over another can result from the response to herbivory (Milchunas et al.1988). Grazing can have a positive effect on an area through nutrient cycling, trampling, or wallowing (Milchunas et al. 1988). Grazing also may increase forb abundance and production for white-tailed deer under intermediate disturbances (Fulbright and Ortega 2013, Holechek et al. 1982). Maintaining or increasing plant diversity is one of the most important goals to habitat managers in semi-arid environments (Fulbright and Ortega 2013, Oba et al. 2001). Plant species richness can increase with moderate grazing intensities but may decline rapidly under heavy grazing pressure (Fulbright and Ortega 2013). Diet overlap can even occur between white-tailed deer and cattle at times of the year when forbs are more abundant than grasses or browse species and vice versa. (Fulbright and Ortega 2013).

Forbs play a key role in the diet of white-tailed deer, since forbs provide energy for productive processes (Gallina 1993). Sandy soils and rainfall patterns affect forb productivity, and peak forb growth may occur in the fall (Drawe and Box 1968). With heavy grazing, diet overlap between cattle and deer occurred and forb consumption by cattle was higher in these areas (Ortega et al. 1997, Thill and Martin 1989). The hump-backed model is commonly used to relate plant species richness with a range of standing crop, maintaining the balance of species richness, diversity, and composition (Smith and Rushton 1994). Tracy and Faulkner (2006) speculate that high plant species richness in pastures can be difficult to measure since some species tend to decline in abundance more often than others.

During drought conditions and heavy grazing, a higher probability of competition between white-tailed deer and cattle can develop (Fulbright and Ortega 2013). Determining the correct stocking rate is necessary to ensure forage production and nutrients for wildlife (Fulbright and Ortega 2013, Ortega et al. 1997). White-tailed deer may move up to 2 km from an area where cattle are being heavily grazing or concentrated (Cooper et al. 2008). Being able to maintain intermediate disturbance to an area and concentrations of grazing herbivores may help improve the white-tailed deer habitat.

Many researchers have found that seasonal precipitation has a great influence on aboveground forage production (Abdel-Magid et al. 1987, Patton et al. 2007, White 1985, Yan et al. 2015). The water accessible for plant growth is found in the upper layers of the soil and may contain the precipitation accumulated from the previous year's growing season (Patton et al. 2007). Prior year precipitation has a major impact of the next years forage production. Temporal patterns, such as seasonal precipitation, have a stronger influence than total quantities of precipitation in arid and semi-arid ecosystems (Yan et al. 2015). Yan et al. (2015) found that annual and growing season precipitation was positively correlated with plant species richness.

Precipitation has a great influence on seed germination, seed bank, and aboveground forage production during succeeding.

Plant-soil feedback influences the performance of a broad range of plant species over relatively long-term scales and is generally consistent across a wide range of soil conditions (Harrison and Bardgett 2010). Abiotic factors also had an important role in microbial production, nutrient cycling, and plant production (Harrison and Bardgett 2010). Stochastic rainfall is common in south Texas rangelands and helps enhance the water movement through stages of the plants growing cycles.

My objective was to assess the influence of grazing utilization on white-tailed deer preferred forb standing crop and plant species richness during the fall growing season (2012-2019). My specific objectives were to: 1.) determine the relationship between grass disappearance resulting from herbivory and forb standing crop on the East Foundation ranches located in the Jim Hogg, Kenedy, Starr, and Willacy counties; and 2.) determine how large ungulate grazing affected plant species richness. I hypothesized that standing crop of forbs would increase with increasing cattle grazing utilization, with forbs preferred by white-tailed deer increasing up to some moderate level of utilization and forbs not preferred by deer increasing up to a higher than moderate level of utilization, and then decline with increasing utilization.

Methods

Study Area

My research occurred on four ranches of the East Foundation, an Agricultural Research Organization that promotes the advancement of land stewardship through ranching, science, and education. Six study sites of 2500 ha each were selected on the East Foundation properties (Figure 2). These study sites are in the Wild Horse Desert, which includes the Tamaulipan Thorn scrub, Laguna Madre Barrier Islands & Coastal Marshes, Rio Grande Valley, and Coastal Sand Plains ecoregions (East 2007) . Three study sites were located on the north (SAV site #1), central (SAV site #2), and southern (SAV site #3) area of the San Antonio Viejo Ranch (SAV) (60,034 ha) which was in Jim Hogg and Starr counties. The other 3 sites were located on the Buena Vista Ranch (BV) (6,113 ha) in Jim Hogg County, the Santa Rosa Ranch (SR) (7,544 ha) in Kenedy County, and the El Sauz Ranch (EELS) (10,984 ha) located in Willacy and Kenedy counties. The ELS consists of active sand dunes, live oak (*Quercus virginiana)* mottes, and saline sub-tropical to semi-arid habitats. Santa Rosa Ranch also contains live oak mottes. Most of the other areas (SAV & BV) are rolling sand plains and some caliche soils containing black brush (*Acacia rigidula)* and mesquite (*Prosopis glandulosa*) with an undergrowth of diverse browse species.

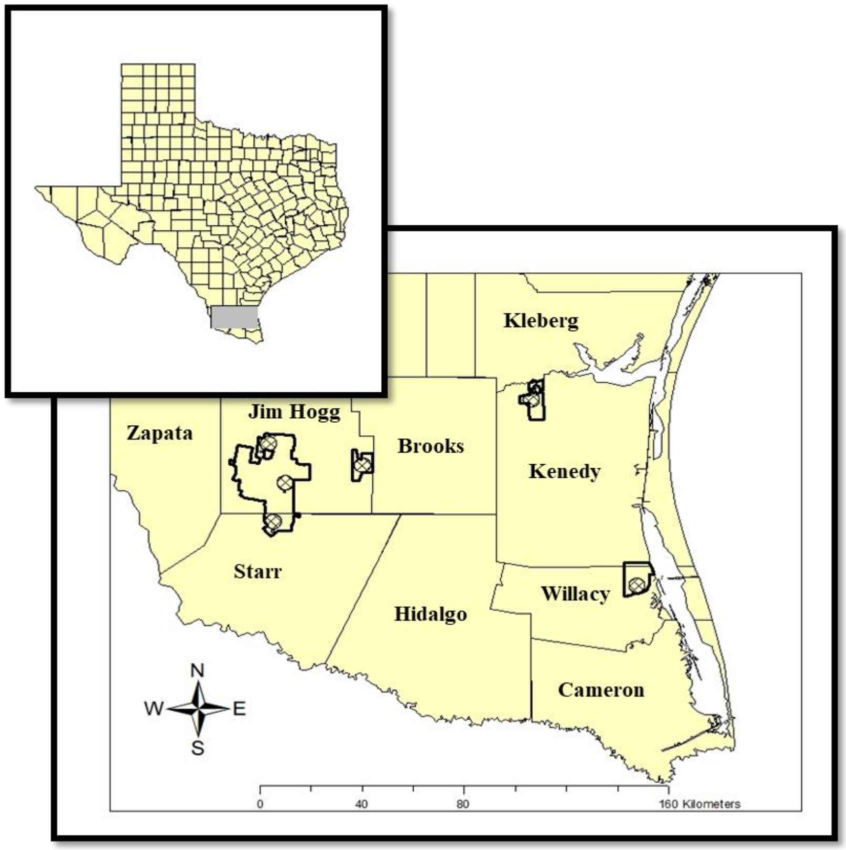

Figure 2. Location of the four ranches of the East Foundation where the study sites were located during 2012-2019.

Rainfall in south Texas is irregular. Most of the rainfall occurs during May-June, and September-October, and a moderate amount during July-August (Fulbright et al. 1990). Table 1 shows the monthly rainfall totals in the study sites. During the autumn months, seed establishment occurs. Rainfall most likely increases the seed bank for the perennial forage that would sprout during the autumn months. An average yearly rainfall of 46 to 70 cm is prominent for the region.

Table 1. Mean monthly rainfall (cm) during 2011-2019 among all study sites.

	January	February	March	April	May	June	July	August	September	October	November	December	Total
2011	4.4	0.2	0.9	0.0	2.4	5.4	3.4	0.5	3.8	2.8	0.2	4.9	28.9
2012	0.6	8.4	3.3	3.3	6.5	1.2	6.4	2.2	5.5	0.8	2.3	0.2	40.7
2013	3.9	0.5	0.0	5.8	10.6	2.6	3.1	2.4	16.8	1.3	4.5	5.3	56.6
2014	1.8	1.0	5.0	0.3	7.3	2.8	2.4	5.9	19.5	3.0	11.0	3.3	63.3
2015	3.5	3.0	12.0	12.4	12.3	8.2	1.1	2.4	8.4	17.2	2.7	1.2	84.5
2016	5.7	0.0	7.8	1.7	9.6	10.1	1.4	11.3	5.7	1.5	4.6	4.5	58.2
2017	1.5	2.7	9.9	4.0	6.6	5.4	2.2	4.9	2.6	4.1	2.8	6.7	53.3
2018	1.6	1.5	1.1	2.4	2.7	23.9	0.8	1.4	29.2	6.4	3.1	3.4	77.6
2019	2.8	0.7	2.5	5.2	5.5	7.3	3.3	1.0	10.3	2.6	6.0	1.8	49.0

Dominant soils series at the 6 study sites include: Nueces-Sarita association, Delmita, Comitas, Galveston, Mustang, Palobia, Sauz, Yturria, Copita, McAllen, and Zapata (Hines 2016). Using the USDA textural class, 81% of the sampling points were classified as being in a sandy soil (>85% sand); 14% of the sampling points located in a loamy sand (between 70%-85% sand); and the remaining 5% of sampling points were found to be in sandy loam soil (52%-70% sand). The SAV site #1 had 100% of the sampling points in sandy soils; site #2 had 86% of the sampling points in sandy soil and 14% of the sampling points in loamy sand; and finally at site #3, 16% of the sampling points were found in sandy soils, 62% in loamy sand, and 22% in sandy loam soils (Figure 3). The BV study site had 96% of the sampling points in sandy soils, 2% in loamy sand, and 2% in sandy loam. In the SR study site, 100% of the sampling points were found in a sandy soil. Lastly, in the EELS study site 88% of the sampling points were found in the sandy soil, 8% in the loamy sand, and 4% in a sandy loam soil.

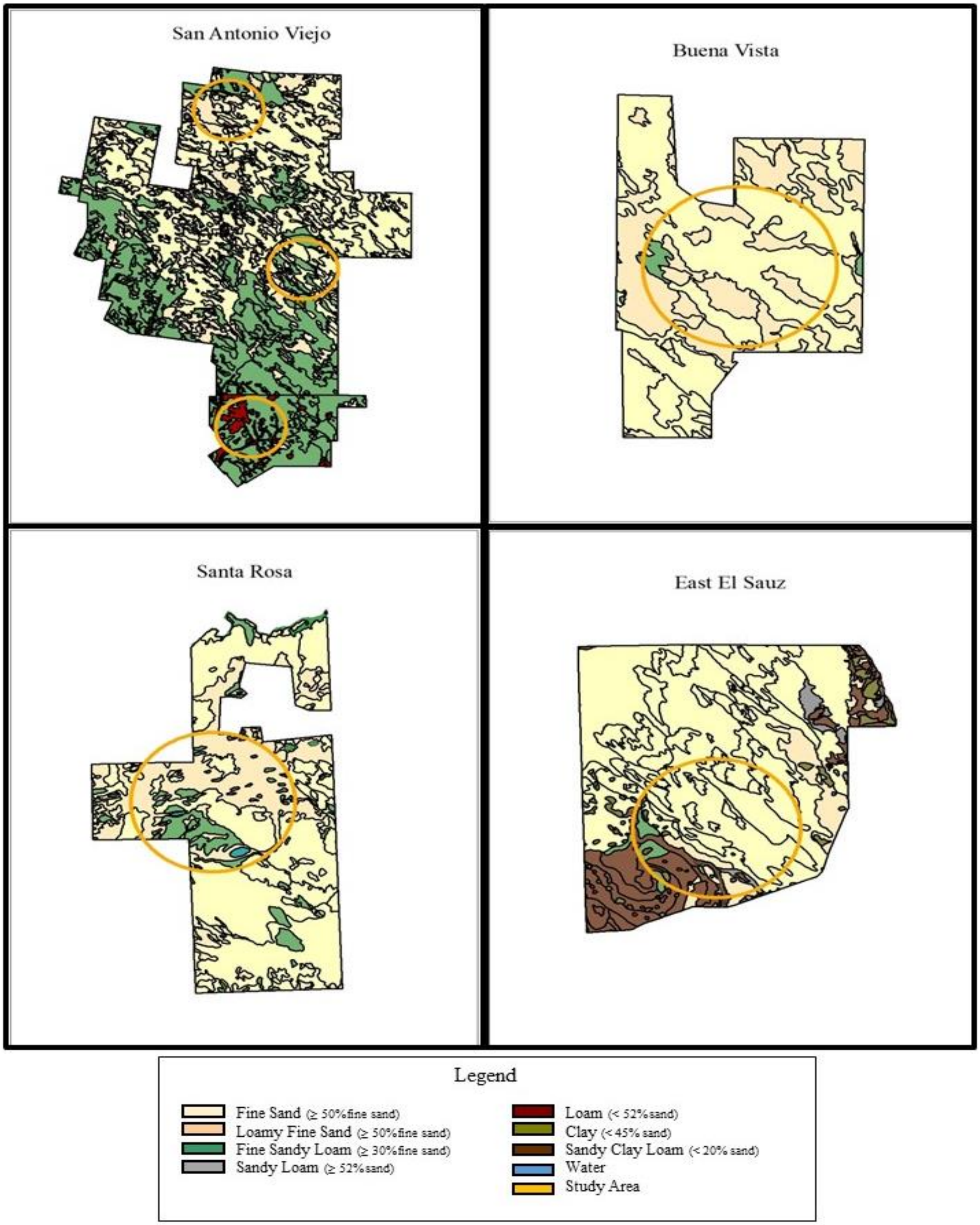

Figure 3. Soil series of all the ranches and corresponding study sites used.

Data Collection

I used 50 grazing exlosures that were randomly allocated using ArcMap GIS (Geographic Information System) software, 100 m apart from each other, in each one the six 2500 ha study sites from 2012. Beginning in 2013, the exclosures were moved annually corresponding to a specific random cardinal direction (North, East, South, West) generated from the function RANDBETWEEN in Excel. The exclosures were constructed from 4 six-gauge wire cattle panels (1.5 m × 1.5 m) wired together to prevent collapsing and secured with a t- post in each corner. At least 10 m from each grazing exclosure, to allow adequate distance for possible vegetation trampling that might occur from curious cows inspecting the exclosure, I marked a paired point with a t-post. The paired point was for measurement of forage where large herbivores could graze to show availability of the forage that was consumed by grazing herbivores had similar percentages of plant species and bare ground, and similar distribution of vegetation. Using the difference in forage standing crop of the exclosure and the paired point, I determined the disappearance of grasses and forbs during the autumn since peak plant productivity happens during this time (Fulbright and Ortega 2013).

During autumn, I estimated the forage standing crop and species richness of grasses and forbs in the exclosure and the paired point. A 0.25-m^2 PVC frame was placed within the center of the exclosure and used hand pruners to clip the forage at ground level to estimate forage standing crop (kg/ha) and determine percentages of the plants and plant species richness. The north cardinal direction was always clipped at the paired point. Plant species richness was measured at plot-scale (number of species per 0.25-m^2). The difference in number of species found inside the exclosure and outside paired point was included in the data set. The clipped forbs and grasses were separated in the following categories; grass, preferred forbs, and non-preferred forbs. Preferred forbs and non-preferred forb species for white-tailed deer was identified from research by Hines 2016. Not all shrub seedlings were collected in the bags, but rather recorded in the notes section and a written percentage of the shrub species cover found in the sampling frame. After the autumn sampling, exclosures were moved each year at least 10 m away from the previous location, so that the destructive method of clipping would not be a factor. The paired point was moved as well. Lastly, the new areas were marked in the GPS (Global Positioning System) to be located the next sampling season.

The clipped forage from inside the exclosure and the outside paired point was separated into preferred forbs, non-preferred forbs, and grasses and placed in paper bags and dried at 45°C in a portable drying room trailer. I then recorded the dry weight of each sample from the exclosures and the paired points to the nearest 0.1g (Multi-Purpose Compact Bench Scale, Ranger 3000, Ohaus Corporation). I used the recorded values of forage standing crop in the exclosure and the paired point during that season to determine percent utilization and forage disappearance. I determined plant species richness inside of the exclosures and the paired points.

I used historical rainfall records from PRISM Climate Data for all locations. The rainfall records that I used were from 2012-2019 in the months of August through November, since these months were more influential towards forb standing crop. The rainfall measurements (millimeters) were used to determine which months and amount of rainfall were important for forage standing crop and plant species richness.

Statistical Analyses

Since the main objective of the study was to determine the effect of grazing (grass disappearance) on forbs for deer, I excluded all negative values of grass utilization (grass standing crop inside of the exclosure – grass standing crop outside of the exclosure). Considering, that the areas with negative utilization were low productivity sites that herbivores did not graze, these values was excluded from the data set. The negative values was derived from when forage standing crop was more outside the exclosure than inside. Therefore, for the analysis I used a reduced data set, which included all data with positive values of grass disappearance, and the complete data set.

I used three hundred randomly allocated cattle exclosures and paired plots per year to determine how white-tailed deer preferred forb standing crop was affected by grazing herbivores. To determine this, I first calculated forage standing crop for preferred forbs, non-preferred forbs, and grasses. I included abiotic factors such as soil (sand percentage), August through November precipitation (mm), Palmer Drought Severity Index (PDSI), and Keetch-Byram Drought Index (KBDI) at each location.

I used a complete data set and reduced data set to determine if there was any difference in variables that impacted forage standing crop of forbs. From the complete data set, I was able to calculate forage standing crop (kg/ha) for grasses (Table 2), preferred forbs (Table 3), and non-preferred forbs (Table 4) among study sites throughout all the years (2011-2019). The tables shown helps identify the most productive and least productive years during the years of the study.

I used an analysis of variance (ANOVA) and PROC RSREG in SAS to assess relevant models (<2 delta AICs) and which variables influenced forage standing crop with 85% confidence intervals (CI). 85% confidence intervals were used to include variables that may have been influential in the models that were tested so that model-selection and parameter-evaluation

Table 2. Average grass standing crop (kg/ha) among study sites throughout the years (2012-2019). Study sites are labeled as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	2012 In	2012 Out	2013 In	2013 Out	2014 In	2014 Out	2015 In	2015 Out	2016 In	2016 Out	2017 In	2017 Out	2018 In	2018 Out	2019 In	2019 Out
1	755 ± 146	252 ± 74	386 ± 84	189 ± 48	1 155 ± 128	882 ± 90	1380 ± 153	1328 ± 149	1391 ± 180	1018 ± 46	508 ± 116	306 ± 72	326 ± 48	519 ± 74	590 ± 87	469 ± 67
2	263 ± 47	17 ± 5	209 ± 45	134 ± 26	564 ± 81	426 ± 121	1767 ± 245	1105 ± 197	1942 ± 500	839 ± 122	352 ± 71	136 ± 25	699 ± 140	551 ± 86	512 ± 87	535 ± 119
3	1 346 ± 499	336 ± 104	1 039 ± 192	577 ± 111	1 186 ± 161	1 033 ± 171	3044 ± 512	2317 ± 524	2027 ± 318	1169 ± 244	1451 ± 218	694 ± 165	1203 ± 209	1044 ± 270	898 ± 113	524 ± 122
4	177 ± 49	71 ± 16	178 ± 53	77 ± 30	803 ± 126	512 ± 82	1871 ± 227	1092 ± 191	1422 ± 153	522 ± 88	1253 ± 141	616 ± 78	948 ± 116	581 ± 75	1115 ± 131	726 ± 120
5	412 ± 75	61 ± 12	521 ± 94	253 ± 50	2 240 ± 236	1 514 ± 220	1313 ± 180	1220 ± 180	1416 ± 203	854 ± 129	404 ± 65	309 ± 55	1107 ± 146	975 ± 166	549 ± 67	649 ± 81
6	801 ± 140	209 ± 40	912 ± 138	371 ± 77	1 716 ± 194	638 ± 77	1986 ± 359	1047 ± 194	1632 ± 164	868 ± 129	1117 ± 317	776 ± 166	1204 ± 143	731 ± 100	906 ± 164	738 ± 114

Table 3. Average preferred forb standing crop (kg/ha) among study sites throughout the years (2012-2019). Study sites are labeled as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	2012 In	2012 Out	2013 In	2013 Out	2014 In	2014 Out	2015 In	2015 Out	2016 In	2016 Out	2017 In	2017 Out	2018 In	2018 Out	2019 In	2019 Out
1	129 ± 17	82 ± 18	256 ± 34	252 ± 94	591 ± 65	476 ± 51	235 ± 41	219 ± 41	159 ± 35	94 ± 27	39 ± 26	10 ± 5	393 ± 60	376 ± 57	84 ± 25	97 ± 20
2	136 ± 25	37 ± 10	263 ± 57	202 ± 32	278 ± 36	208 ± 26	258 ± 50	198 ± 44	84 ± 18	39 ± 10	94 ± 26	54 ± 12	452 ± 76	310 ± 54	140 ± 27	152 ± 36
3	34 ± 20	11 ± 10	82 ± 34	29 ± 18	52 ± 18	44 ± 13	24 ± 16	10 ± 6	3 ± 3	8 ± 5	4 ± 1	8 ± 5	93 ± 32	75 ± 23	30 ± 13	7 ± 7
4	67 ± 15	27 ± 8	346 ± 58	197 ± 39	764 ± 96	806 ± 123	458 ± 82	217 ± 63	47 ± 16	52 ± 25	163 ± 26	100 ± 0	278 ± 52	299 ± 65	239 ± 35	184 ± 40
5	272 ± 81	34 ± 16	502 ± 135	289 ± 59	480 ± 200	297 ± 48	218 ± 64	99 ± 31	271 ± 69	65 ± 25	49 ± 17	7 ± 3	127 ± 38	97 ± 32	92 ± 26	109 ± 27
6	101 ± 28	91 ± 21	498 ± 77	508 ± 115	418 ± 63	498 ± 97	144 ± 47	141 ± 52	217 ± 44	156 ± 67	146 ± 40	206 ± 94	332 ± 107	241 ± 56	200 ± 56	187 ± 41

Table 4. Average non-preferred forb standing crop (kg/ha) among study sites throughout the years (2012-2019). Study sites are labeled as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	2012 In	2012 Out	2013 In	2013 Out	2014 In	2014 Out	2015 In	2015 Out	2016 In	2016 Out	2017 In	2017 Out	2018 In	2018 Out	2019 In	2019 Out
1	196 ± 38	134 ± 25	73 ± 30	56 ± 21	42 ± 13	167 ± 55	254 ± 60	204 ± 63	99 ± 46	122 ± 66	27 ± 25	75 ± 51	138 ± 55	150 ± 56	35 ± 19	14 ± 8
2	312 ± 61	190 ± 34	119 ± 34	129 ± 38	12 ± 11	43 ± 32	181 ± 35	177 ± 42	78 ± 22	46 ± 10	62 ± 15	42 ± 9	56 ± 17	82 ± 32	16 ± 11	8 ± 8
3	0	0	0	0	44 ± 37	0	5 ± 3	29 ± 29	1 ± 1	12 ± 12	5 ± 5	2 ± 1	0	8 ± 8	0	8 ± 8
4	146 ± 30	88 ± 21	588 ± 83	520 ± 67	91 ± 33	75 ± 21	297 ± 65	206 ± 50	108 ± 16	104 ± 22	110 ± 27	162 ± 26	34 ± 16	89 ± 72	6 ± 3	17 ± 8
5	109 ± 31	48 ± 19	614 ± 110	396 ± 73	73 ± 40	77 ± 51	83 ± 32	67 ± 47	118 ± 28	126 ± 41	36 ± 17	39 ± 13	96 ± 28	101 ± 28	16 ± 12	31 ± 12
6	326 ± 129	204 ± 66	688 ± 179	443 ± 74	265 ± 77	185 ± 52	330 ± 196	81 ± 44	257 ± 67	249 ± 62	182 ± 43	110 ± 13	499 ± 80	487 ± 92	224 ± 80	178 ± 71

criteria would coincide with each other (Arnold 2010). I used PROC GLM to analyze important interactions from covariates that affected the response variable. I used response surface methodology to develop a model to predict forage standing crop of different vegetation components. The variables that were included in in the complete models included rainfall (October through November), drought indices (PDSI & KBDI), sand percentage, and grazing utilization (forage disappearance). I used Plotly Chart Studio to develop a three-dimensional model to produce a humpback plot to "show" the peak forb standing crop.

I determined how grazing herbivores, soil, and rainfall affected plant species richness. Species richness was the total number of plant species found in the exclosures and the paired points. I used analysis of variance and PROC RSREG in SAS to determine the best model (<2 delta AICs) and which variables influenced plant species richness. In the graphs, grass disappearance (kg/ha) was converted to herbivore percent use.

Results

Forb Standing Crop (complete data set)

September rainfall ($\hat{\beta}$ = 0.00404, 85% CI: 0.00252 to 0.00555; standardized $\hat{\beta}$: 0.32363, standardized 85% CI: 0.20232 to 0.44494) and sand ($\hat{\beta}$ = 0.15125, 85% CI: 0.12615 to 0.17634; standardized $\hat{\beta}$ = 0.73108, standardized 85% CI: 0.60977 to 0.85239) were the influential variables affecting total forb standing crop (R^2 = 0.6956; Table 5). September rainfall ($\hat{\beta}$ = 0.00629, 85% CI: 0.00396 to 0.00778; standardized $\hat{\beta}$ = 0.47529, standardized 85% CI: 0.29961 to .58794), use ($\hat{\beta}$ = -0.00891, 85% CI: -0.01724 to 0.00058198; standardized $\hat{\beta}$ = -0.15318, standardized 85% CI: -0.29636 to -0.01), and sand ($\hat{\beta}$ = 0.1178, 85% CI: 0.08685 to 0.14877; standardized $\hat{\beta}$ = 0.53696, standardized 85% CI: 0.39589 to 0.67814) influenced preferred forb standing (R^2 = 0.5976). For total forbs there was an important interaction from use x sand (P=0.0617).

With over 90% grazing use and 385 mm of September rainfall produced a peak total forb standing crop of 726 kg/ha (Figure 4). With over 35% grazing use and 0 mm of August rainfall produced a peak total forb standing crop of 224 kg/ha (Figure 5). With over 90% grazing use and 425 mm of September rainfall produced a peak preferred forb standing crop of 688 kg/ha (Figure 6). With 5% grazing use and 0 mm of August rainfall produced a peak preferred forb standing crop of 140 kg/ha (Figure 7). With 20% grazing use and 90% sand in the soil produced a peak total forb standing crop of 302 kg/ha (Figure 8). With no grazing and 85% sand produced a peak preferred forb standing crop of 225 kg/ha (Figure 9). Peak total forb standing crop of 666 kg/ha occurred when September rainfall was 325 mm and having 90% sand in the soil (Figure 10). Peak total forb standing crop of 291 kg/ha occurred when August rainfall was 5 mm and 90%

Table 5. Variables affecting total, preferred, and non preferred forbs standing crop in a eight year on the East Foundation ranch study sites from 2012-2019 for the complete data set.

Rank	Response Variable	Covariates	β Estimate	Standardized β	AIC	Δ AIC	R^2	85% Confidence Limits		Standardized 85% Confidence Intervals		Model Weight
1	Total Forbs				-33.0152	0	0.6956					0.360595
		September rainfall	0.00404	0.32363				0.00252	0.00555	0.20232	0.44494	
		Sand	0.15125	0.73108				0.12615	0.17634	0.60977	0.85239	
2	Total Forbs				-31.2886	1.7266	0.6974					0.152088
		August rainfall	-0.00129	-0.04297				-0.00505	0.00247	-0.16856	0.08261	
		September rainfall	0.00392	0.31377				0.00235	0.00548	0.18805	0.43949	
		Sand	0.15246	0.73696				0.1269	0.17803	0.61338	0.86054	
3	Total Forbs				-31.1398	1.8754	0.6964					0.141183
		September rainfall	0.00396	0.31772				0.0024	0.00553	0.19251	0.44293	
		Sand	0.15125	0.73109				0.12589	0.1766	0.60852	0.85366	
		use	-0.00157	-0.0287				-0.0084	0.00525	-0.15305	0.09565	
4	Total Forbs				-27.5362	5.479	0.6989					0.023295
		August rainfall	-0.00152	-0.05062				-0.00552	0.00249	-0.18436	0.08312	
		September rainfall	0.00384	0.30792				0.00221	0.00548	0.17706	0.43878	
		Sand	0.15363	0.74261				0.12702	0.18024	0.61399	0.87123	
		use	0.00168	0.03071				-0.01336	0.01673	-0.24355	0.30496	
		use^2	-0.00004181	-0.06475				-0.0021824	0.00013463	-0.33799	0.2085	
1	Preferred Forbs				-11.9761	0	0.5976					0.222923
		September rainfall	0.00629	0.47529				0.00396	0.00778	0.29961	0.58794	
		Sand	0.1178	0.53696				0.08685	0.14877	0.39589	0.67814	
		use	-0.00891	-0.15318				-0.01724	-0.00058198	-0.29636	-0.01	
2	Preferred Forbs				-11.3679	0.6082	0.5751					0.16447
		September rainfall	0.00629	0.47529				0.00439	0.00819	0.33195	0.61862	
		Sand	0.1178	0.53696				0.08635	0.14924	0.36362	0.68029	
3	Preferred Forbs				-10.2573	1.7188	0.5999					0.094389
		August rainfall	-0.00159	-0.05016				-0.00624	0.00305	-0.19642	0.0961	
		September rainfall	0.00573	0.43271				0.00375	0.0077	0.28372	0.58171	
		Sand	0.11931	0.54388				0.08777	0.15086	0.40008	0.68768	
		use	-0.00879	-0.15101				-0.0172	-0.00037254	-0.29562	-0.0064	
4	Preferred Forbs				-10.1085	1.8676	0.5987					0.087622
		September rainfall	0.00589	0.44524				0.00396	0.00782	0.29942	0.59107	
		Sand	0.1189	0.54201				0.8727	0.15053	0.39782	0.68619	
		use	-0.00529	-0.091				-0.02283	0.01224	-0.39249	0.21048	
		use^2	-0.0004818	-0.07036				- 0.00025311	0.00015675	-0.36965	0.22893	

Table 5. continued

Rank	Response Variable	Covariates	β Estimate	Standardized β	AIC	Δ AIC	R^2	85% Confidence Limits		Standardized 85% Confidence Intervals		Model Weight
5	Preferred Forbs				-8.5432	3.4329	0.6023					0.04006
		August rainfall	-0.00206	-0.00648				-0.00694	0.00282	-0.21851	0.08892	
		September rainfall	0.00571	0.43173				0.00372	0.0077	0.28133	0.58214	
		Sand	0.12142	0.55349				0.08899	0.15385	0.40566	0.70132	
		use	-0.00323	-0.05558				-0.02157	0.0151	-0.37079	0.25964	
		use^2	-0.00007345	-0.10728				-0.0028849	0.00014158	-0.42133	0.20678	
1	Non-Preferred Forbs				11.7468	0	0.6273					0.215278
		Sand	0.24101	0.79204				0.20091	0.28111	0.66027	0.92381	
2	Non-Preferred Forbs				12.988	1.2412	0.6332					0.115738
		Sand	0.24157	0.79389				0.20132	0.28182	0.66162	0.92615	
		use	0.00617	0.07648				-0.0045	0.01684	-0.05579	0.20874	
3	Non-Preferred Forbs				13.3459	1.5991	0.6304					0.096774
		September rainfall	0.00103	0.05608				-0.00142	0.00348	-0.0776	0.18975	
		Sand	0.23898	0.78535				0.1983	0.27965	0.65168	0.91903	
4	Non-Preferred Forbs				13.6865	1.9397	0.6278					0.081621
		August rainfall	0.00095868	0.02176				-0.00495	0.00686	-0.11224	0.15576	
		Sand	0.24029	0.78966				0.19951	0.28106	0.65566	0.92366	
5	Non-Preferred Forbs				18.1121	6.3653	0.6398					0.008929
		August rainfall	0.00168	0.03806				-0.00477	0.00812	-0.10823	0.18434	
		September rainfall	0.00151	0.08248				-0.00111	0.00414	-0.06066	0.22561	
		Sand	0.2365	0.77723				0.19369	0.27931	0.63654	0.91791	
		use	0.00437	0.05413				-0.1984	0.02857	-0.24585	0.35411	
		use^2	0.00003859	0.04063				-0.0002452	0.00032244	-0.25824	0.33951	

sand (Figure 11). Peak preferred forb standing crop of 555 kg/ha occurred when September rainfall was 310 mm and 90% sand (Figure 12). Peak preferred forb standing crop of 167 kg/ha occurred when August rainfall was 0 mm and 90% sand (Figure 13). Data also showed that by having no August rainfall and 90% sand maximized total (291 kg/ha) and preferred (167 kg/ha) forbs standing crop when moisture availability was abundant in September. The only variable that influenced non-preferred forbs ($\hat{\beta}$ = 0.24101, 85% CI: 0.20091 to 0.28111; standardized $\hat{\beta}$ = 0.79204, standardized 85% CI: 0.66027 to 0.92381) was the sand content (90%), with an R^2 of 0.6273.

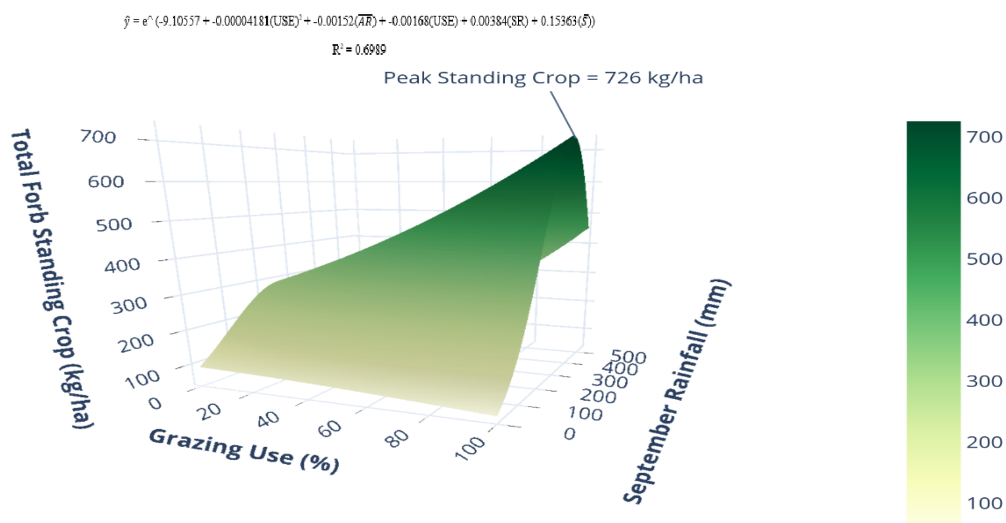

Figure 4. Peak total forb standing crop as affected by September rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

$$\hat{y} = e^\wedge(-9.10557 + -0.00004181(\mathrm{USE})^2 + -0.00152(AR) + -0.00168(\mathrm{USE}) + 0.00384(\overline{SR}) + 0.15363(\bar{S}))$$

$$R^2 = 0.6989$$

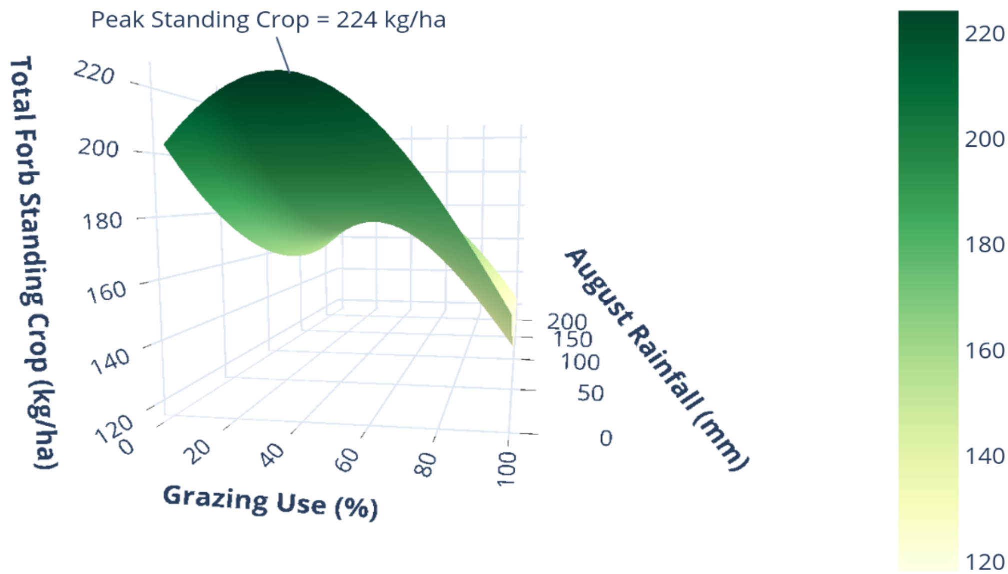

Figure 5. Peak total forb standing crop as affected by August rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\mathrm{USE})^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

$$\hat{y} = e^\wedge(-6.80135 + -0.00007345(\mathrm{USE})^2 + -0.00206(\overline{AR}) + -0.00323(\mathrm{USE}) + 0.00571(\mathrm{SR}) + 0.12142(\bar{S}))$$

$$R^2 = 0.6023$$

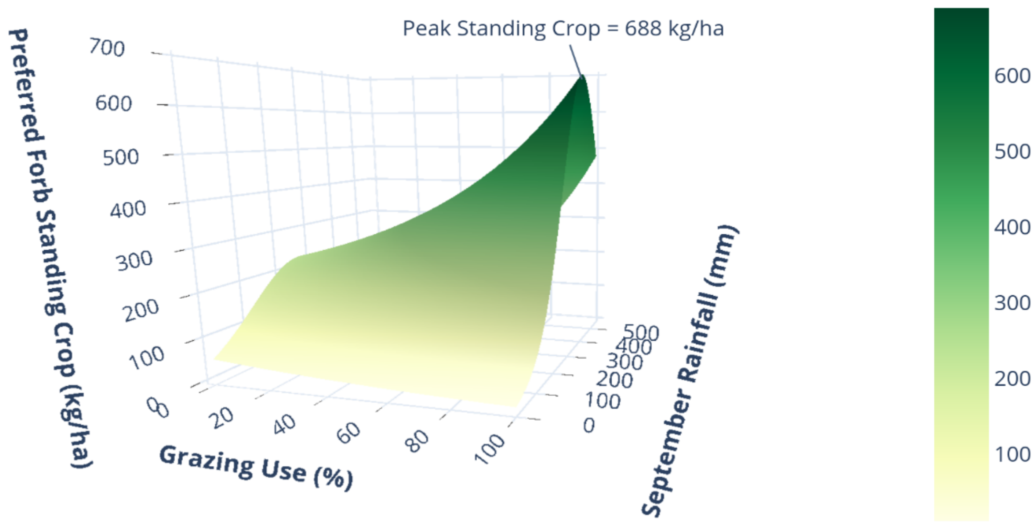

Figure 6. Peak preferred forb standing crop as affected by September rainfall and grazing use using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\mathrm{USE})^2$, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

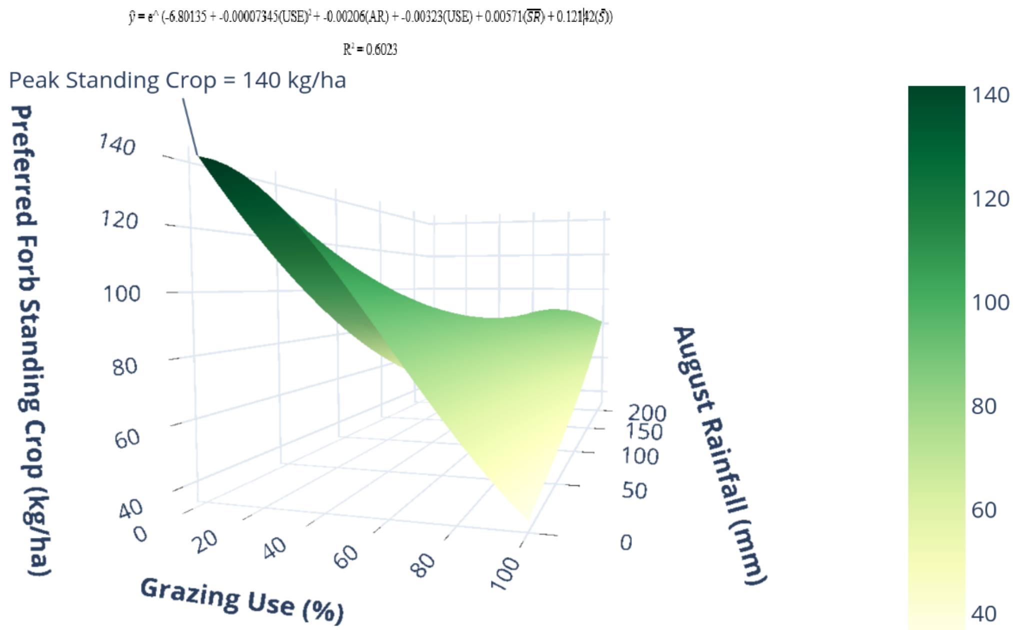

Figure 7. Peak preferred forb standing crop as affected by August rainfall and grazing use using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

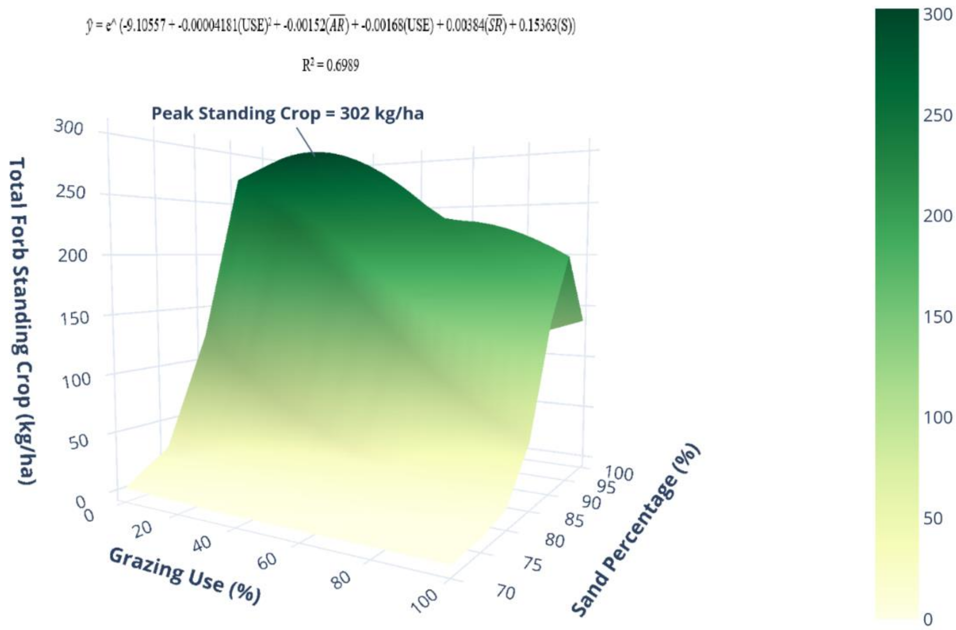

Figure 8. Peak total forb standing crop as affected by grazing use and sand percentage using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

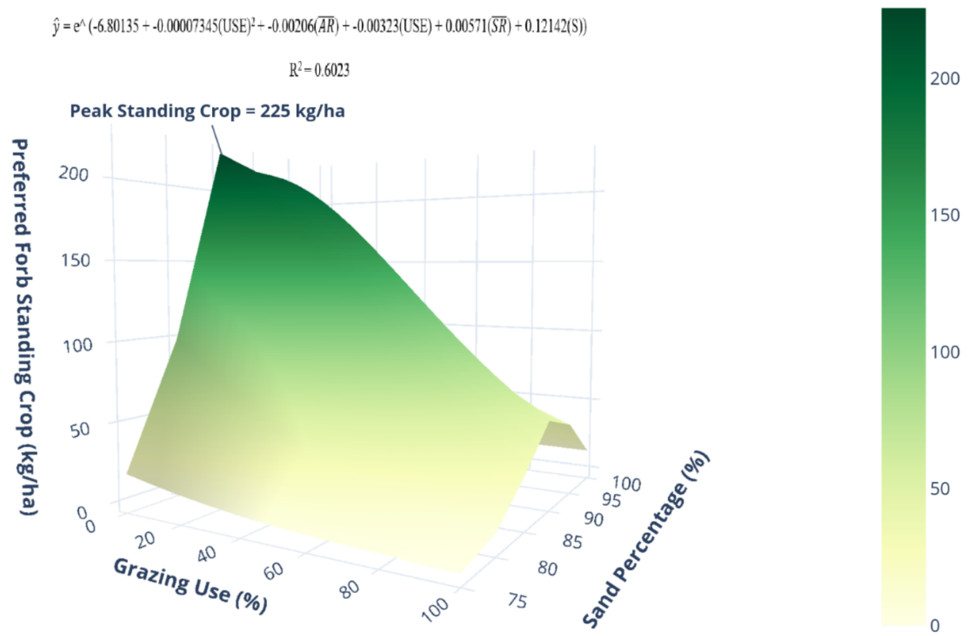

Figure 9. Peak preferred forb standing crop as affected by grazing use and sand percentage using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

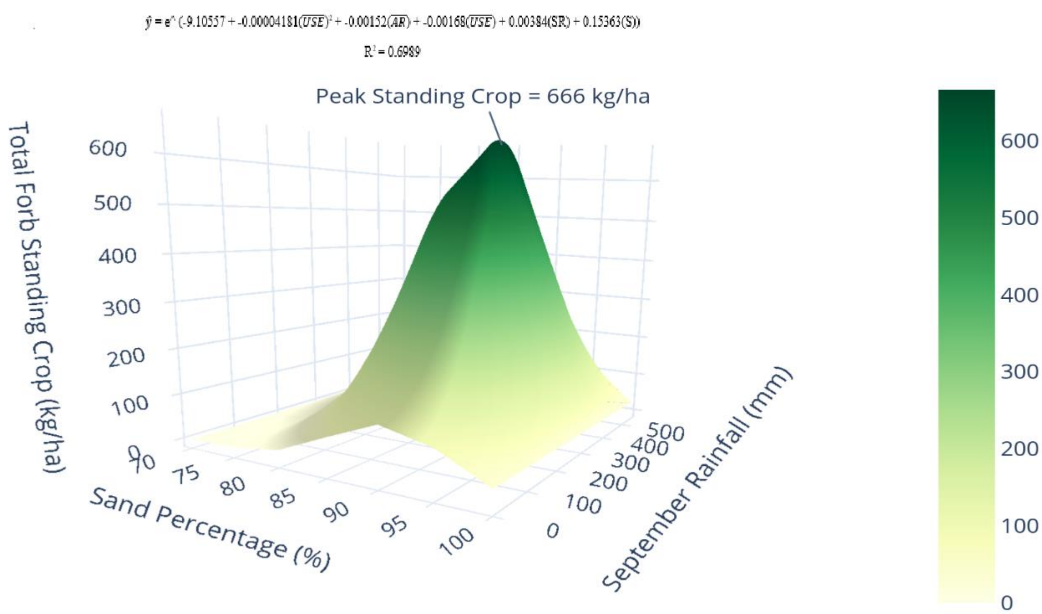

Figure 10. Peak total forb standing crop as affected by September rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, mean August rainfall ($\overline{AR}$), mean grazing use ($\overline{USE}$), September rainfall (SR), and sand (S).

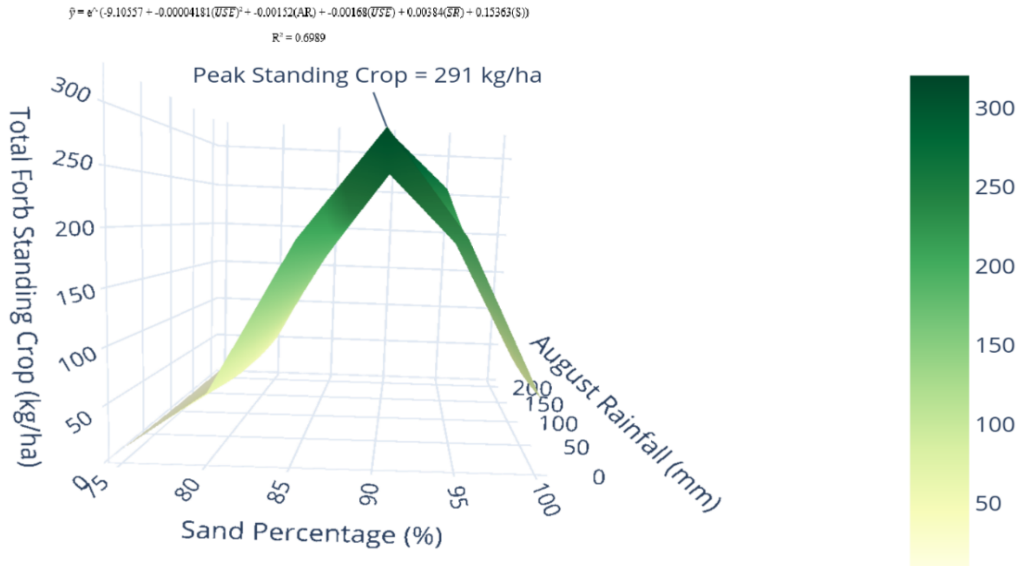

Figure 11. Peak total forb standing crop as affected by August rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use $(\overline{USE})$, September rainfall $(\overline{SR})$, and sand (S).

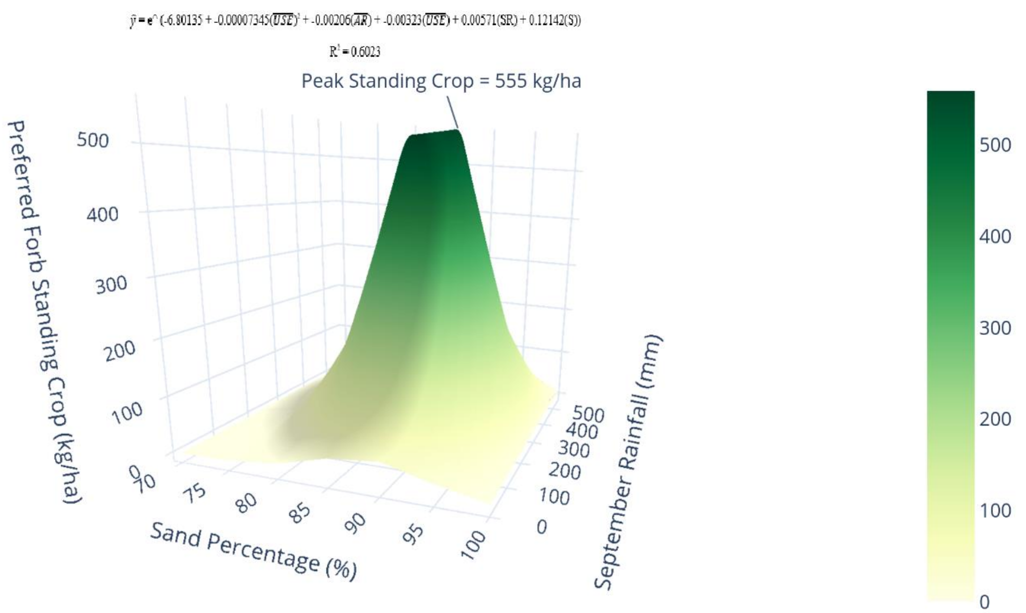

Figure 12. Peak preferred forb standing crop as affected by September rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, mean August rainfall $(\overline{AR})$, mean grazing use $(\overline{USE})$, September rainfall (SR), and sand (S).

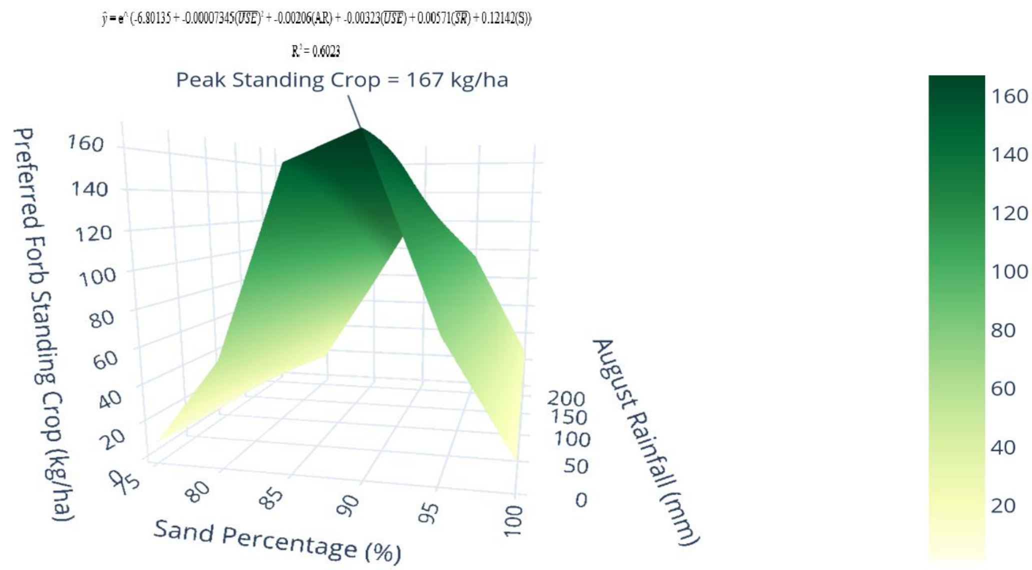

Figure 13. Peak preferred forb standing crop as affected by August rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use $(\overline{USE})$, mean September rainfall $(\overline{SR})$, and sand (S).

Forb standing crop (Reduced data set)

In large ranches, such as where these study sites are located, it is hard to have a homogeneous landscape where cattle can graze most or all the land uniformly. Given this idea, I determined the value of forge standing crop at which cattle avoided sites using all the sampling sites where forage standing crop of grass was equal or higher in the paired point compared to inside the grazing exclosure. Herbivores did not graze sites that were < 562 kg/ha of grass standing crop. The reduced data set (productive sites) included all the sampling points where grass standing crop was > 562 kg/ha.

Table 5 includes average rainfall, percent sand, and percent use for the months of August to November by site (Table 6) and by year (Table 7). Appendix A lists the average rainfall, percent sand, and percent use for the months of August to November individually by site per

Table 6. Average rainfall, soil, number of sampling points used, and grazing use by site from 2012 – 2019 in south Texas. Locations are represented as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	Year	August Rainfall (mm)	September Rainfall (mm)	October Rainfall (mm)	November Rainfall (mm)	Sand Percentage	Number of Exclosures Used	Percent Exclosures Used	Percent USE
1	2012-2019	33	94	41	41	93%	22 ± 2	44 ± 4%	41 ± 3%
2	2012-2019	33	106	39	41	91%	19 ± 3	38 ± 4%	57 ± 3%
3	2012-2019	33	99	42	38	78%	26 ± 1	51 ± 2%	46 ± 2%
4	2012-2019	42	148	29	42	93%	25 ± 3	50 ± 4%	57 ± 2%
5	2012-2019	61	150	49	60	94%	25 ± 2	49 ± 3%	49 ± 4%
6	2012-2019	38	141	79	62	95%	28 ± 1	55 ± 2%	53 ± 3%

Table 7. Averages rainfall, soil, number of sampling points used and grazing use by year from 2012 – 2019 in south Texas. Locations are represented as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	Year	August Rainfall (mm)	September Rainfall (mm)	October Rainfall (mm)	November Rainfall (mm)	Sand Percentage	Number of Exclosures Used	Percent Exclosures Used	Percent USE
1-6	2012	20	55	8	23	92%	14 ± 2	27 ± 3%	81 ± 1%
1-6	2013	24	167	13	45	90%	14 ± 3	28 ± 4%	57 ± 1%
1-6	2014	59	196	30	111	92%	28 ± 2	55 ± 2%	44 ± 3%
1-6	2015	24	84	171	27	90%	29 ± 2	59 ± 2%	39 ± 3%
1-6	2016	113	57	15	46	90%	35 ± 1	70 ± 1%	52 ± 1%
1-6	2017	56	32	46	29	91%	20 ± 2	41 ± 3%	59 ± 2%
1-6	2018	14	291	64	31	90%	26 ± 2	52 ± 3%	39 ± 2%
1-6	2019	10	102	26	67	91%	25 ± 1	51 ± 2%	32 ± 3%

year. The percent of sampling points included in the reduced data set ranged from 38% to 55%. Combining all locations by year 27% to 70% of the sampling points were included in the reduced data set. During the drought of 2012 grazing use was 81 ±1% throughout all study sites. Only 27 ± 3% of the sampling sites in 2012 at all the ranches were considered grazeable for herbivores. Rainfall was the driving factor that affected grazeable areas on these ranches.

When using the reduced data August rainfall ($\hat{\beta}$ = -0.00723, 85% CI: -0.01171 to -0.00276; standardized $\hat{\beta}$ = -0.20226, standardized CIs: -0.32733 to -0.07719), September rainfall ($\hat{\beta}$ = 0.00203, 85% CI: 0.00014966 to 0.0039; standardized $\hat{\beta}$ = 0.13586, standardized CIs: 0.01004 to 0.26167), sand ($\hat{\beta}$ = 0.21018, 85% CI: 0.18013 to 0.24023; standardized $\hat{\beta}$ = 0.8532, standardized CI: 0.73122 to 0.97518), and use^2 ($\hat{\beta}$ = -0.00038935, 85% CI: -0.00073852 to -0.00004017; standardized $\hat{\beta}$ = -0.56519, standardized CIs: -1.07206 to -0.05831) were the influential variables affecting total forb standing crop, with an R^2 of 0.7472 (Table 8). August rainfall ($\hat{\beta}$ = -0.00643, 85% CI: -0.01211 to -0.0007561; standardized $\hat{\beta}$ = -0.16351, standardized CIs: -0.3078 to -0.01922), September rainfall ($\hat{\beta}$ = 0.00457, 85% CI: 0.00219 to 0.00695; standardized $\hat{\beta}$ = 0.27894, standardized CI: 0.13379 to 0.42409), sand ($\hat{\beta}$ = 0.18904, 85% CI: 0.15091 to 0.22716; standardized $\hat{\beta}$ = 0.69774, standardized CI: 0.55701 to 0.83846), and use^2 ($\hat{\beta}$ = -0.00049444, 85% CI: -0.00093748 to -0.0000514; standardized $\hat{\beta}$ = -0.65261, standardized CIs: -1.23737 to -0.06784) were the influential variables affecting preferred forb standing crop with an R^2 of 0.6635. For total forbs an important interaction was sand x August rainfall (*P*=0.0134). For preferred forbs the only important interaction was use x September rainflall (*P*=0.0929).

With 85% grazing use and 415 mm of September rainfall produced a peak total forb standing crop of 356 kg/ha (Figure 14). With 45% grazing use and 0 mm of August rainfall produced a peak total forb standing crop of 289 kg/ha (Figure 15). With over 90% grazing use and 550 mm of September rainfall produced a peak preferred forb standing crop of 504 kg/ha (Figure 16). With 35% grazing use and 0 mm of August rainfall produced a peak preferred forb standing crop of 154 kg/ha (Figure 17). With 55% grazing use and 95% sand in the soil produced

Table 8. Variables affecting total, preferred, and non preferred forbs standing crop in a eight year on the East Foundation ranch study sites from 2012-2019 for the reduced data set.

Rank	Response Variable	Covariates	β Estimate	Standardized β	AIC	Δ AIC	R^2	85% Confidence Limits		Standardized 85% Confidence Intervals		Model Weight
1	Total Forbs				-18.7944	0.1353	0.7472					0.173369
		August rainfall	-0.00723	-0.20226				-0.01171	-0.00276	-0.32733	-0.07719	
		September rainfall	0.00203	0.13586				0.00014966	0.0039	0.01004	0.26167	
		Sand	0.21018	0.8532				0.18013	0.24023	0.73122	0.97518	
		use	0.03182	0.43862				-0.00435	0.06799	-0.06003	0.93727	
		use^2	-0.00038935	-0.56519				-0.00073852	-0.00004017	-1.07206	-0.05831	
2	Total Forbs				-18.1626	0.7671	0.7216					0.126409
		August rainfall	-0.00591	-0.1652				-0.01022	-0.0016	-0.28577	0.04464	
		September rainfall	0.00297	0.19922				0.00118	0.00476	0.07893	0.3195	
		Sand	0.19711	0.80013				0.16789	0.22633	0.68151	0.91875	
3	Total Forbs				-18.0115	0.9182	0.7321					0.117211
		August rainfall	-0.00859	-0.2401				-0.0295	-0.00422	-0.36219	-0.11802	
		Sand	0.21778	0.88406				0.18807	0.24749	0.76346	1.00465	
		use	0.04147	0.57164				0.00582	0.07711	0.08027	1.06301	
		use^2	-0.00050317	-0.73042				-0.00084169	-0.00016465	-1.22182	-0.23901	
1	Preferred Forbs				4.0612	0.8789	0.6635					0.160572
		August rainfall	-0.00643	-0.16351				-0.01211	-0.0007561	-0.3078	-0.01922	
		September rainfall	0.00457	0.27894				0.00219	0.00695	0.13379	0.42409	
		Sand	0.18904	0.69774				0.15091	0.22716	0.55701	0.83846	
		use	0.03118	0.39085				-0.01471	0.07708	-0.18442	0.96613	
		use^2	-0.00049444	-0.65261				-0.00093748	0.0000514	-1.23737	-0.06784	
2	Preferred Forbs				4.5266	1.3443	0.6307					0.127236
		September rainfall	0.00575	0.35043				0.00347	0.00802	0.21181	0.48905	
		Sand	0.17303	0.63864				0.013595	0.2101	0.5018	0.77548	
		use	-0.01934	-0.24238				-0.03044	-0.00824	-0.38151	-0.10326	
3	Preferred Forbs				5.0282	1.8459	0.6421					0.099012
		August rainfall	-0.00435	-0.11062				-0.00981	0.00111	-0.24948	0.02823	
		September rainfall	0.00538	0.32784				0.00306	0.00769	0.18685	0.46883	

Table 8. continued

Rank	Response Variable	Covariates	β Estimate	Standardized β	AIC	Δ AIC	R^2	85% Confidence Limits		Standardized 85% Confidence Intervals		Model Weight
		Sand	0.17712	0.65376				0.13983	0.21441	0.51611	0.79141	
		use	-0.01858	-0.23282				-0.02968	-0.00747	-0.37194	-0.09369	
4	Preferred Forbs				5.1175	1.9352	0.6414					0.094689
		September rainfall	0.00533	0.32503				0.003	0.00766	0.18294	0.46713	
		Sand	0.17966	0.66313				0.1417	0.21762	0.52303	0.80323	
		use	0.01358	0.17024				-0.03046	0.05763	-0.38183	0.72231	
		use^2	-0.00032954	-0.43496				-0.0007563	0.00009722	-0.99824	0.12832	
1	Non-Preferred Forbs				13.0555	0	0.6214					0.218814
		Sand	0.24034	0.78829				0.199984	0.28083	0.65547	0.9211	
2	Non-Preferred Forbs				14.3346	1.2791	0.627					0.115431
		August rainfall	-0.0035	-0.07573				-0.0093	0.0026	-0.21014	0.05868	
		Sand	0.24326	0.79788				0.20228	0.28424	0.66347	0.93229	
3	Non-Preferred Forbs				14.5318	1.4763	0.6255					0.104593
		September rainfall	-0.00119	-0.06447				-0.00367	0.00129	-0.19884	0.06991	
		Sand	0.24244	0.7952				0.20147	0.28341	0.66082	0.92958	
4	Non-Preferred Forbs				14.8976	1.8421	0.6226					0.08711
		Sand	0.23886	0.78344				0.19758	0.28013	0.64806	0.91881	
		use	0.0032	0.03559				-0.00896	0.01535	-0.09978	0.17097	
5	Non-Preferred Forbs				17.8834	4.8279	0.6456					0.019575
		August rainfall	-0.00598	-0.13517				-0.01254	0.00057124	-0.28324	0.01291	
		September rainfall	-0.00211	-0.11413				-0.00485	0.00064271	-0.26309	0.03483	
		Sand	0.25495	0.83622				0.21092	0.29898	0.6918	0.98064	
		use	0.04248	0.47318				-0.01052	0.09549	-0.11719	1.06355	
		use^2	-0.00039495	-0.46324				-0.0009066	0.0001167	-1.06335	0.13687	

a peak total forb standing crop of 362 kg/ha (Figure 18). With 40% grazing use and 95% sand produced a peak preferred forb standing crop of 179 kg/ha (Figure 19). Peak total forb standing crop of 456 kg/ha occurred when September rainfall was 285 mm and having 95% sand in the soil (Figure 20). Peak total forb standing crop of 347 kg/ha when August rainfall was 0 mm and 90% sand (Figure 21). Peak preferred forb standing crop of 371 kg/ha occurred when September rainfall was 330 mm and 90% sand (Figure 22). Peak preferred forb standing crop of 157 kg/ha when August rainfall was 0 mm and 90% sand (Figure 23). Data also showed that by having no August rainfall and 90% sand maximized total (347 kg/ha) and preferred (157 kg/ha) forbs standing crop when moisture availability was abundant in September. The only variable that influenced non-preferred forbs was the sand content (90%) ($\hat{\beta}$ = 0.25495, 85% CI: 0.21092 to 0.29898; standardized $\hat{\beta}$ = 0.78829, standardized CI: 0.65547 to 0.9211) with an R^2 of 0.6214.

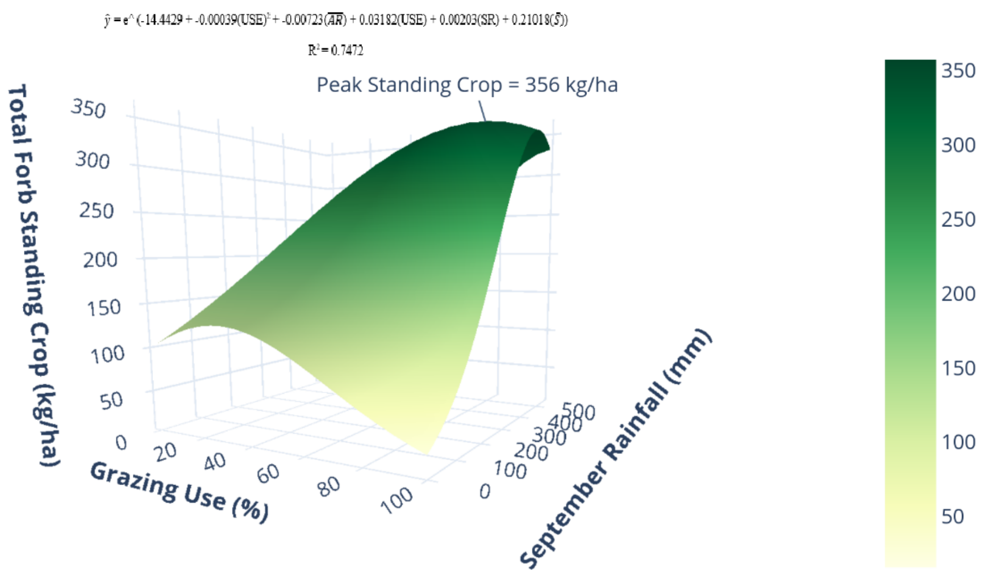

Figure 14. Peak total forb standing crop as affected by September rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

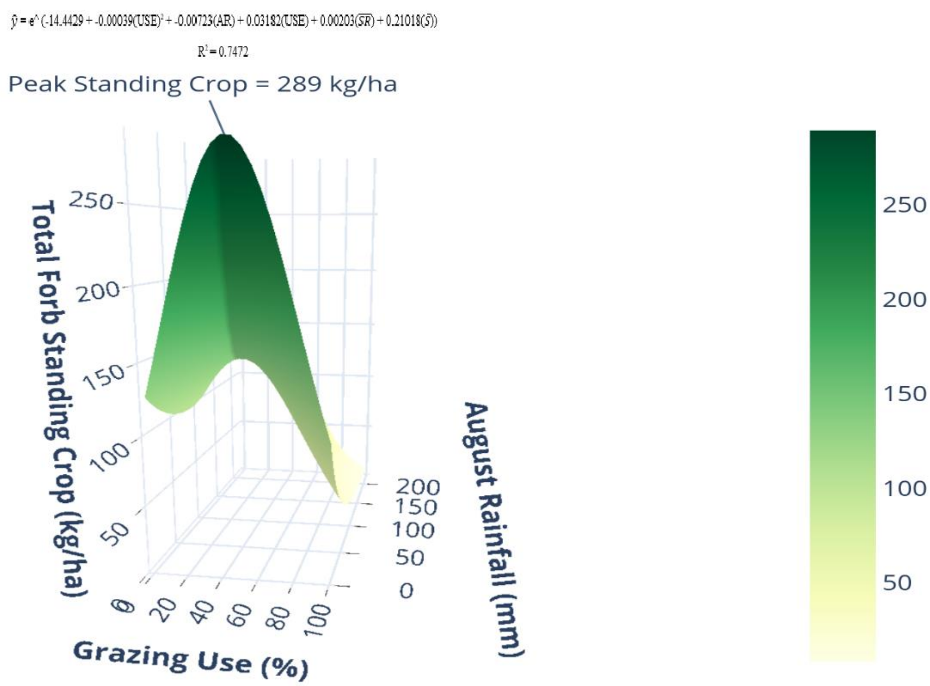

Figure 15. Peak total forb standing crop as affected by August rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

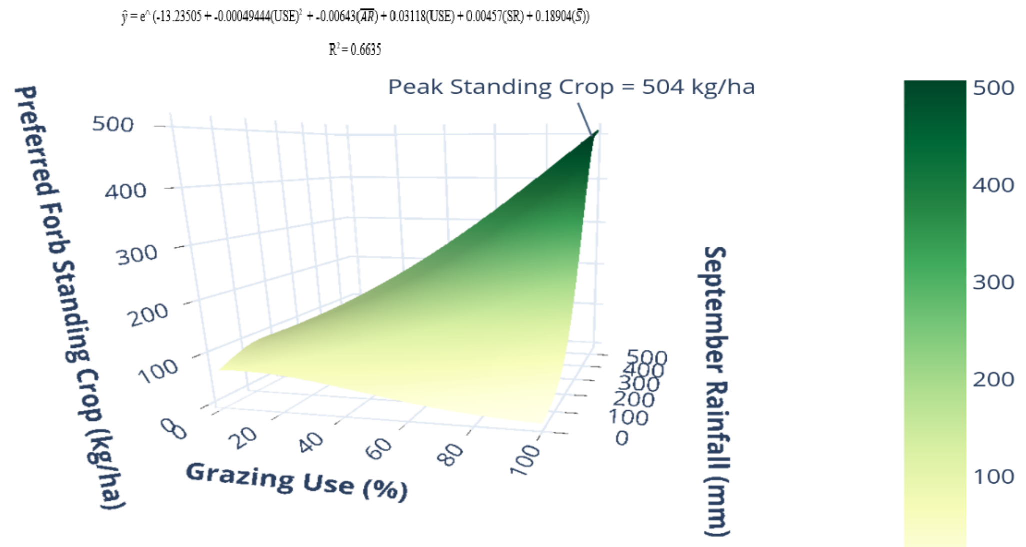

Figure 16. Peak preferred forb standing crop as affected by September rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

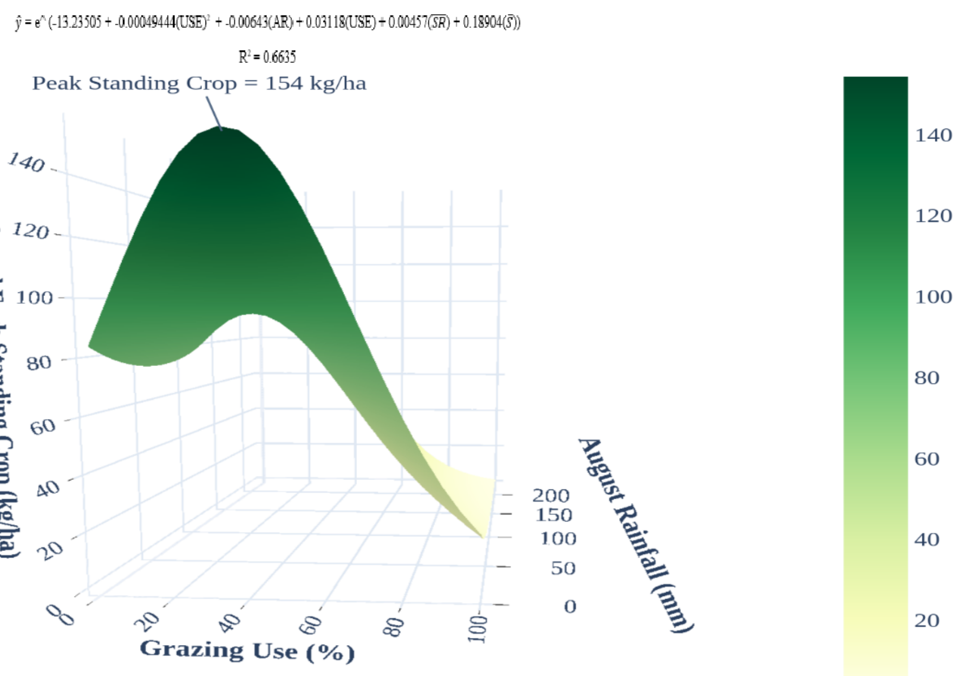

Figure 17. Peak preferred forb standing crop as affected by August rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

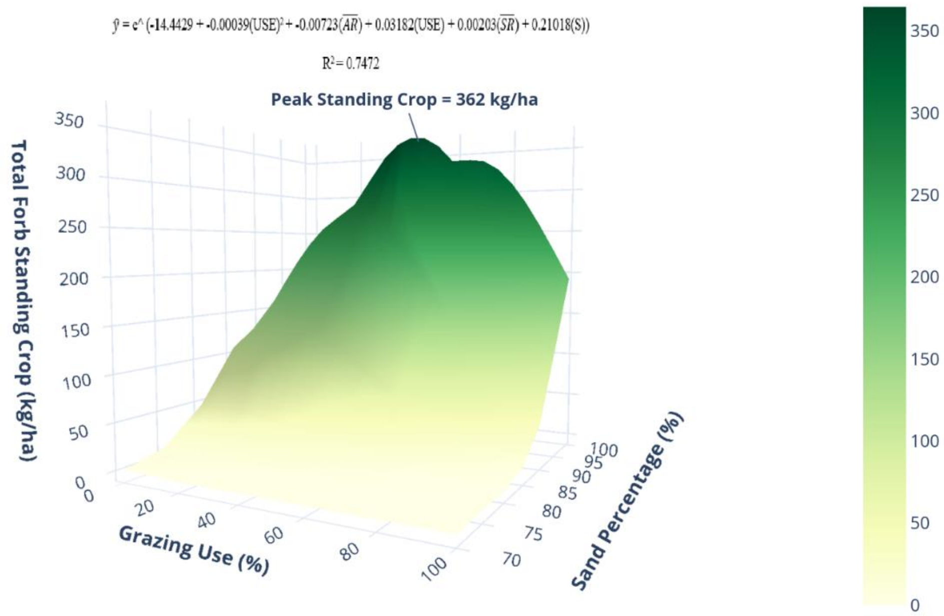

Figure 18. Peak total forb standing crop as affected by grazing use and sand percentage using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

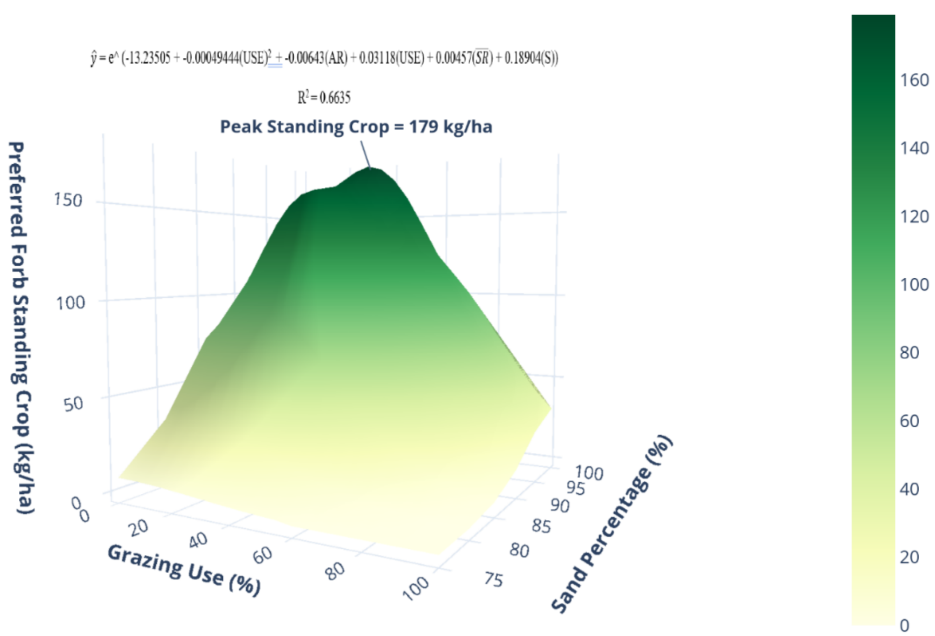

Figure 19. Peak preferred forb standing crop as affected by grazing use and sand percentage using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

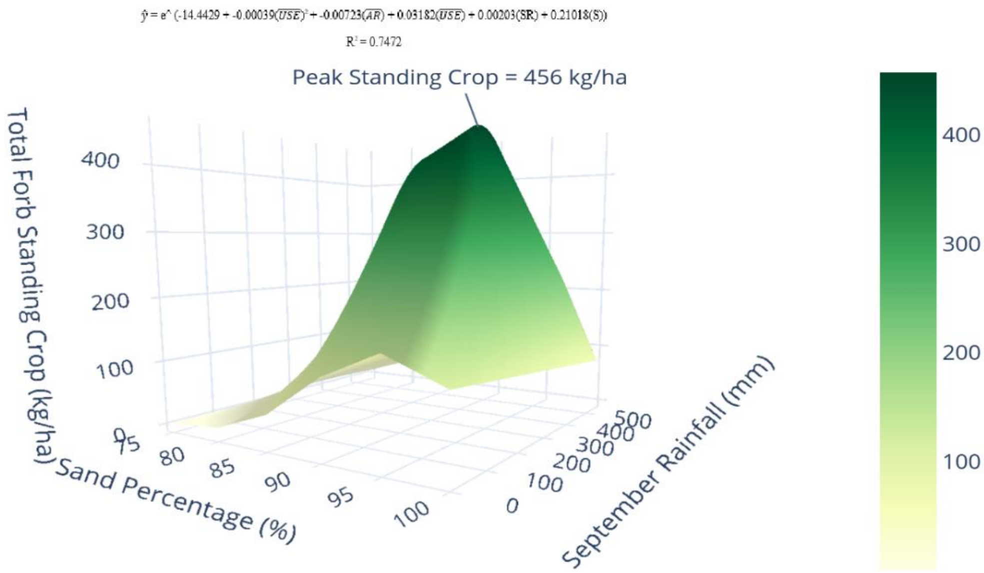

Figure 20. Peak total forb standing crop as affected by September rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, mean August rainfall $(\overline{AR})$, mean grazing use $(\overline{USE})$, September rainfall (SR), and sand (S).

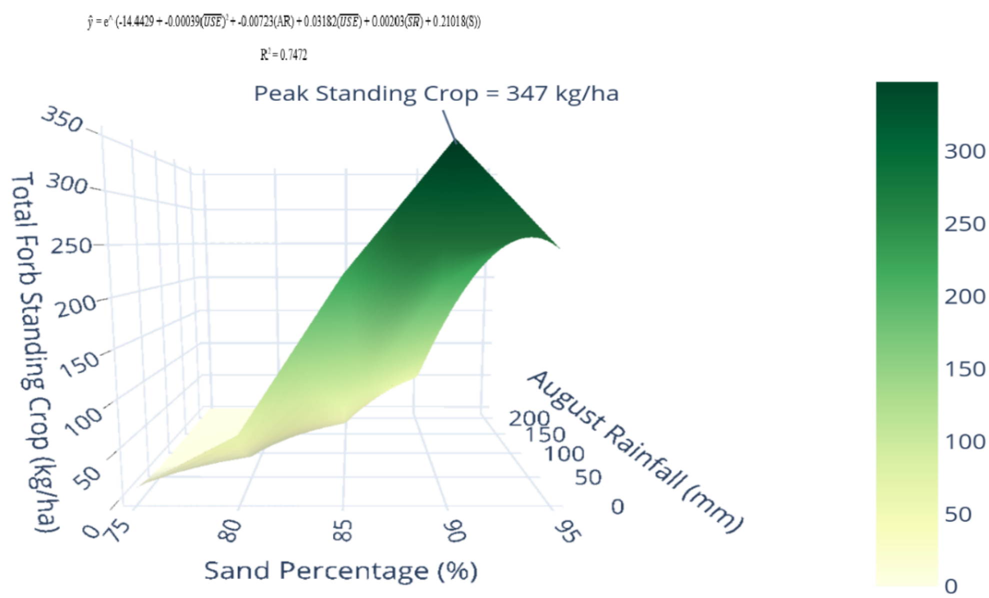

Figure 21. Peak total forb standing crop as affected by August rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use $(\overline{USE})$, September rainfall $(\overline{SR})$, and sand (S).

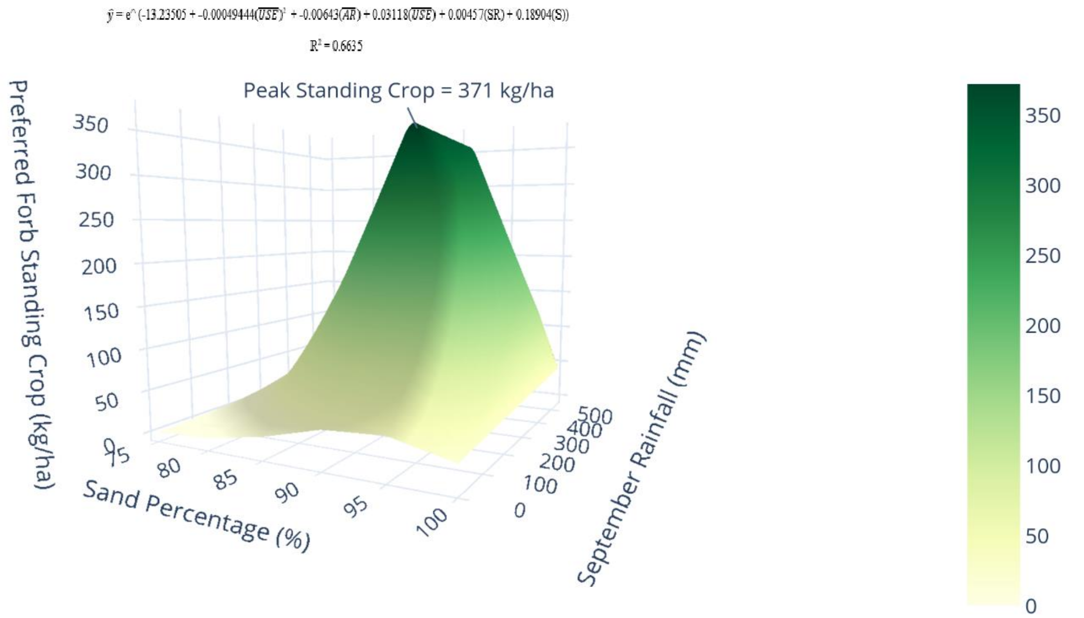

Figure 22. Peak preferred forb standing crop as affected by September rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, mean August rainfall $(\overline{AR})$, mean grazing use $(\overline{USE})$, September rainfall (SR), and sand (S).

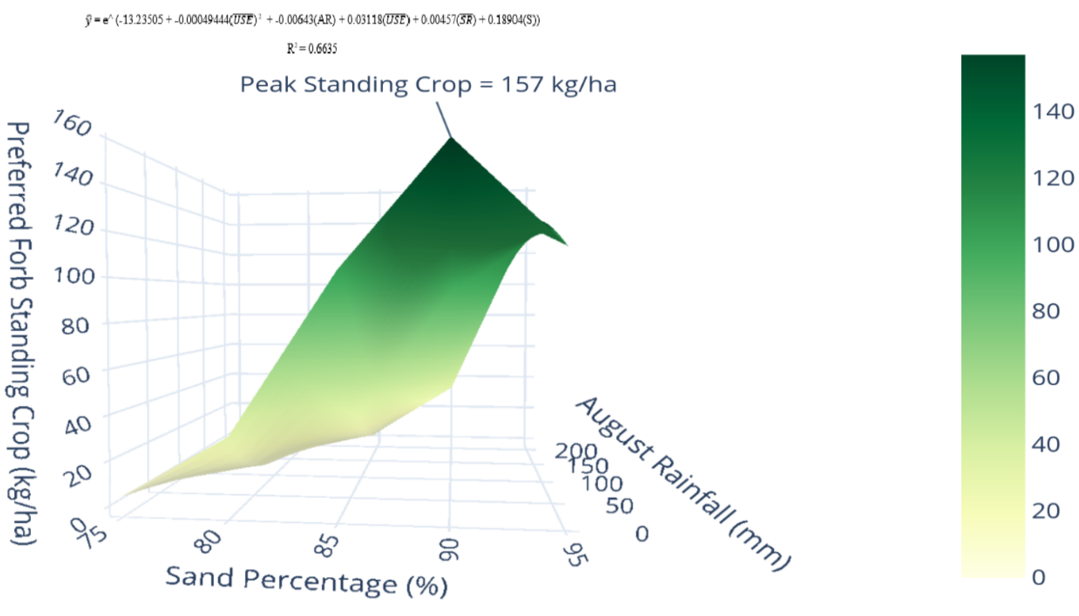

Figure 23. Peak preferred forb standing crop as affected by August rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: mean grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use $(\overline{USE})$, September rainfall $(\overline{SR})$, and sand (S).

Plant Species Richness (Complete data set)

During autumn 2012 – spring 2019, I identified a total of 221 forb species (Appendices A & C) and 74 grass/grass-like species (Appendix B). Preferred forbs consisted of 192 species (Appendix A) and non-preferred consisted of 29 species (Appendix C).

September rainfall ($\hat{\beta}$ = 0.00152, 85% CI: 0.000516 to 0.00253; standardized $\hat{\beta}$ = 0.27468, standardized CI: 0.09325 to 0.4561) and sand ($\hat{\beta}$ = 0.04243, 85% CI: 0.02577 to 0.05909; standardized $\hat{\beta}$ = 0.46208, standardized CI = 0.28065 to 0.6435) were the most influential variables affecting plant species richness with the complete data set with an R^2 of 0.3192. (Table 9).

With 65% grazing use and 230 mm of September rainfall produced a peak plant species richness of 2 species per 0.25m^2 (Figure 24). With 50% grazing use and 0 mm of August rainfall produced a peak plant species richness of 2 species per 0.25m^2 (Figure 25). With 15% grazing use and 85% sand in the soil produced a peak plant species richness of 11 species per 0.25m^2 (Figure 26). The peak plant species richness, 10 species per 0.25 m^2, occurred when September rainfall was 540 mm and 95% sand (Figure 27). With no rainfall in August, 95% sand, and abundant September rainfall 8 species per 0.25 m^2 occurred (Figure 28).

Table 9. Variables affecting plant species richness in the study sites on the East ranches from 2012-2019 for the complete data set.

Rank	**Response Variable**	**Covariates**	**β Estimate**	**Standardized β**	**AIC**	**Δ AIC**	**R^2**	**85% Confidence Limits**		**Standardized 85% Confidence Intervals**		**Model Weight**
1	Plant Species Richness				-72.3532	0	0.3192					0.237135
		September rainfall	0.00152	0.27468				0.00051647	0.00253	0.09325	0.4561	
		Sand	0.04243	0.46208				0.02577	0.05909	0.28065	0.6435	
2	Plant Species Richness				-71.5913	0.7619	0.3366					0.162013
		August rainfall	-0.00181	-0.13607				-0.00428	0.00066296	-0.13607	-0.32201	
		September rainfall	0.00135	0.24347				0.00031745	0.00238	0.05732	0.42961	
		Sand	0.04414	0.4807				0.02734	0.06094	0.29772	0.66367	
3	Plant Species Richness				-70.5272	1.826	0.3217					0.095167
		September rainfall	0.001519	0.28682				0.0005443	0.00263	0.09827	0.47536	
		Sand	0.04255	0.46344				0.02572	0.05938	0.28015	0.64672	
		use	0.00103	0.05115				-0.00274	0.00479	-0.13633	0.23863	
4	Plant Species Richness				-68.0064	4.3468	0.3423					0.026984
		August rainfall	-0.00203	-0.15231				-0.00462	0.00057378	-0.34778	0.04316	
		September rainfall	0.00142	0.25576				0.00033993	0.00249	0.06138	0.45015	
		Sand	0.04504	0.49049				0.02766	0.06242	0.30121	0.67977	
		use	0.00224	0.11139				-0.00329	0.00776	-0.16412	0.38691	
		use^2	-0.00001856	-0.06476				-0.00009632	0.0000592	-0.3361	0.20658	

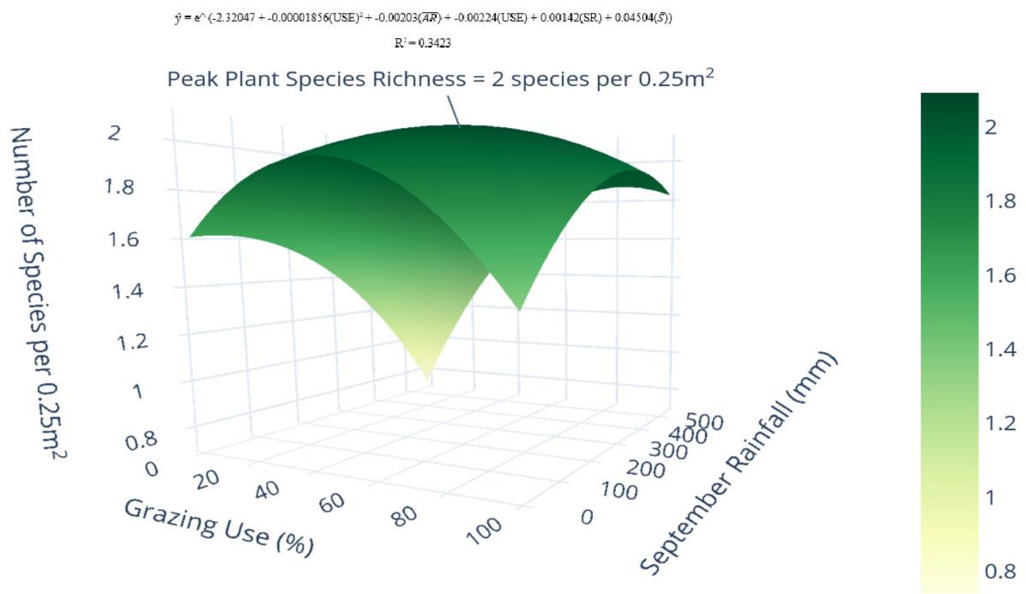

Figure 24. Peak plant species richness as affected by September rainfall and grazing use using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

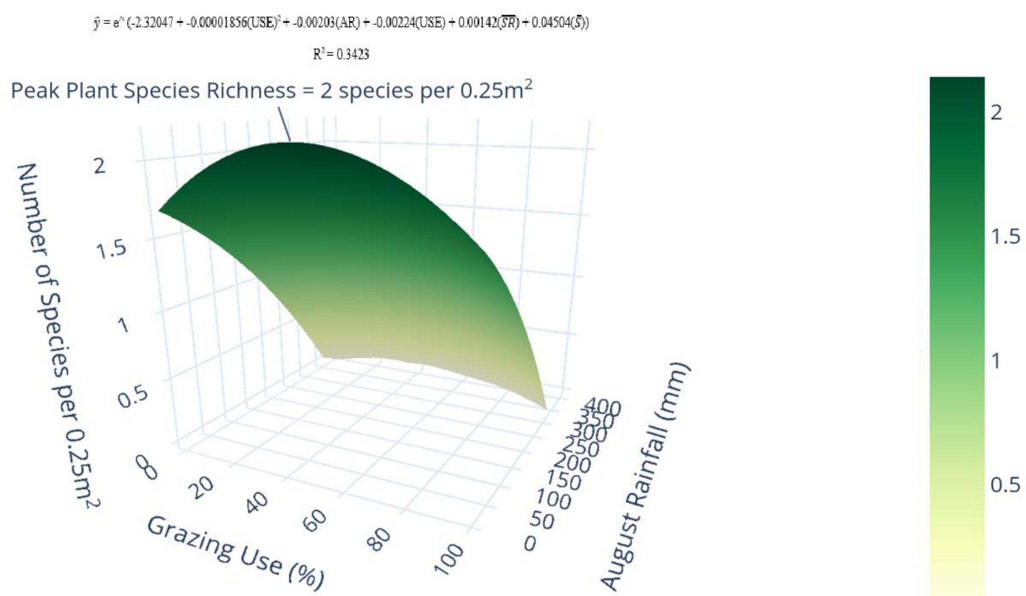

Figure 25. Peak plant species richness as affected by August rainfall and grazing use using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

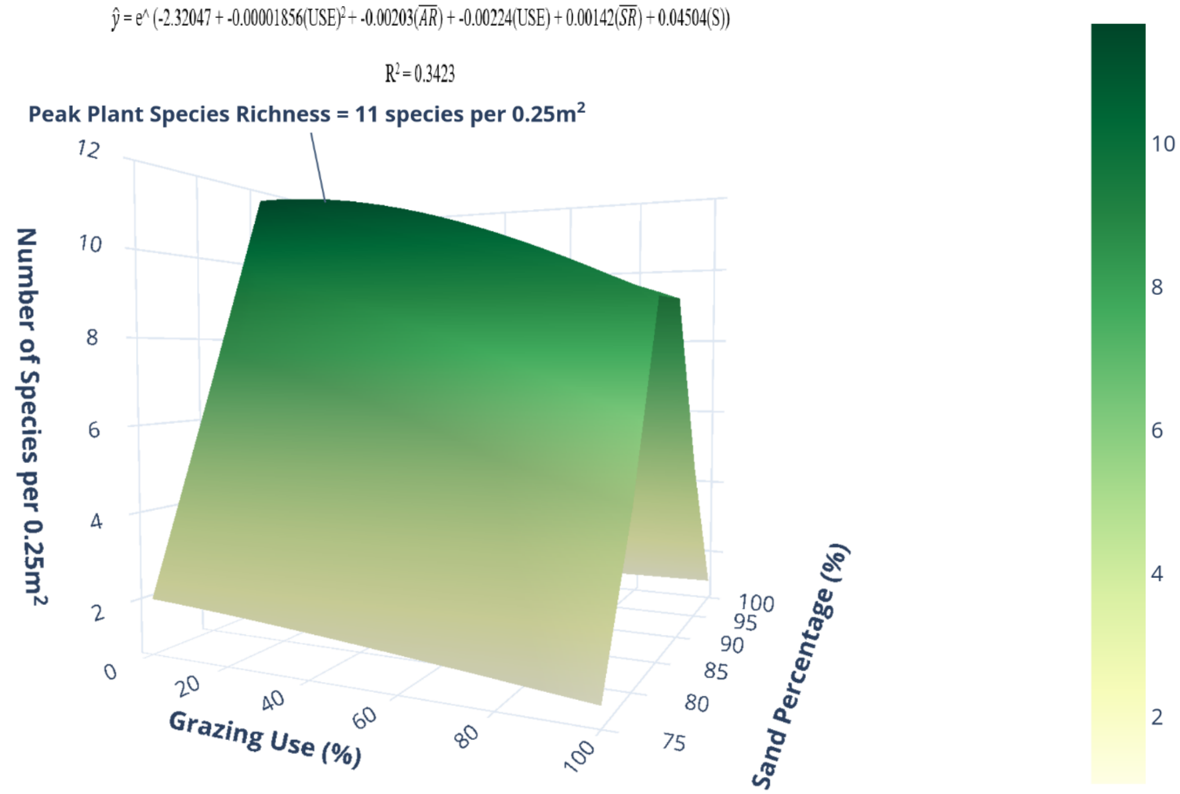

Figure 26. Peak plant species richness as affected by grazing use and sand percentage using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use (USE)^2, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

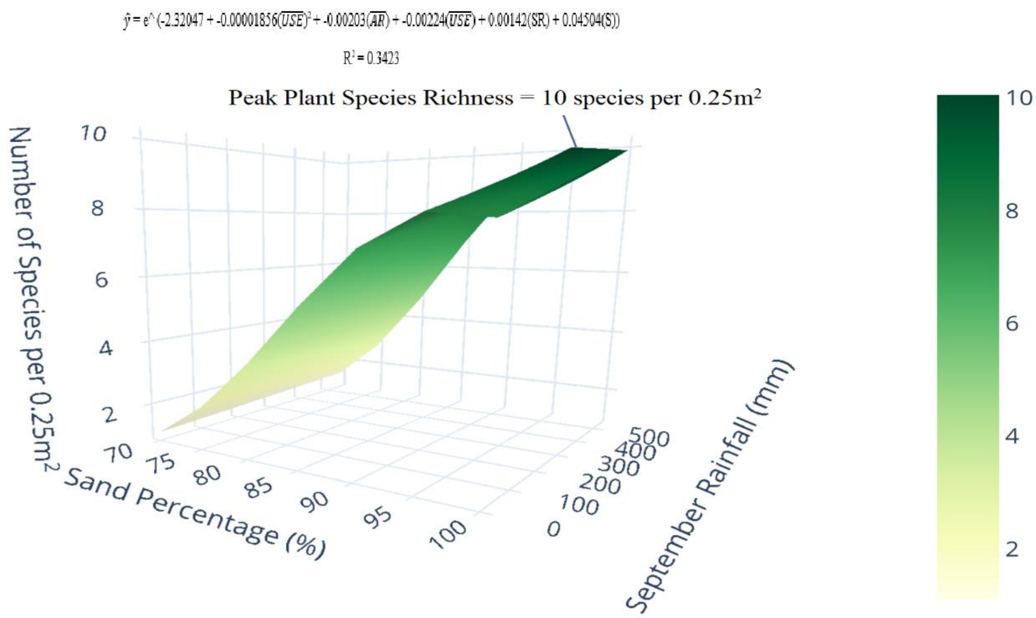

Figure 27. Peak plant species richness as affected by September rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\overline{USE})^2$, mean August rainfall $(\overline{AR})$, mean grazing use $(\overline{USE})$, September rainfall (SR), and sand (S).

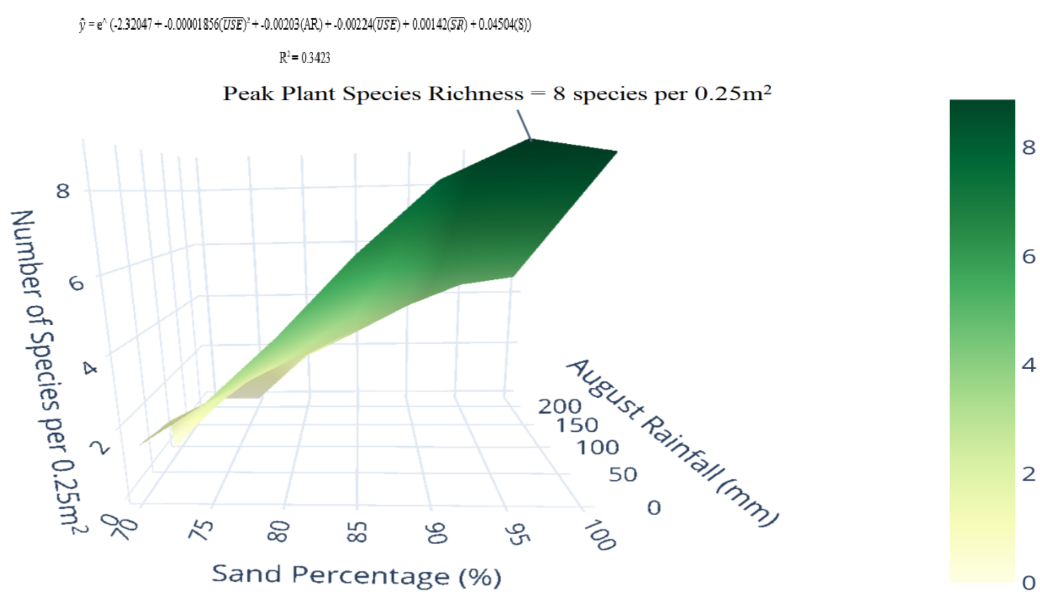

Figure 28. Peak plant species richness as affected by August rainfall and percent sand using the complete data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use $(\overline{USE})$, mean September rainfall $(\overline{SR})$, and sand (S).

Plant Species Richness (Reduced Data Set)

August rainfall ($\hat{\beta}$ = -0.00386, 85% CI: -0.00584 to -0.00189; standardized $\hat{\beta}$ = -0.31544, standardized CI: -0.4769 to -0.15398), sand ($\hat{\beta}$ = 0.0615, 85% CI: 0.0485 to 0.0754; standardized $\hat{\beta}$ = 0.73437, standardized CI: 0.57488 to 0.89385) use ($\hat{\beta}$ = 0.01958, 85% CI: 0.00344 to 0.03572; standardized $\hat{\beta}$ = 0.78814, standardized CI: 0.13831 to 1.43798), and use^2 ($\hat{\beta}$ = -0.00020324, 85% CI: -0.0003565 to -0.00004993; standardized $\hat{\beta}$ = -0.86155, standardized CI: -1.51143 to -0.21168) influenced plant species richness with an R^2 of 0.531 (Table 10). The next model I analyzed included August rainfall ($\hat{\beta}$ = -0.00324, 85% CI: -0.00517 to -0.00131; standardized $\hat{\beta}$ = -0.2648, standardized CI: -0.42228 to -0.10732) and sand ($\hat{\beta}$ = 0.05744, 85% CI: 0.04415 to 0.07072; standardized $\hat{\beta}$ = 0.68086, standardized CI: 0.52338 to 0.83833) influenced plant species richness and had a R^2 of 0.488.

With 60% grazing use and 235 mm of September rainfall produced a peak plant species richness of 8 species per $0.25m^2$ (Figure 29). With 50% grazing use and 0 mm of August rainfall produced a peak plant species richness of 8 species per $0.25m^2$ (Figure 30). With 65% grazing use and over 95% sand in the soil produced a peak plant species richness of 9 species per $0.25m^2$ (Figure 31). The peak plant species richness, 8 species per $0.25m^2$, occurred when September rainfall was 230 mm and 95% sand (Figure 32). With no rainfall in August, 95% sand, and abundant September rainfall 8 species per $0.25m^2$ occurred (Figure 33). August rainfall and sand were the factors that influenced plant species richness in productive sites. Grazing use was a significant factor in the response models that I analyzed.

Table 10. Variables affecting plant species richness in the study sites on the East ranches from 2012-2019 for the reduced data set.

Rank	Response Variable	Covariates	β Estimate	Standardized β	AIC	Δ AIC	R^2	85% Confidence Limits		Standardized 85% Confidence Intervals		Model Weight
1	Plant Species Richness				-94.0575	0	0.531					0.222256
		August rainfall	-0.00386	-0.31544				-0.00584	-0.00189	-0.4769	-0.15398	
		Sand	0.06195	0.73437				0.0485	0.0754	0.57488	0.89385	
		Use	0.01958	0.78814				0.00344	0.03572	0.13831	1.43798	
		Use^2	-0.00020324	-0.86155				-0.0003565	-0.00004993	-1.51143	-0.21168	
2	Plant Species Richness				-93.8069	0.2506	0.488					0.196082
		August rainfall	-0.00324	-0.2648				-0.00517	-0.00131	-0.42228	-0.10732	
		Sand	0.05744	0.68086				0.04415	0.07072	0.52338	0.83833	
3	Plant Species Richness				-92.5638	1.4937	0.496					0.105317601
		August rainfall	-0.00299	-0.24404				-0.00498	-0.001	-0.40624	-0.08184	
		September rainfall	0.00047155	0.09237				0.00035462	0.0013	-0.06946	0.25419	
		Sand	0.05638	0.66833				0.04292	0.06984	0.50874	0.82791	
4	Plant Species Richness				-92.0575	1.9535	0.532					0.083687
		August rainfall	-0.00378	-0.30888				-0.00587	-0.0017	-0.47906	-0.13869	
		September rainfall	0.00012026	0.02356				-0.00075377	0.00099429	-0.14765	0.19476	
		Sand	0.0615	0.72902				0.0475	0.0755	0.56303	0.895	
		Use	0.01901	0.76508				0.00215	0.03586	0.08655	1.4436	
		Use^2	0.00011096	-0.8329				-0.00035919	-0.00003378	-1.52262	-0.14319	

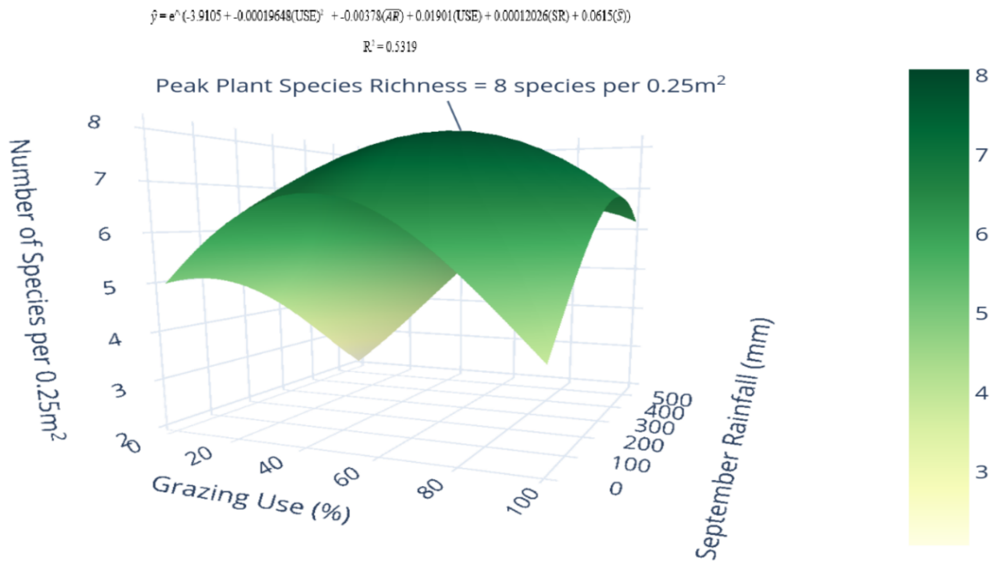

Figure 29. Peak plant species richness as affected by September rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use (USE)^2, mean August rainfall ($\overline{AR}$), grazing use (USE), September rainfall (SR), and mean sand ($\bar{S}$).

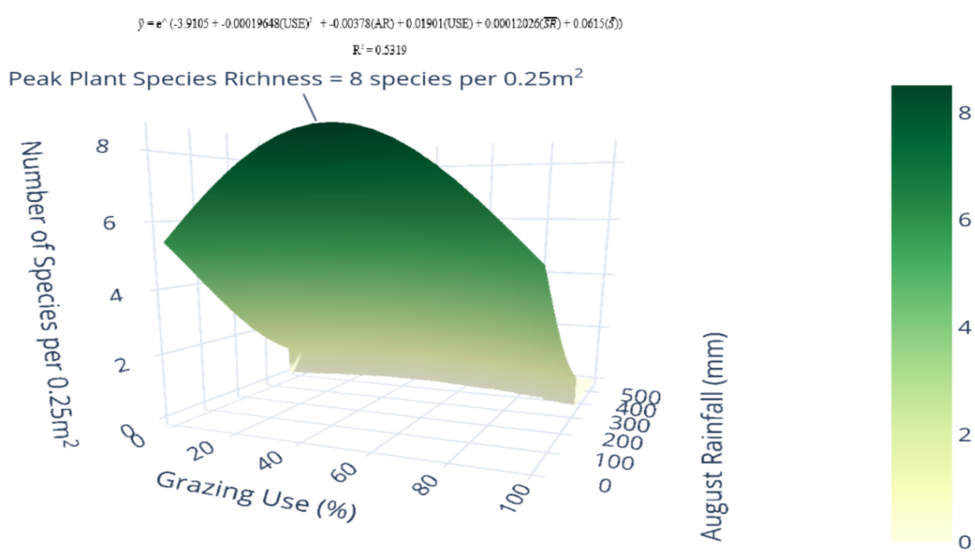

Figure 30. Peak plant species richness as affected by August rainfall and grazing use using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use (USE)^2, mean September rainfall ($\overline{SR}$), grazing use (USE), August rainfall (AR), and the mean sand ($\bar{S}$).

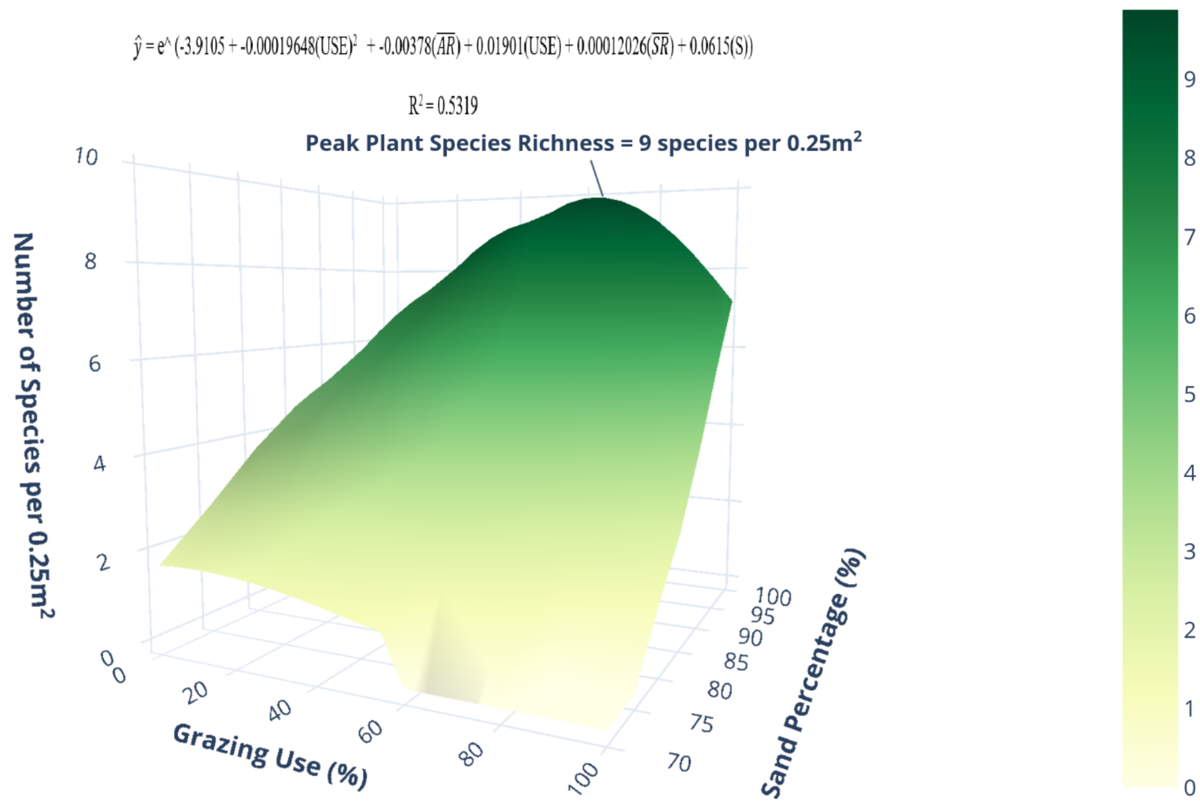

Figure 31. Peak plant species richness as affected by grazing use and sand percentage using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(USE)^2$, mean September rainfall ($\overline{SR}$), grazing use (USE), mean August rainfall ($\overline{AR}$), and sand (S).

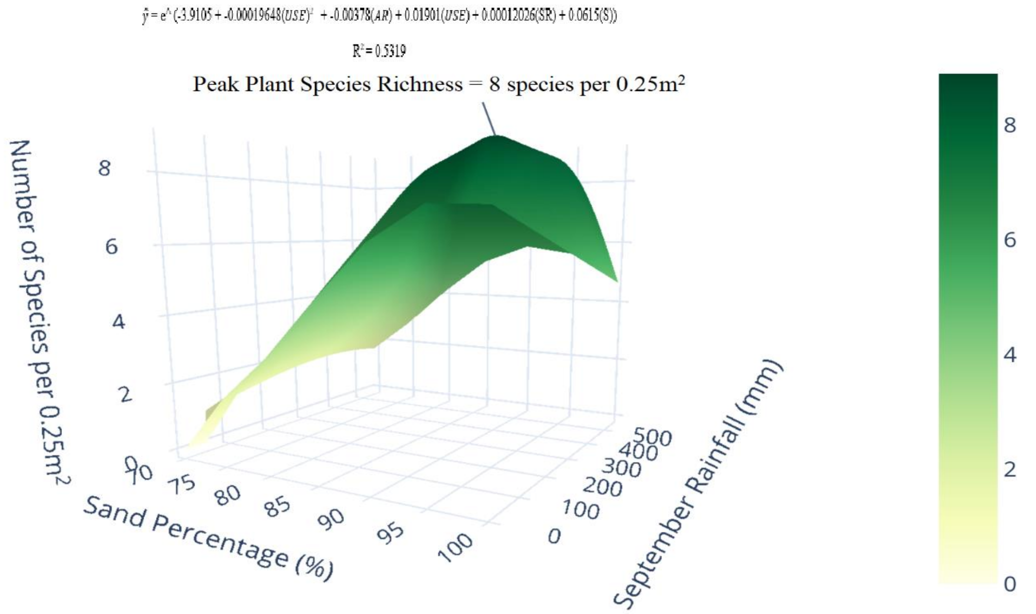

Figure 32. Peak plant species richness as affected by September rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\overline{USE})^2$, mean August rainfall ($\overline{AR}$), mean grazing use ($\overline{USE}$), September rainfall (SR), and sand (S).

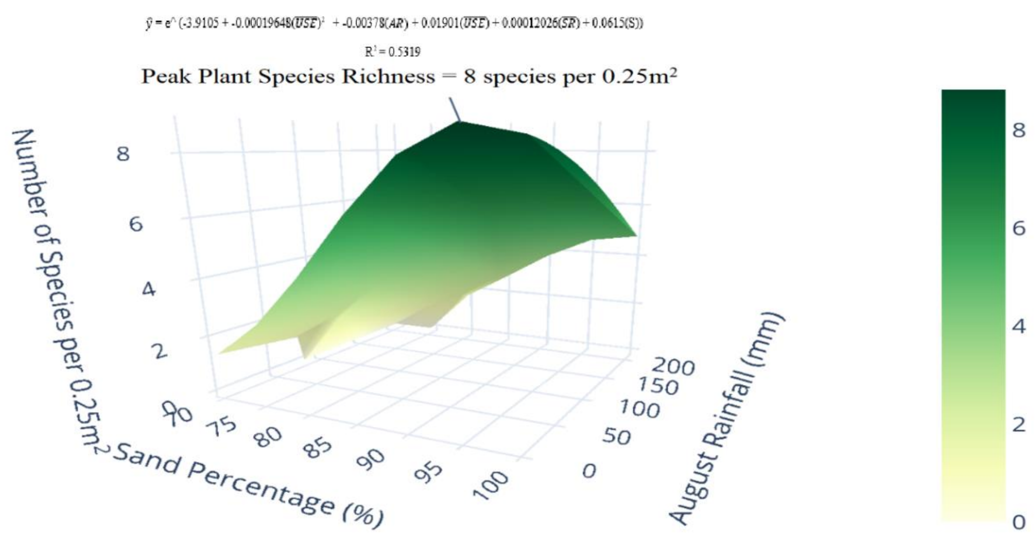

Figure 33. Peak plant species richness as affected by August rainfall and percent sand using the reduced data set from all East ranches study sites from 2012-2019. The model above to generate the graph included variables such as: grazing use $(\overline{USE})^2$, August rainfall (AR), mean grazing use ($\overline{USE}$), mean September rainfall ($\overline{SR}$), and sand (S).

Discussion

In this study, grazing had little effect on forb standing crop of preferred forbs for white-tailed deer. Even when grazing use was included in the best models, it showed a very limited effect on deer forbs. Abiotic factors were much more an influence on forb standing crop. There are several possible reasons for this result, such as overgrazing and variable rainfall in the study area. In a non-equilibrium environment, as in south Texas, stochastic abiotic influencers had a larger role on plant productivity than herbivores (Illius and O'Connor 1999, Derry and Boone 2009, Ellis and Swift 1988). Additionally, in 2011 and 2012 the worst drought since the 1950's occurred in south Texas, and in 2013 considerable rain did not occur until September. A legacy effect from cattle and wildlife overgrazing and drought more likely masked the effect of grazing utilization in this area. In drought-prone environments and overgrazed rangelands, 8 years may be a short period of time to probe the real effect of cattle grazing on deer preferred forbs. Other researchers have found that overgrazed rangelands may take a decade or more to recover especially in semi-arid environments with variable rainfall (Ruppert et al. 2015, Smith et al. 2007, Vetter 2009, Ryerson and Parmenter 2001). It may take many years for grazing herbivores to actually have an impact on forb standing crop for deer.

Using the complete data set, abiotic factors, such as soil and rainfall, were the most influential on forb standing crop as stated by Milchunas et al (1994). I found that total forb standing crop was primarily affected by September rainfall and sand percentages with a maximum total forb standing crop of 666 kg/ha. One interaction affecting forage standing crop of total forbs in the complete data set was use x sand which means that forb standing crop depended on percent change of use and how much sand was found in the soil. Just as reported by Jones et al (2016) where multiple factors were the drivers for forb production. Production of forbs was driven by with almost no rainfall in August and having a high September rainfall increased the amount of forb standing crop. My explanation for these results is that by having a low amount of August rainfall grass cover would be low, allowing a very high forb standing crop in September when forb outcompete grasses. The peak species richness, 10 species per $0.25m^2$, occurred when September rainfall was plentiful (540 mm) and 95% sand. Plant species richness was most influenced by September rainfall and sand percentages just as I found in the total forb standing crop. Other studies show the same results of environmental factors (rainfall and soil) affecting plant species richness as well (Xia et al. 2010, Grace et al. 2000, Robertson et al. 2010).

Herbivores do not graze all the areas of the rangeland uniformly (Bailey and Brown 2011, Fuhlendorf and Engle 2001). Herbivores also avoid areas of low to no forage availability, high brush density, rock cover, high surface slope, water and unpalatable forage species can affect how the area is grazed (Hanselka et al. 2009, Hohlt et al. 2009). In the case of this study, one-third to over half of the sampling sites were not grazed based on low grass biomass. Some areas of the ranches could be left ungrazed from water distribution, pasture deferment, and road proximity. The minimum value of grass standing crop in the sampling sites grazed by herbivores was 562 kg/ha. The implication of this result is very important for the calculation of correct stocking rate of cattle as well as the management of population densities of important wildlife species, such as nilgai (*Boselaphus tragocamelus*), and sites of productivity not being grazed by cattle should not be considered in the calculation of grazeable areas when estimating correct stocking rate as recommended by Ortega and Bryant (2005), Fulbright and Ortega (2013), and Hohlt et al. (2009). Grazable area should be considered when calculating correct stocking rate when based upon total area and actual area that cattle can graze, since incorrect estimates of standing crop of the entire area can result to the overgrazing and degradation of the rangeland

(Fulbright and Ortega 2006). I determined the areas of the site that were being used from averages of grass standing crop inside and outside of the exclosure by site and by year, as rainfall increased a larger number of areas were grazed by herbivores. When looking at averages by site, sampling points used (areas) ranged from 38 to 55%.

Using the reduced data set for total and preferred forbs shown different influential factors in the model. Rainfall and sand were the most important factors, but use was also selected in the best model to predict the forb standing crop. An interaction affecting total forb standing crop in the reduced data set included sand x August rainfall where forb standing crop depended on sand in the soil and amount of rainfall in September. Another interaction occurred affecting preferred forb standing crop in the reduced data set included September rainfall and use where forb standing crop depended on percent change in use and amount of rainfall in September. Although grazing (use) had an influence in the model, it was not a major contributor compared to rainfall and soil. Similarly, Gann et al (2019), mentioned that with variable rainfall in an arid environment, rainfall was much more influential than herbivory.

Plant species richness response was different using the complete data set compared with the reduced data set. Grazing (use) was selected in the model as a factor that influenced species richness, with the reduced data set even when the major affecting factors were rainfall and sand. In the complete data set only rainfall and sand were the most influential factors. The plant species richness value was higher in the complete data set, since areas where grazing herbivores could not venture may have other species that may be less resistant to herbivory. Plant species richness may not be impacted directly by grazing use from the variable rainfall in south Texas just as other studies have shown in semi-arid rangelands (Milchunas et al 1988, Osem et al 2002, Zhang et al 2017, Walker and Wilson 2002).

Conclusion

The legacy effect from overgrazing by cattle and wildlife and the worst drought since the 1950's, an eight-year study may not be long enough to see herbivory impact on forbs preferred by deer. The grazing optimization hypothesis may work on landscapes in climax conditions but not in sub-climax rangelands. Even when grazing was selected as a factor when analyzing only the productive sites (reduced data set) rainfall and soils more important and probably masked the effect of grazing probably due to the initial condition of the landscape and the drought. It is clear however that herbivores avoided less productive sites and therefore the implication of this finding in the estimation of grazeable area to calculate correct stocking rate is a very important of my study to grazing management.

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Appendix A. Rainfall, soil, number of sampling points used and grazing use by year from 2012 – 2019 in south Texas. Locations are represented as: 1 – San Antonio Viejo Site 1, 2 – San Antonio Viejo Site 2, 3 – San Antonio Viejo Site 3, 4 – Buena Vista, 5 – Santa Rosa, 6 – El Sauz.

Site	Year	August Rainfall (mm)	September Rainfall (mm)	October Rainfall (mm)	November Rainfall (mm)	Sand Percentage	Number of Exclosures Used	Percent Exclosures Used	Percent USE
1	2012	11	36	4	21	94%	18	36%	74%
2	2012	21	36	2	20	93%	7	14%	97%
3	2012	29	41	4	38	81%	17	34%	65%
4	2012	24	32	6	38	96%	3	6%	84%
5	2012	29	99	2	16	95%	13	26%	91%
6	2012	8	85	30	6	95%	23	46%	77%
1	2013	9	132	3	42	95%	10	20%	53%
2	2013	16	146	14	35	90%	5	10%	48%
3	2013	20	223	3	46	78%	24	48%	46%
4	2013	21	157	16	17	89%	3	6%	56%
5	2013	51	215	21	49	94%	17	34%	66%
6	2013	28	128	20	80	94%	26	52%	72%
1	2014	82	114	30	108	93%	33	66%	29%
2	2014	43	132	5	105	93%	15	30%	60%
3	2014	19	146	6	73	79%	25	50%	16%
4	2014	64	241	8	90	94%	21	42%	54%
5	2014	85	229	28	120	94%	38	76%	38%
6	2014	62	313	103	168	96%	33	66%	65%
1	2015	3	51	186	11	92%	40	80%	9%
2	2015	12	80	178	12	90%	33	66%	50%
3	2015	13	67	177	11	75%	19	38%	47%
4	2015	2	49	97	19	93%	36	72%	35%
5	2015	24	135	131	44	95%	30	60%	33%

Appendix A. continued

Site	Year	August Rainfall (mm)	September Rainfall (mm)	October Rainfall (mm)	November Rainfall (mm)	Sand Percentage	Number of Exclosures Used	Percent Exclosures Used	Percent USE
1	2016	108	61	2	38	92%	33	66%	40%
2	2016	96	35	3	58	90%	41	82%	46%
3	2016	124	47	23	51	80%	31	62%	58%
4	2016	113	26	6	48	93%	35	70%	67%
5	2016	202	58	48	31	94%	32	64%	52%
6	2016	33	117	6	51	94%	38	76%	53%
1	2017	26	14	29	18	92%	13	26%	55%
2	2017	64	23	32	20	92%	9	18%	81%
3	2017	41	37	68	20	78%	29	58%	58%
4	2017	87	37	29	41	94%	36	72%	61%
5	2017	51	55	51	46	94%	13	26%	74%
6	2017	65	25	68	31	95%	22	44%	27%
1	2018	7	296	67	20	92%	8	16%	30%
2	2018	7	275	59	21	90%	22	44%	50%
3	2018	4	188	46	18	78%	27	54%	34%
4	2018	13	479	60	15	93%	33	66%	51%
5	2018	39	307	68	67	94%	32	64%	23%
6	2018	12	201	84	46	94%	34	68%	49%
1	2019	13	51	7	69	93%	19	38%	40%
2	2019	3	117	17	57	91%	19	38%	23%
3	2019	16	46	13	49	78%	33	66%	48%
4	2019	9	159	13	66	93%	34	68%	45%
5	2019	11	100	44	107	94%	21	42%	11%
6	2019	5	138	65	54	95%	26	52%	23%

Appendix B. List of most common forbs preferred by white-tailed deer, determined from previous research regarding forb palatability to deer in south Texas, identified on 4 East Foundation ranches, autumn 2012-autumn 2019.

FORBS- NATIVE ANNUALS	
Common Name	**Scientific Name**
Blue Curls	*Phacelia congesta*
Camphor Daisy	*Rayjacksonia phyllocephala*
Camphor Weed	*Heterotheca subaxillaris*
Common Broomweed	*Amphiachyris dracunculoides*
Common Buckwheat	*Eriogonum multiflorum*
Cory's Croton	*Croton coryi*
Cow Pen Daisy	*Verbesina encelioides*
Cut Leaved Evening Primrose	*Oenothera laciniata*
Desert Goosefoot	*Chenopodium pratericola*
Desert Mint	*Hedeoma drummondii*
Downy Ground Cherry	*Physalis pubescens*
False Dandelion	*Pyrrhopappus pauciflorus*
Glasswort	*Salicornia bigelovii*
Golden Tick Seed	*Coreopsis basalis*
Hooker's Plantain	*Plantago hookeriana*
Indian Chickweed	*Mollugo verticillata*
Laredo Flax	*Linum elongatum*
Laredo Sandmat	*Euphorbia laredana*
Kidder's Lazy Daisy	*Aphanostephus skirrhobasis var. kidderi*
Lazy Daisy	*Aphanostephus ramosissimus var. ramosissimus*
Low Amaranth	*Amaranthus polygonoides*
Nueces Green Thread	*Thelesperma nuecense*
Northern Croton	*Croton glandulosus var. septentrionalis*
Park's Croton	*Croton parksii*
Partridge Pea	*Chamaecrista fasciculata*
Pinnate Tansy Mustard	*Descurainia pinnata*
Plains Gaura	*Gaura brachycarpa*
Prairie Aster	*Aster subulatus var. ligulatus*
Rabbit Tobacco	*Diaperia candida*
Red Berry Nightshade	*Solanum campechiense*
Red Seeded Plantain	*Limonium carolinianum*
Ridgeseed Euphorbia	*Euphorbia glyptosperma*
Rio Grande Phlox	*Phlox drummondii ssp. drummondii*
Rio Grande Skullcap	*Scutellaria muriculata*
Rose Palafoxia	*Palafoxia rosea*

Appendix B. continued

Common Name	Scientific Name
Texas Palafoxia	*Palafoxia texana var. ambigua*
Rough Buttonweed	*Diodia teres*
Sandbell	*Nama hispidum*
Runyon Sunflower	*Helianthus praecox ssp. runyonii*
Scrambled Eggs	*Corydalis micrantha ssp. texensis*
Sand Sunfower	*Helianthus praecox ssp. argophyllus*
Sandy Land Bluebonnet	*Lupinus subcarnosus*
Scratch Daisy	*Croptilon rigidifolium*
Short Gland Clammy Weed	*Polanisia erosa ssp. breviglandulosa*
Showy Palafoxia	*Palafoxia hookeriana*
Silverleaf Sunflower	*Helianthus argophyllus*
Annual Seepweed	*Suaeda linearis*
Snake Cotton	*Froelichia drummondii*
Stinging Nettle	*Urtica chamaedryoides*
Texas Croton	*Croton texensis*
Texas Groundsel	*Senecio ampullaceus*
Texas Heliotrope	*Heliotropium texanum*
Texas Sleepy-Daisy	*Xanthisma texanum*
Three Lobed Florestina	*Florestina tripteris*
Tropic Croton	*Croton glandulosus var. pubentissimus*
Tufted Flax	*Linum imbricatum*
White Leaf Croton	*Croton leucophyllus*
White Pricklepoppy	*Argemone sanguinea*
Winged Flax	*Linum alatum*
Woolly Croton	*Croton capitatus var. lindheimeri*
Woolly Tidestromia	*Tidestromia lanuginosa*

FORBS- NATIVE PERRENIALS

Common Name	Scientific Name
American Snoutbean	*Rhynchosia americana*
American Nightshade	*Solanum americanum*
Ashy Dogweed	*Thymophylla tephroleuca*
Beach Ground Cherry	*Physalis cinerascens var. spathulifolia*
Bearded Dalea	*Dalea pogonathera*
Big Foot Water Clover	*Marsilea macropoda*
Blue-Eyed Grass	*Sisyrinchium biforme*
Bracted Sida	*Sida Ciliaris L. var. mexicana*
Bracted Zornia	*Zornia bracteata*

Appendix B. continued

Common Name	Scientific Name
Bull Nettle	*Cnidoscolus texanus*
Bush Sunflower	*Simsia calva*
Cardinal Feather	*Acalypha radians*
Catclaw Sensitive Briar	*Mimosa microphylla*
Coast Globe Amaranth	*Gomphrena nealleyi*
Prostrate Fleabane	*Erigeron procumbens*
Creeping Bundle Flower	*Desmanthus virgatus var. depressus*
Creeping Burhead	*Echinodorus cordifolius*
Creeping Lady's-Sorrel	*Oxalis corniculata var. wrightii*
Crowded Heliotrope	*Heliotropium confertifolium*
Crow Poison	*Nothoscordum bivalve*
Dalea Sp.	*Dalea sp.*
Dollar Weed	*Hydrocotyle bonariensis*
Drummond's Wood Sorrel	*Oxalis drummondii*
Dwarf Dalea	*Dalea nana*
Engelmann's Daisy	*Engelmannia peristenia*
Evolvulus Species	*Evolvulus alsinoides var. angustifolius or nuttallianus*
False Ragweed	*Parthenium confertum*
Fendler's Ivy Leaf Ground Cherry	*Physalis hederifolia var. fendleri*
Few Flowered St. John's Wort	*Hypericum pauciflorum*
Golden Dalea	*Dalea aurea*
Goldenweed	*Isocoma drummondii*
Goldenrod	*Solidago canadensis*
Gray's Milkpea	*Glactia heterophylla*
Hairy Evolvulus	*Evolvulus nuttallianus*
Heartleaf Fanpetals	*Sida cordata*
Hibera del Soldado	*Waltheria indica*
Hoary Milkpea	*Galactia canescens*
Indian Mallow Species	*Abutilon sp.*
Karnes Sensitive Briar	*Schrankia latidens*
Knotweed Leaf-Flower	*Phyllanthus polygonoides*
Lindheimer Tephrosia	*Tephrosia lindheimeri*
Mexican Bastardia	*Bastardia viscosa*
Tropical Mexican Clover	*Richardia brasiliensis*
Prairie Mexican Clover	*Richardia tricocca*
Mexican Evening Primrose	*Oenothera speciosa*
Mexican Hat	*Ratibida columnifera*
Mistflower (Blue)	*Conoclinium coelestinum*

Appendix B. continued

Common Name	Scientific Name
Old Plainsman	*Hymenopappus scabiosaeus*
Oreja de Perro	*Tiquilia canescens*
Padre Island Mistflower	*Conoclinium betonicifolium*
Palm Leaf Globe Mallow	*Sphaeralcea pedatifida*
Penny Leaf Wood Sorrel	*Oxalis dichondrifolia*
Pidgeon Berry	*Rivina humilis*
Pincushion Daisy	*Gaillardia suavis*
Plains Black Foot Daisy	*Melampodium cinereum*
Prairie Bur	*Krameria lanceolata*
Prairie Dalea	*Dalea compacta*
Purple Pleat Leaf	*Alophia drummondii*
Pussyfoot Dalea	*Dalea obovata*
Rainlily	*Cooperia drummondii*
Rio Grande Ayenia	*Ayenia limitaris*
Ruellia Sp.	*Ruellia sp.*
South Texas Rushpea	*Pomaria austrotexana*
Saltwort	*Batis maritima*
Savannah Milkweed	*Asclepias oenotheroides*
Sawtooth Frog Fruit	*Phyla nodiflora*
Scarlet Pea	*Indigofera miniata*
Scarlet Spiderling	*Boerhavia coccinea*
Sea Ox Eye	*Borrichia frutescens*
Sedge Species	*Cyperus sp.*
Sensitive Plant	*Mimosa strigillosa*
Shrubby Beebalm	*Monarda fruticulosa*
Showy Sida	*Sida lindheimeri*
Shruby Indian Mallow	*Abutilon abutiloides*
Sida Species	*Sida sp.*
Silky Evolvulus	*Evolvulus sericeus*
Silver Bladderpod	*Physaria argyraea*
Silver Croton	*Croton argyranthemus*
Silver Leaf Nightshade	*Solanum elaeangnifolium*
Skeleton Leaf Golden Eye	*Viguiera stenoloba*
Tampico Seepweed	*Suaeda tampicensis*
Slender Evolvulus	*Evolvulus alsinoides var. angustifolius*
Spadeleaf Sida	*Sida physocalyx*
Spiny Aster	*Aster spinosus*
Square Bud Daisy	*Tetragonotheca repanda*
Summer Cedar (Dogfennel)	*Eupatorium capillifolium*

Appendix B. continued

Common Name	Scientific Name
Sweet Gaura	*Gaura drummondii*
Texas Senna	*Chamaecrista flexuosa var. texana*
Texas Snoutbean	*Rhynchosia senna var. texana*
Texas Vervain	*Verbena halei*
Torrey's Croton	*Croton incanus*
Tube Tounge	*Justicia pilosella*
Wavy Leaved Gaura	*Gaura sinuata*
Western Ragweed	*Ambrosia psilostachya*
White Flower Mallow Sp.	*Abutilon sp.*
Widow's Tear	*Commelina erecta var. angustifolia*
Wild Mercury	*Ditaxis humilis*
Wild Onion	*Allium canadense*
Wild Oregano	*Lippia graveolens*
Winecup	*Callirhoe involucrata var. lineariloba*
Woodland Sensitive Pea	*Chamaecrista calycioides*
Narrow Leaf Shrubby Wood Sorrel	*Oxalis frutescens ssp. angustifolia*
Woolly Cotton Flower	*Gossypianthus lanuginosus var. lanuginosus*
Woolly Dalea	*Dalea austrotexana*
Woolly Globe Mallow	*Sphaeralcea lindheimeri*
Woolly Stemodia	*Stemodia lanata*
Yellow Flameflower	*Phemeranthus aurantiacus*
Yellow Ground Cherry	*Physalis cinerascens*
Yellow Wood Sorrel	*Oxalis dellenii*

FORBS- NATIVE BOTH ANNUALS PERRENIALS

Common Name	Scientific Name
Beaked Vervain	*Glandularia quadrangulata*
Blackeyed Susan	*Rudbeckia hirta*
Bladder Mallow	*Herissantia crispa*
Bristle Leaf Dogweed	*Thymophylla tenuiloba*
Euphorbia species	*Euphorbia sp.*
Hierba del Sapo	*Eryngium nasturtiifolium*
Indian Blanket	*Gaillardia pulchella*
Net Leaf Rabbit's Ears	*Zornia reticulata*
Pennsylvania Cudweed	*Gamochaeta pensylvanica*
Polly Prim	*Polypremum procumbens*
Scorpion's Tail	*Heliotropium angiospermum*
Southern Pepperweed	*Lepidium austrinum*

Appendix B. continued

Common Name	Scientific Name
Shaggy Portulaca	*Portulaca pilosa*
Sueda Species	*Suaeda linearis or tampicensis*
Virginia Pepperweed	*Lepidium virginicum var. medium*

FORBS- NON NATIVE ANNUALS

Common Name	Scientific Name
Common Purslane	*Portulaca oleracea*
Hedge Parsley	*Torilis arvensis*
Slim Lobe Celery	*Cyclospermum leptophyllum*
Tender Leaf-Flower	*Phyllanthus tenellus*

FORBS- NON NATIVE PERRENIALS

Common Name	Scientific Name
Straggler Daisy	*Calyptocarpus vialis*
Spreading Sida	*Sida abutifolia*

FORBS- NON NATIVE BOTH ANNUALS AND PERRENIALS

Common Name	Scientific Name
Yard Mallow	*Malvastrum coromandelianum*

Appendix C. List of grasses identified on 4 East Foundation ranches, autumn 2012 – spring 2019.

GRASSES - NATIVE PERRENIALS	
Common Name	**Scientific Name**
Alkali Sacaton	*Sporobolus airoides*
Broomsedge Bluestem	*Andropogon virginicus*
Brownseed Paspalum	*Paspalum plicatulum*
Buffalograss	*Buchloe dactyloides*
Bushy Bluestem	*Andropogon glomeratus*
Crinkleawn	*Trachypogon secundus*
Fringed Signalgrass	*Urochloa ciliatissima*
Green Sprangletop	*Leptochloa dubia*
Gulf Cordgrass	*Spartina spartinae*
Gulfdune Paspalum	*Paspalum monostachyum*
Gummy Lovegrass	*Eragrostis curtipedicellata*
Hairy Grama	*Bouteloua hirsuta*
Halls Panicum	*Panicum hallii*
Hooded Windmillgrass	*Chloris cucullata*
Inland Saltgrass	*Distichlis spicata*
Knot Grass	*Setaria reverchonii subsp. firmula*
Knotroot Bristlegrass	*Setaria parviflora*
Little Bluestem	*Schizachyrium scoparium*
Longtom Paspalum	*Paspalum lividum*
Marsh-hay Cord Grass	*Spartina patens*
Multiflower False-Rhodesgrass	*Trichloris pluriflora*
Pan-American Balsam Scale	*Elionurus tripsacoides*
Pink Pappusgrass	*Pappophorum bicolor*
Plains Bristlegrass	*Setaria leucopila*
Purple Dropseed Grass	*Sporobolus purpurascens*
Purpletop Tridens	*Tridens flavus*
Red Grama	*Bouteloua trifida*
Red Lovegrass	*Eragrostis secundiflora*
Sand Dropseed	*Sporobolus cryptandrus*
Sand Lovegrass	*Eragrostis trichodes*
Sand Witchgrass	*Digitaria arenicola*
Schribner's Panicgrass	*Dichanthelium oligosanthes*
Seacoast Bluestem	*Schizachyrium littorale*
Shoregrass	*Monanthochloë littoralis*
Silver Bluestem	*Bothriochloa laguroides*
Slender Grama	*Bouteloua repens*
Slim Tridens	*Tridens muticus*

Appendix C. continued

Common Name	Scientific Name
Southern Witchgrass	*Panicum capillarioides*
Southwestern Bristlegrass	*Setaria scheelei*
Spartina Sp.	*Spartina sp.*
Switchgrass	*Panicum virgatum*
Tanglehead	*Heteropogon contortus*
Texas Crabgrass	*Digitaria texana*
Texas Grama	*Bouteloua rigidiseta*
Texas Tridens	*Tridens texanus*
Texas Wintergrass	*Nassella leucotricha*
Thin Paspalum Grass	*Paspalum setaceum*
Tumblegrass	*Schedonnardus paniculatus*
Tumble Love Grass	*Eragrostis sessilispica*
Tumble Windmillgrass	*Chloris verticillata*
Vine Mesquite	*Panicum obtusum*
White Tridens	*Tridens albescens*

GRASSES- NATIVE ANNUALS

Common Name	Scientific Name
Fall Witchgrass	*Panicum capillare*
Needle Grama	*Bouteloua aristidoides*
Oldfield Threeawn	*Aristida oligantha*
Southern Sandbur	*Cenchrus echinatus*

GRASSES- NATIVE BOTH PERRENIALS AND ANNUALS

Common Name	Scientific Name
Coastal Sandbur	*Cenchrus spinifex*
Dropseed Sp.	*Sporobolus sp.*
Purple Threeawn	*Aristida purpurea*
Sandbur Sp	*Cenchrus sp.*
Threeawn Species	*Aristida sp.*
Whorled Dropseed	*Sporobolus pyramidatus*

GRASSES- NON NATIVE PERRENIALS

Common Name	Scientific Name
Bermuda Grass	*Cynodon dactylon*
Buffelgrass	*Pennisetum ciliare*
Dallisgrass	*Paspalum dilatatum*
Guinea Grass	*Megathyrsus maximus*

Appendix C. continued

Common Name	Scientific Name
Kleberg Bluestem	*Dichanthium annulatum*
Lehmann's Lovegrass	*Eragrostis lehmanniana*

GRASSES- NON NATIVE ANNUALS

Common Name	Scientific Name
Durban Crowfoot	*Dactyloctenium aegyptium*
Hairy Crabgrass	*Digitaria sanguinalis*
Mediterranean Lovegrass	*Eragrostis barrelieri*
Spike Burgrass	*Tragus berteronianus*

GRASSES- NON NATIVE BOTH PERRENIALS AND ANNUALS

Common Name	Scientific Name
Red Natal Grass	*Melinis repens*

GRASSES- EITHER NATIVE OR NON AND PERRENIALS OR ANNUALS

Common Name	Scientific Name
Crabgrass Species	*Digitaria sp.*

Appendix D. List of non-preferred deer forbs, determined from previous research regarding forb palatability to deer in south Texas, identified on 4 East Foundation ranches, autumn 2012-autumn 2019.

NON-PREFERRED FORBS NATIVE PERENNIALS	
Common Name	**Scientific Name**
False Ragweed	*Ambrosia confertiflora*
Skeleton-leaf Goldeneye	*Viguiera stenoloba*
Oreja de Perro	*Tiquilia canescens*
Ashy Dogweed	*Thymophylla tephroleuca*
Shrubby Beebalm	*Monarda fruticulosa*
Spotted Beebalm	*Monarda punctata*
Berlander's Trumpet	*Acleisanthes obtusa*
Scarlet Musk Flower	*Nyctaginea capitata*
Silverleaf Nightshade	*Solanum eleagnifolium*
Sawtooth Frog-Fruit	*Phyla incisa*

NON-PREFERRED FORBS NATIVE ANNUALS	
Common Name	**Scientific Name**
Cowpen Daisy	*Verbesina encelioides*
3-Lobed Florestina	*Florestina tripteris*
Small Flowered Gumweed	*Grindelia microcephala*
Camphor Weed	*Heterotheca subaxillaris*
Showy Palafoxia	*Palafoxia hookeriana*
Rose Palafoxia	*Palafoxia rosea*
Texas Palafoxia	*Palafoxia texana*
Wooly Croton	*Croton capitatus*
Cory's Croton	*Croton coryi*
Tropic Croton	*Croton glandulosus*
White-leaf Croton	*Croton leucophyllus*
Texas Croton	*Croton texensis*
Sandbell	*Nama hispidum*

NON-PREFERRED FORBS BOTH NATIVE PERENNIALS AND ANNUALS	
Common Name	**Scientific Name**
Texas Thistle	*Cirsium texanum*
Bristleleaf Dogweed	*Thymophylla tenuiloba*
White Prickly Poppy	*Argemone albiflora*
Trailing Four o'clock	*Allionia incarnata*

NON-PREFFERED FORBS NON NATIVE ANNUALS	
Common Name	**Scientific Name**
Prickly Russian Thistle	*Salsola tragus*

Appendix D. continued

Common Name	**Scientific Name**
Velvet Leaf	*Abutilon theophrasti*

VITA

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I. Professional Experience

Education

2020 – M.S. Candidate in Range and Wildlife Management, Texas A&M University-Kingsville. Expected Defense Date: April 2020. Expected Graduation Date: August 2020. Supervisor: Alfonso Ortega-Santos.

2017 – B.S. Range and Wildlife Management, Minor in Biology, Texas A&M University-Kingsville.

Work History

2017 – Present: Graduate Research Assistant – Caesar Kleberg Wildlife Research Institute, Kingsville, TX 78363

2013 - 2017: Vegetation Technician – Caesar Kleberg Wildlife Research Institute, Kingsville, TX 78363

2015 - 2017: Vegetation Technician – East Wildlife Foundation, Hebbronville, TX

2014: Student Researcher – Texas A&M University-Kingsville

Honors and Awards

2014: High Placing Individual in the Undergraduate Poster Presentation at the Texas Chapter of the Wildlife Society in Corpus Christi, TX.

2014 - 2018: Second place high scoring team in the Plant Identification contest at the Texas Chapter of the Wildlife Society.

2014 - 2018: Second place high scoring team in the Plant Identification contest at the Texas Section Society for Range Management.

2018 – Second high scoring individual in the plant identification contest at the Texas Section Society for Range Management.

II. Technical Skills

Proficient in Microsoft Office products (Excel, Word, Power Point)
Competent in Geographic Information Systems (Arc GIS)
Competent in SAS 9.4 Statistical Analysis Program
Experience in plant identification of Texas plants (forbs, grasses, shrubs, and cacti), with emphasis in plants of south Texas.

III. Teaching Experience

2017: Texas A&M University-Kingsville
Graduate Teaching Assistant

2018: Texas A&M University-Kingsville
Graduate Teaching Assistant