INVASIVE LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) IN CHIHUAHUA, MEXICO: CONSEQUENCES OF INVASION

By

ALFONSO DE JESUS SANCHEZ MUÑOZ

Bachelor of Animal Science – Ingeniero Zootecnista
Universidad Autónoma de Chihuahua
Chihuahua, México
1974

Master of Science in Range Management
University of Arizona
Tucson, Arizona
1978

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 2009

INVASIVE LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) IN CHIHUAHUA, MEXICO: CONSEQUENCES OF INVASION

Dissertation Approved:

Dr. Karen R. Hickman

Dissertation Adviser

Dr. Terrence G. Bidwell

Dr. Daren D. Redfearn

Dr. Mahesh N. Rao

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGMENTS

I am very grateful with so many people and institutions that support me to make the accomplishment of this great step into my life.

First, to God for giving me health and understanding.

To my committee members; Dr Terry G. Bidwell, Dr Daren D. Redfearn, Dr. Mahesh N. Rao, and specially Dr Karen R. Hickman for her professional guidance, enormous patient and friendship shown in the elaboration of this dissertation.

To Oklahoma State University (OSU); to Dr David Henneberry and his International AG program for their interest and efforts to accomplish this academic joint program between OSU and UACH. To Dr Keith Owens and Dr James Steigler as Department Heads for their support, and to summer visitor professors at UACH: Drs David Lewis, Kenneth Rashield, Steve W. Hallgren, Daren D. Redfearn, Mike Smolen and Terry G. Bidwell. To the NREM department faculty, and Karen Sebring from ISS.

To OSU Animal Science Department, Drs Clint Krehbiel , Gerald Horn, Robert Wetteman, Udaya DeSilva, Donna, and colleague Luis Burciaga for the opportunity to work and be assisted by them in the lab.

To Universidad Autónoma de Chihuahua (UACH), To Javier Martinez and Salvador Alcantar deans of the Facultad de Zootecnia y Ecologia, UACH, Carmelo Pinedo and members of the Range Department, at Zootecnia, UACH.

To PROMEP and CONACYT, Mexican institutions that supported financially my studies and project needs.

To La Campana Experiment Station Personnel: Alicia Melgoza, Mario Royo, Socorro Gonzalez, Antonio Chavez, and Carlos Morales for their support with local data.

To OSU community, many fellows that gave me support, guidance and unconditional friendship, Alberto Grado, Brady Allred, Chad Cummings, Eahsan Shahriary, Jasper Dung, Jesus Santillano, John Weir, Ken Nelson, Leonard Bombom, Leonardo Carlos, Mario Gutierrez, Ojani Vega, Raymond Moranz, Scott Robertson, and Stephen Winter.

To Stillwater community; Jose and Ana Raquel Urdaneta, Mario and Bety Gutierrez, Father Ken, Luz and Raul Esteves, Enrique and Belinda Sanchez, Saint Xavier Church community, and to the city in general for their friendly environment that me and my family received.

To my family; my siblings; Francisco, Guillermo, and Rosario, my Children; Arlette, Alfonso, Adriana, and recently Edith, for their support and comprehension for being physically far from them, but always close in my hearth.

To my wife Soco for being more than my love, my partner in this adventure, in the field, in the lab, always taking care of me, and being my inspiration to accomplish this task at this point of my life.

I dedicate this dissertation to my late parents, Josefina and Alfonso for their love, guidance and support in the good and in the hard times.

TABLE OF CONTENTS

Chapter 1. LEHMANN LOVEGRASS PLANT COMMUNITY DYNAMICS OVER 20 YEAR PERIOD IN CENTRAL CHIHUAHUA, MEXICO

Page

TABLE OF CONTENTS

Chapter 3. VARIATION IN FORAGE NUTRIENT VALUE AND PRODUCTION OF LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) IN INVADED RANGELANDS OF CENTRAL CHIHUAHUA, MEXICO

LIST OF TABLES

Chapter 1. LEHMANN LOVEGRASS PLANT COMMUNITY DYNAMICS OVER 20 YEAR PERIOD IN CENTRAL CHIHUAHUA, MEXICO

LIST OF TABLES

Chapter 3. VARIATION IN FORAGE NUTRIENT VALUE AND PRODUCTION OF LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) IN INVADED RANGELANDS OF CENTRAL CHIHUAHUA, MEXICO

Table Page

LIST OF FIGURES

Chapter 1. LEHMANN LOVEGRASS PLANT COMMUNITY DYNAMICS OVER 20 YEAR PERIOD IN CENTRAL CHIHUAHUA, MEXICO

Figure Page

Figure Page

CHAPTER 1

LEHMANN LOVEGRASS PLANT COMMUNITY DYNAMICS OVER 20 YEAR PERIOD IN CENTRAL CHIHUAHUA, MEXICO

Abstract: Plant community dynamics, including vegetation changes in cover (%), species richness, diversity, evenness and similarity indices were assessed in a bunchgrass type rangeland in central Chihuahua, Mexico over a 20 year period (1985-2005). The goal of this study was to quantify the progressive invasion of Lehmann lovegrass (*Eragrostis lehmanniana*) from its original source of introduction in the mid-1960's. Vegetation was recorded along 46 permanent transects located and evenly distributed from 3 000 to 6 000 m distance from the original Lehmann lovegrass seed source. Vegetation changes were evaluated by using a pair t-test ($P < 0.05$) comparison among years. From all species; 15% disappeared, 30% declined, 49% remained unchanged and 6% increased in cover. Most grasses reduced cover over 50%, *Bouteloua gracilis* appeared in site, and invasive Lehmann lovegrass expanded cover for over 200 times. Six forbs species disappeared and five declined in cover by more than 80%. Two semi-shrubs: *Gutierrezia microcephala* and *Viguiera decurrens* disappeared. Seventy percent of shrubs remained unchanged, where *Prosopis glandulosa* appeared and *Nolina texana* expanded by 5 times. Species richness (species per transect) decreased from 15 species in 1985 to 6 species in 2005 from 3 000 to 4 500 m from the original seed source. Similarly, plant diversity (Shannon's index) declined from 1985 (from 2 - 3.5 to 1 - 2.5 index value) in 2005. Vegetation changes in the 20 year period affected the abundance of many plant species and community diversity, Lehmann lovegrass exhibited a significant and progressive invasion of this central rangeland of Chihuahua.

Key Words: diversity, evenness, invasive, plant cover, richness, similarity index

INTRODUCTION

Grasslands throughout the world continue to be destroyed by human population growth that requires further development of agricultural fields, improper grazing management, housing development, and urban sprawl (Hoekstra et al. 2005). An additional, yet often ignored threat to these native plant communities is the introduction of non-native species for use as livestock forage, erosion control, or to improve grazing opportunities (Wilsey and Polley 2006). In the last half of the 20^{th} century, non-native species were commonly introduced due to their availability, rapid establishment, and lower cost in relation to native species for restoration or livestock production. Land managers often recommend seeding exotic grass species for rehabilitation of degraded grasslands because of these advantages, adaptation to a broad range of environmental conditions and tolerance of heavy disturbance levels (Ratzlaff and Anderson 1995). Many of these range improvement practices have now been criticized because of the negative effects on biodiversity (Fulbright 1996).

Many of the invasions in the western hemisphere have occurred because of imported C_4 African grasses (Williams and Baruch 2000; Redfearn and Nelson 2003). Lehmann lovegrass is one example of a perennial, warm-season grass native to Africa introduced into North America for grassland restoration (Herbel et al. 1973; Bock et al. 1986; Cox 1992). Lehmann lovegrass has raised concerns since its introduction into the southern Arizona semi-desert grasslands in 1932 (Cox et al. 1988). Despite these concerns, Lehmann lovegrass was considered in the 1950's as a promising grass for stabilization of degraded rangelands in the southern US and was extensively seeded across Arizona after repeated droughts and overgrazing had degraded native rangeland (McGinley 1999). Subsequently native private and public rangelands in the region were invaded by Lehmann lovegrass. For instance, Lehmann lovegrass was introduced both in the late 1930's for research (i.e. reseeding trials) in New Mexico and in a 1945 mesquite control study in Arizona was conducted on the Santa Rita Experimental Range (SRER). After 13 years this invasive grass became an established population (Tixier et al. 1959). Lehmann lovegrass spread by 1958 throughout the 145 000 ha SRER station, becoming one of the dominant grass species (Cox and Ruyle 1986; Anable, et al. 1992). Lehmann lovegrass was estimated to be spreading at the rate of 6 to 10 m/year and 23 years after introduction the spread rate was estimated at 175 m/year (Anable et al.1992).

Lehmann lovegrass was considered in the 1970's an ecological threat for rangeland stability due to its aggressive spread beyond target areas, displacing of native species and lowering species richness (Cable 1971; Geiger et al. 2003), and was shown to reduce the floral and faunal diversity of native rangelands (Bock et al 1986). For instance, many species of birds and other animals are threatened when the floristic composition of native plant communities is reduced, altering the native habitat (Whitford 1997; Flanders et al. 2006). Invasion of

Lehmann lovegrass through the southern US has been calculated occasionally and by 1980's had doubled its extent relative to its presence in the 1960's. Based on its ecological characteristics researchers predicted that Lehmann lovegrass had reached the limits of its distribution by early 1990's, however recent data showed that this invasive grass continues to spread throughout Arizona and New Mexico rangelands (Shussman et al. 2006).

Lehmann lovegrass has been used not only in the revegetation of degraded lands in the southwestern USA (McClaran and Anable 1992) but also in rangelands of Chihuahua, Mexico (Melgoza et al. 1986; Royo 1988). In the mid 1960's, Lehmann lovegrass was introduced into Chihuahua, Mexico, for reseeding and erosion control research (Royo 1988) at the Campo Experimental "La Campana" research station from the National Forest, Agriculture and Livestock Research Institute (INIFAP) managed by Mexican government through the Secretary of Agriculture, Livestock, Rural Development and Food (SAGARPA). Since then, it has invaded rangelands throughout the region primarily at altitudes from 1 100 to 1 600 m that have an annual rainfall of at least 150 to 220 mm (Melgoza et al. 1986). Anecdotal information suggests Lehmann lovegrass replaces the native grasses and becomes the dominant perennial grass.

Despite the long term presence of Lehmann lovegrass in central Chihuahua, few ecological studies have been conducted in that region to analyze vegetation changes and implications derived from the invasion of this perennial grass. The goal of this research was to quantify changes in floristic composition in Chihuahua rangeland invaded by Lehmann lovegrass following a 20 year period. The specific objectives of the study were first to assess changes in Lehmann lovegrass cover along transects of increasing distance (i.e. 3 000 to 6 000 m) from the original (i.e. mid-1960's) point of introduction. Second, to assess individual changes in plant species cover and shifts in dominance in the La Sierra pasture community. Third, assess changes in plant community composition (e.g. species richness, diversity, evenness and similarity) from 1985 to 2005 that occurred in association with Lehmann lovegrass invasion.

METHODS

To assess changes in native plant community with invasion of Lehmann lovegrass over a 20 year period, plant species cover and species richness were measured in 1985 and 2005 on long-term permanent transects established at La Campana in central Chihuahua. La Campana is located 82 km north of Chihuahua City (29°16"11"N, 106°21'27"W. Fig. 1) an d consists of approximately 2 900 ha arranged as a narrow strip 1.5 km wide and 16 km long located within the Encinillas basin. Rangeland ecology and livestock production are the primary research topics at La Campana. La Campana has four vegetation types represented along an altitudinal gradient from 1 500 to 2 500 m. From the bottomlands and progressing from east to west the types are the alkaline grassland in part of the Encinillas basin, the blue grama shortgrass prairie located in the central flat lands, the oak - bunchgrass type at the mountain piedmont, and the oak forest in the highest altitudes at La Campana mountain or "Sierra del Nido".

In mid 1960's Lehmann lovegrass was planted at La Campana for forage production and erosion control research. The original planting occurred in small observation plots (i.e. less than 0.5 ha total) located 3 km east of the Pan American Highway 45 which runs north and south through the research station. This transition area has been intensively managed and already invaded with Lehmann lovegrass (Fig. 2). Long term vegetation monitoring transects were established in the La Sierra pasture to the west of the highway in vegetation characterized as oak-bunchgrass. This site is described as piedmont hills where bunchgrass is located in the water runoff fans formations and exhibits rolling hills with 20 to 40% slopes. Climate is denoted as very dry with warm summers and average annual temperatures from 14 to 17℃, with 7 to 8 months of dry season and 215 days of frost free period (SARH 1978). Annual precipitation, which typically falls primarily in the summer, averaged 382 mm from 1981 to 2005 period (Fig. 3). However, in 1985, the first sampling period, precipitation was 448 mm and in 2005, the second sampling period, precipitation was 246 mm, 36% below longterm average.

Historic dominant vegetation along the longterm vegetation monitoring site consisted of bunchgrasses composed of species within the main genera, *Bouteloua, Muhlenbergia, Aristida, Elyonurus, Trachypogon*, and *Schizachyrium* interspersed with oaks (*Quercus* spp.) (SARH 1978). Permanent transects (n=46) were systematically located parallel to and distributed from 191 to 2 801 m west from the highway fence line of the La Sierra pasture which represents a range of approximately 3 000 to 6 000 m from the original Lehmann lovegrass seed source. Transects were established in 1959 and sampled at least every decade by La Campana personnel. Data for this study came from 1985 (20 m long transects) and 2005 (30 m long transects) sampling. Actual transect locations were mapped (Fig. 2) by locating transect points with a global positioning system (GPS) device and using the Arc-Map 9.2 version software (ArcGIS 2006). Transect points were located in UTM Zone 13 Mercator coordinate system. Actual transect distance from original source point for Lehmann lovegrass was determined by generating a geographic information system (GIS) map (Fig. 2).

Permanent transects were established in 1959 and basal cover vegetation has been used as the more established measure method for long term studies. Data were collected by measuring the basal intersect (cm) for grass and forb species and aerial intersect for semi-shrub, shrub, and tree species using the line intercept method (Elzinga 1998). Species cover change was expressed as the actual mean cover percentage for each species in total transects from 1985 and 2005. Data obtained for analysis had sums of basal or aerial cover of each species, therefore cover values (%) for each species were calculated on a per meter basis by dividing total individual species cover by number of meters of the transect. Data were analyzed by a paired t-test comparison between years by using SPSS version 15 statistical program.

Plant species richness (S = number of species sampled per transect), species diversity, using the *Shannon*-Wiener index {[$H' = -\Sigma\, pi \cdot (\ln pi)$] where *pi* = proportion of species *i* in the community} (Magurran 1988, Barbour et al. 1999), and evenness of species abundances (Pielou's J index = $H'/\ln S$) were also calculated for each transect and both sampling years (Hickman et al. 2004). Sorensen's similarity index {[$Ss = 2a/2a+b+c$] where a = number of species in both sample A (1985) and sample B (2005) (joint occurrences); b = number of species in sample B but not in sample A; and c = number of species in sample A but not in sample B (Krebs 1999) were calculated to assess similarity in plant community composition between 1985 and 2005. Plant community parameters were calculated using Ecological Methodology software (Krebs 2001).

RESULTS

Following a 20-year period, the invasive Lehmann lovegrass (*Eragrostis lehmanniana*) increased in cover over 2 000% (from 0.11 to 2.99%) throughout the entire study area (Table 1). In 1985, Lehmann lovegrass was only present in one transect with a basal cover of 103 cm, whereas in 2005 the invasive grass spread to 44 of the 46 transects covering a total of 4 132 cm. Perennial grass cover in 1985 was due to native species where transects located from 3 000 to 4 500 m from Lehmann lovegrass seed source showed an average basal cover of 6% and from 4 500 to 6 000 m distance was of 10%. After the 20 year period, native grasses were reduced to less than 1% cover in the 3 000 to 4 500 m and to 2% in the 4 500 to 6 000 m distance. However Lehmann lovegrass invaded the area covering 4% in the closest area and 2% in farther area (Fig. 4).

Overall vegetation basal or aerial cover changes which occurred following a 20 year period (1985-2005) in La Sierra pasture at La Campana research station in Chihuahua, included: 17% of all species disappeared from permanent transects, 30% were reduced in cover, 6% increased cover and 49% exhibited no significant change ($P < 0.05$) (Table 1).

A total of ten species disappeared from 1985 to 2005 and comprised: a grass species (*Muhlenbergia emersleyi);* six forbs: *Clitoria mariana, Commelina sp, Macrosiphonia hypoleuca, Nictaginaceae sp, Paronychia stacea, and Zornia dyphylla*; two semi-shub species: *Gutierrezia microcephala* and *Viguiera decurrens* and an oak species: *Quercus oblonguifolia* (Tables 1 and 2).

Eighteen species had significant reductions in cover following the 20 year period. Nine species were reduced ($P < 0.05$) in cover to less than 10% of the 1985 composition. Another nine species exhibited a 17 to 46% reduction in cover in 2005 relative to 1985 (Tables 1 and 2). Two species (*Bouteloua gracilis* and *Prosopis glandulosa)* were not present in 1985 (Table 1). *Nolina texana,* a native shrub species increased cover by 556% (Table 2).

Changes in plant species cover along the study site varied as distance from the Lehmann lovegrass original planting (seed source) increased (Fig. 2). Therefore, the following results describe the changes in species abundance relative to distance from original Lehmann lovegrass seed source.

In 1985, the native grasses: *Aristida spp., Andropogon hirtiflorus, Bouteloua hirsuta, Leptoloma cognatum,* and *Lycurus phleoides* were abundant in transects located from 3 000 to 4 500 m from the original Lehmann lovegrass seed source and by 2005 were reduced to nearly zero cover ($P < 0.05$) in 2005 (Fig. 5). Similarly, *Elyonurus barbiculmis, Trachypogon secundus* and *Muhlenbergia lanata*, were more abundant in transects located from 4 000 to 6000 m in 1985 and exhibited reduced cover in 2005. However, one native grass species, *Bouteloua gracilis*, was not present in 1985 but appeared as a new species occurrence in 2005 (Fig. 6).

Eragrostis lehmanniana was present only in one transect in 1985, and spread throughout the study area up to 5 500 m of distance from its origin, being more abundant within the range from 3 800 to 4 750 m in 2005 (Fig. 6).

Five forb species (*Aspicarpa lanata, Bulbustylis juncoides, Euphorbia spp., Galactia wrightii,* and *Hedyotis pigmae*) (Fig. 7) and two semi-shrub species (*Gutierrezia microcephala* and *Viguiera cordifolia*) (Fig. 8) were also significantly reduced in cover to nearly zero percent in 2005. *G. sarothrae*, was present along different transects throughout the study site in 2005 (Fig. 8) relative to 1985.

Shrub species exhibited fewer changes in cover from 1985 to 2005, with only two species exhibiting reduced cover (*Mimosa dysocarpa* and *M. lindheimeri*) in 2005 along the transects closest to the original seed source of Lehmann lovegrass (Fig. 9). However in 2005 both of these shrub species exhibited increased cover along transects located at a distance of over 4 750 m from the original seed source. In contrast, two other species had increased presence for 2005. *Quercus emoryi* an oak tree had a high cover in 1985 was declined by 2005 (Fig. 9). The other 27 species exhibited no significant change in cover from 1985 to 2005 (Tables 1 and 2).

Plant community parameters differed from 1985 to 2005 as distance from the original Lehmann lovegrass seed source increased. Therefore, results will be discussed relative to distance from original site of introduction. Species richness (number of species per transect) along transects within 4 800 m of original seed source decreased from 15 species in 1985 to 6 species in 2005. Whereas transects located from the 4 800 m to 6 000 m showed a species richness increase from 6 species per transect in 1985, to 12 species in 2005 (Fig. 10).

Similarly to species richness, plant community diversity (number of species and individuals per species) tended to be greater in 1985 (Shannon's index value higher than 2.50) from the 3 000 to 4 800 m distance from seed source at La Sierra pasture, however a reverse trend was shown along the transects located at 5 500 to 6 000 m distance where diversity was lower in 1985 relative to diversity 2005 (Fig. 11).

Evenness or equitability index values were not different among years or between transects located from 3 500 to 5 500 m, however evenness was lower at the further transects located from 5 500 to 6 000 m from seed source in 1985 than in 2005 (Fig. 12).

Vegetative composition similarity was low (Sorensen's values were less than 0.30) for most transects regardless of distance from Lehmann lovegrass seed source for vegetation comparison between 1985 and 2005 at La Sierra pasture (Fig. 13).

DISCUSSION

The plant community in the La Sierra study site experienced an increase in Lehmann lovegrass over a 20-year period. In 1985 Lehmann lovegrass was limited in occurrence to a single site within 3 200 m of the original seed source. After 20 years, and a long-term 13 year drought, the grass had spread throughout the study sites. The grass has spread 6 000 m from the original seed source. A general trend was observed along each transect in which the most abundant perennial grasses were replaced by Lehmann lovegrass. A study in southwest Arizona estimated Lehmann lovegrass to spread at a rate of 175 m/yr (Anable et al. 1992). In this study, the rate of spread was estimated at 142 m/yr. This value may be an underestimate given that no measurements were taken during the intervening years and Lehmann lovegrass might have been present at an earlier time

Lehmann lovegrass increased in occurrence from one to 44 transects and up to 2 600% in cover. This compares to the invasion in southern Arizona (Tixier 1959; Cox and Ruyle 1986; Anable et al. 1992) where this grass spread in 16 years from one plot to be the dominant species on most plots (Angell and McClaran 2001). Invasive species as Lehmann lovegrass can change persistence through time by acclimatization or shifts in morphology, physiology, and resource allocation. Therefore, it is important to study invasive species in the perspective of medium or long term periods (Strayer et al. 2006).

Lehmann lovegrass tended to be a strong competitor that can produce a monotypic stand similar to what crested wheatgrass invasions had produced in adjacent native rangelands in semi-arid western US (Krzic et al. 2000; Wilsey and Polley 2006).

This vegetation change at the La Sierra pasture resulted in loss of species diversity where ten species were lost and 18 species declined, two new species appeared, and other two others increased in cover.

Species richness was reduced by half at the closest transects from Lehmann lovegrass seed source of La Sierra pasture in 2005, suggesting that invasive Lehmann lovegrass increased in abundance, as species richness was declined. This supports in previous studies in southern Arizona where exotics reduced species richness in communities with low primary productivity (Bock 1986; Angell and McClaran 2001; McLaughlin and Bowers 2006). However, at a distance farther from the original seed source (4 500 to 6 000 m) species richness was not affected, possibly due to the increase in cover in this area of *Aristida, Bouteloua hirsuta, Gutierrezia sarothrae, Mimosa lindheimeri Nolina texana,* and Lehmann lovegrass.

Similarly, the plant community was more diverse in 1985 than in 2005 in the closest transect area from 3 000 to 4 500 m distance from seed source, however diversity was similar in the area further the 4 500 m suggesting that shifts in species abundance in 2005 replaced species that were reduced in 1985.

Evenness of species abundance was not different among years and possibly was maintained by the shifts in species and Lehmann lovegrass abundance in 2005. Differential species richness and diversity accounts might explain the low vegetation similarity index (less than 0.30) among the 20 year period (Ratliff 1993).

Loss of species diversity and cover shifts could also responded to the recurrent drought for the 14 previous years (1990 to 2004) in the semiarid region of Chihuahua State (Nunez-Lopez et al. 2007; Ortega et al. 2008). Decline of the dominant native grasses related to drought has been described in US semi-arid rangelands (Robinett 1992; Martin and Morton 1993) and this decline probably occurred previously to the lovegrass increase (Martin and Severson 1988). Similarly the northern Chihuahuan desert had experienced drought for 13 years and diminished *Bouteloua eriopoda* cover to 39% (1956), cover had decreased to close to zero by 2001. Nevertheless this can be species specific because in the same study, *Aristida* cover declined after the drought, but recovered during the post drought period (Yao et al. 2006).

IMPLICATIONS

Monitoring vegetation should be addressed in a long time frame where changes could improve or deteriorate the community values. This can be expressed as productivity or ecological diversity relating shifts in species composition and climate change as persistent drought.

Invasion of Lehmann lovegrass can dominate the plant community and change the biological complexity to a single grass species in Chihuahuan grassland. Essential components for sustainable production. An ecological issue that nowadays is receiving and demanding an increased attention worldwide.

LITERATURE CITED

Anable, M.E., M.P. McClaran and G.B. Ruyle. 1992. Spread of introduced Lehmann lovegrass *Eragrostis lehmanniana* Nees. in Southern Arizona, USA. Biological Conservation 61:181-188.

Angell, D.L. and M.P. McClaran. 2001. Long-term influences of livestock management and a non-native grass on grass dynamics in the Desert Grassland. Journal of Arid Environment 49:507-520.

ArcGIS, 2006. ESRI (Environmental System Research Institute), User guide. Redlands, CA.

Barbour, M.G., J.H, Burk, W.D. Pitts, F.S Guillian, and M.W. Schwartz. 1999. Terrestrial plant ecology. 3rd. ed. Benjamin Cummings/Prentice Hall. 688 pp.

Bock, C.E., J.H. Bock, K.L. Jepson, and J.C. Ortega. 1986. Ecological effects of planting African grasses in Arizona. National Geography Research 2:456-463.

Cable,D.R. 1971. Lehmann lovegrass in the Santa Rita experimental range 1937-1968. Journal of Range Management 24:17-21.

Cox, J.R., and G.B. Ruyle. 1986. Influence of climatic and edaphic factors on the distribution of *Eragrostis lehmanniana* Nees. in Arizona, USA. Journal of the Grassland Society of South Africa 3:25-29.

Cox, J.R., M.H. Martin, F. Ibarra, J. Fourie, N. Rethman and D. Wilcox. 1988. The influence of climate and soils on the distribution of four African grasses. Journal of Range Management 41:127-139.

Cox, J.R. 1992. Lehmann lovegrass live component biomass and chemical composition. Journal of Range Management 45:523-527.

DiTomaso. 2000. Invasive weeds in rangelands: species, impacts and management. Weed Science: 255-265.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Report Number BLM/RS/ST-98/005+1730. USDI-BLM. Denver, CO. 492p.

Flanders, A.A., W.P. Kuvlesky, D.C. Ruthven, R.F. Zaiglin, R.L. Bingham, T.E. Fulbright, F. Hernandez, and L.A. Brennan. 2006. Effects of invasive exotic grasses on south Texas rangelands breeding birds. The Auk 123:171-182.

Fulbright, T. E. 1996. Viewpoint: A theoretical basis for planning woody plant control to maintain species diversity. Journal of Range Management 49:554-559.

Geiger, E., T. Mau-Crimmins, and H. Schussman. 2003. Spread of non-native grass across southern Arizona: Multiple data sources to monitor change. USDA Forest Service Proceedings RMRS-P-30:116-120.

Herbel, C.H., Abernathy, G.H., Yarbrough, C.C., and Gardner, D.K. 1973. Rootplowing and seeding arid rangelands in the southwest. Journal of Range Management 26:193-197.

Hickman, K.R., D.C. Hartnett, R.C. Cochran, and C.E. Owensby. 2004. Grazing management effects on plant species diversity in tallgrass prairie. Journal of Range Management 57:58-65.

Hoekstra, J.M. T.M. Boucher, T. H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters 8:23-29.

Krebs, C.J. 1999. Ecological methodology. 2nd ed. Benjamin/Cummings. 620 p.

Krebs, C.J. 2001. Programs for Ecological Methodology, 2nd Ed. Version 6. Dept of Zoology, University of British Columbia, Vancouver, D.C. Canada.

Krzic, M, K. Broersma, D.J. Thompson, and A.R. Bomke. 2000. Soil properties and species diversity of grazed crested wheatgrass and native rangelands. Journal of Range Management 53:353-358.

Magurran, A.E. 1988. Ecological Diversity and its Measurement. Princeton Univ Press, Princeton, NJ.

Martin, S.C., and K.E. Severson. 1988. Vegetation response to the Santa Rita grazing system. Journal of Range Management 41:291-295.

Martin, S.C., and H.L. Morton. 1993. Mezquite control increases grass density and reduces soil loss in southern Arizona. Journal of Range Management 46: 170-175.

McClaran, M.P., and M.E. Anable. 1992. Spread of introduced Lehmann lovegrass along a grazing intensity gradient. Journal of Applied Ecology 29: 92-98.

McLaughlin, S.P. and J.E. Bowers. 2006. Plant species richness at different scales in native and exotic grasslands in southeastern Arizona. Western North American naturalist 66:209-221

McGinley, S. 1999. Changing grasslands. Interactions between native and non-native vegetation. Research report. College of Agriculture and Life Sciences (CALS). University of Arizona. Tucson AZ.US.

Melgoza, A., G. Melgoza and M.H. Royo. 1986. Vegetation changes in central Chihuahua State after 26 years.. Pastizales. Vol.17. INIFAP-SARH. Chihuahua, México. (In Spanish)

Nunez-Lopez, D, C.A. Munoz-Robles, V.M. Reyes-Gomez, I. Velasco-Velasco, and H. Gadsden-Esparza. 2007. Drought characterization in selected time scales in Chihuahua, Mexico. Agrociencia 41:253-262. (in Spanish)

Ortega-Ochoa, C., C. Villalobos, J. Martinez-Nevarez, C. M. Britton, and R.E. Sosebee. 2008. Chihuahua's cattle industry and a decade of drought: Economical and ecological implications. Rangelands 30(6):2-7.

Ratliff, R.D. 1993. Viewpoint: Trend assessment by similarity-a demonstration. Journal of Range Management 46:139-141.

Ratzlaff, T.D., and J.E. Anderson. 1995. Vegetal recovery following wildfire in seeded and unseeded sagebrush steppe. Journal of Range Management 48:386-391.

Redfearn, D. and C.J. Nelson 2003. In Barnes, R.F, C.J. Nelson, M. Collins, and K.J. Moore. Forages. An introduction to grassland agriculture. Volume I. 6th. Edition. Iowa State Press. 556pp.

Robinett, D. 1992. Lehmann lovegrass and drought in southern Arizona. Rangelands 14:100-103.

Royo, M. 1988. Autoecology contribution of Africano grass (*Eragrostis lehmanniana*). B.S. Thesis. Facultad de Ciencias Biológicas. Universidad Autónoma de Nuevo León, Mexico. 87p. (In Spanish).

SARH. 1978. Chihuahua. Comision Tecnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero. Subsecretaria de Ganaderia. Secretaria de Agricultura y Recursos Hidraulicos. México.

Schussman, H., E. Geiger, T. Mau-Crimmins, and J. Ward. 2006. Spread and current potential distribution of an alien grass, *Eragrostis lehmanniana*

Nees, in the southwestern USA: comparing historical data and ecological niche models. Diversity and Distributions 12:582-592.

Strayer, D.L. V.T. Eviner, J.M. Jeschke, and M.L. Pace. 2006. Understanding the long-term effects of species invasions. Trends in Ecology and Evolution 21:645-651.

Tixier, J.S., D.R. Kincaid, G.A. Holt, and P.D. Dalton. 1959. The spread of Lehmann lovegrass as affected by mesquite and native perennial grasses. Ecology 40:738-742.

Whitford. 1997. Desertification and animal biodiversity in the desert grasslands of North America. Journal of Arid Environment 37:709-720.

Williams, D.G., and Z. Baruch. 2000. African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biological Invasions 2:123-140.

Wilsey, B.J., and H.W. Polley. 2006. Abovegroud productivity and root-shoot allocation differ between native and introduced grass species. Oecologia 150:300-309.

Yao, J., D.P.C. Peters, K.M. Havstad, R.P. Gibbens, and J.E. Herrick. 2006. Multi-scale factors and long-term responses of Chihuahuan desert grasses to drought. Landscape Ecology 21:1217-1231.

Table 1. Vegetation code, scientific name, change (cover %), p-value and significance, for grasses and forbs at La Sierra pasture from 1985 to 2005.

Code	Scientific name	1985 Mean	2005 Mean	p-value	Sig	
GRASSES						
Arissp	*Aristida* sp.	0.34	0.15	0.008	*	
Andhir	*Andropogon hirtiflorus*	0.50	0.01	0.000	*	
Botbar	*Botriochloa barbinodis*	0.04	0.03	0.775	n.s.	
Boucur	*Bouteloua curtipendula*	0.20	0.08	0.063	n.s.	
Boucho	*Bouteloua chondriosoides*	0.03	0.08	0.130	n.s.	
Boueri	*Bouteloua eriopoda*	0.04	0.16	0.080	n.s.	
Bougra	*Bouteloua gracilis*	0.00	0.11	0.003	*	↑
Bouhir	*Bouteloua hirsuta*	0.62	0.19	0.012	*	
Elybar	*Elyonurus barbiculmis*	0.74	0.05	0.000	*	
Eraleh	*Eragrostis lehmanniana*	0.11	2.99	0.000	*	↑
Hetcon	*Heteropogon contortus*	0.01	0.04	0.546	n.s.	
Lepcog	*Leptoloma cognatum*	0.25	0.05	0.006	*	
Lycph	*Lycurus phleoides*	0.57	0.03	0.000	*	
Muheme	*Muhlenbergia emersleyi*	0.13	0.00	0.060	n.s.	
Muhlan	*Muhlenbergia lanata*	1.09	0.04	0.000	*	
Trasec	*Trachypogon secundus*	4.55	0.16	0.000	*	
FORBS						
Asplan	*Aspicarpa lanata*	0.66	0.02	0.000	*	
Buljun	*Bulbustylis juncoides*	0.20	0.00	0.000	*	
Climar	*Clitoria mariana*	0.03	0.00	0.150	n.s.	
Commsp	*Commelina sp.*	0.03	0.00	0.211	n.s.	
Crialb	*Criptantha albida*	0.01	0.01	0.486	n.s.	
Cropot	*Croton pottsii*	0.29	0.11	0.054	n.s.	
Driare	*Drimaria arenarioides*	0.01	0.01	0.855	n.s.	
Dysdec	*Dyschoriste decumbens*	0.02	0.01	0.512	n.s.	
Dyspen	*Dysodia pentachaeta*	0.02	0.01	0.528	n.s.	
Euphsp	*Euphorbia* sp.	0.05	0.01	0.019	*	
Evonu	*Evolvulus nuttallianus*	0.01	0.01	0.780	n.s.	
Galwri	*Galactia wrightii*	0.79	0.14	0.002	*	
Hedpig	*Hedyotis pigmaea*	0.10	0.01	0.001	*	
Machyp	*Macrosiphonia hypoleuca*	0.03	0.00	0.085	n.s.	
Nictsp	*Nictaginaceae sp.*	0.05	0.00	0.136	n.s.	
Oentou	*Oenothera* sp.	0.01	0.01	0.942	n.s.	
Parset	*Paronychia setacea*	0.01	0.00	0.114	n.s.	
Sidpro	*Sida procumbens*	0.12	0.07	0.291	n.s.	
Solele	*Solanum eleagnifolium*	0.01	0.01	0.701	n.s.	
Zordyp	*Zornia dyphylla*	0.02	0.00	0.172	n.s.	

* = significant at the p-value; n.s. = not significant; ↑ = positive significant change.

Table 2. Vegetation code, scientific name, change (cover %), p-value and significance, for semi-shrubs, shrubs, and trees at La Sierra pasture from 1985 to 2005.

Code	Scientific name	1985 Mean	2005 Mean	p-value	Sig	
SEMI-SHRUBS						
Bacpte	*Baccharis pteronioides*	0.19	0.19	0.982	n.s.	
Brispi	*Brickellia spinulosa*	1.20	0.70	0.165	n.s.	
Gutmic	*Gutierrezia microcephala*	0.28	0.00	0.030	*	
Gutsar	*Gutierrezia sarothrae*	0.60	0.24	0.119	*	
Tribic	*Trixis bicolor*	0.00	0.02	0.323	n.s.	
Vigcot	*Viguiera cordifolia*	0.26	0.01	0.002	*	
Viqdec	*Viguiera decurrens*	0.06	0.00	0.076	n.s.	
SHRUBS						
Acangu	*Acacia angustissima*	0.17	0.06	0.387	n.s.	
Coneri	*Condalia ericoides*	0.00	0.18	0.051	n.s.	
Dalesp	*Dalea sp.*	0.00	0.23	0.323	n.s.	
Dalwis	*Dalea wislizeni*	0.17	0.04	0.111	n.s.	
Daswhe	*Dasylirion wheeleri*	0.14	0.12	0.919	n.s.	
Eyspin	*Eysenhardtia spinosa*	1.33	1.48	0.869	n.s.	
Kralan	*Krameria lanceolata*	0.10	0.01	0.343	n.s.	
Mimbiu	*Mimosa biuncifera*	1.07	1.66	0.327	n.s.	
Mimdys	*Mimosa dysocarpa*	0.69	0.19	0.033	*	
Mimlin	*Mimosa lindheimeri*	4.36	2.00	0.027	*	
Noltex	*Nolina texana*	0.38	2.13	0.043	*	↑
Opunsp	*Opuntia* sp.	0.15	0.03	0.411	n.s.	
Progla	*Prosopis glandulosa*	0.00	0.59	0.038	*	↑
Tecsta	*Tecoma stands*	0.00	0.07	0.323	n.s.	
TREES						
Queemo	*Quercus emoryi*	9.48	2.15	0.017	*	
Queoblo	*Quercus oblonguifolia*	0.22	0.00	0.323	n.s.	

* = significant at the p-value; n.s. = not significant; ↑ = positive significant change.

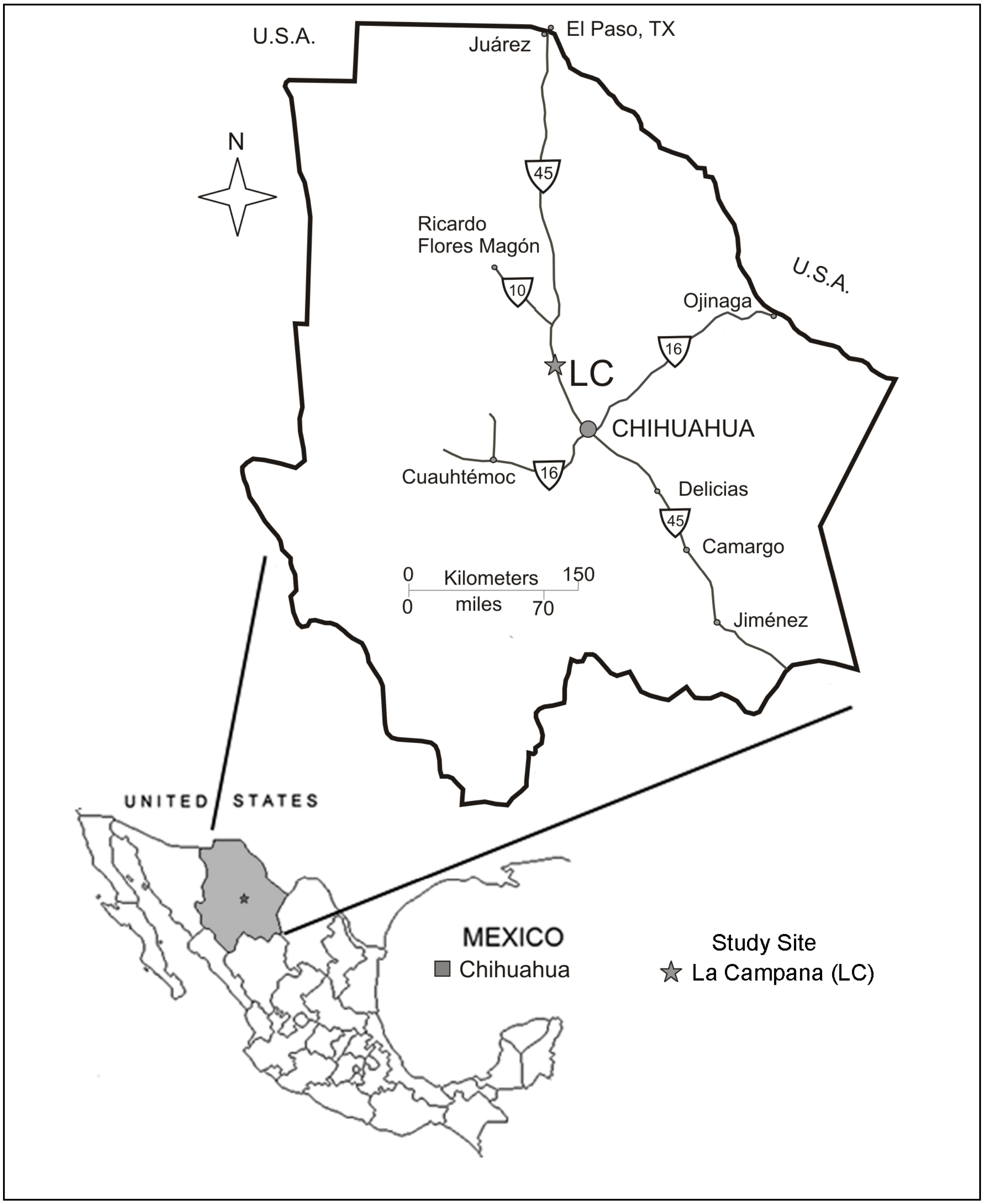


Figure 1. La Campana research site location in Chihuahua, Mexico.

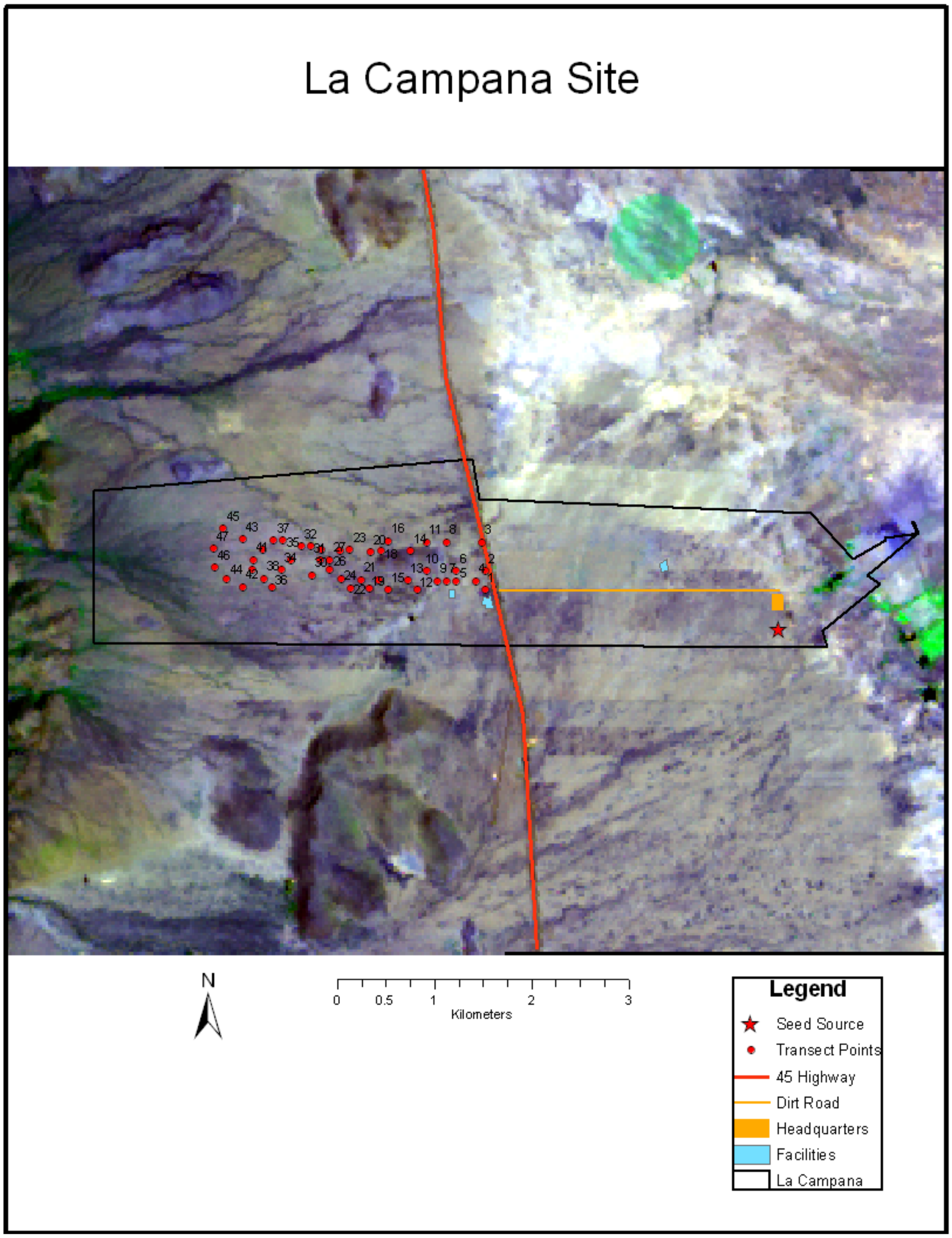


Figure 2. Lehmann lovegrass seed source, transect numbers, and location at La Sierra pasture at La Campana research site in Chihuahua, Mexico.

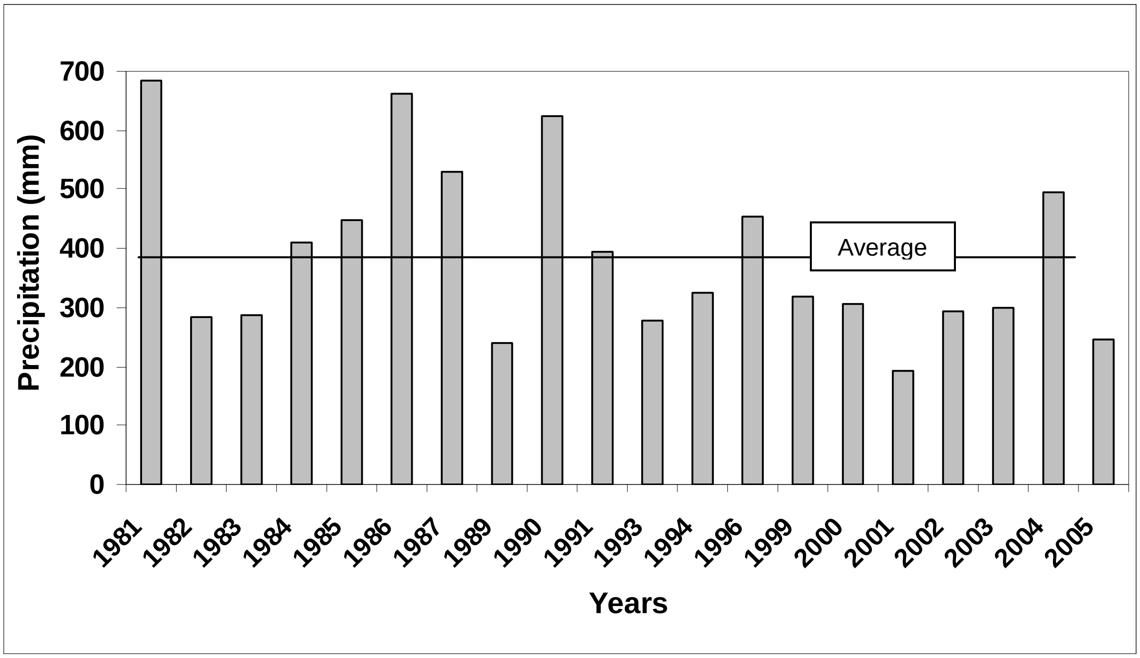


Figure 3. Long-term precipitation data for La Campana research site and 25 year average (382mm/yr).

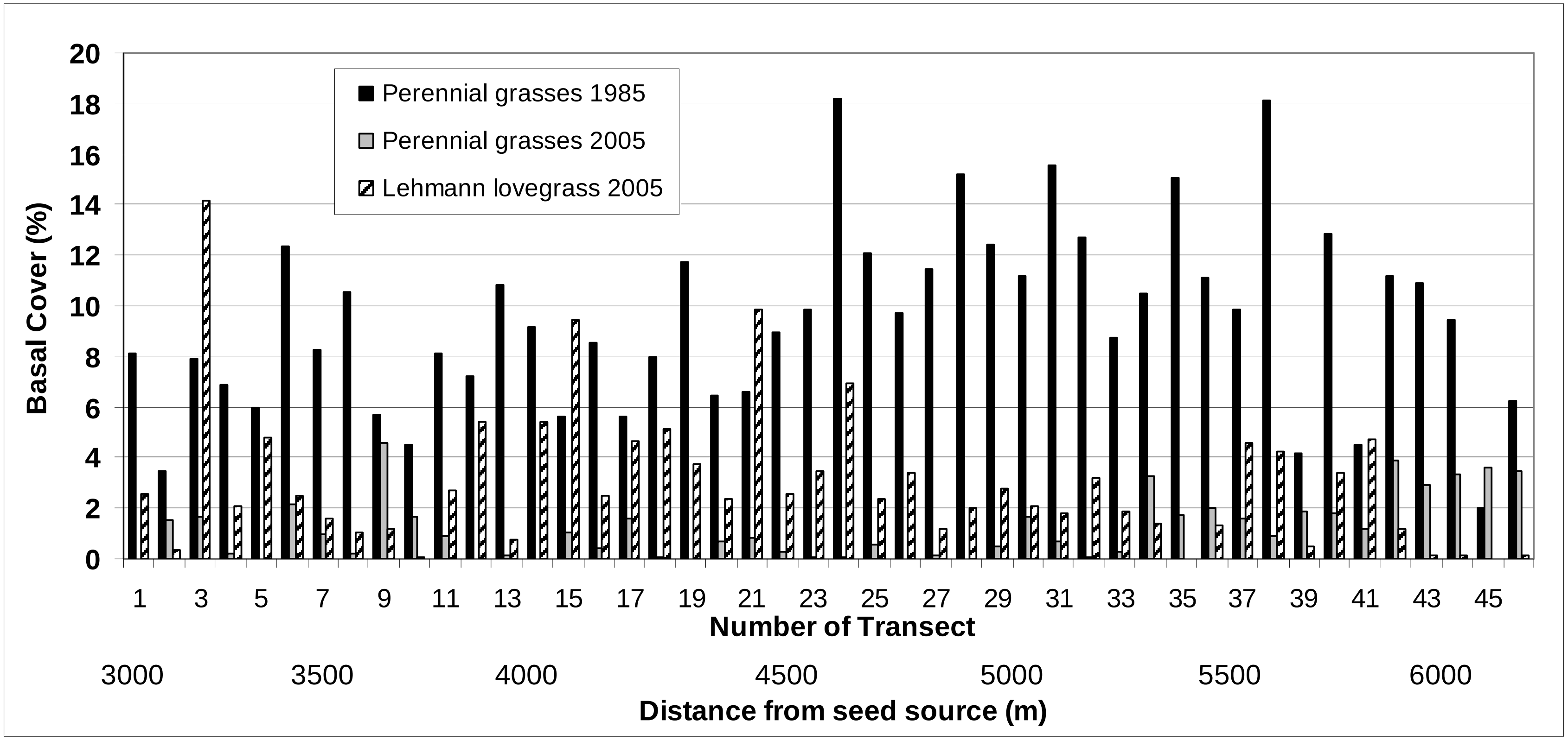


Figure 4. Basal cover for perennial grasses from 1985 to 2005, and cover of Lehmann lovegrass (*Eragrostis lehmanniana)* in 2005, relative to transect number (each set of three bars refer to a transect), and to distance from seed source.

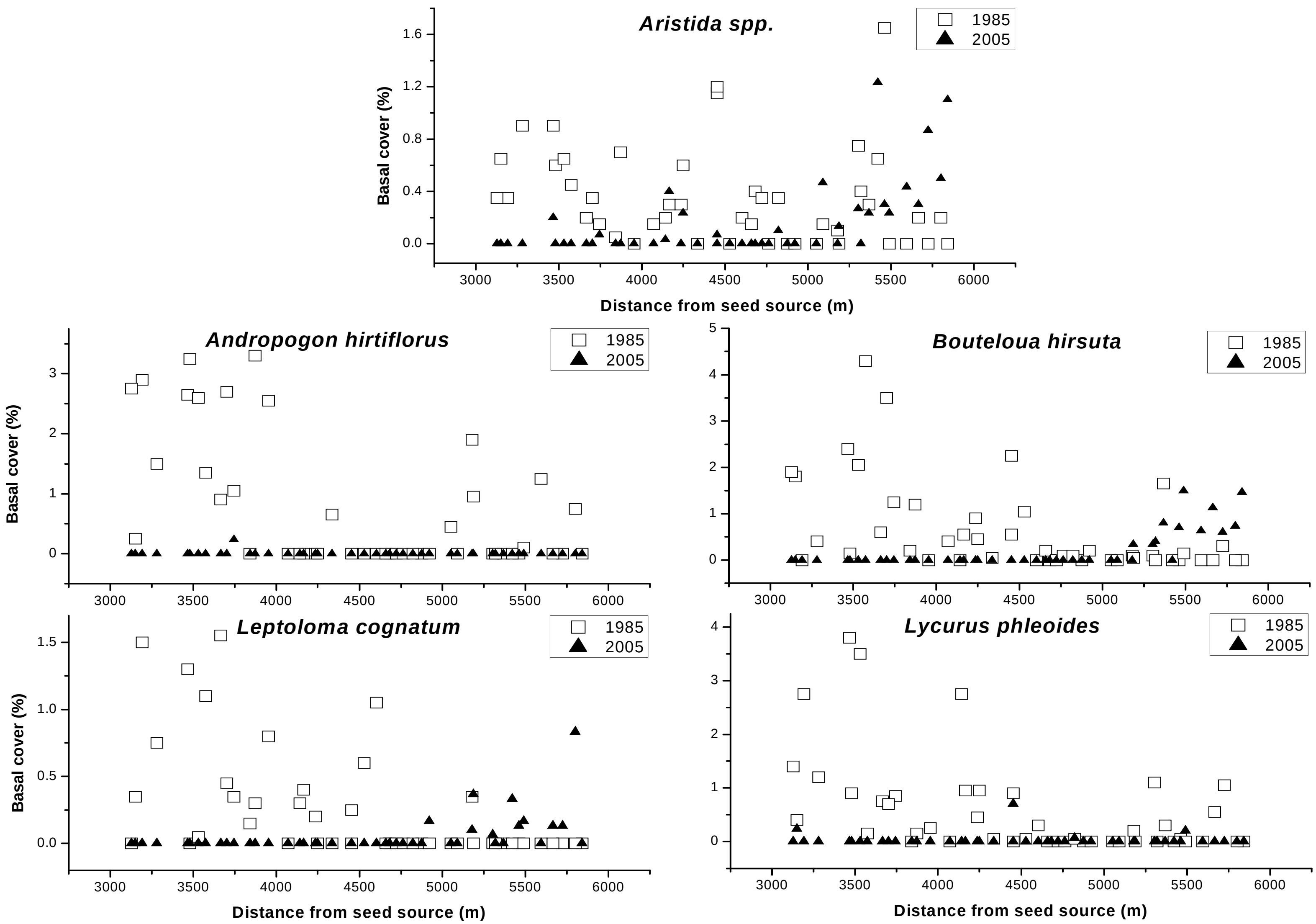


Figure 5. Grass abundance in transects that significantly declined from 1985 to 2005 at La Sierra pasture.

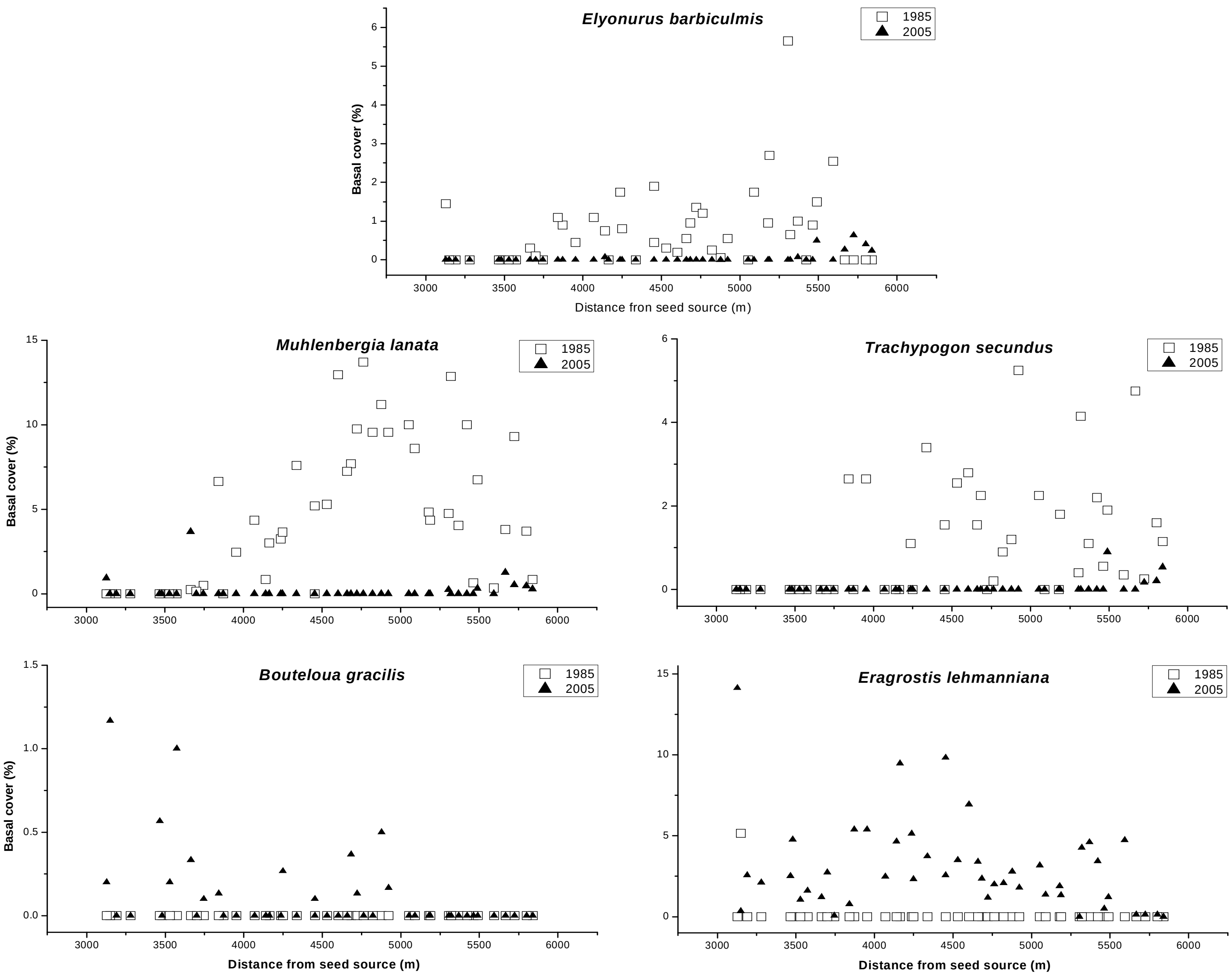


Figure 6. Grass species that significantly changed from 1985 to 2005 at La Sierra pasture.

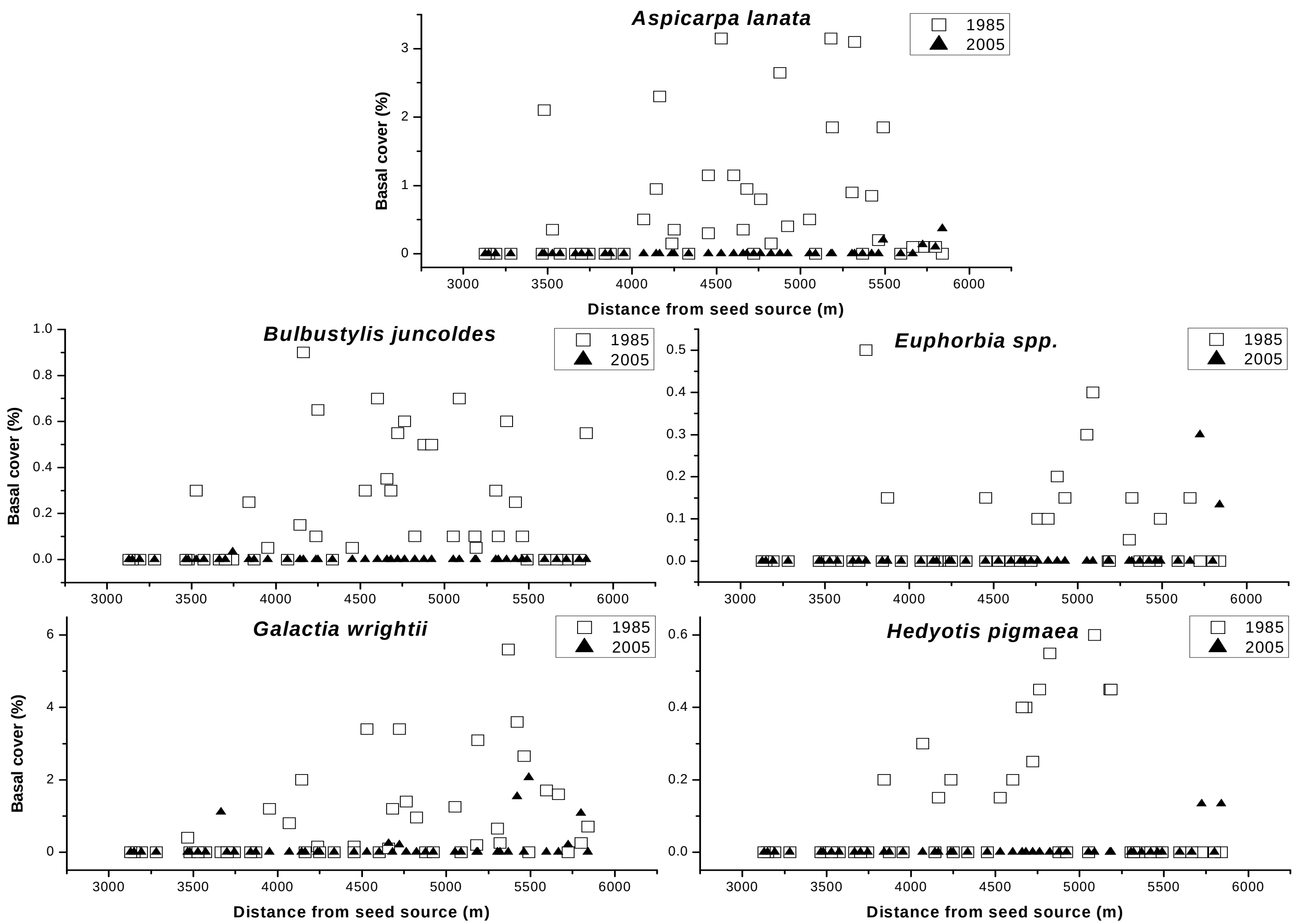


Figure 7. Forbs that significantly declined from 1985 to 2005 at La Sierra pasture.

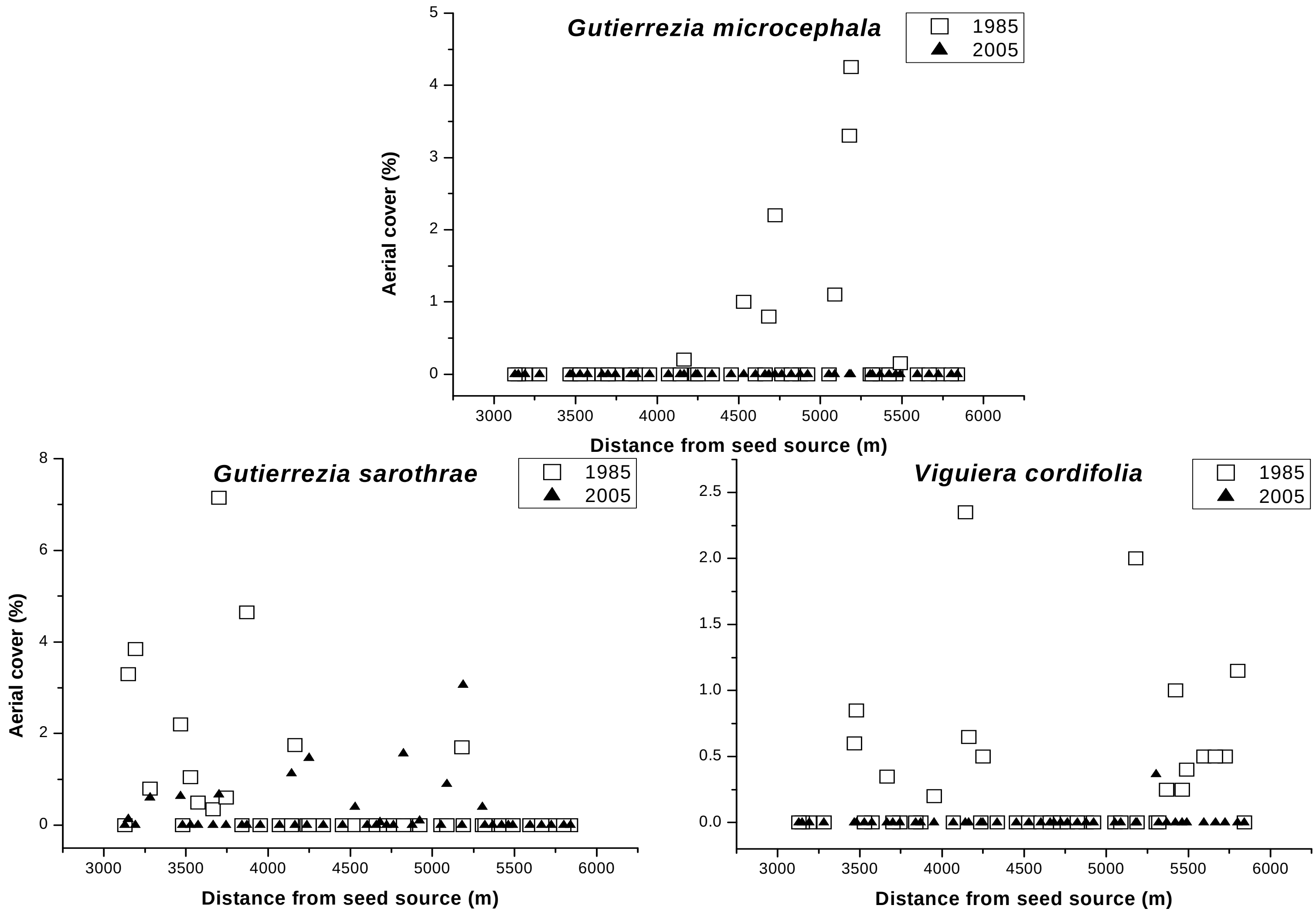


Figure 8. Semi-shrubs species that significantly declined from 1985 to 2005 at La sierra pasture.

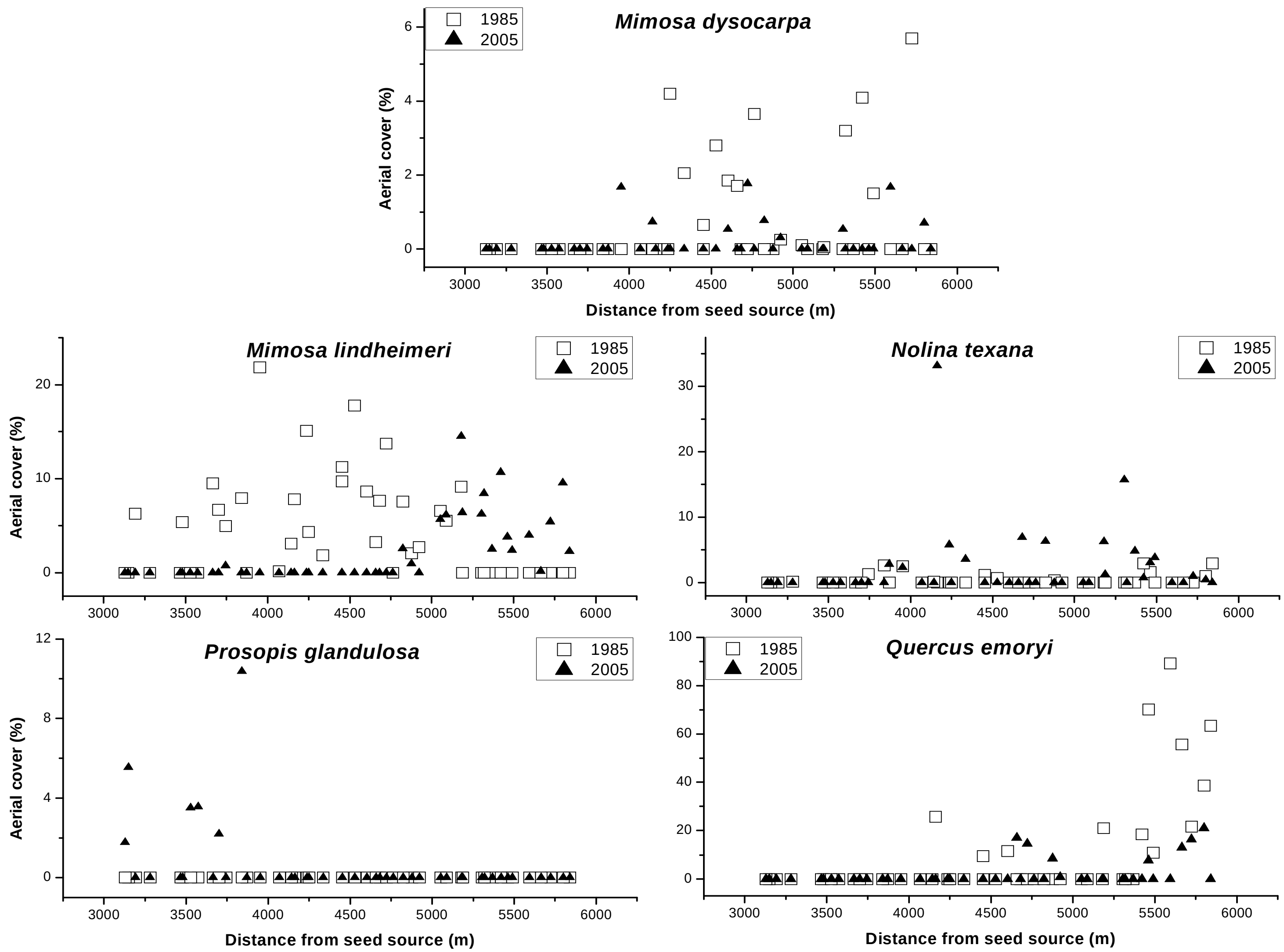


Figure 9. Woody species (shrubs and tree) that significantly declined from 1985 to 2005 at La Sierra pasture.

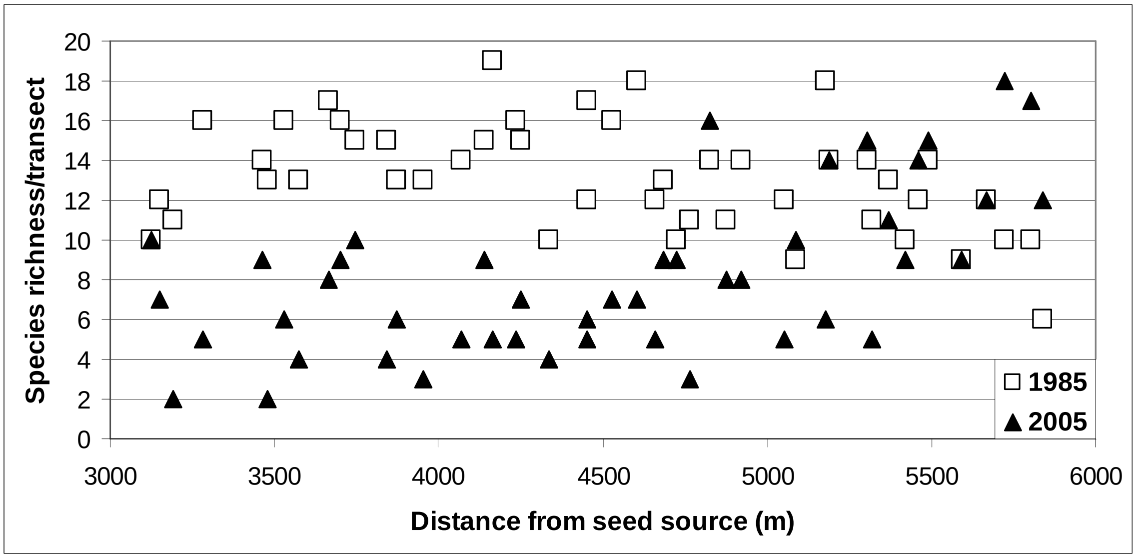


Figure 10. Species richness (number of species per transect) for vegetation composition in 1985 and 2005 at La Sierra pasture.

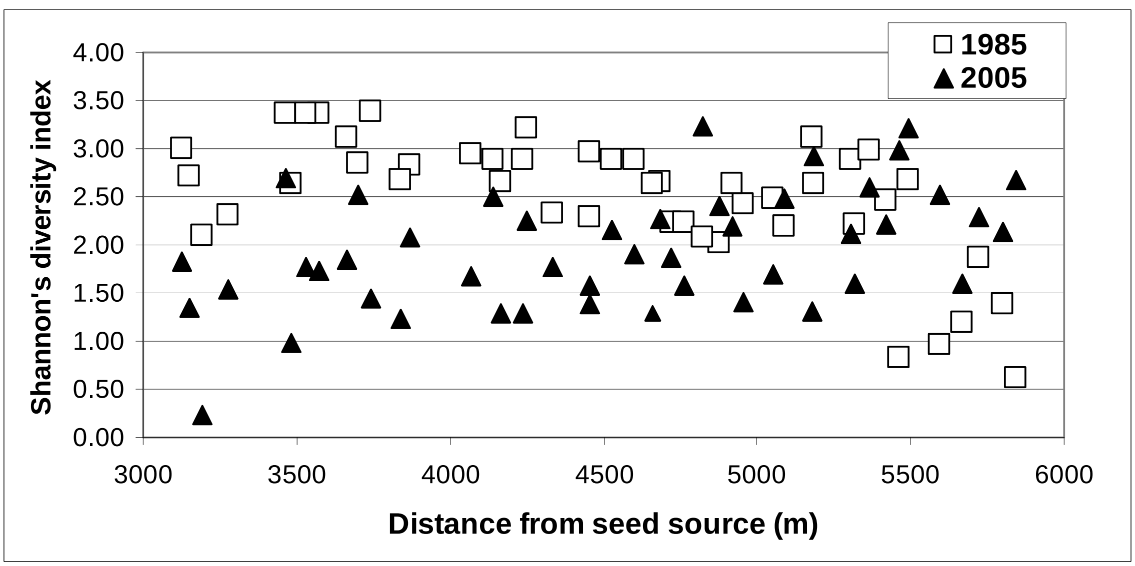


Figure 11. Shannon diversity (H') for vegetation composition in 1985 and 2005 at La Sierra pasture.

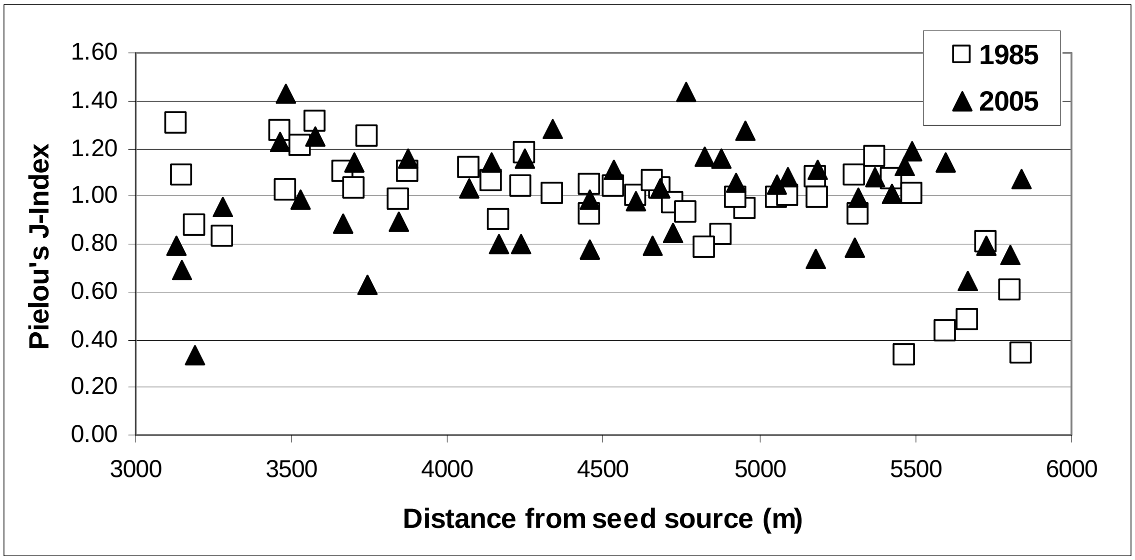


Figure 12. Pielou's evenness J-indexes for vegetation composition in 1985 and 2005 at La Sierra pasture.

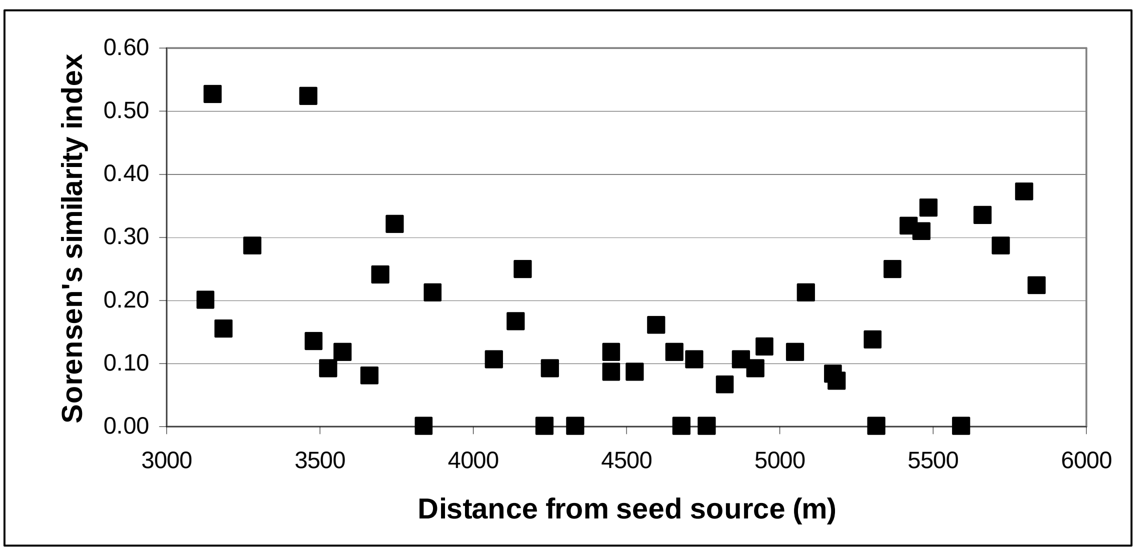


Figure 13. Sorensen's similarity indexes comparing 1985 and 2005 vegetation data at La Sierra pasture.

CHAPTER 2

SOIL AND PLANT COMMUNITY CHARACTERISTICS OF LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) INVADED SITES IN CENTRAL CHIHUAHUA, MEXICO RANGELANDS.

Abstract. Soil characteristics, species richness, community diversity, and species evenness were assessed for areas invaded by Lehmann lovegrass, transition zones (edge of the invaded area) and non invaded native rangelands (sub-sites) at four sites: El pastor (EP), La Campana (LC), San Cristobal (SC), and San Judas (SJ) along the central valley of Chihuahua. Two line intercept transects were placed in each sub-site. Transects were 30 m long and positions were recorded with a GPS device. Vegetation cover (cm) was recorded along the line intercept transect and expressed as species numbers and cover percentage. A soil sample was collected for each transect. Plant species richness, diversity, and evenness were calculated. Data were statistically analyzed using ANOVA and multivariate analysis to determine PCA and CCA relationships between soil attributes and plant species and sub-sites. There were no soil differences among sub-sites within sites. Soil from SC site was different ($P<0.05$) from other sites having higher values for pH, field capacity, electrical conductivity, organic matter, and calcium. PCA ordination separated SC and LC sites and related to salinity and sand respectively. Sites EP and SJ were similar among them and related to phosphorous. Lehmann lovegrass did not significantly affect the plant community attributes of species richness, diversity and evenness among the sites, nevertheless invaded sub-sites showed the lowest values. CCA showed that axis 1 and 2 accounted for the 77% of variation between abundant species and soil attributes. CCA ordination grouped four groups of abundant species in relation to soil attributes. Invasive Lehmann lovegrass was strongly correlated to sand texture, phosphorous, magnesium, and negatively to pH. Dominant species had the most significant presence in sub-site transects. *Eragrostis lehmanniana* was the most dominant species in invaded sites, however *Bouteloua gracilis* was the dominant grass in non-invaded sub-sites at EP and SJ and dominant in transition sub-sites at LC and SC.

Keywords: CCA, diversity, evenness, multivariate analysis, PCA, richness

INTRODUCTION

Invasions by non-native plant species to natural ecosystems are a major concern for livestock producers. Ecologists are also concerned, since biological invasions are considered a primary cause of extinctions (Rogers 2004). Invasive species are considered threats to native ecosystems with low diversity, given previous research has shown that communities with higher species diversity should be more resistant to invaders. However, recently research has suggested that even high native plant diversity can support high exotic plant diversity (Huston 2004). These areas differ in structure, function and plant composition from adjacent non-invaded areas (DiTomaso 2000; Williams and Baruch 2000; Dukes 2002).

Most plant invasions over the past centuries have involved species transported directly or indirectly by humans (Daehler 2003). In addition, human activity has resulted in changes in nutrient dynamics adding to concerns that these modified ecosystems may provide a resource surplus that exotic species can use to invade (Rinella et al. 2007).

Western USA and Northern Mexico rangelands have been deteriorated primarily through overgrazing, thus becoming susceptible to invasions (Di Tomaso 2000; MacDougall et al. 2006). Many of these ecosystems are dominated by perennial bunchgrasses that have been converted to a mix of annual grasses, forbs or shrub species. An attempt to restore deteriorated rangelands in the USA, perennial grass introductions have been tried, and in many instances South African grasses including Lehmann lovegrass (*Eragrostis lehmanniana*) have been selected. Lehmann lovegrass was introduced into southwestern Arizona in the 1930's and 1940's (Cable 1971; McClaran and Anable 1992; McLaughlin and Bowers 2006). Similarly in Chihuahua, Mexico, Lehmann lovegrass was introduced to revegetate depleted rangelands for erosion control and potential forage production. Lehman lovegrass was introduced for evaluation at the "Campo Experimental La Campana" for research purposes in the mid 1960's (Melgoza et al. 1986; Royo 1988).

Lehmann lovegrass is well adapted to semidesert ranges within altitudes from 1 000 to 1 500 m and with precipitation regimes from at least 254 mm in Arizona (Cable 1971) and 150 mm in Chihuahua (Melgoza et al. 1986). It establishes itself quickly from seed broadcast on areas with little or no competition and often develops into almost pure stands replacing more palatable native perennial grasses. It has established more rapidly than any other perennial grass on the Santa Rita Experimental Range in southwestern Arizona (Cable 1971).

In Arizona, management practices such as prescribed fire in different seasons to control Lehmann lovegrass were assessed to determine appropriate techniques to restore native vegetation cover. Unfortunately, seasonal prescribed fire was not a successful tool to reduce Lehmann lovegrass. In many cases, fire promoted the spread (Geiger et al. 2003) by removing litter, exposing the abundant, fire tolerant, Lehmann lovegrass seeds (Cable 1971) for germination. Ruminants were also to spread Lehmann lovegrass throughout uninvaded rangelands, since seeds survive ingestion, digestion and excretion as shown by fistulated ewes in New Mexico (Fredrickson et al. 1997).

Lehmann lovegrass in Chihuahua, Mexico, is distributed in patches throughout the central rangelands where limited research has been conducted, giving the opportunity to learn about the presence of this invasive grass. The goal of this research was to determine if Lehmann lovegrass invasion has affected soil characteristics and plant community structure at four sites. The specific objectives of the study were to assess soil differences in invaded, transition, and non-invaded rangelands and changes in plant community composition associated with varying levels of Lehmann lovegrass invasion.

METHODS

I assessed soil characteristics, plant species richness, diversity, and evenness for areas invaded with Lehmann lovegrass on four sites along the central valley of Chihuahua rangelands. Within these sites, sub-sites of Lehmann lovegrass invaded, transition zones (i.e. low levels of Lehmann lovegrass at the edge of the invaded area), and uninvaded native rangelands were selected for study. Site selection was determined by the following: a) Lehmann lovegrass invasion must have occurred at least 10 years before start of study, b) must be under cattle pasture management, and c) the invaded site must be in areas previously known as productive native rangelands as determined by previous experience (personal observation). The four sites in central grassland of Chihuahua included from north to south: El Pastor, La Campana, San Cristobal and San Judas (Fig. 1). Site characteristics for these areas are described in table 1.

Within each site, two line intercept transects were permanently located in Lehmann lovegrass invaded sub-sites, two at the edge boundary in transition sub-sites of the invaded area, and two transects outside the invaded area, (uninvaded sub-sites). Transects were 30 m long and the two end positions were recorded with a hand held Global Position System (GPS) device. At La Campana, only one transition sub-site transect was established because the transition area had been disturbed with different range seeding and brush control treatments. Along each 30 m transect, vegetation basal cover (cm) intersect was recorded for all grasses and forbs. Canopy cover was recorded for brush and tree species using the line intercept transect method (Elzinga et al. 1998). Basal and canopy cover measurements (cm) of plant species were recorded separately for each meter transect segment. Data were expressed as number of species, number of individuals within species, and cover percentage. All data were collected in July 2006 when vegetation was in actively growing.

At each site three 20 cm deep soil samples were collected within 50 cm along each transect were combined to form one composited soil sample for each transect. Each sample was placed in a plastic bag, air dried, sieved through a 2-mm mesh, and placed in a sealed one-litter plastic container and saved at lab room temperature. Physical and chemical analyses were determined at the Soil, Forage, and Water Laboratory at the Autonomous University of Chihuahua, Mexico.

The first site, El Pastor, located 120 km north of Chihuahua City (29°38'31"N, 106°33'23"W; Fig. 2), is managed as an e jido, or communal grazing land. This site is included in a 1 350 ha pasture having an estimated 80% dominance or invasion of Lehmann lovegrass, forming almost a pure stand. Invasion is predominantly at the northern pastures from highway 10.

The second site, La Campana, is located 82 km north of Chihuahua City (29°16"01"N, 106°23'08"W; Fig. 3). This site is a fede ral Mexican experimental station devoted to range, ecology, and livestock research. Lehmann lovegrass was introduced to the station for research and erosion control purposes in the 1960's. It was introduced about 3 000 m east of the 45 Pan-American highway and currently has spread throughout the station on 683 ha with some areas having an ocular estimation of at least 80% cover of Lehmann lovegrass.

The third site, San Cristobal, is located along the old highway in the Sacramento vicinity, 30 km north of Chihuahua City (28°48'10"N, 106°13'06"W; Fig. 4). Pastures (40 ha) on both sides of the 45 Pan-American highway where visually estimated had at least 80% of Lehmann lovegrass cover. The area is privately owned and moderately grazed by cattle.

The fourth site, San Judas, is located 20 km south of Chihuahua City (28°31'03"N, 105°55'37"W; Fig. 5). The area (185 ha) is part of a private cattle ranch where Lehmann lovegrass was visually estimated to cover at least 80% of the pasture.

Climate for this central region was defined by the Agricultural and Hydraulic Resources Secretary (SARH 1978) as dry temperate with warm summers with an average frost-free period of 210 days, extending from April to October. The mean annual temperature is 17°C, with a daily minimum of -2°C in

December and an average daily maximum of 33℃ in July. The average annual precipitation for La Campana research station is 382 mm (Fig. 6) with 70% falling as rain from June to October. Weather data was not available for the other three sites.

Study site maps were generated using remote sensing and geographic information system procedures. Satellite images which were used corresponded to: LANDSAT TM-5, path 32/row 40 (Chihuahua), from 6 October 2007 provided by University Autonomous of Chihuahua, and specific site images provided by Geo-Eye Foundation to support academic research; El Pastor image was generated by satellite/sensor RS-1 Mono CO, Path/Row-263/050, with Geo-Tiff format from 26 November 2005, and San Cristobal image produced by satellite/sensor IKONOS Geo 1m4m Ortho Kit Bdle BW/MS, from 29 September 2000. Cadastral polygons (shapefiles) for rural areas and ranch properties were obtained from State of Chihuahua, Mexico Government.

The LANDSAT images were processed in IDRISI (2003) Kilimanjaro software at the University Autonomous of Chihuahua (Facultad de Zootecnia) Remote Sensing Laboratory. Image analysis and GIS procedures were developed at the GIS Laboratory at the Oklahoma State University Geography Department. Analysis procedure was as follows: the image was first exported from IDRISI to ERDAS software by using the following IDRISI software route: file; export; software; “ERDIDRIS” command: The exported images were loaded in ERDAS IMAGINE 9.1 (2006) software and subsets for each of the 4 study sites was made by using the area of interest (AOI) tools (polygon) to delineate the target area onto the image; and saved with a proper name and .aoi extension. Using the "data preparation" option in erdas, and AOI delineated was specified in the subset tool was used to create the subset images of study sites.

ArcMap version 9.2 (2006) was used to generate the GIS maps. The images subets were loaded into ArcMap for vector digitizing of the study sites. ArcCatalog application was used to create new vector shapefiles (points, lines and polygons) to save the digitized information. The blank shapefiles were added to ArcMap, and the Editor Tool was used to digitize new features using the images subsets as a reference backdrop. A new set of shapefiles were created as: highway, roads, water points, study area, sampling points and many others.

Data points from sampling transects were groundtruthed using a handheld GPS device, coded and listed the UTM coordinates as X (eastern) and Y (northern) in a Microsoft Excel file and then converted and saved into .dbf file, choosing the extension type: DBF 4 (dBASE IV). This file was added to ArcMap, and selected by right clicking "go x,y data" and the points were displayed as vector features.

The symbology of the vector features were edited for better display, size, color, and other attributes. After all features were properly arranged, the view was changed from data view to layout view and map attributes as north arrow, scale, legend, and labeling were integrated to create the final map composition.

All vegetation inventories for the Chihuahua central rangelands were used to calculate species richness, diversity and evenness for each transect. In some analysis only the most abundant species were used. Abundant species were selected under the criteria of exhibit a minimum accumulated cover of 50 cm in all transects and/or have presence in at least two sites. Dominant species were selected by having more than 1 m of basal cover in transects.

Plant species richness (S= number of species sampled per transect), species diversity, using the *Shannon*-Wiener index {[H' = -Σ *pi*·(ln *pi*)] where *pi* = proportion of species *i* in the community} (Magurran 1988, Barbour, 1999), and evenness of species abundances (Pielou's J index = H'/lnS) were also calculated for each transect and sites (Hickman et al. 2004).

Before statistical analysis, data were tested for normality and homogeneity of variance (Sokal and Rohlf 1995). All data were subjected to a completely randomized analysis. Relationships for soil and vegetation data were compared among sites and between sub-sites within sites. Means were compared using Tukey and Duncan's multiple comparison methods. Analysis of variance (ANOVA) was performed using PROC GLM in SAS (1991) statistical package.

To determine if Lehmann lovegrass invades areas with similar soil characteristics and alters plant community composition, multivariate analysis was used to analyze the relationship between soil characteristics (n=20) measured from each site and the most abundant plant species (n=19) found in the study sites.

PCA was performed for 20 soil variables on 23 sub-sites. Principal component analysis (PCA) was conducted because soil variables had differences in dimensions. Principal components were considered useful when the eigenvalue for each principal component exceeded the broken-stick eigenvalue counterpart (Legendre and Legendre 1998; Jafari et al. 2004).

Ordination was performed using two data matrices: vegetation species and environmental variables or soil attributes in this case. The “length of gradient” rule (RDA<3 or CCA >3) and measured in standard deviation units obtained by detrended correspondence analysis (DCA) was used to select canonical correspondence analysis (CCA) or redundancy analysis (RDA) (Adler and Morales 1999). Decision was to use CCA as the direct gradient analysis method because obtained eigenvalues were 4.65 and 3.05 for first and second axis respectively.

CCA is the technique that selects the lineal combination of environmental variables that maximizes the description of the species scores, (Jafari et al. 2004). CCA is easier to apply (Ter Braak 1987; Jongman et al. 1995), and also it is recognized to perform well with skewed species distributions, with quantitative noise in species abundance data, from unusual sampling designs, and with intercorrelated environmental variables (Palmer 1993).

PCA and CCA had been suggested as useful analyses to test the relationships between invasive and native plant species relative to environmental gradients (Gilbert and Lechowicz, 2005; Smet and Ward 2005). PCA and CCA were performed in this study by using the program CANOCO for windows version 4.5 (2002).

RESULTS

There were physical and chemical soil characteristic differences among all four study sites. Soil from San Cristobal was different from all other sites in that San Cristobal soil had higher pH, electrical conductivity, calcium content, organic matter, and field capacity values. San Cristobal and San Judas soils had similar sand content, lower than the other sites. Values for pH were similar for El Pastor and La Campana soils where San Judas showed the lowest. Manganese soil content was similar and higher for La Campana and San Judas sites. There were no differences in hydraulic conductivity, pores, nitrate, potassium, and sodium content among sites (Table 2). Soil characteristics among sub-sites (i.e. Lehmann lovegrass invaded, transition and uninvaded sub-sites) were not significantly different.

Principal component analysis (PCA) was performed to find and use the most effective soil variables to distinguish the sub-sites for the presence – absence of Lehmann lovegrass in the four study sites. The first two principal components (PC1 and PC2) described most of the variance (56.97%) (Table 3). PC1 was more important for describing the variation of the sub-sites. PCA axis 1 represented soil salinity as described by electrical conductivity (EC), sodium (Na), calcium (Ca), and pH, while PCA axis 2 represented the soil nutrients nitrate (NO_3) and phosphorus (P), clay texture and have a negative correlation with zinc (Zn).

San Cristobal sub-sites (SC) differed from others sites by having a positive relationship with axis 1 and strong relationship with salinity denoted by EC, Na, Ca, and pH, and secondly associated to organic matter (OM) and soil water holding capacity denoted for field capacity, permanent wilting point and saturation soil attributes (FC-PWP-SAT) (Fig. 7). Sub-sites for La Campana site (LC) were conformed into the third quarter of the ordination diagram, more related to sand texture, iron (Fe) and manganese (Mn), however uninvaded sub-site LC5N (Fig. 7) was completely different to other sub-sites and more related to potassium (K) and total porosity (pores). Sub-sites for El Pastor (EP) and San Judas (SJ) were similar among them and were related to phosphorous (P) and inversely related to salinity and water holding capacity (Fig. 7).

The presence or absence of Lehmann lovegrass did not significantly affect the plant community parameters species richness, diversity and evenness among the four rangeland sites. However, from a biological stand point, species richness and diversity tended to decrease with the Lehmann lovegrass invasion at La Campana and San Judas sites and vegetation evenness tended to decrease in areas invaded with Lehmann lovegrass at all sites (Fig. 8).

A total of 46 plant species were found in the Chihuahua central rangelands. From this total, 19 species were selected as abundant (species with minimum accumulated cover of 50 cm in all transects and/or have presence in at least two sites species) and only eight were selected as dominant species (species having more than 1 m of basal cover in transects) (Table 4).

Canonical correspondence analysis (CCA) was performed to show the relations between the 19 abundant species and 20 soil attributes. The first axis (eigenvalue = 0.918) accounted for 28% variation on environmental data (Table

5-a). Correlation between the first axis and the species-soil attributes was 0.992 and the permutation for the Monte Carlo test for the first axis was not significant (*P* = 0.216). Correlation between the second axis (eigenvalue = 0.697) and species and soil variables was 0.991% where the Monte Carlo test was significant (*P* = 0.002) and explained 49.2% variation in data (Table 5-b). The sum of all eigenvalues was 3.284, where the sum of all canonical eigenvalues was 3.215 which mean that soil variables (environment) explained 97.9% of species–soils relationship (Table 5-c).

CCA ordination showed four groups of abundant species in relation to soil attributes. Each environmental factor (soil attribute) was an indicator of the specific habitat. In the first group species: *Chenopodium spp*. (chensp), *Prosopis glandulosa* (progla) and *Sporobolus airoides* (spoair) showed a non-linear relationship with sodium, potassium, and electric conductivity. A second group of seven species: *Aristida* spp (arissp), *Bouteloua curtipendula* (boucur), *Bouteloua hirsuta* (bouhir), *Calliandria* spp. (callsp), *Heteropogon contortus* (hetcon), *Mimosa biuncifera* (mimbiu), and *Schizachirium hirtiflorum* (schhir) were correlated with zinc, calcium, organic mater and water holding capacity (FC-PWP-SAT). A third group of five species: *Applopapus* spp. (applsp), *Brickellia spinulosa* (brispi), *Euphorbia* spp. (euphsp), *Potulaca mundula* (potmun) and *Sida procumbens* (sidpro), were correlated to iron (Fe) and copper (Cu). Species from the fourth group: *Bouteloua gracilis* (bougra), *Chamaechrista nictitans* (chanic), *Eragrostis lehmanniana* (eraleh) and *Tribulus terrestris* (triter) were non-linear correlated with sand texture, phosphorous (P), and magnesium (Mg) (Fig. 9).

Dominant species had the most significant presence in sub-site transects. *Eragrostis lehmannianna* and *Bouteloua gracilis* species were the two grasses which exhibited the most contrast in dominance among sub-sites. *Eragrostis lehmanniana* was the most dominant in invaded sites. *Bouteloua gracilis* was the dominant grass in uninvaded sub-sites at El Pastor and San Judas and in transition sub-sites at La Campana and San Cristobal. *Chamaechista nictitans*, *Bouteloua curtupendula*, and *Calliandria* spp. increased dominance from invaded to uninvaded sub sites at El Pastor, La Campana, and San Cristobal sites. *Tribulus terrestris* and *Brickellia spinulosa* species were more abundant in transition sub-sites at El Pastor and San Cristobal sites. *Sporobolus airoides* was dominant only in one sub-site at La Campana site (Fig. 10).

DISCUSSION

Comparisons among sub-sites showed no differences in soil characteristics suggesting that Lehmann lovegrass does not invade areas with specific soil characteristics, nor does the presence of Lehmann lovegrass after 10 years change soil characteristics. This study illustrated Lehmann lovegrass' ability to invade areas exhibiting a wide range of soil conditions.

Principal component analysis for soil characteristics also separated San Cristobal site from the other sites (Fig. 7), these saline sub-sites were clustered at positive values of PCA Axis 1 (38% of the total variance) having contrast soil characteristics with non-saline sub-sites (El Pastor and San Judas) that were grouped at negative values of PCA Axis 1. While at positive values of PCA Axis 2 (which explained 18% of the residual variance), were related to fertile uninvaded sub-site LC5N clustered with high values of NO_3 and clay probably because is located at lower altitude and received sediments from runoff waters.

The lack of quantifiable differences in plant species richness, diversity, and evenness among sites and sub-sites with varying levels of Lehmann lovegrass invasion, were most likely due to the small sample size (two transects per sub-site) considered. However as a general trend and arguing biological significance, sub-sites invaded with Lehmann lovegrass were lower in species richness, diversity, and evenness than in transition or non-invaded areas within sites. Biological significance is recognized to be important to ecologists and differs from statistical significance. Biological significance refers to the importance of a particular set of measurements in the context of a theoretical hypothesis (Krebs 1999). Small effects can be of ecological importance, such as the differences found in this study, where small trends and shifts in species occurrence can lead to ecological instability.

CCA ordination diagram (Fig. 9) of species scores in relation to the more significant environmental variables. The factors are indicated by arrows pointing in the direction of maximum variation, with their length proportional to the rate of change in each factor, i.e. a longer arrow indicates a more significant factor. Each arrow determines an axis on which the species distribution can be projected. The projection points estimate the ranking of the species along each environmental factor. In order to evaluate the CCA axes, canonical coefficients and correlations between the environmental factors and ordination axes were used (Table 5). The two axes of canonical correspondence analysis explained 77% of variation in soil attributes and species response. From these correlations it was concluded that salinity is strongly correlated with the first CCA axis, followed by K and Na. On the other hand, the second axis is determined by OM. The third axis did not show any further information than the first and second axes. The combination of PCA and CCA resulted in objectively defined groups of species and sub-sites along with their environmental determinants. Species positive related to first axis are adapted to saline soils and negatively associated to forbs and shrubs species. Axis 2 accounted for five grass species and the legumes *Calliandria* (callsp) and *Mimosa* (mimbiu) that were strongly related to organic matter, water holding capacity and clay texture. Opposite to this trend in Axis 2, the invasive *Eragrostis lehmanniana* and *Bouteloua gracilis* the most dominant species were strongly related to sand texture soils, a trend similarly found in Arizona (Cox and Ruyle 1986).

Invasion of Lehmann lovegrass shifted the dominant species from *Bouteloua* species in the native, uninvaded sites to Lehmann lovegrass in the invaded sites, similar to that found in the southwestern US (McClaran and Anable 1992; McLaughlin and Bowers 2006). Other native species that exhibited more abundant cover in uninvaded areas and transition areas were *Bouteloua gracilis, B. curtipendula, Tribulus terrestris, chamaechrista nictitans, Brickellia spinulosa,* and *Calliandria* spp.

IMPLICATIONS

Lehmann lovegrass had the ability to be established in a wide range of soil characteristics preferring sandy soils rather than saline soils in central rangelands of Chihuahua, however Lehmann lovegrass invasion was not limited to specific soil conditions. Plant community species richness, species diversity and evenness were biologically lowered in sites invaded, and these invaded sites were dominated by Lehmann lovegrass.

LITERATURE CITED

Adler and Morales 1999. Influence of environmental factors and sheep grazing in an Andean grassland. Journal of Range Management 52:471-480.

ArcGIS 9.2. 2006. ESRI (Environmental Systems Research Institute) Redlands, CA. USA.

Barbour, M.G., J.H, Burk, W.D. Pitts, F.S Guillian, and M.W. Schwartz. 1999. Terrestrial plant ecology. 3rd. ed. Benjamin Cummings/Prentice Hall. 688 pp.

Cable,D.R. 1971. Lehmann lovegrass in the Santa Rita experimental range 1937-1968. Journal of Range Management 24:17-21.

CANOCO. 2002. Biometris – Plant research international, Wageningen, The Netherlands.

Cox, J.R., and G.B. Ruyle. 1986. Influence of climatic and edaphic factors on the distribution of *Eragrostis lehmanniana* Nees. in Arizona, USA. Journal of the Grassland Society of South Africa 3:25-29.

Daehler, C.C. 2003. Performance comparisons of co-occurring native and alien invasive plants: Implications for conservation and restoration. Annu. Rev. Ecol. Evol. Syst. 34:183-211.

DiTomaso. 2000. Invasive weeds in rangelands: species, impacts and management. Weed Science: 255-265.

Dukes, J.S. 2002. Species composition and diversity affect grassland susceptibility and response to invasion. Ecological Applications 12:602-617.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Report Number BLM/RS/ST-98/005+1730. USDI-BLM. Denver, CO. 492p.

ERDAS IMAGINE 9.1. 2006. Leyca Geosystems Geospatial Imaging. LCC. Atlanta, USA.

Fredrickson, E.L., R.E. Estell, K.M. Havstad, T.Ksiksi, J. Van Tol, and M.D. Remmenga. 1997. Effects of ruminant digestion on germination of Lehmann lovegrass seed. J. Range Manage. 26:193-197.

Geiger, E., T. Mau-Crimmins, and H. Schussman. 2003. Spread of non-native grass across southern Arizona: Multiple data sources to monitor change. USDA Forest Service Proceedings RMRS-P-30:116-120.

Gilbert, B., and M.J. Lechowics. 2005. Invasibility and abiotic gradients. The positive correlation between native and exotic plant diversity. Ecology 86:1848-1855.

Hickman, K.R., D.C. Hartnett, R.C. Cochran, and C.E. Owensby. 2004. Grazing management effects on plant species diversity in tallgrass prairie. Journal of Range Management 57:58-65.

Huston, M.A. 2004. Management strategies for plant invasions: manipulating productivity, disturbance and competition. Diversity and distributions 10:167-178.

IDRISI. 2003. Version 14.01 Kilimanjaro. Clark Labs, Clark University Worcester MA. USA.

Jafari, M., M. A. Zare Chahouki, A. Tavili, H. Azarnivand, and Gh. Zahedi Amiri. 2004. Effective environmental factors in the distribution of vegetation types in Poshtkouh rangelands of Yazd Province (Iran). Journal of arid Environments 56:627-641.

Jongman, R.H. G., C. J. Ter. Break, and O.F.R. Van Tongeren. 1995. Data analysis in community and landscape ecology. Center Fire Agricultural Publishing and Documentation. Wageningen.

Krebs, C.J. 1999. Ecological methodology. 2nd ed. Benjamin/Cummings. 620 p.

Legendre,P., L. Legendre. 1998. Numerical ecology. Amsterdam. 2nd. English Ed.: Developments in Environmental Modeling. Vol 20. Elsevier science, New York, USA. 853pp.

MacDougall, A.S., J.Boucher, R. Turkington, and G.E. Bradfield. 2006. Patterns of plant invasion along an environmental stress gradient. Journal of Vegetation Science 17:47-56.

Magurran, A.E. 1988. Ecological Diversity and its Measurement. Princeton Univ Press, Princeton, NJ.

McClaran, M.P., and M.E. Anable. 1992. Spread of introduced Lehmann lovegrass along a grazing intensity gradient. Journal of Applied Ecology 29: 92-98.

McLaughlin, S.P. and J.E. Bowers. 2006. Plant species richness at different scales in native and exotic grasslands in southeastern Arizona. Western North American naturalist 66:209-221

Melgoza, A., G. Melgoza and M.H. Royo. 1986. Vegetation changes in central Chihuahua State after 26 years.. Pastizales. Vol.17. INIFAP-SARH. Chihuahua, México. (In Spanish)

Palmer, M.W. 1993. Putting things in even better order: The advantages of canonical correspondence analysis. Ecology 74:2215-2230.

Rinella, M.J., M.L. Pokorny, and R. Rekaya. 2007. Grassland invader responses to realistic changes in native species richness. Ecological applications 17:1824-1831.

Rogers, K. 2004. Lehmann lovegrass won't succumb to FIRE. Available from: http://www.eurekalert.org/pub_releases/2004-08/uoa-llw072604.php Consulted January 2009.

Royo, M. 1988. Autoecology contribution of Africano grass (*Eragrostis lehmanniana*). B.S. Thesis. Facultad de Ciencias Biológicas. Universidad Autónoma de Nuevo León, Mexico. 87p. (In Spanish).

SARH. 1978. Comision Tecnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero. Subsecretaria de Ganaderia. Secretaria de Agricultura y Recursos Hidraulicos. Chihuahua, México.

SAS. 1991. User's guide: Statistics, version 8.01. Cary, NC, SAS Inst., Inc.

Smet, M. and D. Ward. 2005. A comparison of the effects of different rangeland management systems on plant species composition, diversity and vegetation structure in a semi-arid savanna. African Journal of Range and Forage Science 22:59-71.

Sokal, R. R. and Rohlf, F. J. 1995. Biometry. 3rd edn. San Francisco: Freeman.

Ter Braak, C.J.F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. Vegetatio 69:69-77

Williams, D.G., and Z. Baruch. 2000. African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biological invasions 2:123-140.

Table 1. Site characteristics in the central valley of Chihuahua, Mexico.

Site	Geology	Soil type	Altitude (m)	Slope (%)	Vegetation (Genus)	Forage production kg/D.M./ha	Climate type	Ave. temp ℃	Precip. mm	Frost free days	Dry season months
El Pastor La Campana San Cristobal	Igneous rocks Limestone and sedimentary rocks	Sandy clay	1400 to 1800	10 to 30	*Bouteloua* *Leptochloa* *Digitaria* *Setaria* *Lycurus* *Heteropogon* *Aristida* *Eragrostis*	410	Dry temperate with warm summer	14 to 17	300 to 400	215	8
San Judas	Igneous rocks Alluvial soils Reddish soils	Sandy loam	1350 to 1500	0 to 7	*Bouteloua* *Digitaria* *Setaria* *Lycurus* *Hilaria* *Aristida* *Eragrostis*	282	Very dry with warm summer	18 to 20	200 to 350	200	9

From: SARH. 1978. Mexico. D.M.: Dry Matter; Ave: Average; temp: temperature; Precip: Precipitation.

Table 2. Mean values and standard deviation ($P< 0.05$) for soil attributes at El Pastor, La Campana, San Cristobal, and San Judas sites in central Chihuahua, Mexico.

Site	Sand (%)	Clay (%)	pH	HC (cm/h)	Pores (%)	FC (%)
El Pastor	71 a ± 3.8	22 bc ± 2.65	5.44 b ± 0.94	14 a ± 4.15	58.7 a ± 2.6	7.2 b ± 0.40
La Campana	70 a ± 7.9	21 c ± 1.67	5.35 b ± 0.68	11 a ± 7.80	57.4 a ± 2.9	7.8 b ± 0.98
San Cristobal	56 b ± 4.9	25 ab ± 1.96	6.62 a ± 0.34	19 a ± 7.41	60.8 a ± 3.1	10.5 a ± 1.00
San Judas	62 b ± 7.6	26 a ± 2.81	4.77 c ± 0.78	12 a ± 6.23	58.8 a ± 3.1	7.2 b ± 1.56
Site	**EC (mmhos)**	**OM (%)**	**NO_3 (kg/ha)**	**P (kg/ha)**	**K (ppm)**	**Ca (ppm)**
El Pastor	0.25 b ± 0.55	0.73 bc ± 0.14	284 a ± 132	10.7 ab ± 4.6	285 a ± 50	1143 b ± 289
La Campana	0.40 b ± 0.23	0.97 b ± 0.38	141 a ± 145	4.9 ab ± 1.2	332 a ± 102	1140 b ± 291
San Cristobal	0.56 a ± 0.94	2.07 a ± 0.24	283 a ± 124	4.1 b ± 2.0	317 a ± 65	3693 a ± 1275
San Judas	0.27 b ± 0.17	0.48 c ± 0.67	278 a ± 123	12.9 a ± 6.1	323 a ± 65	980 b ± 1335
	Mg (ppm)	**Na (ppm)**	**Cu (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Zn (ppm)**
El Pastor	166 a ± 36	375 a ± 73	0.44 bc ± 0.07	5.8 ab ± 2.0	5.6 b ± 1.4	0.76 b ± 0.44
La Campana	105 b ± 21	542 a ± 189	0.37 c ± 0.48	9.5 a ± 5.2	18.2 a ± 7.9	2.41 a ± 1.56
San Cristobal	146 a ± 34	481 a ± 202	0.55 a ± 0.05	2.9 b ± 2.4	9.5 b ± 3.5	1.46 ab ± 0.61
San Judas	135 ab ± 34	383 a ± 150	0.48 ab ± 0.09	4.5 ab ± 3.6	18.8 a ± 7.3	0.98 b ± 0.98

HC = Hydraulic conductivity; FC= Field capacity; EC= Electric conductivity; OM= Organic matter; NO_3 = Nitrates.

Table 3. Principal component analysis (PCA) applied to the correlation matrix for soil and sub-site factors in central Chihuahua, Mexico, rangelands.

a) Variance extracted for first 5 axes of PCA

AXIS	Eigenvalue	% of Variance	Cumulated Variance (%)	Broken-stick eigenvalue
1	7.671	38.357	38.357	3.598
2	3.723	18.615	56.972	2.598
3	2.078	10.392	67.364	2.098
4	1.632	8.162	75.525	1.764
5	1.206	6.029	81.554	1.514

b) First eigenvectors scaled to standard deviation using correlation coefficient between scores for sub-sites (rows) in the main matrix and the column variables (soil attributes).

	Eigenvector					
Soil	PC1	PC2	PC3	PC4	PC5	PC6
Sand	-0.6924	-0.4895	0.1013	0.3445	0.1446	0.1075
Clay	0.2806	0.6916	0.0650	-0.4909	-0.0527	0.1955
pH	0.9207	-0.0785	-0.0478	0.2202	0.1023	-0.0504
HC	0.5659	0.2874	-0.1438	-0.0523	0.3682	-0.1592
Pores	0.3504	0.2090	-0.0585	0.4680	-0.6951	0.1023
FC	0.8949	-0.3531	0.1417	-0.0234	-0.0625	0.1478
PWP	0.8990	-0.3675	0.1117	-0.0282	-0.0717	0.1226
SAT	0.9056	-0.3519	0.1013	-0.0207	-0.0660	0.1215
EC	0.8130	-0.0536	-0.5019	0.0343	-0.0527	0.0053
OM	0.8664	-0.4026	0.1537	0.0549	0.0194	0.0913
NO3	0.1467	0.6126	0.0353	0.3621	-0.4315	-0.1311
P	-0.5146	0.3306	0.0368	0.0102	0.0328	0.7076
K	0.1747	0.1564	-0.8029	0.0890	0.1750	0.3695
Ca	0.9381	-0.0747	0.2293	-0.0716	0.0714	0.0260
Mg	0.0710	0.3687	0.2198	0.6547	0.1738	-0.0763
Na	0.2408	-0.0139	-0.8653	0.1098	0.0990	-0.2280
Cu	0.4904	0.5182	0.2779	-0.4067	-0.0207	-0.1828
Fe	-0.5768	-0.6937	-0.0045	0.0504	-0.0385	-0.1615
Mn	-0.3848	-0.2206	-0.3808	-0.4827	-0.5021	-0.0994
Zn	-0.0233	-0.9354	-0.0009	-0.1022	-0.1390	0.1164

c) Randomization test results

Eigenvalues from randomizations (number of randomizations = 999)					
Axis	Real data	Minimum	Average	Maximum	*P*
1	7.6713	2.4634	3.1705	4.1068	0.001000
2	3.7230	2.1872	2.6634	3.2898	0.001000
3	2.0784	1.8650	2.3024	2.8903	0.941000

Table 4. Scientific and code name for plant species recorded in study sites from Chihuahua central rangelands. Abundant species (*) were selected by accumulated minimum cover of 50 cm and presence in at least two sites. Dominant species (∞) were selected by accumulated minimum cover of 1 m.

GRASSES	Code Name
Aristida spp.	Aristsp *
Agropyrum smittii	Agrsmi
Bouteloua curtipendula	Boucur *∞
Bouteloua gracilis	Bougra *∞
Bouteloua hirsute	bouhir *
Eleonurus barbinodis	Elebar
Eragrostis lehmanniana	eraleh *∞
Heteropogon contortus	Hetcon *
Muhlenbergia spp.	Muhlsp
Panicum spp	Panisp
Schizachirium hirtiflorum	schhir *
Sporobolus airoides	spoair *∞
Tribulus terrestris	triter *∞
SHRUBS	
Aloysia wrightii	Alowri
Applopapus spp.	Applsp *
Asclepia spp.	Asclsp
Brickellia spinulosa	brispi *∞
Dasilirium spp.	Dasisp
Euphorbia spp.golondrina	euphsp *
Mimosa biuncifera	mimbiu *
Opuntia macrosentra	opumac
Prosopis spp.	progla *
Quercus spp.	Quersp

FORBS	Code Name
Allium spp.	allisp
Berlandiera aridata	berari
Calliandria spp.	callsp *∞
Carex spp.	caresp
Chenopodium spp.	chensp *
Croton desvauxii	crodes
Dalea bicolor	dalbic
Desmanthus spp.	desmsp
Dichandra argentea	dicarg
Evolvolus lutalianus	evolut
Froelichia spp.	froesp
Galactea spp.	galasp
Mamilaria spp. (cactus)	mamisp
Nama ciliata	namcil
Potulaca mundula	potmun *
Salsola iberica	salibe
Sida procumbens	sidpro *
Solanum eleagnifolium	solele
Thallium spp.	thalsp
Thelosperma spp.	thelsp
Portulaca oleracea	porole
Chamaechrista nictitans	chanic *∞
Xanthium strumarium	xanstr

Table 5. Canonical correspondence analysis (CCA) for plant species and environmental (soils attributes) data for central Chihuahua rangelands.

a) Eigenvalues and variance	Axis 1	Axis 2
Eigenvalues	0.918	0.697
Variance in species data		
% of variance explained	28.0	49.2
Cumulative % explained	28.0	77.2

b) Monte Carlo test for species-soil variables correlations

Axis	Species - Soil correlation	*P*
1	0.992	0.2160
2	0.991	0.0020

c) Proportion of eigenvalues

Sum of all eigenvalues	3.284
Sum of all canonical eigenvalues	3.215

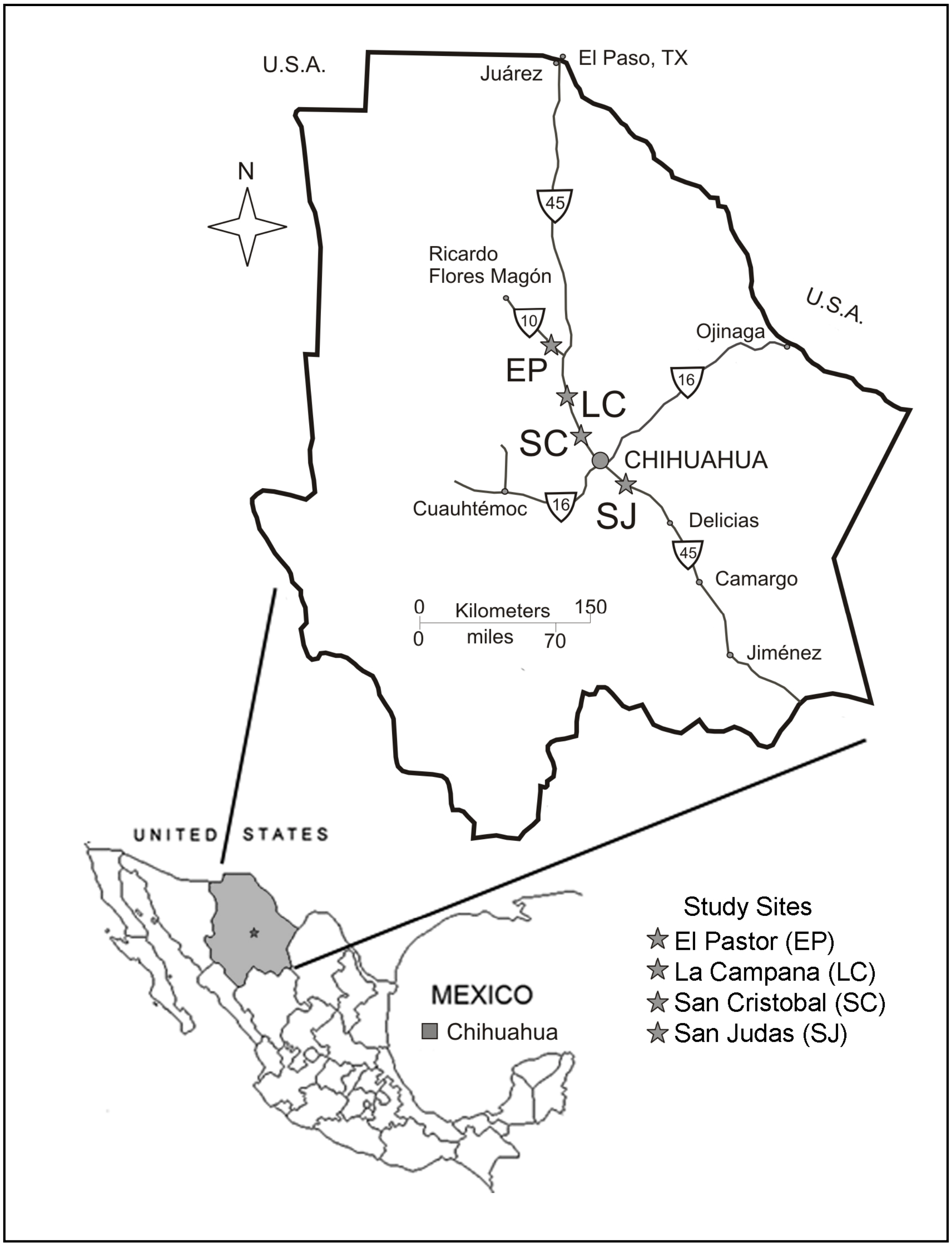


Figure 1. Lehmann lovegrass study areas: El Pastor (EP), La Campana (LC), San Cristobal (SC), and San Judas (SJ) location sites along central rangelands and major highways in Chihuahua, Mexico.

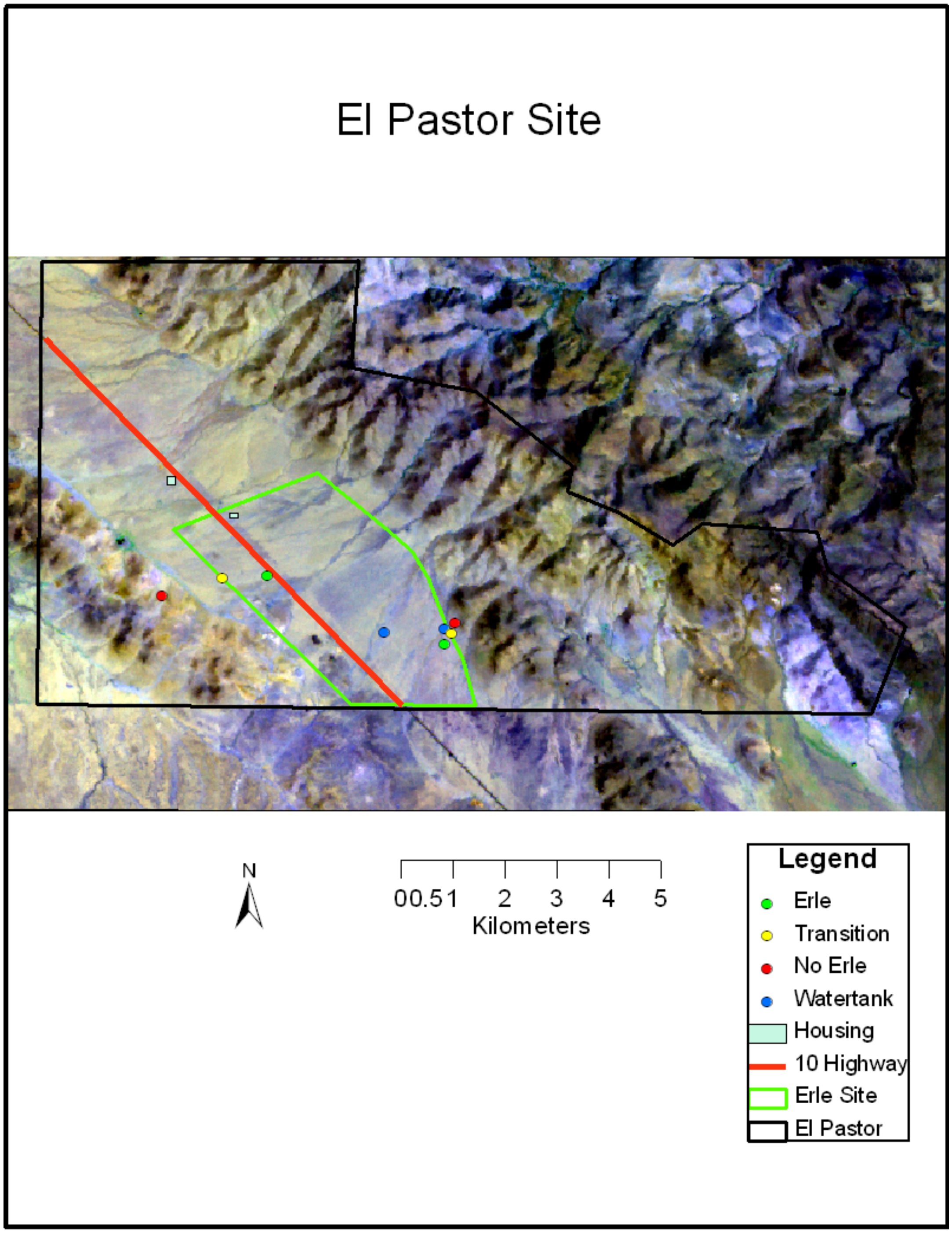


Figure 2. Geographic location for Lehmann lovegrass (Erle), transition (Transition), and uninvaded (No Erle) transects, watertank, 10 highway, houses, Lehmann lovegrass study site (Erle Site) and boundary at El Pastor Site.

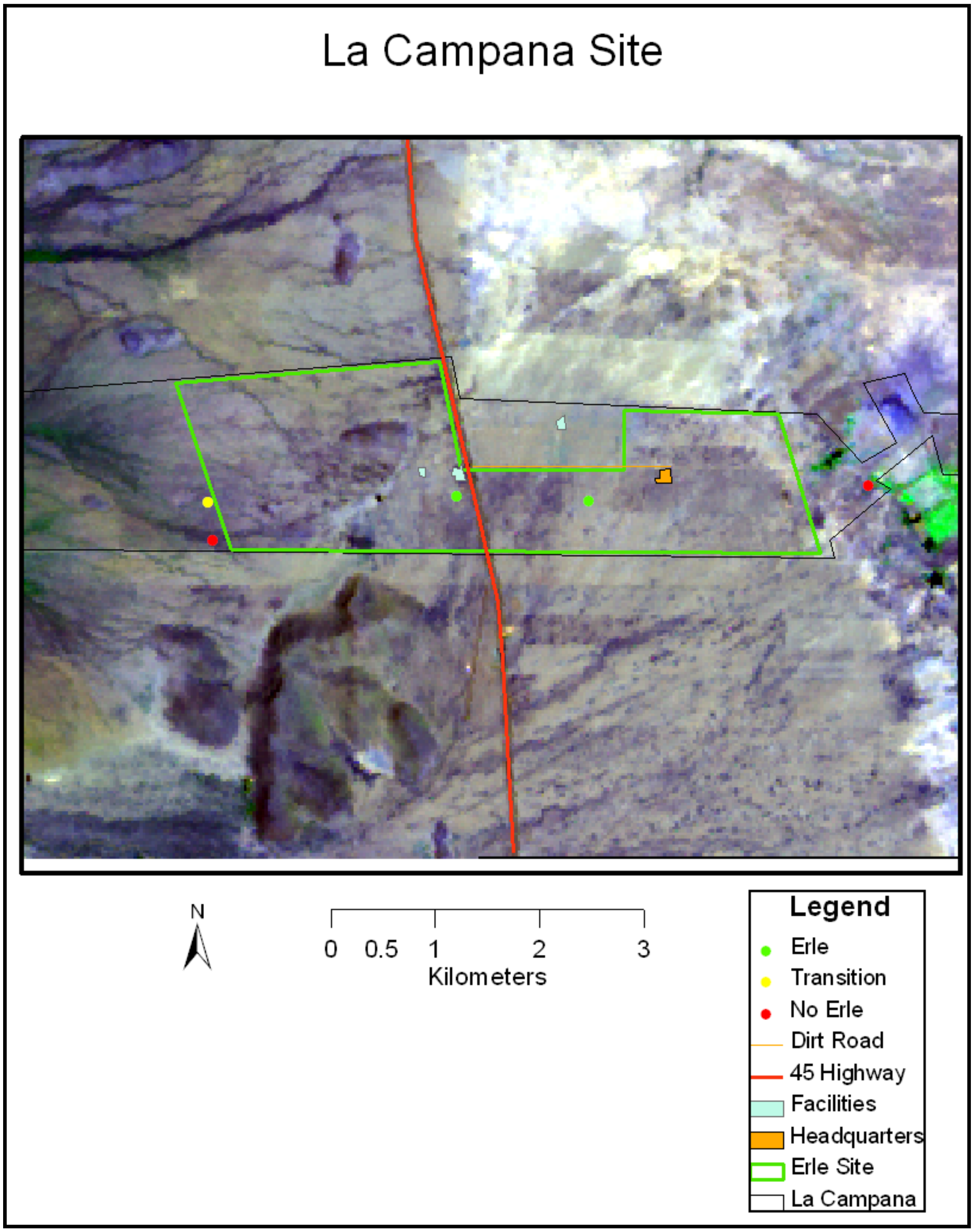


Figure 3. Geographic location for Lehmann lovegrass (Erle), transition (Transition), and uninvaded (No Erle) transects, dirt road, 45 highway, facilities, headquarters, Lehmann lovegrass study site (Erle Site) and boundary at La Campana Site.

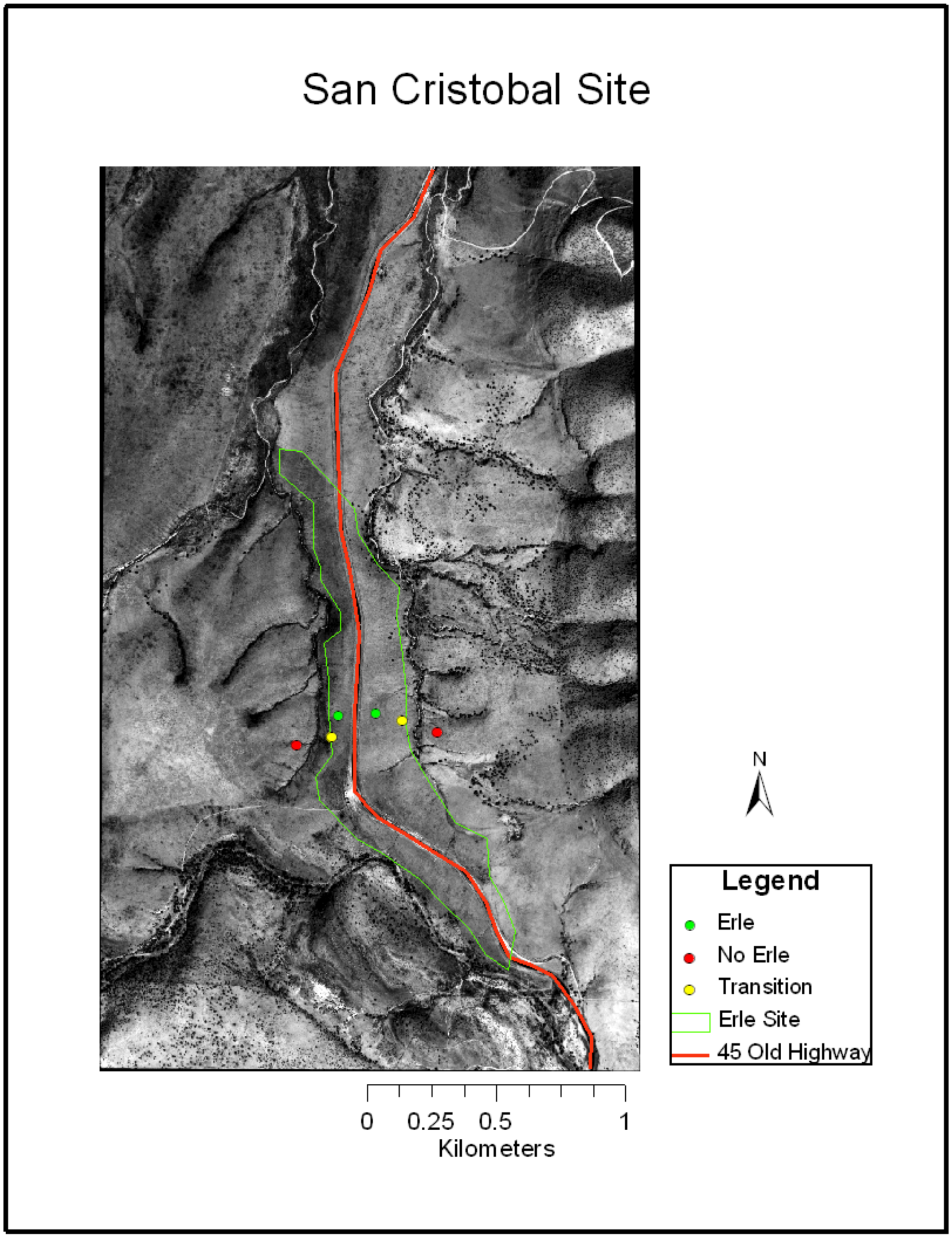


Figure 4. Geographic location for Lehmann lovegrass (Erle), transition (Transition), and uninvaded (No Erle) transects, 45 old highway, Lehmann lovegrass study site (Erle Site) and boundary at San Cristobal Site.

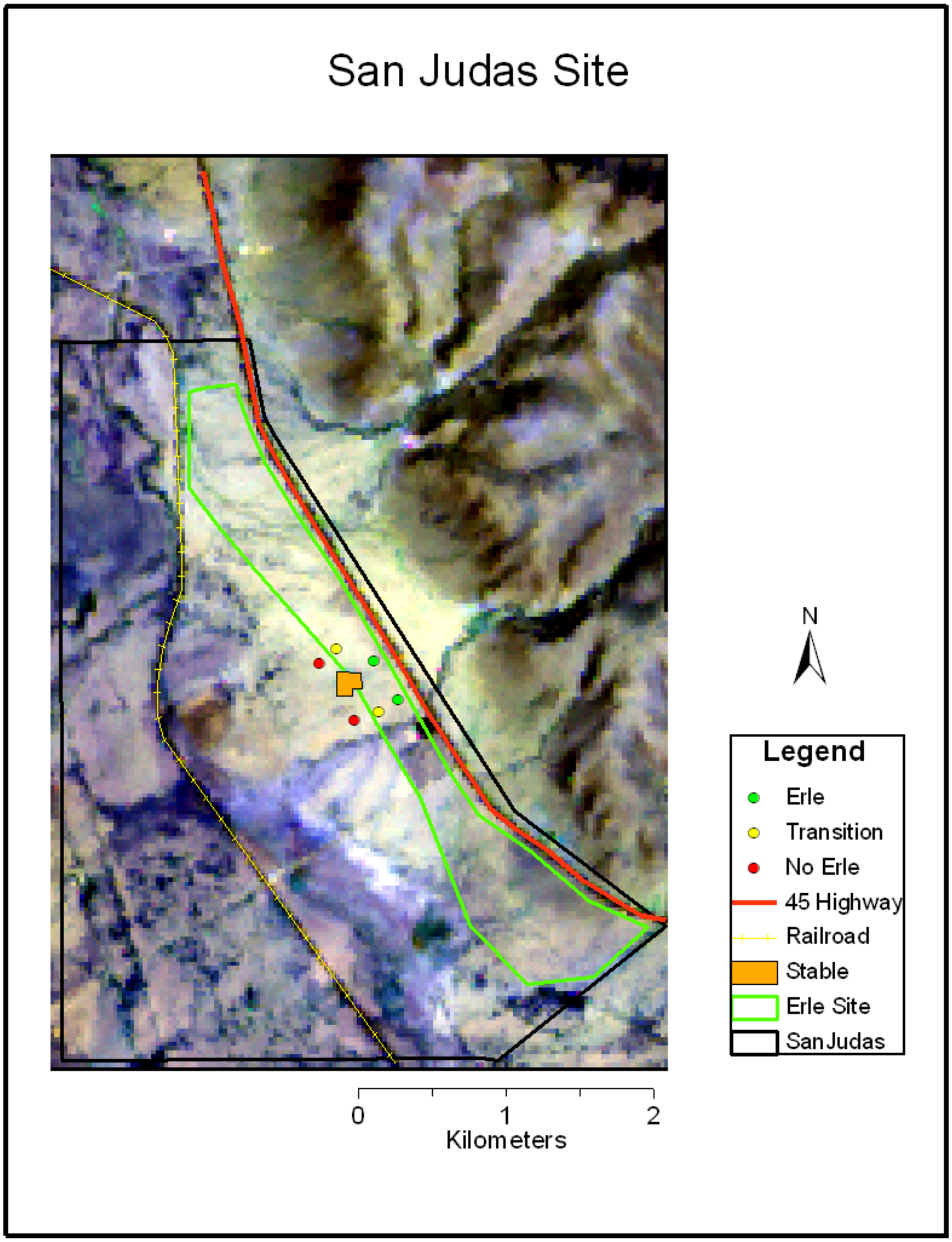


Figure 5. Geographic location for Lehmann lovegrass (Erle), transition (Transition), and uninvaded (No Erle) transects, 45 highway, railroad, stable, Lehmann lovegrass study site (Erle Site) and boundary at San Judas Site.

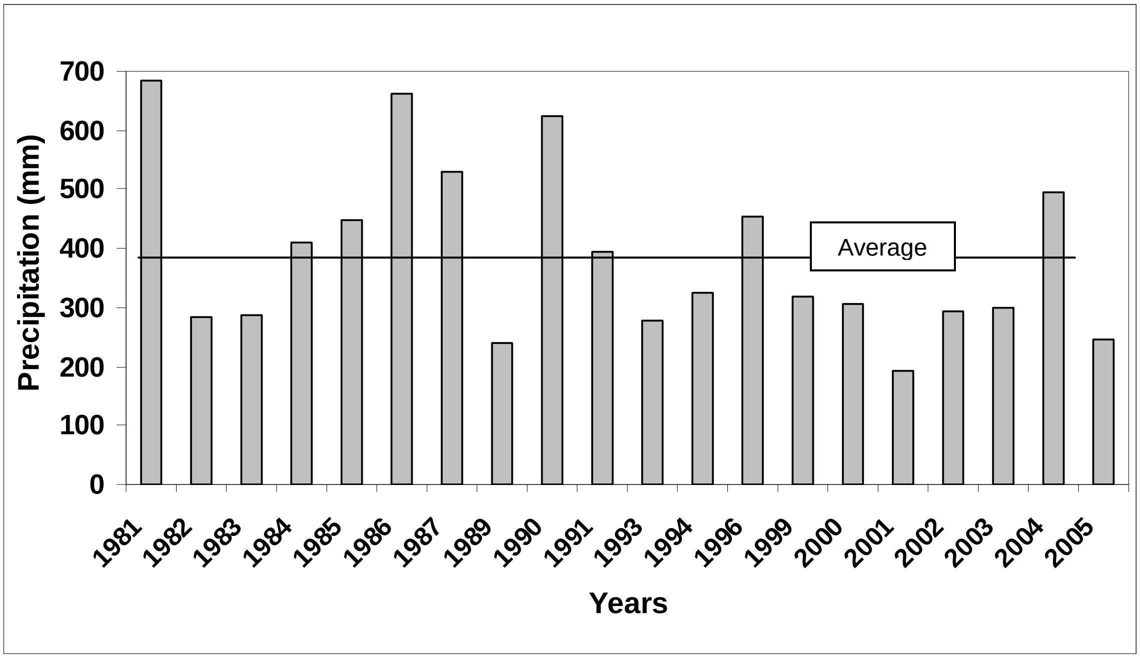


Figure 6. Long-term precipitation data for La Campana research site and 25 year average (382mm/yr).

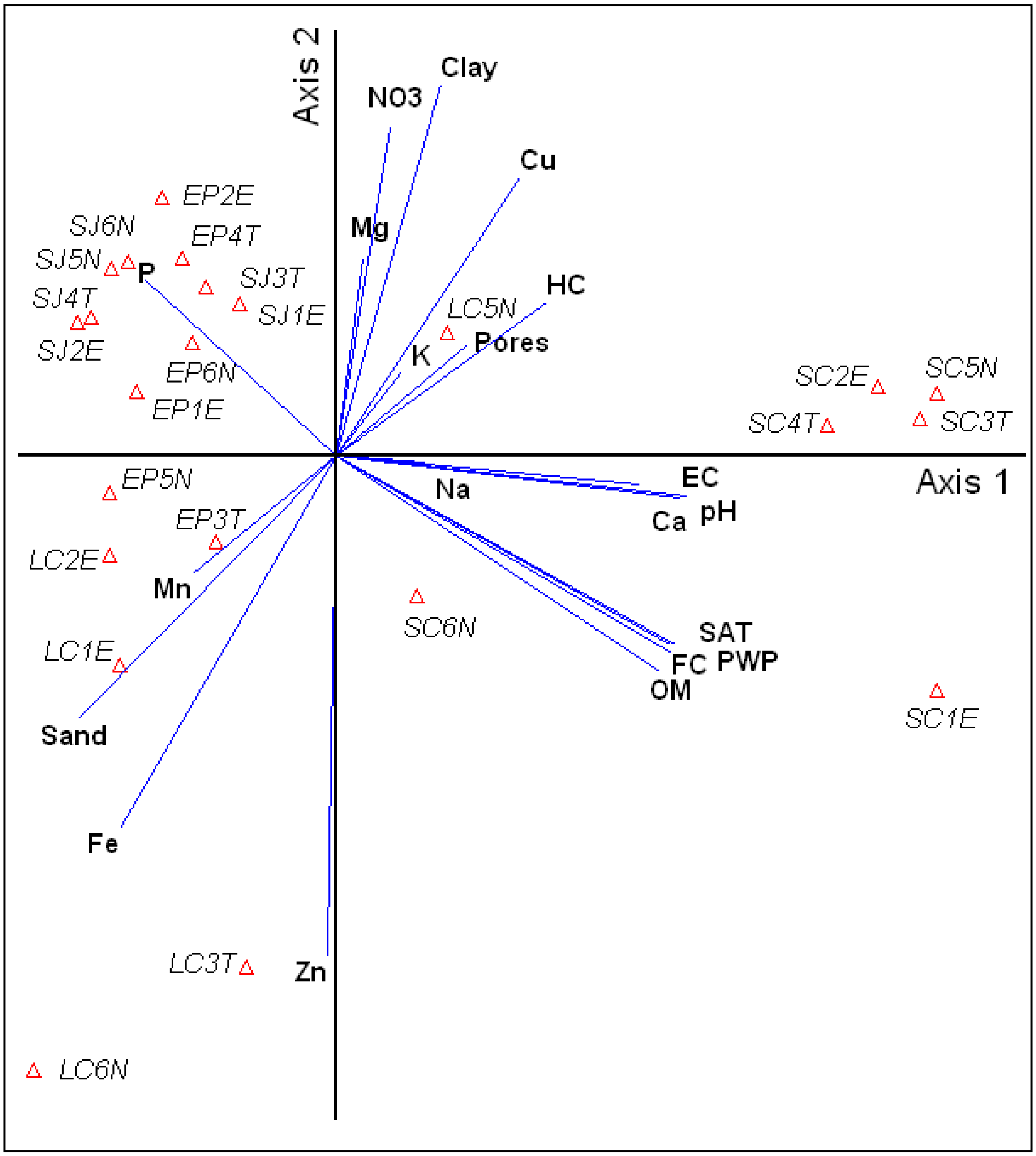


Figure 7. Principal component analysis (PCA) ordination diagram for the relationship among sub-sites (E = Lehmann lovegrass area, T = Transition area, and N = uninvaded area) and environmental data (soil characteristics) in four sites (EP = El Pastor, LC = La Campana, SC = San Cristobal, and SJ = San Judas) at Chihuahua, Mexico, central rangelands.

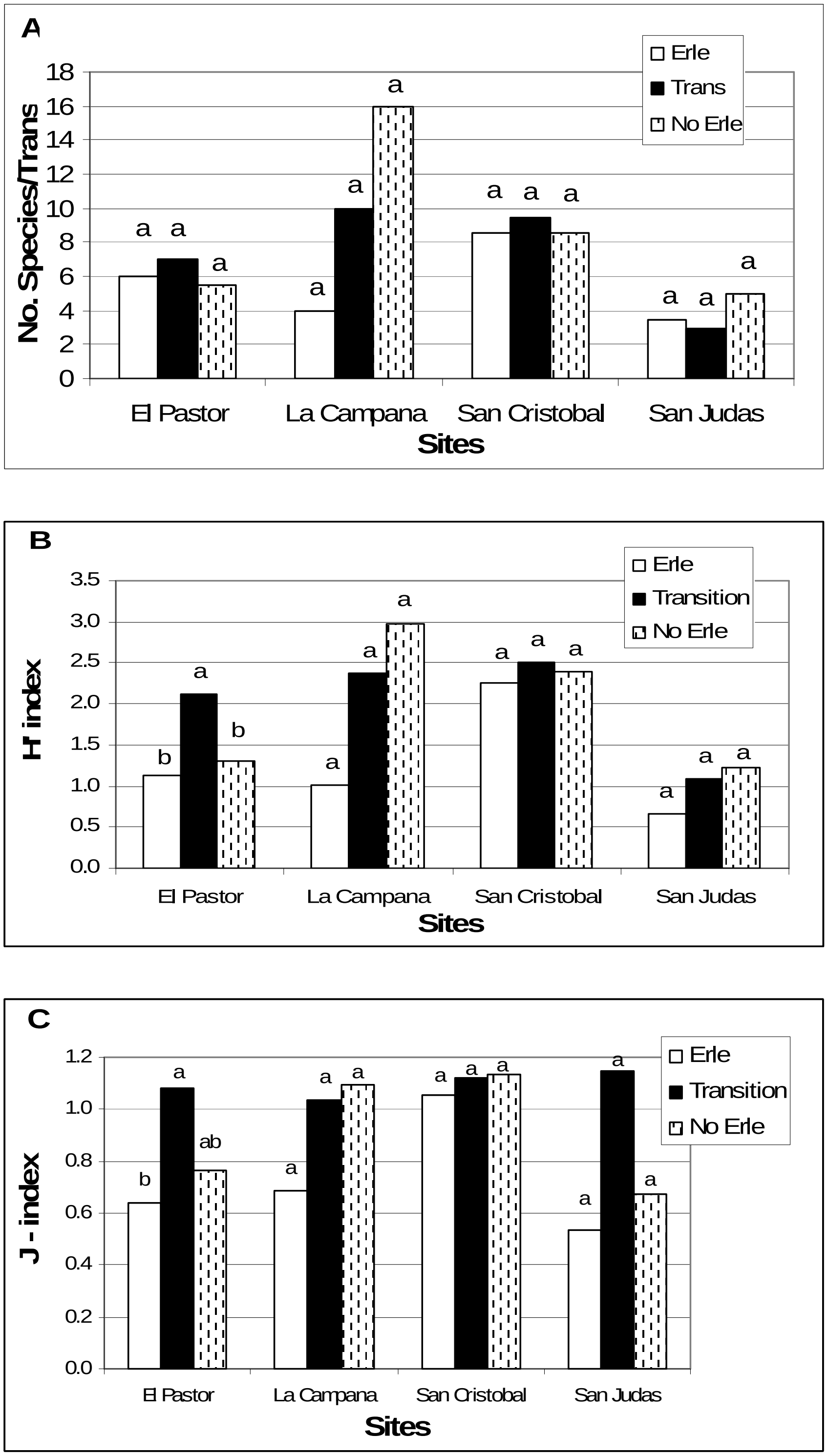


Figure 8. Species richness (**A**), Shannon's Diversity H' index (**B**), and Pielou's evenness J – index (**C**) for vegetation communities in Lehmann lovegrass invasion (Erle), Transition zones (Transition), and uninvaded (No Erle) at El Pastor, La Campana, San Cristobal, and San Judas sites in central Chihuahua, Mexico, rangelands.

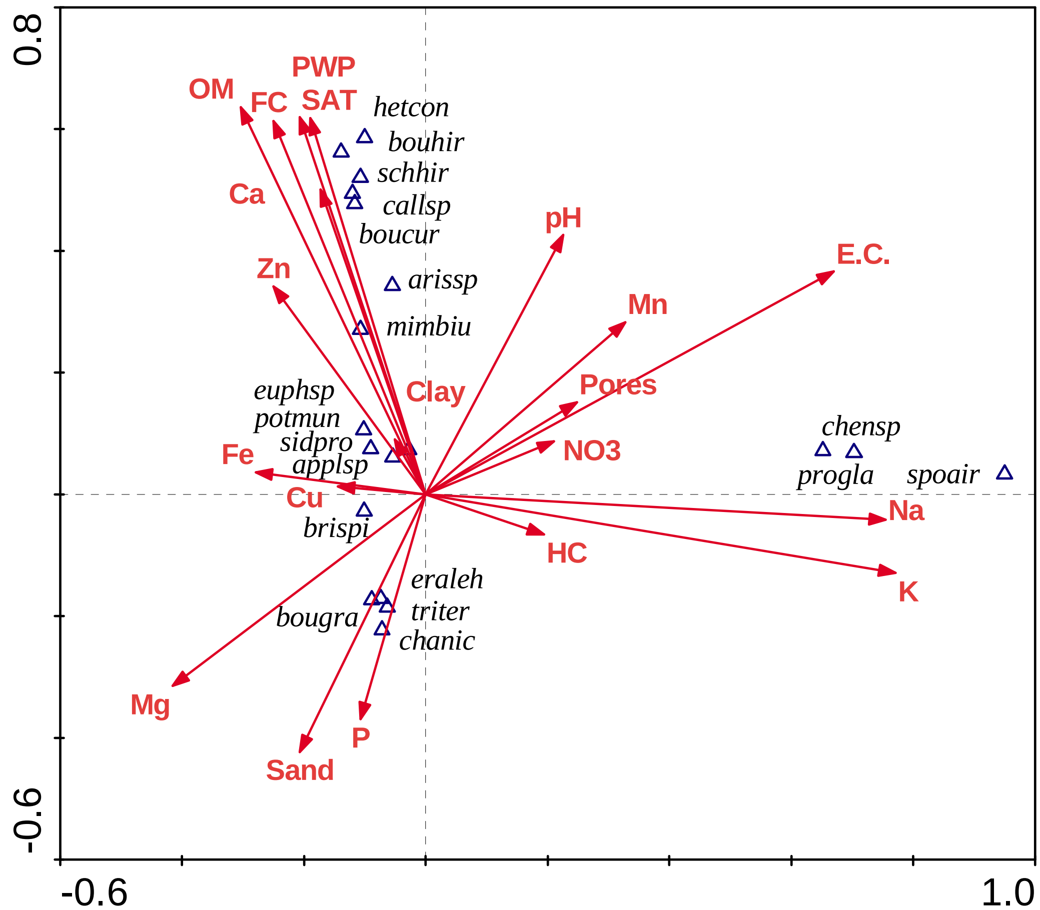


Figure 9. Canonical correspondence analysis (CCA) ordination diagram for the relationship among abundant species and environmental data (soil characteristics) in four sites at Chihuahua, Mexico, central rangelands. (See tables 2 and 3 for abbreviations).

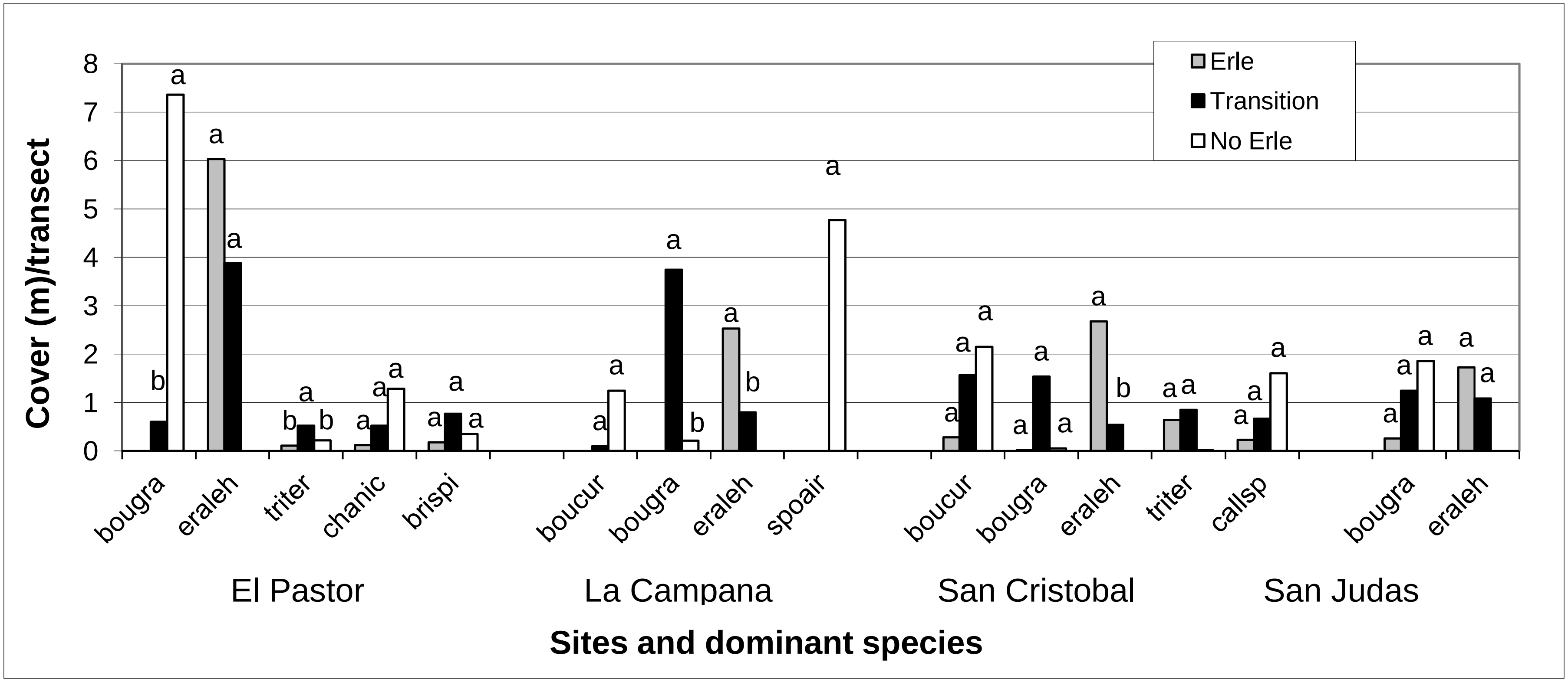


Figure 10. Dominant species mean cover (m/transect) related to presence – absence of Lehmann lovegrass in invaded (Erle), transition (Transition), and uninvaded (No Erle) sub-sites within sites at central Chihuahua, Mexico, grasslands. Values within species with different letters are significantly different at the P < 0.05 probability.

CHAPTER 3

VARIATION IN FORAGE NUTRIENT VALUE AND PRODUCTION OF LEHMANN LOVEGRASS (*Eragrostis lehmanniana*) IN INVADED RANGELANDS OF CENTRAL CHIHUAHUA, MEXICO

Abstract: Forage nutrient value and production were determined for the invasive grass Lehmann lovegrass (LL) in 4 rangeland sites: El Pastor, La Campana, San Cristobal, and San Judas in central valley of Chihuahua, Mexico, in 2004 and 2005. Six 1m² plots were clipped each year in each location. To assess phenological differences in LL forage nutrient value plots were also clipped at vegetative, flowering, and mature stages at San Judas site in 2005. Forage nutrient value and yield were significantly different among both years and the four sites. Annual precipitation at La Campana in 2004 was greater than average and 2005 was below average. Crude protein (CP) was higher for La Campana and the lowest value was found in San Judas in 2005. Highest fiber content (ADF) was for San Judas 2005 and the lowest for La Campana 2004. Forage from El Pastor (2004 and 2005) and San Judas in 2005 showed the highest NDF content relative to forage from other sites. In vitro true dry matter digestibility was similar among sites and years, ranging from 48 to 62%. LL yield was different among years and sites. High precipitation at La Campana in 2004 produced 122% more forage than in 2005. This trend was also found in El Pastor and San Cristobal. The vegetative stage of LL had the higher forage nutrient value than the flowering or mature stage. Considering the four study sites, LL forage nutrient value was below the average value for common forages.

Key Words: ADF, crude protein, invasive species, introduced species, in vitro digestibility, NDF, semi-arid rangelands, yield.

INTRODUCTION

Lehmann lovegrass (*Eragrostis lehmanniana* Nees) is a perennial C_4 grass native to southern Africa. It was intentionally introduced into the southwestern U.S. in the 1930's for seeding degraded rangelands. (Cox et al. 1988b; Schussman et al. 2006). This is an example of non-native forage species that commonly are introduced to improve productivity and grazing opportunities in the southern US Plains from Africa or South and Central America (Sanderson et al. 1999; Redfearn and Nelson 2003; Gillen and Berg 2005; Wilsey and Polley 2006; Moreira et al. 2007). Subsequently, in the mid 1960's, Lehmann lovegrass was introduced into Chihuahua, Mexico, for reseeding and erosion control research (Royo 1988). Introduction was done at the Campo Experimental "La Campana" Research Station of the National Institute for Forestry, Agriculture, and Livestock Research (INIFAP) managed by the Mexican government through the Department of Agriculture (SAGARPA). Since then, this non-native grass has invaded rangelands throughout the region primarily at altitudes from 1 100 to 1 600 m with an annual rainfall of at least 150 to 220 mm (Melgoza et al. 1986), replacing the native grasses as one of the dominant perennial grasses.

Lehmann lovegrass is an opportunistic grass that invades and persists when disturbances, such as overgrazing or drought, reducing the abundance of the more desirable native grasses (Cox et al. 1988a; Robinett 1992). Since 1954 Lehmann lovegrass has spread throughout the Santa Rita Experimental Range in Arizona and now accounts for over 90% of the forage species (Anable et al. 1992). Research conducted at this site has shown that fire stimulates germination and establishment of Lehmann lovegrass seedlings, thus promoting the spread invasion (Ruyle et al. 1988). Lehmann lovegrass responds positively to fire, increasing its canopy cover nearly twice that of native grasses (McGlone and Huenneke 2004).

Throughout the rangelands of the central valley of Chihuahua, Lehmann lovegrass invasion and subsequent dominance in native rangeland have been controversial; Ecologists are concerned Lehmann lovegrass will continue to displace native perennial grass species (Cumming 1989), and some ranchers object to the low palatability of this forage compared to native species. In contrast, some livestock producers with Lehmann lovegrass consider the grass useful for livestock during drought. Regardless, Lehmann lovegrass is continuing to spread and increase in dominance in these rangelands. Given the economic limitations of ranches within the central valley of Chihuahua, range managers want to increase their knowledge concerning the forage nutritive value of Lehmann lovegrass and information on the potential of this grass as forage in their rangelands.

The main objective of this study was to determine if Lehmann lovegrass produces growth with adequate nutritional value. Specific objectives were: 1) determine forage nutritive value 2) estimate forage production, and 3) evaluate forage nutritive value at three phenological stages of growth.

METHODS

Forage samples of Lehmann lovegrass were randomly collected at peak biomass (September-October) prior to grazing at four different sites throughout the central valley of Chihuahua, Mexico during 2004 and 2005. These four sites included; El Pastor, La Campana, San Cristobal and San Judas (Fig. 1).

The first site, El Pastor, located 120 km north of Chihuahua City (29°38'31"N, 106°33'23"W; Fig. 1), is managed as an e jido, or communal grazing land. This site is included in a 1 350 ha pasture having an estimated 80% dominance or invasion of Lehmann lovegrass, forming almost a pure stand. Invasion is predominantly at the northern pastures from highway 10 (Fig. 1). Cattle grazing occur throughout the winter and spring with variable stocking rates.

The second site, La Campana, is located 82 km north of Chihuahua City (29°16"01"N, 106°23'08"W; Fig. 1). This site is a fede ral Mexican experimental station devoted to range, ecology and livestock research. Lehmann lovegrass was introduced to the station for research and erosion control purposes in the 1960's. It was introduced about 3 000 m east of the highway and currently has spread throughout the station on 683 ha with some areas having 80% cover of Lehmann lovegrass. Samples were collected at the entrance pasture (105 ha) along the 45 Pan-American Highway, where 80% of the area was invaded with Lehmann lovegrass. The pasture was deferred from grazing for spring and summer of both sampling years. Forage samples were collected at full growth and before the fall grazing season.

The third site, San Cristobal, is located along the old highway in the Sacramento vicinity, 30 km north of Chihuahua City (28°48’10”N, 106°13’06”W; Fig. 1). Lehmann lovegrass cover is 80% in some areas of the pastures (40 ha) on both sides of the 45 Pan-American Highway. The area is privately owned and moderately grazed by cattle. Forage samples were clipped at peak biomass.

The fourth site, San Judas, is located 20 km south of Chihuahua City (28°31’03”N, 105°55’37”W; Fig. 1). The area (185 ha) is part of a private cattle ranch where Lehmann lovegrass cover is 80% in the pasture. Forage samples were collected from part of the pasture that has been totally deferred from grazing during both years.

Climate for this central region was defined by the Agricultural and Hydraulic Resources Secretary (SARH 1978) as dry temperate with warm summers with an average frost-free period of 210 days, extending from April to October. Average annual precipitation for the area is 382 mm (Fig. 2) with 70% falling as rain from June to October. The mean annual temperature is 17°C, with a daily minimum of -2°C in December and an average d aily maximum of 33°C in July. Weather data was not available for three of the sites, therefore, daily records from the La Campana site, which has a weather station where INIFAP (2006) personnel collect daily records (Table 2), were used.

Soil for the El Pastor, La Campana, and San Cristobal study sites was sandy clay and San Judas had a sandy loam (Table 3). Detailed soil characteristics were taken from soil samples collected in 2005 at each site and analyzed at the University Autonomous of Chihuahua Soil and Water Laboratory (Table 3).

Lehmann lovegrass forage clippings were collected at all sites from late September through early October of 2004 and 2005. Forage samples for the phenological component of the study were all collected in 2005 at San Judas site, the harvest dates and phenological stages were; 28 August (vegetative stage); 4 October (flowering stage), and 18 December (mature stage). Six forage samples from $1m^2$ quadrats were collected randomly for each site.

Aboveground biomass was clipped at 1cm height, bagged, oven-dried (60℃) for 48 h and weighed. To obtain current year' s growth, dead biomass was removed before weighing. For the forage nutritive value analysis, dried forage samples were ground with a laboratory hammer mill and passed through a 1mm mesh at the Animal Science Laboratory, University Autonomous of Chihuahua. A sub-sample of 50 g ground material was collected from each sample, placed in a sealed, labeled plastic bag for transport with an international sanitary permission from Chihuahua to the US in January 2006.

Determination of forage nutritive value included: crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) and in vitro true dry matter digestibility (IVTDMD). Samples were analyzed at the Ruminant Nutrition Laboratory in the Animal Science Department, Oklahoma State University, Stillwater, OK, USA. Nitrogen and crude protein (CP) content of the forage samples were quantified at the Soil, Water and Forage Analytical Laboratory in the Division of Agricultural Science and Natural Resources, Oklahoma State University.

Determination of nitrogen and crude protein (N x 6.25) were determined by the dry combustion method using the Leco TruSpec® Elemental Determinator carbon nitrogen analyzer: (Leco Corporation, 2006). Crude protein was determined according to the National Forage Testing Association (NFTA 1993).

Acid and neutral detergent fiber were determined by the Van Soest detergent system and obtained using an ANKOM 220 fiber analyzer (ANKOM, 2008). In vitro true dry matter digestibility was determined using the ANKOM system DAISY II® (Ammar et al. 2004).

Before statistical analysis, data were tested for normality and homogeneity of variance (Sokal and Rohlf 1995). All data were subjected to a factorial analysis using a completely randomized arrangement where sites and years were used as fixed factors. Means were compared using Tukey's and Duncan's multiple comparison methods. Analysis of variance (ANOVA) was performed using PROC GLM in SAS (1991) statistical package.

RESULTS

Forage nutritive value and yield were different between the two years and among the four sites ($P < 0.05$). Annual precipitation registered at La Campana site showed that year 2004 was above the long term average (382 mm) (Fig. 2) and 2005 was 35% below average. Growing season precipitation (Jun-Sep) was 352 mm for 2004 and declined by over 70% in 2005 (102 mm, Table 2).

Crude protein (CP) concentration was similar (from 5 to 7%) among sites and years, however was higher (8%) at La Campana in 2004 and lowest (3.2%) at San Judas in 2005 (Fig. 3A) nevertheless in 2004 was significantly higher with 6.5%.

Acid detergent fiber (ADF) for Lehmann lovegrass was different ($P < 0.05$) for all sites and years. The highest value was obtained for San Judas in 2005 and the lowest for La Campana in 2004 (Fig. 3B). Forage from El Pastor (2004 and 2005) and San Judas in 2005 showed the highest ($P < 0.05$) NDF concentration relative to forage from other sites (Fig. 4A).

In vitro true dry matter digestibility (IVTDMD) was similar among sites and years ($P > 0.05$) ranging from 48 to 62%, only La Campana (2004) showed significantly higher IVTDMD content in 2004 relative to all other sites (Fig. 4B).

Lehmann lovegrass yield was different ($P<0.05$) among years and sites. The effect of variable summer rains (Jun-Sep) (Table 2) was reflected in production at La Campana where the year with high precipitation, 2004, resulted in 122% more forage production than in 2005. This trend was also found in El Pastor with 162% increase, and San Cristobal with 65% more forage produced in 2004 relative to 2005. San Judas site consistently produced approximately 2 000 kg/ha both years (Fig. 5).

Differences in forage nutrient value of Lehmann lovegrass were found among the three phenological stages sampled. Vegetative Lehmann lovegrass had the greatest CP content (Fig. 6A), relative the more advanced phenological stages. Fiber concentration for Lehmann lovegrass (ADF and NDF) was significantly higher for the mature stage (Figs. 6B and 7A) than in the vegetative and flowering stages. In vitro digestibility of Lehmann lovegrass dry matter was significantly higher (28%) in the vegetative stage than the flowering and mature stages (Fig. 7B).

DISCUSSION

Forage nutritive value of Lehmann lovegrass was highly variable among sites and years. In general, mature Lehmann lovegrass produced relatively poor forage quality at all sites and the lower precipitation in 2005 reduced forage nutrient value relative to 2004. The response of Lehmann lovegrass to precipitation levels supports previous studies that have shown production, nutrient value and digestibility of forage grasses are greatly influenced by weather seasons (Chavez 1984; Cox et al. 1990; Kloppenburg et al. 1995; Stritzler et al. 1996; Haferkamp et al. 2005; Mortenson et al. 2005; Ganskopp et al. 2007). Drought is one of the major factors ranchers recognize as a serious threat reducing the survival of perennial plants.

This was also recognized in southern Arizona where Lehmann lovegrass and black grama (*Bouteloua eriopoda*) were affected (20 and 35% mortality respectively) by the winter 1988 and spring 1989 drought, which following below average summer and October rains, some patches recovered and Lehmann lovegrass seedlings successfully established in bare patches, in contrast, no black grama seedlings survived (Robinett 1992).

In a previous study, Lehmann lovegrass in Arizona exhibited similar CP content (Cox 1992) relative to the findings in this Chihuahua study. Lehmann lovegrass exhibited low crude CP content compared to native grasses in southern US (Cox 1992; NRC 1996; Mortenson et al. 2005). Lehmann lovegrass CP at vegetative stage was similar as CP reported for La Campana's *Bouteloua eriopoda* and *B. hirsuta* (9.0 and 9.9% respectively, but lower than *B. gracilis* (11.3%) (Chavez 1984). Nevertheless, ruminants are well adapted to rely on low CP forages (Waghorn and Clark 2004). San Judas site was too low in protein content in 2005 to consider using the forage to support the maintenance requirements for livestock production (Cox 1992), However, under the average precipitation levels of 2004, CP was significantly higher (Fig. 3A). Similarly, low CP was found for semi-arid warm-season weeping lovegrass, switchgrass and kleingrass in Argentina (Stritzler et al. 1996). Protein content can also be variable among congeneric species, for example old world bluestem (*Bothriochloa bladhii)* was superior in protein content than *B. caucasica* and *B.ischaemum* (Philipp et al. 2005).

Fiber is formed by cellulose, hemicellulose and lignin. ADF determination expresses the content of cellulose, lignin and fiber-bound and heat damaged nitrogen (Moore et al. 2007). Lehmann lovegrass ADF content was higher for El Pastor and San Judas sites (over 50%) for both years than for old world bluestem grass (Philipp et al. 2005). Nevertheless, La Campana and San Cristobal samples from 2004 with compared similar (Fig. 3B). Neutral detergent fiber (NDF) expresses the content of cellulose, hemicellulose and lignin. NDF values (75 to 78%) found for Lehmann lovegrass in Chihuahua (Fig. 4A) denoted as poor quality grass when compared to perennial ryegrass (48%) (Waghorn and Clark 2004) and to wheatgrass (66%) (Ganskopp and Bohnert 2006).

In vitro true dry matter digestibility for most Lehmann lovegrass samples within sites and years were similar and ranged from 48 to 53% (Fig. 4B), This range was lower to ryegrass (62 to 86%), white clover (76 to 82%) (Waghorn and Clark 2004), and wheatgrass (62 to 73%) (Gillen and Berg 2005). Compared with grass hay (41%) (Denek and Deniz 2004) or *Bouteloua gracilis* (42%), *Pascopyrum smithii* (45%), and *Stipa comata* (35%) (Morgan et al. 2004), Lehmann lovegrass produced higher IVTDMD. Only La Campana forage samples in 2004 had IVTDMD over 60%.

Lehmann lovegrass biomass productivity was affected by differential rainfall, where the above average rainfall (2004) year produced significantly more dry matter yield, averaging 2 681 kg/ha within El Pastor, La Campana, and San Cristobal sites relative to the dry 2005 which averaged 1 300 kg/ha (Fig. 5). Similar yield response to differential precipitation was also found in Arizona (Cox 1990) and with a five year shift in growing season rainfall pattern that produced fluctuations on aboveground biomass for *Bouteloua gracilis* (100 to 500 kg/ha), *Pascopyrum smithii* (100 to 300 kg/ha), and *Stipa comata* (250 to 650 kg/ha) in the North American Great Plains (Morgan et al. 2004).

Lehmann lovegrass in Central Chihuahua showed highest nutrient values in the vegetative stage and declined with advancing maturity. This response could be explained by several previous studies that showed the decline in forage quality with increasing maturity was due to a shift in the proportion of leaf, stem and dead matter as well as the nutrient composition of each constituent that occurs with plant development (Haferkamp et al. 2002; Ammar et al. 2004; Waghorn and Clark, 2004).

Lehmann lovegrass significantly declined in CP (more than 50 %) and digestibility (22%) from vegetative to flowering or mature phenological stages (Figs. 6A and 7B). This response is natural for forages changing phenological stages from vegetative to boot, and to anthesis stages or from summer to fall, as found in six Northern Great Basin grasses in Oregon (Haferkamp et al. 2002; Balasko and Nelson 2003; Ganskopp et al. 2007). Lehmann lovegrass CP (10.5%) found at the vegetative stage in this study was at a level suitable for livestock production and comparable to other forage species (Angell et al. 1990; Redfearn and Nelson 2003).

Fiber (ADF and NDF) increased for the mature stage of Lehmann lovegrass (Figs. 6B and 7A) which lower digestibility to levels where any forage is classified as low nutritive feed (Ganskopp et al. 1999; Haferkamp et al. 2005). Similar findings were found in New Mexico (Kloppenburg et al. 1995), Oklahoma (Basurto-Gutierrez 2004), and in Iran (Arzani et al. 2006) where range forages exhibited greater nutritional values as based on protein, fiber, and organic matter digestibility in the summer period and declined during the fall and winter months. Warm-season eastern gamagrass and big bluestem showed similar response in Alabama (Lewis et al. 2006). Similar trends were found in rye grass (Waghorn and Clark 2004), and in brome, orchardgrass and meadow hay (NRC 1996). When grasses start to decline in forage quality the grazing animals depend more heavily on alternative highly palatable forages that can be also shrubs (Ganskopp et al. 1999).

Digestibility (IVTDMD) of Lehmann lovegrass was very low and equivalent to other low quality forages or senescent pastures (Ganskopp and Bohnert 2006). This low digestibility is related to the chemical composition of Lehmann lovegrass with its high fiber content and low crude protein concentration. However, the highest in vitro dry matter digestibility for Lehmann lovegrass was found at the vegetative stage suggesting that the best stage for livestock grazing of Lehmann lovegrass would be at the vegetative stage (Kloppenburg et al. 1995). Forage quality standards suggest that it is more important to obtain a small increase in forage digestibility than a proportional increase in forage yield. (Redfearn and Nelson 2003).

The major concerns of a low input livestock production system include nutritional quality of forage and seasonal amount of forage production. However, it is important to note that predicting forage quality requires quantifying both nutritive value of the forage and voluntary intake by livestock (Mertens 2007). In the Central Rangelands of Chihuahua, Lehmann lovegrass appears to have an adequate level of production fails to provide adequate nutritional composition for livestock throughout the growing season. Similar to this study, to evaluate the nutritive value of Lehmann lovegrass, found comparable fluctuations in the nutritive value at three phenological stages (Chavez 1984). These results suggest that management of Lehmann lovegrass for forage production should focus on maintaining the majority of plants in the vegetative stage in order to maintain adequate forage nutritive value. In areas where Lehmann lovegrass has become dominant and maintenance of the vegetative stage would be difficult, growth in the flowering and mature phenological stages will not be able to provide adequate nutrition. Therefore protein supplementation would be required for proper livestock forage nutritional needs.

IMPLICATIONS

Introductions of grass species for erosion control or improved grazing opportunities have been common and have resulted in invasion of native systems by those grasses, resulting in the non-native species becoming dominant in grasslands (Wilsey and Polley 2006) this new dominance may alter ecosystems and rangeland aboveground productivity.

Lehmann lovegrass invasion is aggressive and has become the dominant grass on many sites in Central Chihuahua. This situation can be a serious problem because animals feeding from single forage all year round should be able to meet all nutrient requirements for high levels of animal production (Waghorn and Clark 2004). Even though Lehmann lovegrass typically produces a low (20 to 40%) basal cover, and can produce significantly more forage, relative to native rangeland, forage nutritive value is too low for lactating and maintenance cows and ewes (Cox 1992).

Forage nutritive value for Lehmann lovegrass was similar among sites. Even when significant differences were found between years, value ranges for nutritional attributes were generally low. Under ideal climatic conditions it seems that Lehmann lovegrass produces adequate protein content in the vegetative stage to support livestock production.

LITERATURE CITED

Ammar, H., S. Lopez, J.S. Gonzalez, and M.J. Ranilla. 2004. Seasonal variations in the chemical composition and in vitro digestibility of some Spanish leguminous shrub species. Animal Feed Science and Technology 115:327-340.

Anable. M.E., M.P. McClaran, and G.B. Ruyle. 1992. Spread of introduced Lehmann lovegrass Eragrostis lehmanniana Nees. In Southern Arizona, USA. Biological Conservation 61:181-188.

Angell, R.F., R.F. Miller, and M.R. Haferkamp. 1990. Variability of crude protein in crested wheatgrass at defined stages of phenology. Journal of Range Management 43:196-189.

ANKOM. 2008. Procedures. ANKOM Technology Corp., 140 Turk Hill Park, Fairport, NY. 14450. USA. URL:http://www.ankom.com/09_procedures/procedures1.shtml. *Accessed 5 July 2007*.

AOAC. 1980. Official Methods of Analysis of the Association of Official Analytical Chemists. Washington, D.C.

Arzani, H., A. Ahmadi, H. Azarnivand, and A. A. Jafari. 2006. Determination and comparison of forage quality in five range species at different phenological stages. Iranian Journal of Agricultural Sciences 37:303-311.

Balasko, J.A., and C.J. Nelson. 2003. Grasses for northern areas. *In*: R.F Barnes, C.J. Nelson., M Collins, and K.J. Moore [EDS.], Forages: An introduction to grassland agriculture, 6th ed., Ames: Iowa State Univ. Press. p. 171-190.

Basurto-Gutierrez, R. 2004. Impact of forage type and nitrogen supplementation on forage intake and nitrogen metabolism in beef steers. [dissertation]. Stillwater, OK: Oklahoma State University. p. 185.

Chavez, S. A. 1984. Contenido y fluctuación de nutrientes de las especies forrajeras consumidas por el ganado en los agostaderos de Chihuahua. Pastizales XV: 1-40.

Cox, J.R., M.H. Martin, F.A. Ibarra, J.H. Fourie, N.F.G. Rethman, and D.G. Wilcox. 1988a. The influence of climate and soils on the distribution of four African grasses. Journal of Range Management 41:127-139.

Cox, J.R., G.B. Ruyle, J.H. Fourle, and C. Donaldson. 1988b. Lehmann lovegrass-Central South Africa and Arizona, USA. Rangelands 10:53-55.

Cox, J.R., G.B. Ruyle, and B.A. Roundy. 1990. Lehmann lovegrass in southeastern Arizona: Biomass production and disappearance. Journal of Range Management 43:367-372.

Cox, J.R. 1992. Lehmann lovegrass live component biomass and chemical composition. Journal of Range Management 45:523-527.

Cumming, K. 1989. Lehmann lovegrass and simple time control grazing. Rangelands 11:150-153.

Denek, N. and S. Deniz. 2004. The determination of digestibility and metabolizable energy levels of some forages commonly used in ruminant nutrition by in vitro methods. Turkish Journal of Veterinary & Animal Sciences 28:115-122.

Galyean, M.L. 1997. Laboratory procedures in animal nutrition research. Department of Animal and Food Sciences. Lubbock, TX: Texas Tech University. 189 p.

Ganskopp, D., T. Svejcar, F. Taylor, J. Farstvedt, and K. Paintner. 1999. Seasonal cattle management in 3 to 5 year old bitterbrush stands. Journal of Range Management 52:166-173.

Ganskopp, D., and D. Bohnert. 2006. Do pasture-scale nutritional patterns affect cattle distribution on rangelands? Rangeland Ecology & Management 59:189-196.

Ganskopp, D., L. Aguilera, and M. Vavra. 2007. Livestock forage conditioning among six northern Great Basin grasses. Rangeland Ecology and Management 60:71-78.

Gillen, R.L., and W.A. Berg. 2005. Response of perennial cool-season grasses to clipping in the Southern Plains. Agronomy Journal 97:125-130.

Haferkamp, M.R., E.E. Grings, R.K. Heitschmidt, and M.D. MacNeil. 2002. Quality and persistence of forages in the Northern Great Plains. Journal of Range Management 55:482-487.

Haferkamp, M.R., M.D. MacNeil and E.E. Grings. 2005. Predicting nitrogen content in the Northern Mixed-grass prairie. Rangeland Ecology & Management 58:155-160.

Humphrey, N. 1994. History, Status and Management of Lehmann lovegrass. Rangelands 16: 205-206.

INIFAP. 2006. Basic climatic statistics for Chihuahua State (1961-2003). (In Spanish). Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias. Libro tecnico No.1. Chihuahua, Mexico

Kloppenburg, P.B., H.E. Kiesling, R.E. Kirksey, and G.B. Donart. 1995. Forage quality, intake, and digestibility of year long pastures for steers. Journal of Range Management 48:542-548.

Leco Corporation. 2006. Leco TruSpec® Elemental Determinator. St. Joseph, MI. http://www.leco.com/products/organic/truspec/pdf/truspec%20(209-150).pdf. *Accessed 3 April 2008*.

Lewis, J.S., S.S. Ditchkoff, J.C. Lin, R.B. Muntifering, and A.H. Chappelka. 2006. Nutritive quality of Big Bluestem (*Andropogon gerardii*) and Eastern Gamagrass (*Tripsacum dactyloides*) exposed to tropospheric ozone. Rangeland Ecology and Management 59:267-274.

Machado, C.F., S.T. Morris, J. Hodgson, C. Matthew, and N. Auza. 2007. Seasonal variation in the quality of a Lucerne-based pasture and its relationship with morphological and maturity estimates. Australian Journal of Experimental Agriculture 47:575-582.

Maynard, L. A., J. K. Loosli, H. F. Hintz, and R. G. Warner. 1979. Animal nutrition. 7th Ed. New York, NY. McGraw Hill.

McDonald, P., R.A. Edwards, J.F.D. Greenhalgh, and C.A. Morgan. 2002. Animal nutrition. 6td. Ed. Pearson Prentice Hall.

McGlone, C.M., and L.F. Huenneke. 2004. The impact of prescribed burn on introduced Lehmann lovegrass versus native vegetation in the northern Chihuahuan Desert. Journal of Arid Environment 57:297-310.

Melgoza, A., G. Melgoza and M.H. Royo. 1986. Vegetation changes in central Chihuahua State after 26 years. (In Spanish). Pastizales. Vol.17. INIFAP-SARH. Chihuahua, México.

Mertens, D.R. 2007. Digestibility and intake. *In*: R.F Barnes, C.J. Nelson, K.J. Moore, and M. Collins [EDS.]. Forages. The science of grassland agriculture. 6th ed., Ames: Iowa State University Press. p. 487-508.

Moore, J.E., A.T. Adesogan, and S.W. Coleman. 2007. Predicting forage quality. *In*: R.F. Barnes, C.J. Nelson, K.J. Moore, and M. Collins. [EDS.] Forages: The science of grassland agriculture, 6th ed., Blackwell Publishing. P.553-568.

Morgan, J.A., A.R. Moster, D.G. Milchunas, D.R.LeCain, J.A. Nelson, and W.J. Parton. 2004. CO_2 enhances productivity, alters species composition, and reduces digestibility of shortgrass steppe vegetation. Ecological applications 14:208-219.

Moreira, A.L., R. Andrade, A.C. Ruggieri, and A.J. Saran Junior. 2007. Avaliacao de forrageiras de inverno irrigadas sob pastejo. Ciencia Agrotecnia Lavras 31:1838-1844.

Mortenson, M.C., G.E. Schuman, L.J. Ingram, V. Nayigihugu, and B.W. Hess. 2005. Forage production and quality of a mixed-grass rangeland interseeded with *Medicago sativa* ssp. *falcata*. Rangeland Ecology and Management 58:505-513.

NFTA. 1993. Forage analyses procedures. National Forage Testing Association Omaha, NE. Pp. 79-81.

NRC. 1996. Nutrient requirements of beef cattle. 7th Ed. National Research Council. Washington, DC. National Academy Press.

Philipp, D., V.G. Allen, R.B. Mitchell, C.P. Brown, and D.B. Wester. 2005. Forage nutritive value and morphology of three Old World Bluestem under a range of irrigation levels. Crop Science 45:2258-2268.

Redfearn, D.D., and C.J. Nelson. 2003. Grasses for southern areas. *In*: R.F Barnes, C.J. Nelson., M Collins, and K.J. Moore [EDS.], Forages: An introduction to grassland agriculture, 6th ed., Ames: Iowa State Univ. Press. P.149-169.

Robinett, D. 1992. Lehmann lovegrass and drought in Southern Arizona. Rangelands 14:100-103.

Royo, M. 1988. Autoecology contribution of Africano grass (*Eragrostis lehmanniana*). (In Spanish). B.S. Thesis. Facultad de Ciencias Biológicas. Universidad Autónoma de Nuevo León, Mex. 87p.

Ruyle, G. B., Roundy, B.A., and Cox. J.R. 1988. Effects of burning on germinability of Lehmann lovegrass. Journal of Range Management 41:404-406.

SAS. 1991. User's guide: Statistics, version 8.01. Cary, NC, SAS Inst., Inc.

Sanderson, M.A., P. Voigt and R.M. Jones. 1999. Yield and quality of warm-season grasses in central Texas. Journal of Range Management 52:145-150.

Shussman, H., E. Geiger, T. Mau-Crimmins and J. Ward. 2006. Spread and current potential distribution of an alien grass, *Eragrostis Lehmanniana* Nees, in the southwestern USA: comparing historical data and ecological niche models. Diversity Distributions 12:582-592.

Sokal, R. R. and Rohlf, F. J. 1995. Biometry. 3rd edn. San Francisco: Freeman.

SARH. 1978. Comision Tecnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero. Subsecretaria de Ganaderia. Secretaria de Agricultura y Recursos Hidraulicos. Chihuahua, México.

Stritzler, N.P., J.H. Pagella, V.V. Jouve, and C.M. Ferri. 1996. Semi-arid warm-season grass yield and nutritive value in Argentina. Journal of Range Management 49:121-125.

Waghorn, G.C., and D.A. Clark. 2004. Feeding value of pastures for ruminants. New Zealand Veterinary Journal 52:320-331.

Wilsey B., and H.W. Polley. 2006. Aboveground productivity and root-shoot allocation differ between native and introduced grass species. Oecologia 150:300-309.

Table 1. Site characteristics in the central valley of Chihuahua Mexico.

Site	Geology	Soil type	Altitude (m)	Slope (%)	Vegetation (Genus)	Forage production kg/D.M./ha	Climate type	Ave. temp ℃	Precip. mm	Frost free days	Dry season months
El Pastor La Campana San Cristobal	Igneous rocks limestone and sedimentary rocks	Sandy clay	1400 to 1800	10 to 30	*Bouteloua* *Leptochloa* *Digitaria* *Setaria* *Lycurus* *Heteropogon* *Aristida* *Eragrostis*	410	Dry temperate with warm summer	14 to 17	300 to 400	215	8
San Judas	Igneous rocks Alluvial soils Reddish soils	Sandy loam	1350 to 1500	0 to 7	*Bouteloua* *Digitaria* *Setaria* *Lycurus* *Hilaria* *Aristida* *Eragrostis*	282	Very dry with warm summer	18 to 20	200 to 350	200	9

From: SARH. 1978. Mexico. D.M.: Dry Matter; Ave: Average; temp: temperature; Precip: Precipitation.

Table 2. Monthly temperature (℃), precipitation (mm) and relative humidity (%) for La Campana site for 2004 and 2005

Month	2004 T.Min (℃)	2004 T.Ave (℃)	2004 T.Max (℃)	2004 Precip (mm)	2004 Hum (%)	2005 T.Min (℃)	2005 T.Ave (℃)	2005 T.Max (℃)	2005 Precip (mm)	2005 Hum (%)
Jan	0.65	5.81	16.03	28.50	29.13	1.11	7.26	18.87	19.00	31.39
Feb	0.00	6.52	18.69	0.00	29.52	2.38	7.57	16.68	35.00	32.50
Mar	4.84	11.19	22.58	39.00	38.03	2.61	11.58	21.13	0.00	37.77
Apr	7.13	14.13	25.00	5.00	40.97	8.51	18.40	26.16	0.00	40.76
May	11.00	19.97	30.65	2.50	49.52	12.05	23.63	30.18	14.99	50.56
Jun	14.07	21.60	32.83	41.50	54.70	16.30	27.50	34.36	1.02	59.43
Jul	16.35	23.39	32.16	145.00	54.71	18.46	28.46	34.05	4.06	56.71
Aug	15.13	20.00	29.03	102.00	49.42	16.65	23.40	29.51	97.29	49.78
Sep	11.50	16.87	26.97	63.50	45.07	13.89	22.80	30.47	37.08	45.48
Oct	7.55	13.06	23.81	28.50	40.52	9.43	17.81	25.43	18.54	39.00
Nov	0.68	7.60	18.53	41.00	33.07	1.50	12.59	23.04	0.00	34.86
Dec	-2.95	4.61	16.74	0.00	26.23	-0.42	7.70	19.76	18.79	27.64
Total				496.50					245.77	

T: Temperature; Min: Minimum; Ave: Average; Max: Maximum; Precip: Precipitation; Hum: Relative humidity.

Table 3. Soil properties for El Pastor, La Campana, San Cristobal, and San Judas study sites in Chihuahua, Mexico.

a) Physical soil properties

Sites	Sand (%)	Silt (%)	Clay (%)	pH	HC cm/h	BD (g/cm³)	RD (g/cm³)	Pores (%)	FC (%)	PWP (%)	SAT (%)	EC mmhos/cm
El Pastor	75	4	21	5.44	13.64	1.08	2.82	61.70	7.04	4.19	27	0.28
La Campana	69	10	21	4.98	21.44	1.04	2.51	58.57	7.04	4.50	29	0.24
San Cristobal	63	14	23	6.75	15.45	0.79	2.16	63.43	11.87	7.06	46	0.60
San Judas	59	16	25	5.14	9.05	0.89	2.36	62.29	7.30	4.35	28	0.35

HC: Hydraulic Capacity; BD: Bulk Density; RD: Real Density; FC: Field Capacity; PWP: Permanent Wilting Point; SAT: Saturation; EC: Electrical Conductivity

b) Chemical soil properties

Sites	OM (%)	NO_3 kg/ha	P (%)	K ppm	Ca ppm	Mg ppm	Na ppm	Cu ppm	Fe Ppm	Mn ppm	Zn ppm
El Pastor	0.68	429	9.30	250	1038	150	363	0.42	6.80	5.22	0.78
La Campana	0.99	248	3.50	300	988	113	450	0.44	14.32	21.94	2.26
San Cristobal	2.33	180	3.50	313	4650	113	300	0.50	1.46	3.84	2.26
San Judas	0.40	294	2.90	250	1063	138	425	0.62	3.68	26.06	1.08

OM: Organic matter; NO_3: Nitrate

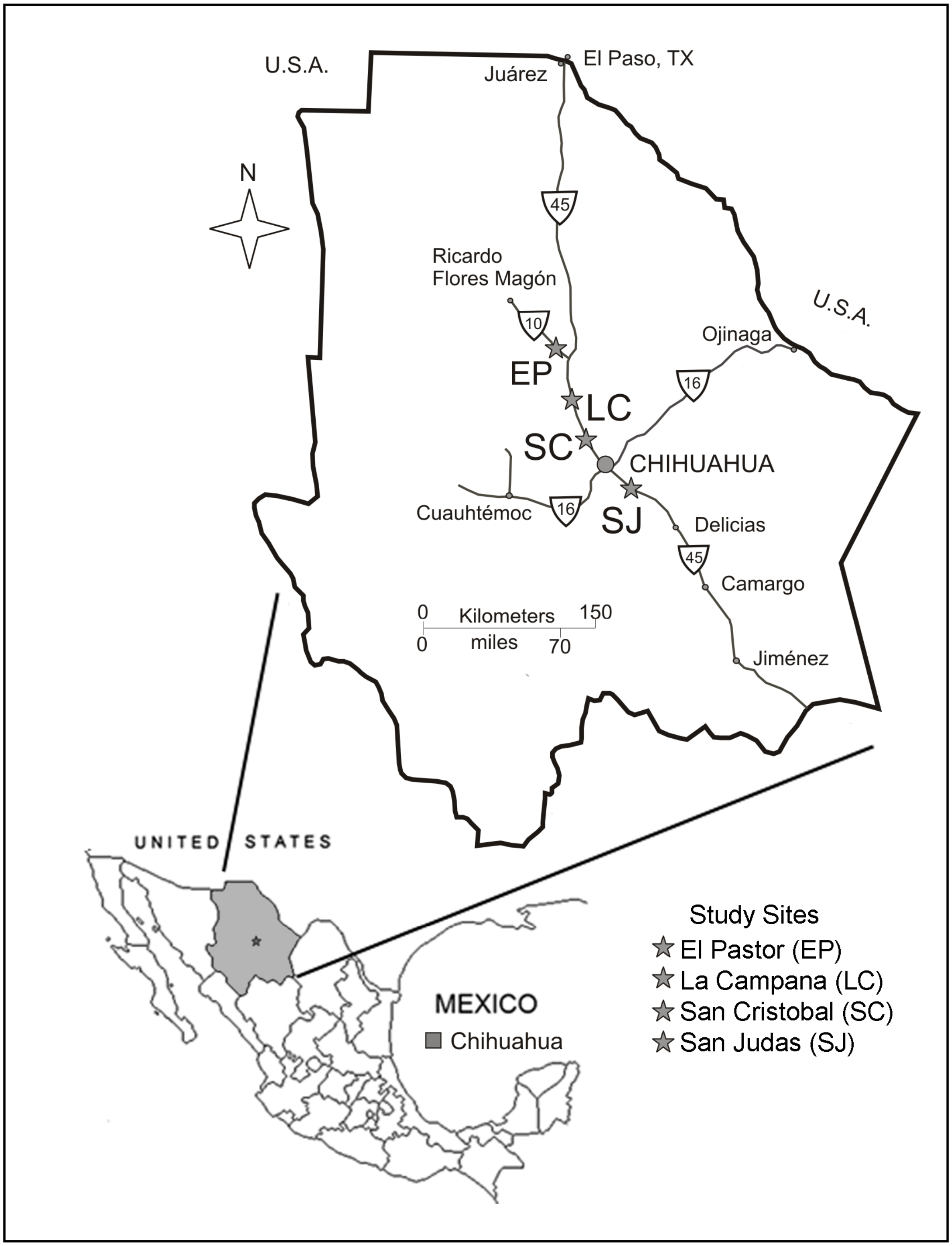


Figure 1. Lehmann lovegrass study areas: El Pastor (EP), La Campana (LC), San Cristobal (SC), and San Judas (SJ) location sites along central rangelands and major highways in Chihuahua, Mexico.

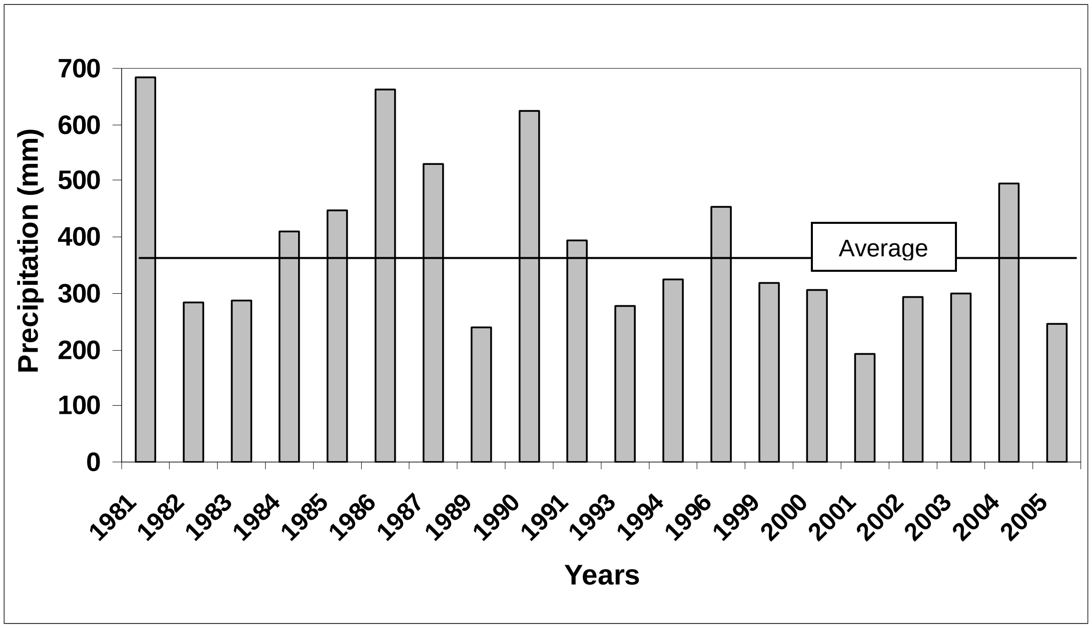
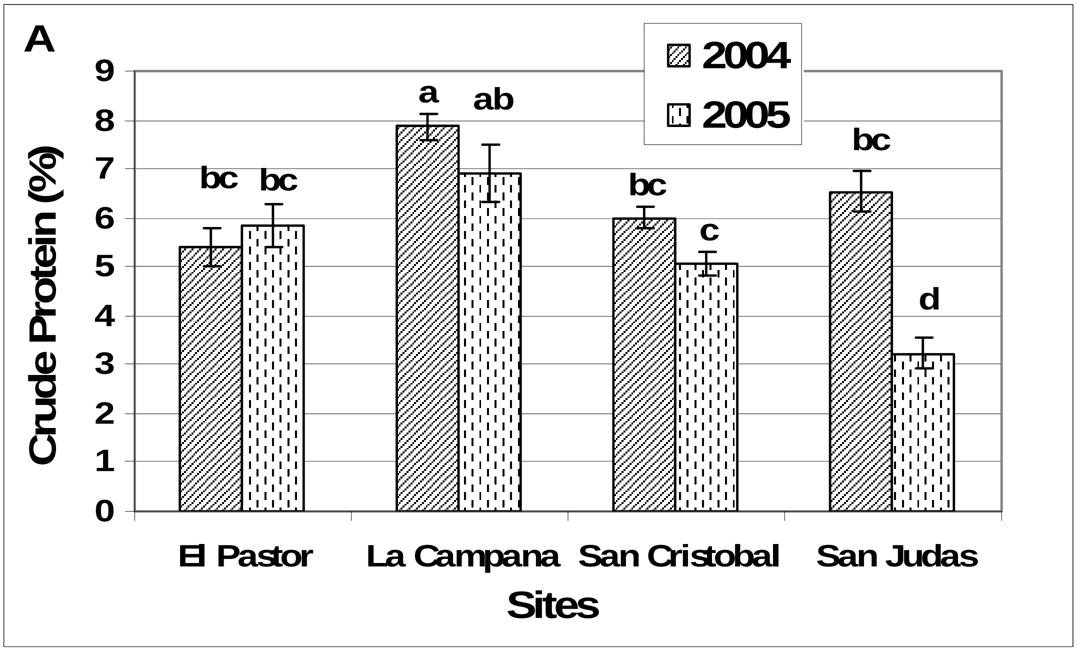


Figure 2. Long term precipitation data for La Campana site (25 year average 382 mm per year).



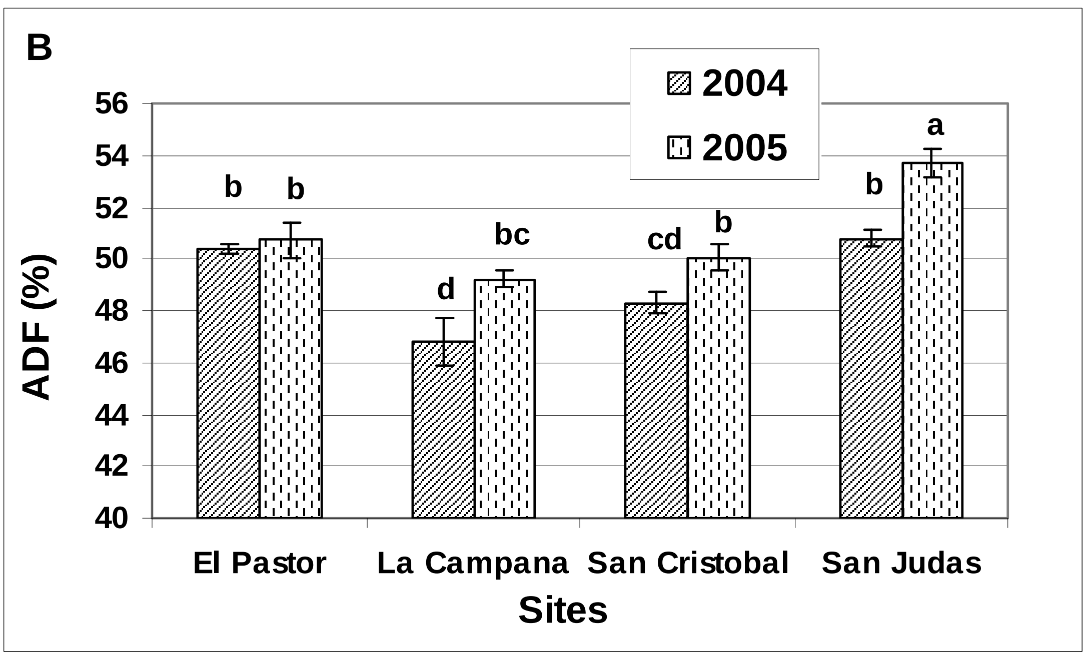
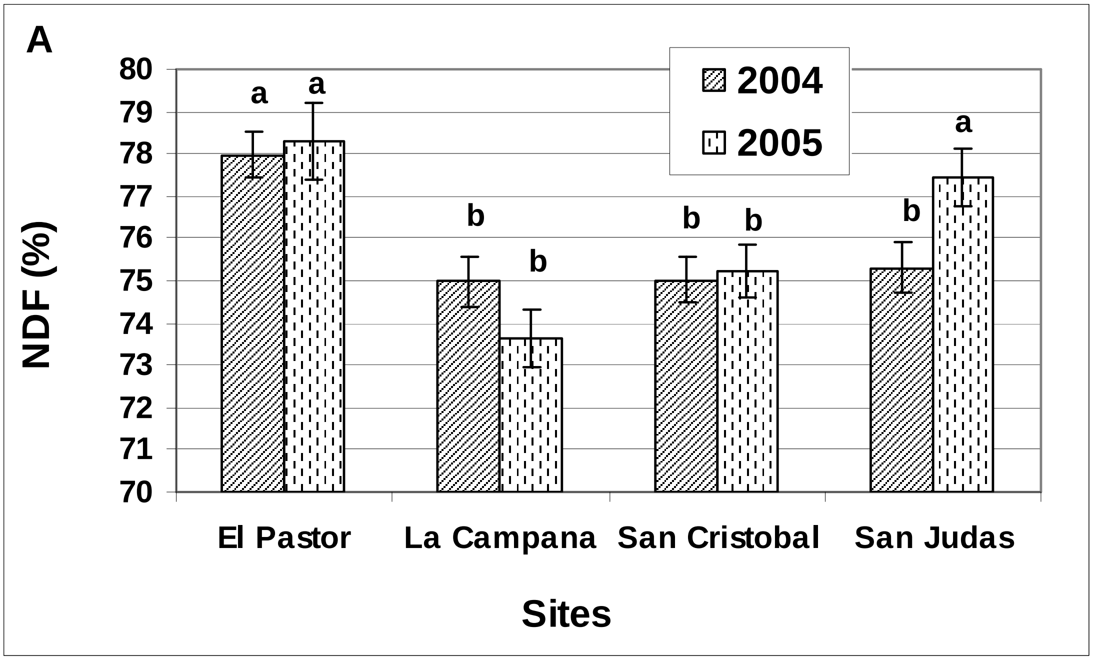


Figure 3. Nutritional values for Lehmann lovegrass content; (**A**) crude protein, and (**B**) acid detergent fiber (ADF), at El Pastor, La Campana, San Cristobal, and San Judas sites in Chihuahua, Mexico. Bars represent treatment mean± SE. Different letters above bars indicate significant differences (P <0.05) among years and sites.



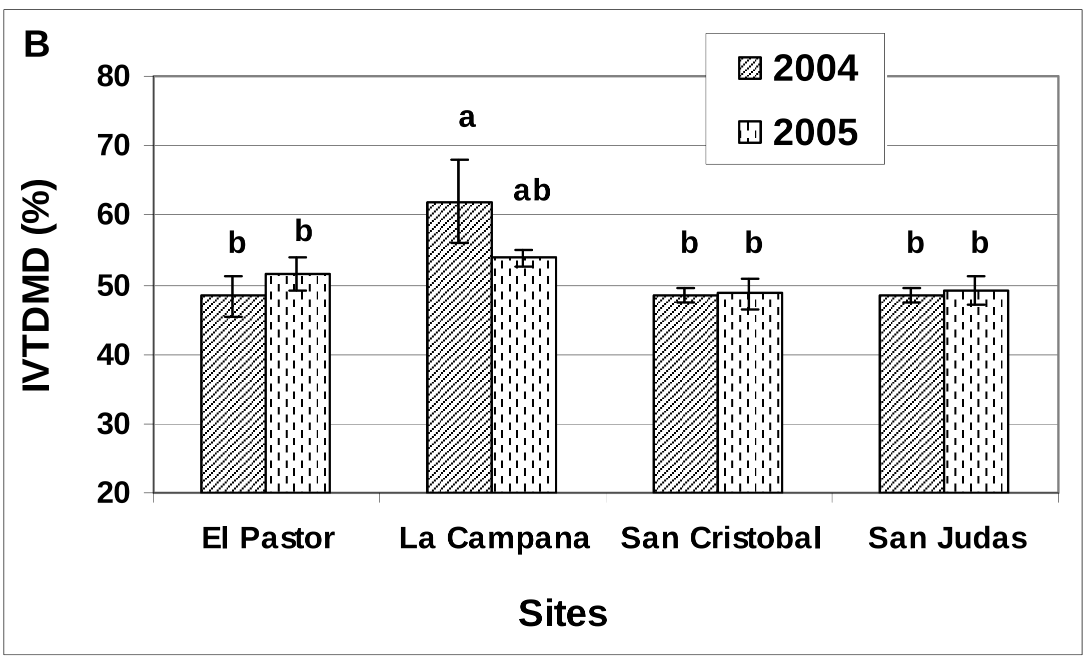


Figure 4. Nutritional values for Lehmann lovegrass content; (**A**) neutral detergent fiber (NDF), and (**B**) in vitro true dry matter digestibility (IVTDMD), at El Pastor, La Campana, San Cristobal, and San Judas sites in Chihuahua, Mexico. Bars represent treatment mean± SE. Different letters above bars indicate significant differences (P <0.05).

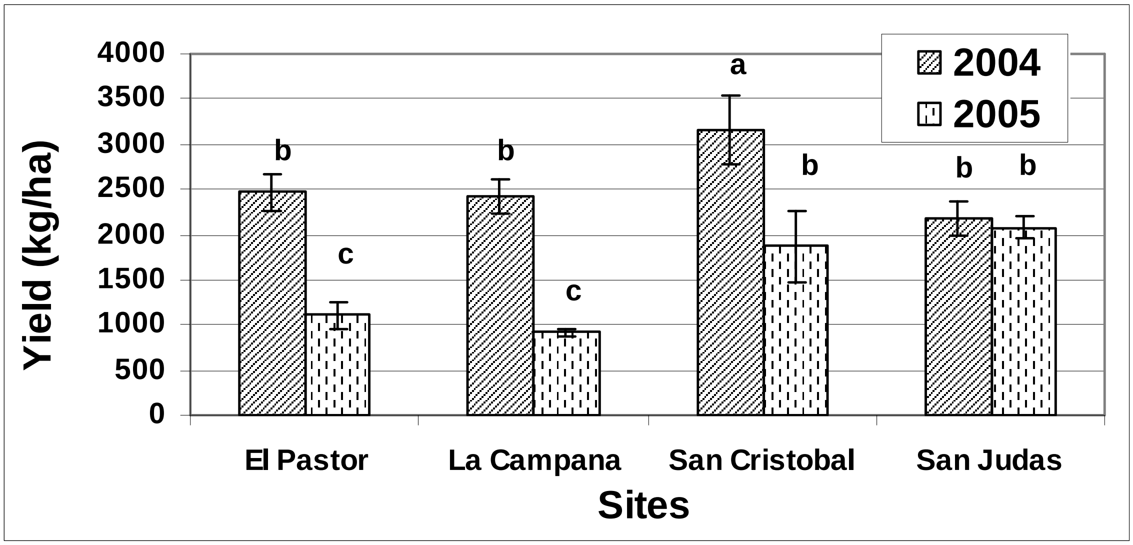


Figure 5. Lehmann lovegrass dry matter yield (kg/ha) at El Pastor, La Campana, San Cristobal, and San Judas sites in Chihuahua, Mexico. Bars represent treatment mean± SE. Different letters above bars indicate significant differences (P <0.05) among sites and years.

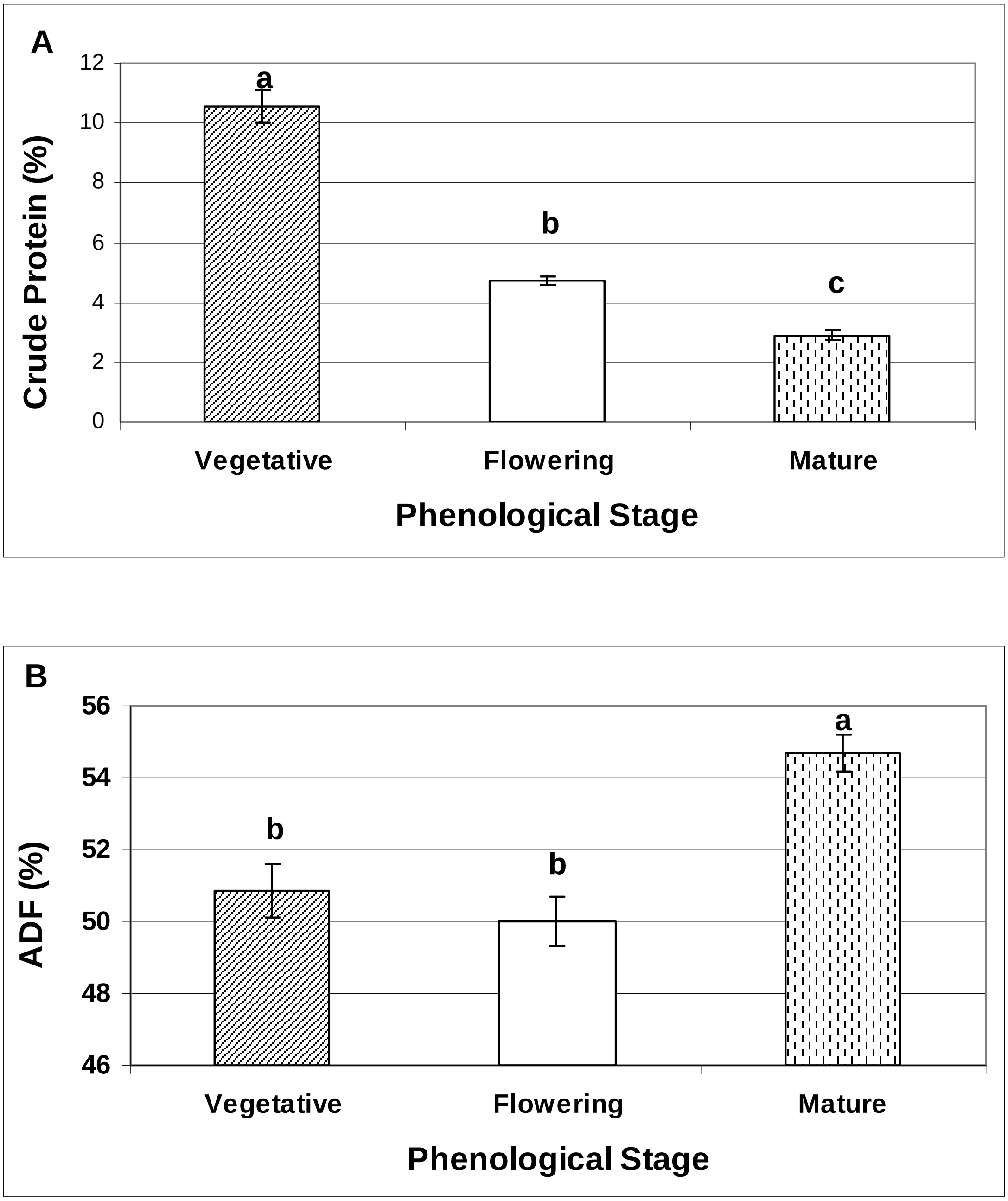


Figure 6. Nutritional values for Lehmann lovegrass content; (**A**) crude protein, and (**B**) acid detergent fiber (ADF), at three phenological stages: vegetative, flowering, and mature in Chihuahua, Mexico. Bars represent treatment mean± SE. Different letters above bars indicate significant differences ($P < 0.05$) among phenological stages.

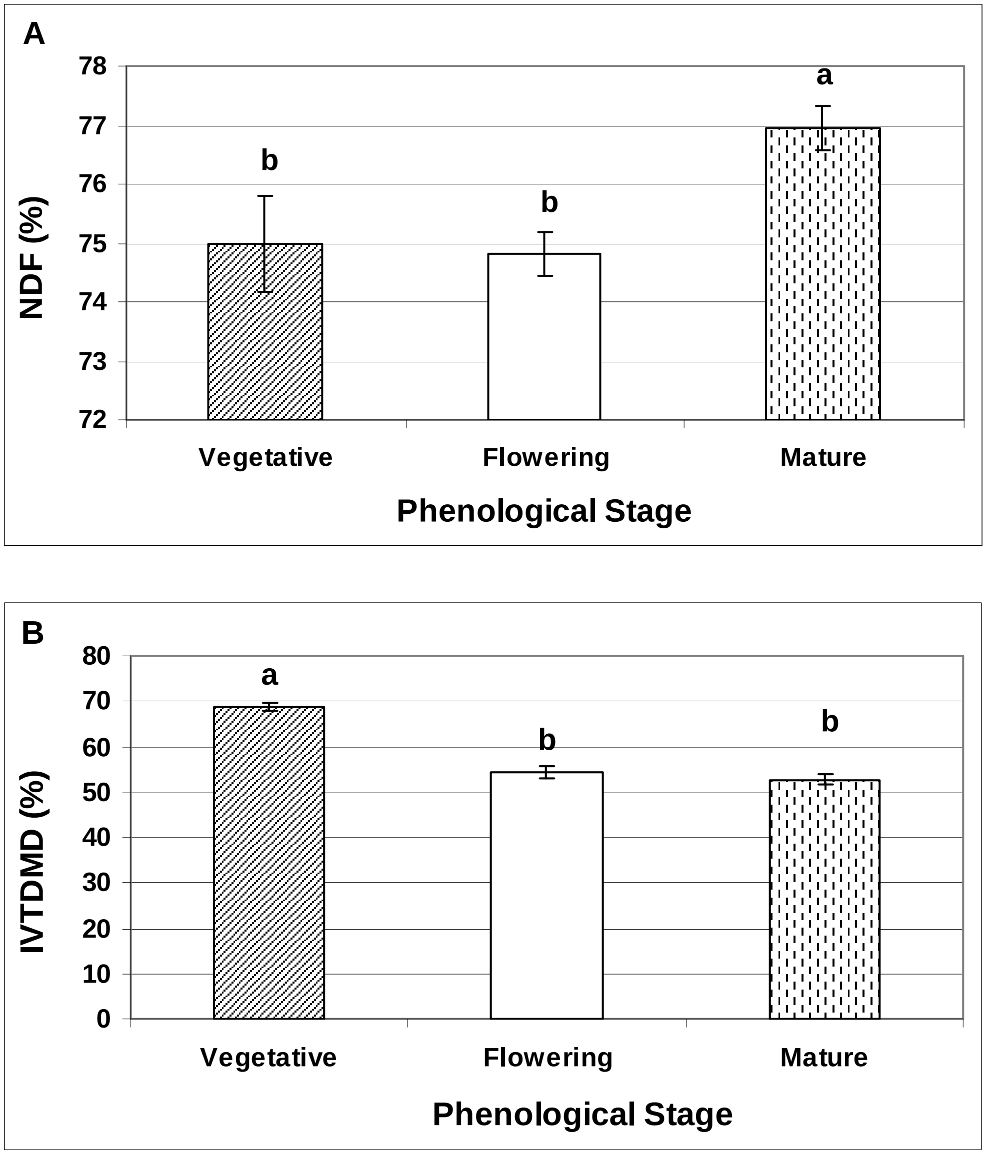


Figure 7. Nutritional values for Lehmann lovegrass content; (**A**) neutral acid detergent (NDF); and (**B**) in vitro true dry matter digestibility (IVTDMD), at three phenological stages: vegetative, flowering, and mature in Chihuahua, Mexico. Bars represent treatment mean± SE. Different letters above bars indicate significant differences (P <0.05) among phenological stages.

VITA

ALFONSO DE JESUS SANCHEZ MUNOZ

Candidate for the Degree of

Doctor of Philosophy

Dissertation: INVASIVE LEHMANN LOVEGRASS (Eragrostis lehmanniana) IN CHIHUAHUA, MEXICO: CONSEQUENCES OF INVASION

Major Field: Natural Resource Ecology and Management

Biographical:

Personal Data:

Education: B.S. in Animal Science: Ingeniero Zootecnista from the Universidad Autónoma de Chihuahua, México, in June, 1974.

Completed the requirements for the Master of Science in The University of Arizona at Tucson, AZ in May of 1978.

Completed the requirements for the degree of Doctor of Philosophy in Oklahoma State University, at Stillwater, Oklahoma in May, 2009.

Experience:
Research member at Rancho Experimental La Campana- in Chihuahua, Mexico, from 1974 to 1979.
Research leader for Agriculture products at Ely Lilly and Company (ELANCO) de Mexico, from 1979 to 1982.
Professor and Researcher at the Facultad de Zootecnia y Ecología, Universidad Autónoma de Chihuahua, from 1983 to present.

Professional Memberships:
Society for Range Management
Weed Science Society of America
American Association for the Advancement of Science