APPLICATION OF COMPUTER MODELING IN BUFFELGRASS PASTURES STUDIES

By

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DEDICATION

I dedicate this dissertation to my wife Imelda and my son Jerónimo, both source of love and enthusiasm in my life.

Also, this research work is dedicated to the memory of my mother Angelita and proudly to my brothers and sisters and their children.

I dedicate this dissertation to all my friends that gave me support in difficult times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Pastures established using buffelgrass (*Cenchrus ciliaris* L.) have shown heterogeneous responses in terms of forage production and permanence. A good alternative for determining establishment sites and predict trends in buffelgrass conditions is the use of simulation models. The objectives of this research were to determine the factors that regulate successfulness in buffelgrass pastures and to develop a model to determine suitability in areas managed for buffelgrass pastures, based on environmental, ecological, and management variables. Above ground biomass production was considered to determine suitability in sites with buffelgrass. Eight ranches with different geographic locations, environmental situations, and management conditions were sampled as preliminary study sites to measure and model plant production. The resulting model was used to estimate plant production in the 37 sampling sites of the study areas. Results of the study indicate that basal area is a good modeling parameter to estimate production in buffelgrass plants. I also found that plant production in buffelgrass is negatively affected by population density. I concluded that there exist a positive correlation between pasture management and buffelgrass plant production. Correlation analyses demonstrate that there exist significant correlations between Pasture Condition Index (PCI) and mean annual temperatures, aspect, pasture age, nitrogen and sodium content. However, after performing stepwise regressions, only three variables were significant: pasture age (PA), nitrogen content (N_2), and mean annual temperature (MAT); the last two, produce a negative response on PCI.

INTRODUCTION

Natural rangelands of Sonora, Mexico, have been degraded and today no longer have the potential to support and sustain a highly productive cattle industry. Thus, the establishment of artificial pastures using forage species introduced from other regions of the world could contribute to increase the production of food for livestock, as part of an integrated approach to accomplish an ecologically managed rangeland.

Pastures established using buffelgrass (*Cenchrus ciliaris* L.) have shown heterogeneous responses in terms of forage production and permanence. This circumstance has motivated federal and state government agencies, as well as some university researchers, to develop research programs to understand the factors and processes that determine the favorable development of buffelgrass pastures in Sonora.

Given the extent of the area dedicated to the cattle industry in Sonora, over 0.5 million hectares, the amount of economic resources required by the operative actions during the sampling and field studies in the rangelands studied, are very large. Considering this, it is necessary to look for strategies or methodologies to solve the problem at low cost, with fewer people, and in the shortest time.

A good alternative for determining establishment sites and predict trends in buffelgrass conditions is the use of models. Models are simply representations of how a system operates in the real world. This includes empirical models that are developed considering the statistical relationships that exist between dependent and independent variables.

Hypothesis

The suitability for a buffelgrass pasture is defined by natural factors; however, that suitability can also be influenced by anthropogenic factors and attributes inherent to the components of the pasture ecosystem itself.

Objectives

The objectives of this work are:

1. Determine the factors that regulate successfulness in buffelgrass pastures.

Although buffelgrass has been used for more then 50 years in Sonora, Mexico, there is not a complete knowledge of the factors and ways in which those factors interact to define the optimal conditions that this species requires to grow successfully. Thus, some pastures can be prosperous and even spread into adjacent areas; other pastures can grow for a given period of time and then decline and, in other cases, buffelgrass can have failures in germination, conditions that lead to low density populations (Ibarra et al. 1995a), situations undesirable for grazing purposes. The later two cases generate economical problems for ranchers and cause ecological deterioration in the areas where the natural vegetation was removed. For this reason, it is very important to know the agents that control the establishment and permanence of buffelgrass pastures.

2. Develop a model to determine suitability in areas managed for buffelgrass pastures, based on environmental, ecological, and management variables. By modeling buffelgrass habitats and the interactions of different factors related with the species life

cycle, it should be possible to predict, under different scenarios, the successfulness of buffelgrass pastures for a geographical area, in the central region of Sonora, Mexico.

LITERATURE REVIEW

Range condition is a term commonly used to express the actual capacity of a grazing area to be used in range management. It is defined as the state of the vegetation of a range site, in relation to the climax plant community for that site. Thus, a plant community in a succession stage is in good condition, and it will be in undesirable condition when in retrogression (National Research Council, 1994).

Bonham (1989) suggests the term “vegetation condition” rather than “range condition” be used. Vegetation condition relates the current status of vegetation to the potential of the site to produce a given vegetation unit. This term agrees with the range condition concept in the fact that the more advanced the successional stage, the better the vegetation condition. However, we must keep in mind that a subclimax vegetation community may be more useful for livestock grazing than a climax community.

Frequently, range managers use four categories to classify pastures into range condition categories based on the climax vegetation concept: excellent, good, fair and poor. According to Smith (1978), estimating range condition based on the climax approach could present some problems: 1) the range condition scale of poor to excellent may conflict with management objectives and may produce a negative effect in the appreciation of the range managers; 2) There could be difficulties in defining climax vegetation and; 3) The concept does not consider undesirable species because they are not part of the climax stage. This author recommends using the concept of range condition based mainly on soil characteristics instead of vegetation composition.

In order to establish buffelgrass pastures, natural plant communities are cleared, leaving some perennial herbs, shrubs and trees for browsing and shade. Leaving 15% of native vegetation is the current regulation in Sonora. Some species such as false mesquite (*Calliandra eriophylla*), mesquite (*Prosopis* spp), palo verde (*Cercidium* spp), and ironwood (*Olneya tesota*) should not be removed. For this reason, the range condition concept based only on vegetation composition can not be applied to these grazing areas given the lack of successional stages (disclimax situation) in the system.

McIvor et al. (1995) developed the *Quantitative Condition Index* which is based on vegetation and soil characteristics for grazing areas of northern Australia. Because this model considers botanical composition and basal area of perennial bunchgrasses, it can be adequately applied to buffelgrass populations. Soil characteristics for this model are measured following the procedures of Tongway and Smith (1989).

Many studies have been carried out to determine environmental factors that regulate buffelgrass biological processes such as germination, establishment, growth, production, and reproduction. With respect to soil pH, Gausman et al. (1954) found that buffelgrass had a low tolerance to soil salinity. Graham and Humphreys (1970) later corroborated this result. Following thirteen years of experimentation, Ebersohn (1970), found that buffelgrass pastures can be established and produce high yields in places where soil pH is acidic. However, he concluded that productivity would be greater in slightly alkaline soils, and even more so in pastures with run-on water. Hanselka and Johnson (1991) and Ibarra-Flores et al. (1991) also concluded that slightly alkaline soils (pH = 7 - 8) are more suitable for buffelgrass than slightly acidic soils (pH = 6 - 7).

Soil texture is another characteristic that affects establishment of buffelgrass. According to Cox et al. (1988) and Hanselka and Johnson (1991), buffelgrass seedlings exhibit good germination in loamy soils, but that declines when sand, silt, or clay content approaches 100%. The problem is evident when soils contain 20% or more of clay (Ibarra-Flores et al., 1991) since seedlings gradually lose vigor and die when established in silt, silt loam, silty clay loam, silty clay, and clay soils. On the other hand, buffelgrass persists in well-drained loam, sandy loam, clay loam, and sandy clay loam soils. It actively spreads by seed in sandy loam soils in northwest Mexico (Cox et al., 1988). Hanselka and Johnson (1991) specify that a good cover can be obtained on gravely, sandy, loamy and loamy clay soils but the management will be more critical.

It has been demonstrated that nutritional quality of unfertilized buffelgrass in native rangeland pastures varies seasonally but, according Gonzalez and Everitt (1980), is typically low. Wiedenfeld et al. (1985) and later Cabanillas-Cruz (1996), found that buffelgrass yields could be increased with nitrogen applications; phosphorus applications also significantly increased buffelgrass yields but only when combined with high nitrogen levels. Ibarra-Flores et al. (1995a) detected that the amount of nitrogen and organic carbon in soils are low where the grass spreads, intermediate where the species persists, and high where the plant dies. These authors also mention that low available soil phosphorus may limit buffelgrass productivity, but concentrations below 0.1 mg/kg in soil, do not impact the plant's ability to either establish itself from seed or survive.

Wiedenfeld et al. (1985) found that annual rainfall rates strongly influence overall yields of buffelgrass. They calculated an increase of 18 kg/ha per mm of rainfall and

estimated that rainfall use efficiency for buffelgrass increased over the control by an average of 2.2 and 2.8 times at 112 and 224 kg N/ha, respectively. They concluded that N availability on soils where buffelgrass was grown greatly enhanced the efficient utilization of the rainfall received in these areas. Hanselka and Johnson (1991) found that buffelgrass can be prosperous in areas with minimum precipitation of 300 mm with over 50% falling during the summer. Buffelgrass predominates and spreads to adjacent non planted sites when planted in areas where summer rainfall varies from 350 to 550 mm and winter rainfall is less than 400 mm (Ibarra-Flores et al. 1995a). When summer rainfall exceeds 550 mm, buffelgrass survival is limited by allelopathy, competition with more productive plants and insect predation (Ibarra-Flores et al., 1995b). High water table levels inhibit its establishment (Hanselka and Johnson, 1991).

Several authors have studied the role of temperature on buffelgrass establishment and growth. The Wiedenfeld et al. (1985) studies, found that warm temperatures accelerate nutrient cycling in buffelgrass pastures increasing nutrient requirements. Woodard (1980) found that buffelgrass shows high yields in South Texas, but its distribution is limited by cold climate conditions and poorly drained soils. Ibarra-Flores et al. (1995a) mention that buffelgrass predominates and spreads to adjacent non-planted sites, when planted in areas where mean minimum winter temperatures rarely fall below 5 ^{o}C, and soil texture is loamy.

A number of authors consider that topographic characteristics of grazing areas are important factors for forage production. Ahlgren et al. (1946) found that the average annual yields of dry matter produced in grazed pastures are smaller in areas with slopes

of 26 to 35% than those with 15 to 25%; this is supported by Perez-Corona et al. (1994). Hanselka and Johnson (1991) established that best sites for buffelgrass pastures should be in plain topography; they remark that rolling hills can be good, but more management practices would be required.

It is generally accepted that south (S) aspects are warmer and drier than north (N) aspects (Shreve, 1915; Haase, 1969). However, some investigations indicate that warmest and driest slopes face south-southwest (SSW) or southwest (SW) rather than S, and the coolest, wettest slopes face north-northeast (NNE) or northeast (NE) rather than N (Hall, 1902; Ayyad and Dix, 1964; Geiger, 1965; Haase, 1969; Meyer, 1983). The effect of aspect has not been studied in buffelgrass grazing areas but some particular response should be expected from pastures established in different exposures in relation to temperature and moisture regimes.

Usually, determining suitable areas for exotic grasses or measuring and monitoring annual production in pastures is performed using field applied methods. Field techniques produce very precise measurements; however, sometimes are very difficult to accomplish due to high economic costs, time consuming, people hiring and training, and material and equipment requirements.

One alternative approach is to develop models to achieve these goals. Models are mathematical equations capable to represent the performance of a biologic process occurring in the real world. In grazing lands, one of these processes could be forage production.

According to Clark et al. (1993), simple univariate statistical techniques may not adequately assess the multidimensional nature of habitats utilized by species. However, univariate statistical tests can be used to assess the validity of individual model variables and to better understand the role of each variable before proceeding with full model development and testing (Kvamme, 1985; Schamberger and O'Neil,1986).

Pereira, and Itami (1991) contend that "multivariate statistical models, being inductive, empirical models, when appropriately tested against real habitat use data, offer the potential to minimize validation problems". Multiple regression analysis is one of different types of multivariate statistical models that can be applied in determining habitat suitability for plant species.

A multivariate statistical model that can help to typify habitat suitability is the one created by Kleinbaum and Kupper (1978) and called the *all-possible-regressions procedure* (also known as stepwise regression). This method requires fitting every possible regression equation associated with every possible combination of the independent variables. Thus, for *m* independent variables, the number of resulting models will be 2^m-1. Then the equations are grouped in sets involving 1, 2, 3,…, *m* variables, and ordered according some desired criterion (i.e. coefficient of determination, r^2). The models with higher r^2 are grouped again for further examination. The best model is then selected (in terms of R^2 values) from the last group. Regression model equation has the form:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots \beta_m X_m + e$$

where $\boldsymbol{Y}$ is to represent the dependent variable. This equation relates the behavior of the dependent variable $\boldsymbol{Y}$ to a linear function of the set of independent variables $\boldsymbol{X_1, X_2, \ldots X_m}$. The $\boldsymbol{\beta_j}$'s are the parameters that specify the nature of the relationships, and $\boldsymbol{e}$, is the random error term. One application of multiple regression models has been the definition of suitable areas to establish exotic grasses in grazing lands. Many models have been developed to represent biological and ecological processes in plant sciences but, up to date, only one is known for buffelgrass. Ibarra-Flores et al. (1995a) developed a model to predict buffelgrass survival in different sites. In this model, they related survival regimes for buffelgrass pastures by multivariate statistical analyses using climatic factors and soil characteristics. Considering that establishment and biological development of buffelgrass do not depend only on climatic factors and soil characteristics, this model has some limitations on its predictions. However, it can be improved by including other variables such as topographic factors, plant attributes, and management practices, in order to obtain better results.

The Plant

Taxonomic characteristics

Buffelgrass (*Cenchrus ciliaris* L.) is a perennial warm-season bunchgrass, with culms erect to geniculate spreading, 50-100 cm tall; sheaths laterally compressed and keeled, glabrate or sparsely pilose with long slender hairs; hairs near collar usually sparse, white, and straight, reaching 5 mm with enlarged bases; ligule membranous, cilliated, diminute, 1.3-1.8 mm long; blades glabrate, scabrous, barely asperous, sometimes lightly pilose,

specially on lower surface 16-34 cm long, 7.8-20 mm wide, the midrib prominent. Panicle dense, cilindric and spikelike, 4.5-12.5 cm long, 1.3-1.6 mm wide; raquis flexible, escabrous, with internodes 0.8-1.7 cm wide; spikes barely pubescent, 6.8-9.6 mm long, 2.8-4.5 wide; peduncle diminute, densely pilose, 0.5-1.5 mm long, 1-2 mm wide, bristles erect or disperse, 6-7 mm long, 0.5-0.7 mm wide, long-ciliate, pubescent on the internal margins, connate only at the base or lightly above, antrorsely barbate, very often with plumose tips, external verticil with spines similar to bristles, shorter than the internal spines; 2-4 spikelets per spike, 5.5-6.8 mm long; first glume 2.2-2.9 mm long, 1-1.5 mm wide, thin and membranous, 1-veined; second glume 5-6.1 mm long 5-6 veined; palea partially included, 2.5-5 mm long; fertile floret 5.2-6.6 mm long, 1-1.5 mm wide covering the 3 mm long, turgescent, and ovoid caryopsis (Felger, 2001; Beetle and Johnson, 1991).

This species is native from Africa, Asia, and the Middle East. It predominates on sandy soils and annual precipitation ranges from 200 to 1,200 mm (Cox et al., 1988).

Biology

Buffelgrass is a warm season perennial bunchgrass characterized by purple, gray, or yellowish-brown bristly seedheads with long stems rising from a knotty base. It grows from one to four feet tall and a mass of long and tough roots, which can grow to eight feet deep. Its narrow leaves are light green in color and range from one to four inches in length (Douglas King Co., 1999). This species usually is also named *Pennisetum ciliare* but, according to some plant taxonomists, one can tell the difference between *Cenchrus*

and *Pennisetum*, because the bristles on *Pennisetum* are separate and on *Cenchrus* they are fused. Its seeds are spread by wind and animals. Buffelgrass is similar in appearance to millet; in fact, the genus name *Cenchrus* comes from the Greek word "kegchros" which means millet. Buffelgrass is of high economic value to livestock, especially in Texas for cattle, but is low for wildlife. It withstands heavy grazing and is used for range reseeding, pasture, hay production, revegetation, erosion control, and soil stabilization. It also is fast recovering from drought and heavy grazing (http://www.geocities.com/deeds1980/).

Seed formation is apomictic, asexual; so vast quantities of *C. ciliaris* seeds generate naturally, without pollen transfer. Moreover, the aggressive expansion of *C. ciliaris* rhizomes rapidly forms dense monocultures of newly colonized sites. This, however, means that *C. ciliaris* tends to have limited genetic exchange (Perrott and Chakraborty, 1999).

This highly nutritious grass is considered excellent for pasture in hot, dry areas and is valued for its production of palatable forage and intermittent grazing during droughty periods in the tropics. Yield of some strains also makes it good for forage during the wet seasons. The grass, fed green, turned into silage, or made into hay is said to increase flow of milk in cattle and impart a sleek and glossy appearance (Duke, 1983); per 100 g, the fresh plant is reported to contain on a zero-moisture basis, 11.0 g protein, 2.6 g fat, 73.2 g total carbohydrate, 31.9 g fiber, and 13.2 g ash; per 100 g, hay is reported to contain on a zero-moisture basis 7.4 g protein, 1.7 g fat, 79.2 g total carbohydrate, 35.2 g fiber, and 11.7 g ash (Gohl, 1981).

C. ciliaris is reported to be lactagogue: related species are recorded as being anodyne, diuretic, and emollient, and are folk remedies for kidney pain, tumors, sores and wounds (Duke and Wain, 1981).

Most of the data indicates that post-harvest maturation requires a time of a few weeks to 18 months. Only seed that has been stored for at least 6 months should be sown, however, in Tanzania, 1-month old seed had a 90% germination rate, with the maximum of 92.5% being reached at 18 months. Most seeds germinate within 24 hours (Bogdan, 1977). According to Reed (1976), germination is improved up to 70% by storing seed up to 2 years under dry conditions. Duke (1981) reports that annual productivity for buffelgrass ranges from 1 to 26 MT/ha, but some strains give as high as 37 MT/ha, depending on the conditions. Total annual yields of green fodder vary from 34–56 MT/ha in three to four cuttings.

Buffelgrass is reported to tolerate disease, drought, fire, fungus, grazing, heavy soil, insects, limestone, low pH, and sand (Duke, 1978). However, due to its apomictic seed formation, *C. ciliaris* presents a lack of genetic diversity and it has been speculated that may be susceptible to the effects of some natural enemies (Morisawa, 2000). Thus, the following fungi have been reported by Duke (1983) to attack buffelgrass: *Beniowskia sphaeroides, Cerebella andropogonis, C. cenchroides, Claviceps* sp., *Fusarium heterosporum, Puccinia cenchri* var. *africana, Sorosporium cenchri, S. dubiosum, S. penniseti, Sphacelotheca panjabensis, Tolyposporium cenchri, Uredo cenchricola, Ustilago penniseti.* It is also parasitized by *Striga hermonthica.* In addition, the same author has isolated the following nematodes from buffelgrass: *Criconemoides* sp.,

Helicotylenchus cavenessi, H. dihystera, H. microcephalus, H. pseudorobustus, Peltamigratus nigeriensis, Pratylenchus sp., and *Scutellonema clathricaudatum*. A sucker insect named “mosca pinta” or spittlebug (*Aeneolamia albofasciata* Lall.), can also be cited as a natural enemy of buffelgrass (Miranda-Zarazúa and Ramirez-Moreno, 1995; Martin-Rivera et al., 1996).

Ecology

Buffelgrass is a drought-tolerant, warm-season, perennial forage grass, which is grown throughout many arid and semi-arid regions in the world (Jessup et al., 1999). It is very successful in regions where annual precipitation ranges between 250-750 mm (and as high as 2670 mm) and the minimum winter temperature does not fall below 5^{o}C (41^{o}F). It thrives from sea level to 2000 m, in dry sandy regions, on shallow soils of marginal fertility. Such characteristics extend its production range and increase its value for pasturage. It responds to rainfall by developing brighter color and an increase in growth rate, giving highest yields when rain is plentiful. In Australia, buffelgrass withstood 5-day flooding without any loss of plants, and 20-day flooding with losses of 20–85% (Anderson, 1970).

In its introduced range, buffelgrass is most abundantly found in the plains of the Sonoran Desert, where it is commonly found along rocky hillsides in desertscrub and xeroriparian communities (Miller et al., 1999). The biology of this grass ideally suits it for dry communities and colonization of other disturbed sites, especially following fires.

Humans have spread *C. ciliaris* for livestock forage in pastures, but its biological characteristics contribute to copious natural dispersal (Trix, 2000).

The dense growth of this rhizomatous grass and the narrow leaves that dry out promptly after the rainy season provides high surface area on which wildfires spread easily and further benefit this fire-adapted species. After a fire, fire-tolerant perennial grasses benefit from the increase in solar penetration to the ground surface (Trix, 2000). The light provides energy for photosynthesis in emerging leaves and this environment increases the plant's nitrogen use efficiency (Ojima, et al., 1994).

It is important to mention that *C. ciliaris* exudes phytotoxic chemicals that inhibit germination and growth of some other plants (Nurdin and Fulbright, 1990). Consequently, re-colonization by extirpated native plants could be difficult once *C. ciliaris* has established.

Buffelgrass is reported to tolerate a pH of 5.5–8.2 (Duke, 1978; Duke 1979).

METHODS

The Study Area

The area selected for this study comprises the central region of Sonora, Mexico, between 28^0 30' and 29^0 30' North latitudes and between the coastal zone and the Sonora-Chihuahua states boundary (Figure 1).

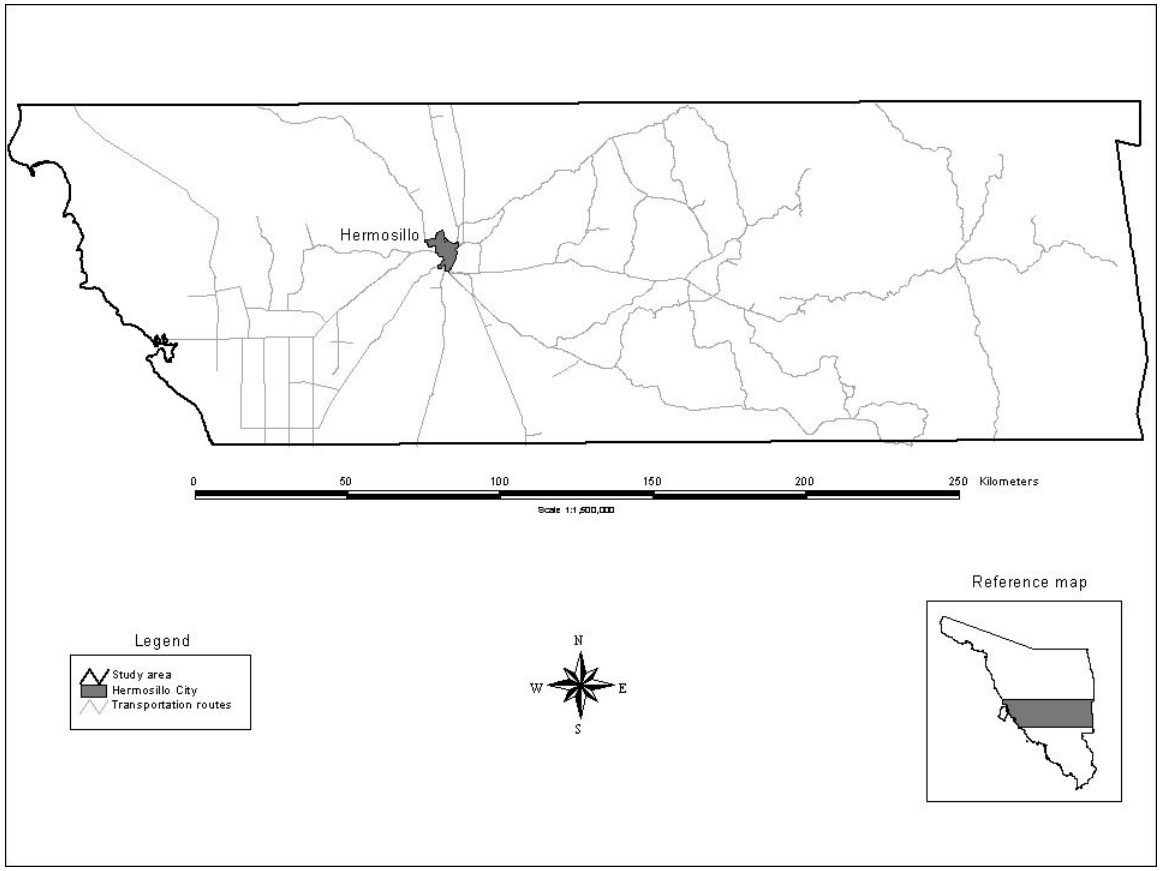

Figure 1. Study Area Location

Mean annual precipitation in this area ranges from less than 300 mm to over 900 mm, while mean annual temperature range from 21^oC to 25^oC (Figures 2 and 3).

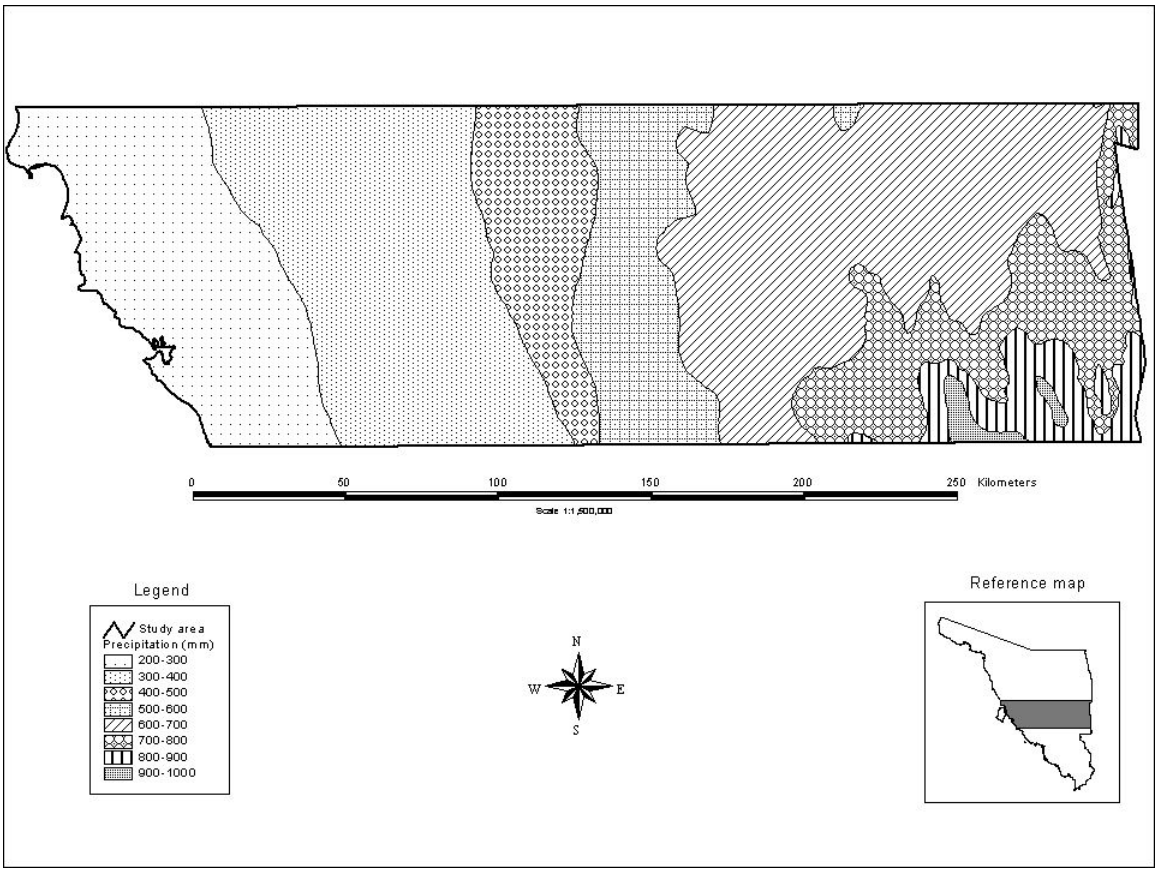

Figure 2. Precipitation in the Study Area

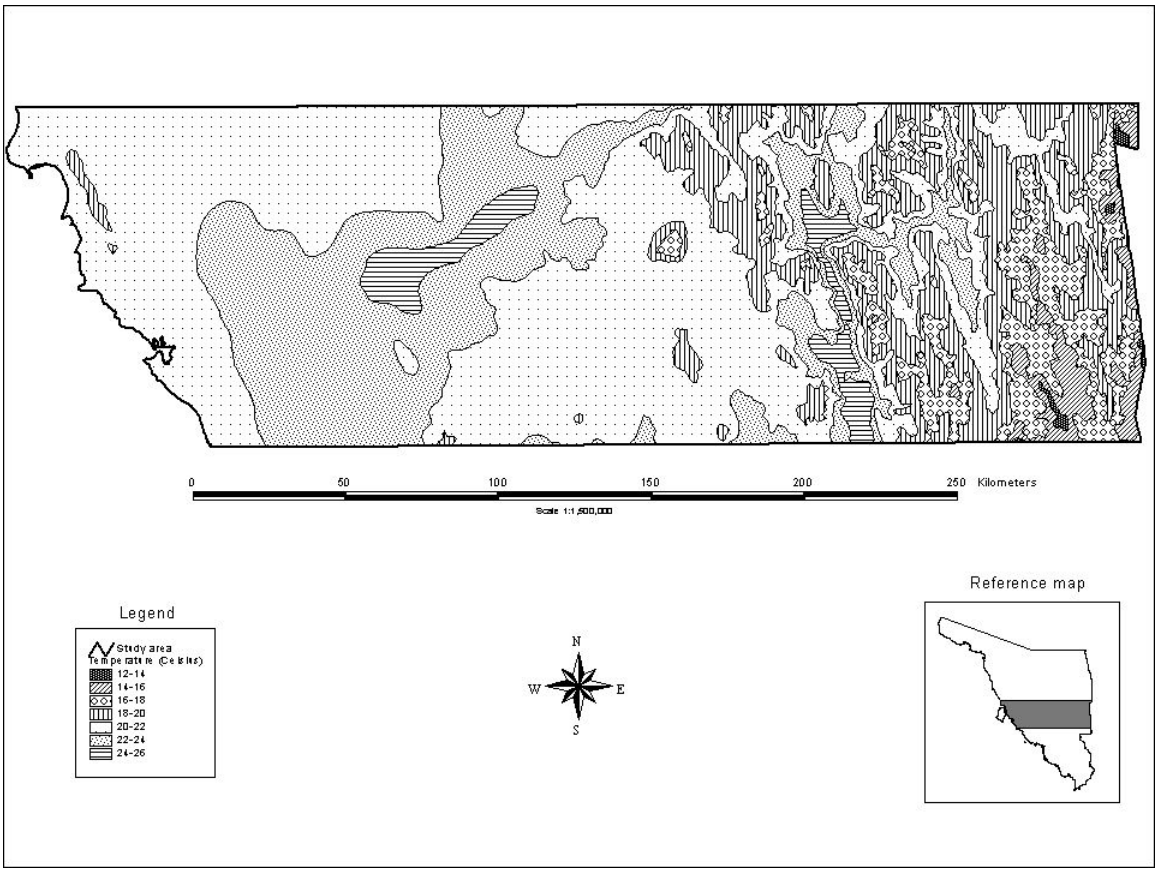

Figure 3. Isotherms in the Study Area

According to the soil classification system created by FAO, there are 10 different soil types in the study area: cambisols, feozems, fluvisols, litosols, luvisols, regosols, rendzinas, solonchaks, xerosols, and yermosols (Figure 4).

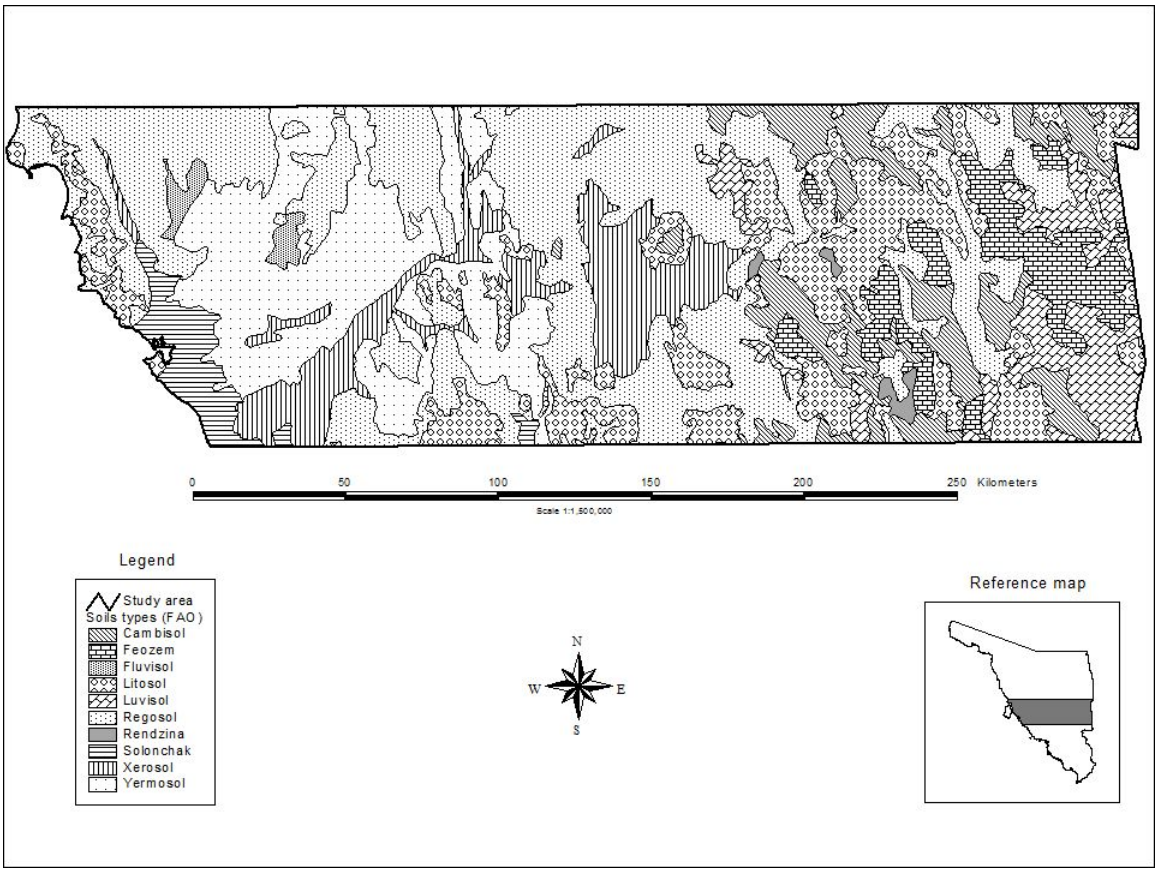

Figure 4. Distribution of Soil types in the Study Area

The characteristics of soils types are described on Table 1.

Table 1. General description of FAO soil types found in the study area (Buol et al., 1991; Fitzpatrick, 1985).

SOIL No.	SOIL TYPE	SOIL CHARACTERISTICS
1	Cambisols	Soils with light color; they usually change in structure and consistency due to *in situ* intemperization.
2	Feozems	Soils with black, lixiviated surface.
3	Fluvisols	Soils developed from alluvial deposits, having only one diagnostic horizon within a depth of 125 cm. This horizon can be an "A" or "H" horizon.
4	Litosols	Shallow soils, over hard rock.
5	Luvisols	Soils with clayed horizons and median to high content of bases (NH4OAc)
6	Regosols	Thin soils over non consolidated materials, without diagnostic

		horizons.
7	Rendzinas	Thin soils over calcic material (over 40% calcium carbonate).
8	Solonchaks	Soils with high accumulation of soluble salts.
9	Xerosols	Dry soils from semiarid regions.
10	Yermosols	Desertic soils.

The physiography of the study area is defined by 14 categories, according to INEGI (Instituto Nacional de Estadística Geografía e Informática): Bajadas with rolling hills, rolling hills, complex rolling hills, complex rolling hills with cañadas, alluvial plains, saline deltaic plains, high sierras with cañadas, steep sierras, steep complex sierras, steep complex sierras with rolling hills, folded sierras, alluvial intermountain valleys, intermountain valleys, and intermountain valleys with rolling hills (Figure 5).

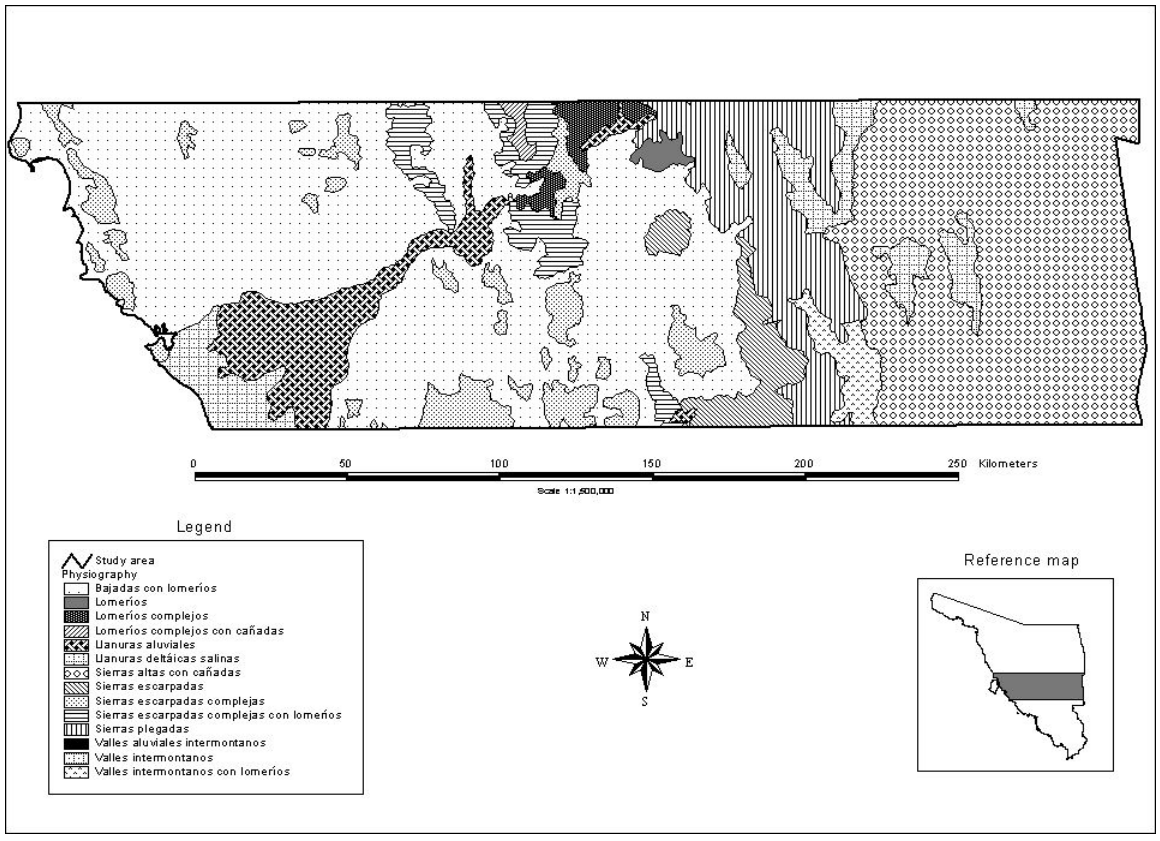

Figure 5. Physiography in the Study Area

A general description for physiography is given on Table 2.

Table 2. Physiographic classes for the study area (INEGI, 1981).

CLASS No.	CLASSES	CLASSES CHARACTERISTICS
1	Bajadas con lomeríos	Alluvial fans with rolling hills
2	Lomeríos	Rolling hills
3	Lomeríos complejos	Complex rolling hills
4	Lomeríos complejos con cañadas	Complex rolling hills with canyons
5	Llanuras aluviales	Alluvial plains
6	Llanuras deltáicas salinas	Saline deltaic plains
7	Sierras altas con cañadas	High sierras with canyons
8	Sierras escarpadas	Steep sierras
9	Sierras escarpadas complejas	Steep and complex sierras
10	Sierras escarpadas complejas con lomeríos	Steep and complex sierras with canyons
11	Sierras plegadas	Folded sierras
12	Valles aluviales intermontanos	Intermountain alluvial valleys
13	Valles intermontanos	Intermountain valleys
14	Valles intermontanos con lomeríos	Intermountain valleys with rolling hills

If we follow the classification of Brown and Lowe (1994), the plant communities of the study area include the Central Gulf Coast Subdivision, the Lower Colorado River Subdivision, the Plains of Sonora Subdivision, the Semidesert Grassland, the Sinaloan Thornscrub, the Sinaloan Deciduous Forest, the Madrean Evergreen Woodland, and the Petran Montane Conifer Forest (Figure 6).

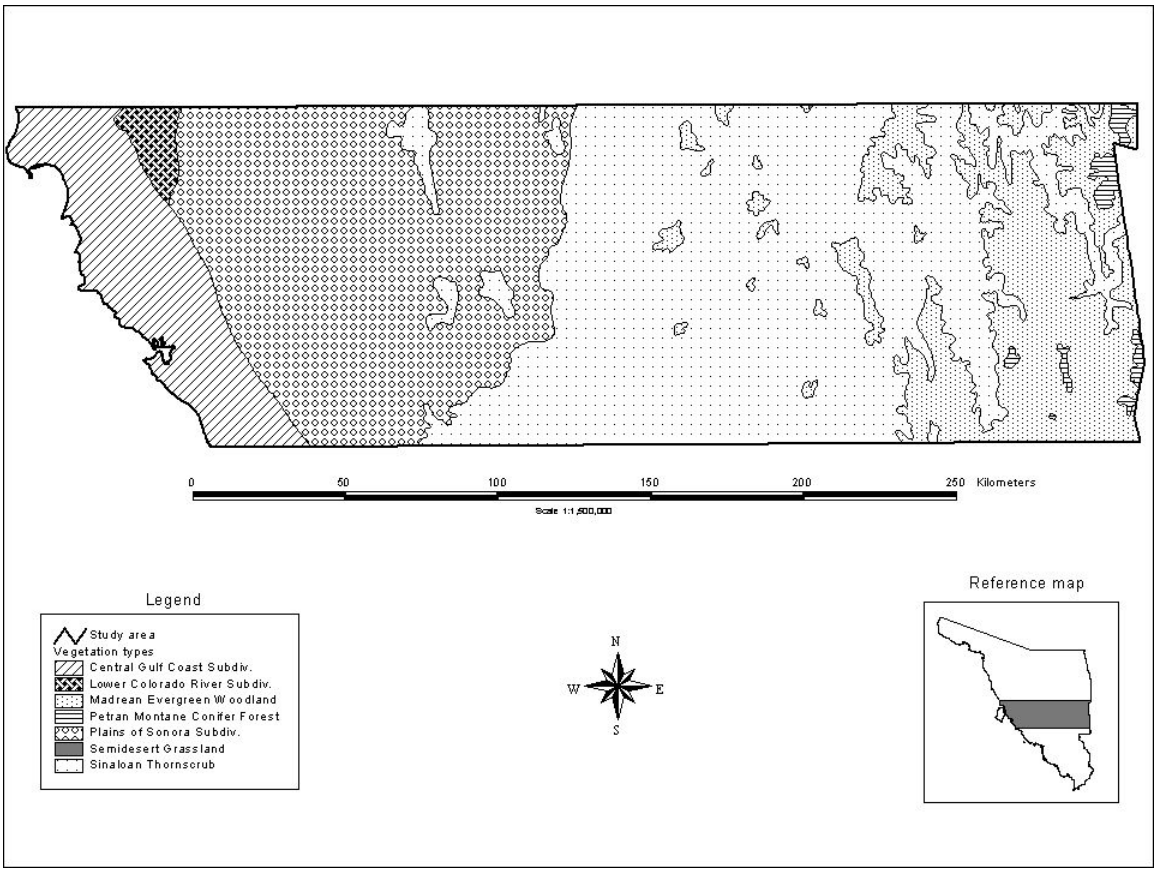

Figure 6. Vegetation Types in the Study Area

The climate in the study area is very heterogeneous with hot and dry categories in the coasts and deserts to very wet and cold in the sierras. Thus, there are 15 different climatic categories covering the entire area (Figure 7).

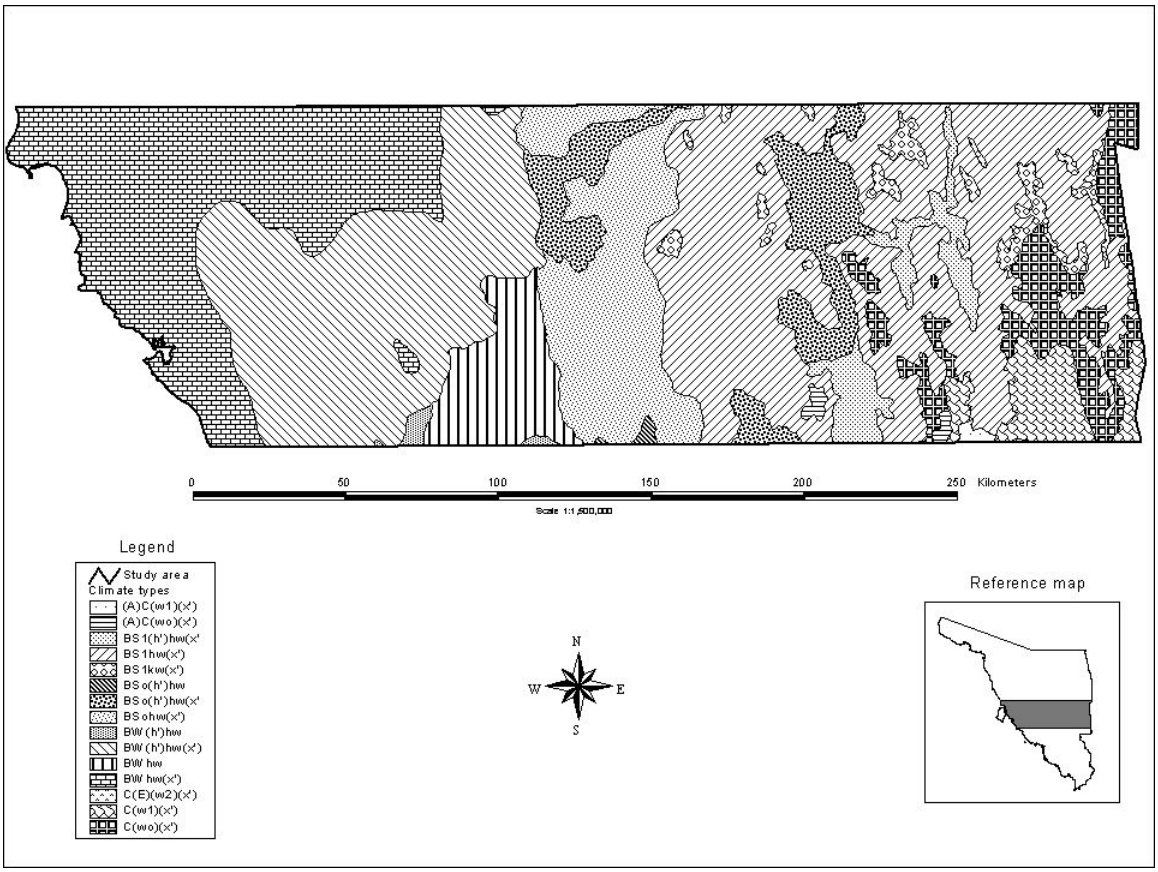

Figure 7. Climate Types in the Study Area

The climate system followed is the Köppen system modified for Mexican conditions by García, E. (1981). Climatic types are described on Table 3.

Table 3. Climate types for the study area.

TYPE No.	CLIMATE TYPE	CLIMATE CHARACTERISTICS
1	(A)C(wo)(x')	Semi-hot subhumid with summer rains; relation P/T < 43.2; percentage of winter rains > 10.2 with respect to the annual.
2	(A)C(w1)(x')	Semi-hot subhumid with summer rains; relation P/T between 43.2 and 55.0; percentage of winter rains > 10.2 with respect to the annual.
3	BSohw(x')	Dry or steparian; relation P/T < 22.9; semi-hot with fresh winter and summer rains; percentage of winter rains > 10.2 with respect to the annual.
4	BSo(h')hw	Dry or steparian; relation P/T < 22.9; hot with summer rains; percentage of winter rains between 5.0 and 10.2 with respect to the annual.
5	BSo(h')hw(x')	Dry or steparian; relation P/T < 22.9; hot with summer rains; percentage of winter rains > 10.2 with respect to the annual
6	BS1hw(x')	Dry or steparian; relation P/T > 22.9; semi-hot with fresh winter and summer rains; percentage of winter rains > 10.2 with respect to the annual.
7	BS1(h')hw(x')	Dry or steparian; relation P/T > 22.9; hot with summer rains; percentage of winter rains > 10.2 with respect to the annual.
8	BS1kw(x')	Dry or steparian; relation P/T > 22.9; temperate with hot summer and summer rains; percentage of winter rains > 10.2 with respect to the annual.
9	BWhw	Very dry or desertic; semi-hot with fresh winter and summer rains; percentage of winter rains between 5.0 and 10.2 with respect to the annual.
10	BWhw(x')	Very dry or desertic; semi-hot with fresh winter and summer rains; percentage of winter rains > 10.2 with respect to the annual.
11	BW(h')hw	Very dry or desertic; hot with summer rains; percentage of winter rains between 5.0 and 10.2 with respect to the annual.
12	BW(h')hw(x')	Very dry or desertic; hot with summer rains; percentage of winter rains > 10.2 with respect to the annual.
13	C(wo)(x')	Temperate subhumid with summer rains; relation P/T < 43.2; percentage of winter rains > 10.2 with respect to the annual.
14	C(w1)(x')	Temperate subhumid with summer rains; relation P/T between 43.2 and 55.0; percentage of winter rains > 10.2 with respect to the annual.
15	C(E)(w2)(x')	Semi-cold subhumid with summer rains; percentage of winter rains > 10.2 with respect to the annual.

Determination of Factors that Affect Plant Production in Buffelgrass Pastures

Above ground annual plant biomass production was considered as an indicator for successfulness in buffelgrass pastures. In order to determine the factors that affect production in buffelgrass pastures, it is necessary to measure annual plant production per unit area and relate that production to different factors to know which of them define production rates.

In determining net production of buffelgrass plants, the best way is to clip the plants and then dry and weigh the harvested material; however, in situations where annual produced biomass has been removed for any cause (i.e. grazing), it is difficult to obtain that measurement and it is necessary to look for other methods, like simulation models, to have production values.

In Sonora, Mexico, it is a common practice that ranchers let the animals to use the pastures over the entire year so it is difficult to find pastures in appropriate conditions to measure above ground annual plant biomass production by direct methods. Thus, it was imperative for this study to create a simulation model to estimate plant production and be able to determine the factors that affect biomass production in buffelgrass pastures.

Eight ranches with different geographic locations (Figure 8), environmental situations, and management conditions were sampled as preliminary study sites to measure and model plant production. The resulting model was used to estimate plant production in the 37 sampling sites of the study areas.

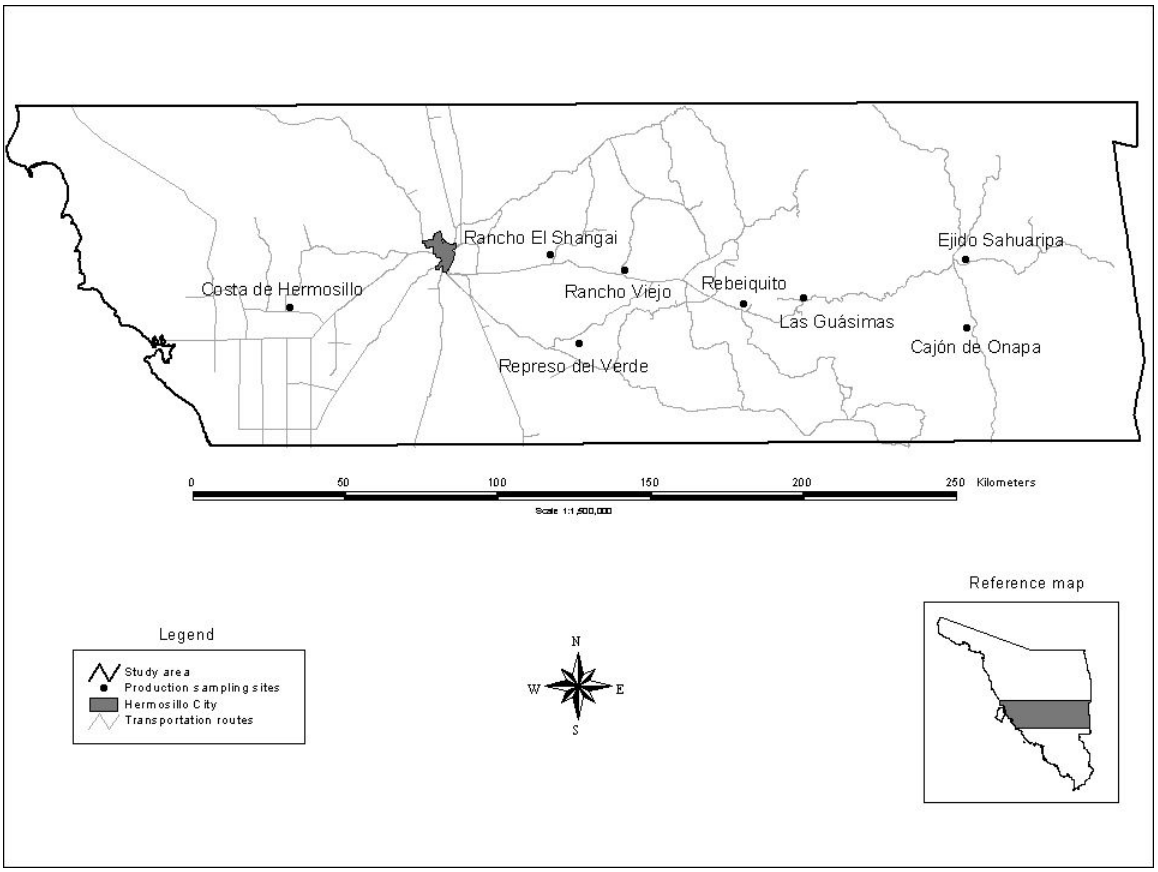

Figure 8. Sampling sites for modeling aboveground biomass production

In each of these sites, twenty-five plants were clipped. Before a plant was harvested, its height, herbage cover diameter and basal diameter were measured. Diameter measurements were then converted to area by applying the equation used to calculate the area of a circle (Πr^2), assuming that buffelgrass plants have a circular shape when seen from a vertical projection. Once measurements were recorded, above ground biomass was clipped at 2-4 cm from the ground. The removed material was stored in paper bags, taken to the laboratory, oven dried and weighed. The resulting values for production were

normalized by removing all extreme values or outliers. Finally, average production per plant per site was computed.

Ecological factors and soil characteristics were recorded and computed as independent variables. Data for these variables were collected directly in the field, especially those related to soil characteristics and plant attributes. Soil samples were collected by taking one sample per soil type in each one of the eight study sites. These samples were obtained at 0-30 cm depth and then dried, passed through a 2 mm sieve, and taken to laboratory for physical and chemical analyses. Soil characteristics incorporated in this research include:

Soil Nitrogen Content. Soil nitrogen content was determined using the method called Nitrate Determination with Phenoldisulphonic Acid as described by Richards (1980) and Bremner and Mulvaney (1982).

Soil Phosphorus Content. According Smith (1974) and Fitzpatrick (1996), when phosphorus content in plants is low, growth is detained; maturity delayed, and roots undersized. Available phosphate was determined by the method of Dickman and Bray, as described by Chapman and Pratt (1991) and Olsen and Sommers (1982).

Cation Exchange Capacity (CEC). The cation exchange capacity is a very important indicator of the aptitude that a soil has to retain cations, to know its general chemical reactivity (Buol, et al., 1991). When there exist low content of cations in the soil, an intense lixiviation criterion can be assumed (Fitzpatrick, 1985; Fitzpatrick, 1996). CEC was measured following the methodology described by Richards (1980).

Exchangeable Cations. Four exchangeable cations were determined: Calcium, Magnesium, Sodium and Potassium. Percent of exchangeable cations can be important to define some of the soil characteristics such as alkalinity. For example, a soil with <20% exchangeable sodium is considered slightly alkaline; a moderately alkaline soil will have 20-50% exchangeable sodium, and a soil with over 50% exchangeable sodium, will be considered as strongly alkaline. Calcium and magnesium were determined by titrating with etilendiamin-tetraacetatum as described by Richards (1980); sodium and potassium were measured by flammometry (Richards, 1980).

Percent of Exchangeable Cations. Percent of exchangeable cations can be important to define some of the soil characteristics such as alkalinity. For example, a soil with <20% exchangeable sodium is considered slightly alkaline; a moderately alkaline soil will have 20-50% exchangeable sodium, and a soil with over 50% exchangeable sodium, will be considered as strongly alkaline. Percent of exchangeable cations was measured following the methodology described by Richards (1980).

Soil Percent Saturation. It refers to the amount of water that a given soil can retain against the force of gravity. The amount of water remaining after a soil over-saturated is freely drained, would define the 100% saturation for that soil (Brooks, et al., 1993). This soil characteristic was determined by recording the water volume that is added to a soil sample, as described by Richards (1980).

Soil pH. This soil characteristic determines the rate of acidity or alkalinity. Normally, soil pH varies between 3 and 9 and the two main factors that control it are the organic matter and the amount and type of cations. The soil pH tends to be correlated to precipitation:

the higher the precipitation rate, the lower the soil pH due to the scarcity of cations (Fitzpatrick, 1985; Fitzpatrick, 1996). In this study, soil pH was measured for a soil solution ratio of 1:2 using a potentiometer with glass electrode as described by Richards (1980) and McLean (1982).

Soil Electrical Conductivity. The electrical conductivity is commonly used to determine the total concentration of ionized components in soil solutions. It is closely related to exchangeable cations and correlated to total dissolved solids (Buol et al, 1991; Soil Survey Division Staff, 1993). Soil electrical conductivity (mmohs/cm) was measured by the Wheatstone Bridge method (Richards, 1980).

Soil Organic Matter. Soil organic matter was estimated by using a modified version of the Walkley-Black method described by Richards (1980).

Soil Texture. This soil property helps to determine the supplying facility of nutrients, water, and air. There is a high correlation between soil texture and most of the properties of soils (Gavande, 1976). Soil texture analyses (percent of sand, silt, and clay) were done by the hydrometer method (Gavande, 1976).

Statistical Analysis

Correlation analyses were performed to determine the type and intensity of relationships existing between buffelgrass annual production and plant attributes, soil characteristics and environmental factors. Variables with significant correlation to buffelgrass annual production would indicate the factors that affect forage production.

After that, stepwise regression computations (according Kleinbaum and Kupper,1978) including production and independent variables were performed to create simulation models which, after validation, would be applied to predict production in determined sites in central Sonora, Mexico.

In order to validate the model equation, a new site within the study area was sampled. The geographic location of this site has the following UTM coordinates: X = 595,400 and Y = 3,234,565. In this site, as in the other study sites, soil sampling was made to know the characteristics of the soil. Also, 30 buffelgrass plants were measured at their base to record the diameter and determine their basal area; after this operation, the plants were clipped at 4.0 cm from the base. The harvested biomass was oven dried and weighted to determine production. Then, the observed production values were compared to the values resulting from equation computation realizing a means comparison using the Student's *t* and DHS statistical tests (Sall and Lehman, 1996) using the JMP IN program version 3.2 (SAS Institute Inc.).

Modeling Suitability for Buffelgrass Pastures

A model was developed considering the Pasture Condition Index (PCI) as an expression of suitability for buffelgrass. This dependent variable corresponds to a modified version of the *Quantitative Condition Index* created by McIvor et al. (1995) to be applied in this study. This index is calculated using the following equation:

$$PCI = (VC + SC + PMI) / 3$$

Where *VC* corresponds to the Vegetation Component, *SC* refers to the Soil Component, and *PMI* corresponds to the Pasture Management Index. As seen in Figure 9, it takes a number of steps to compute the pasture condition index, given the calculation routines for the index components. Units and weights for the elements shown in the figure are given and described in the corresponding paragraphs of the text.

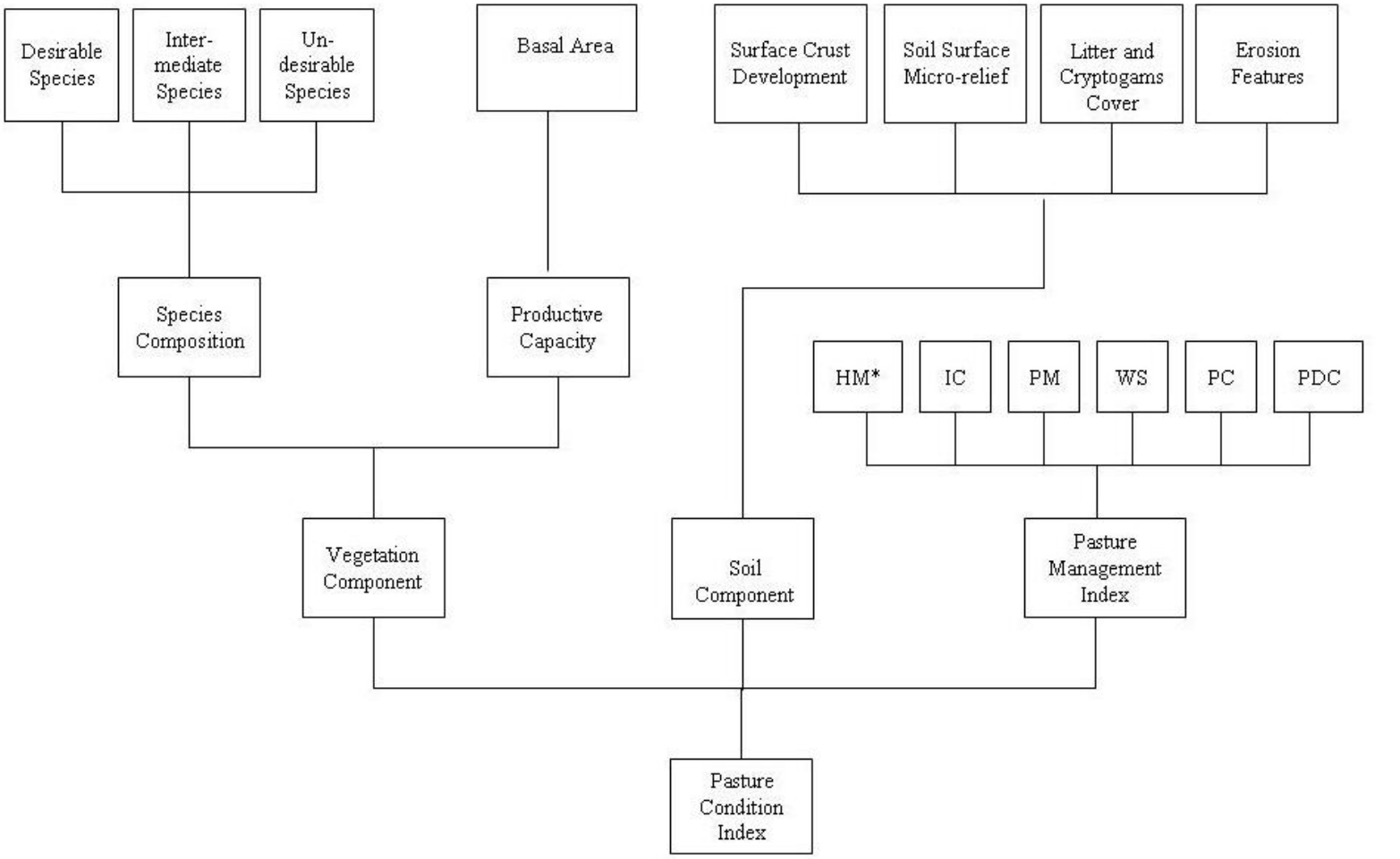

Figure 9. Diagram of parameters integration to compute the Pasture Condition Index.

Vegetation Component

The vegetation component was determined by averaging the values of pasture species composition and relative yield. The calculation of these two plant attributes is described in the next paragraphs.

Species Composition: The contribution of species composition to the vegetation component is based on the desirability of the species present at a given site to grazing animals. Thus, desirable species are plant species with higher nutritional value, the most palatable and preferred by grazers. Intermediate species are less preferred for grazing and have lower nutritional value for animal production. Undesirable species are represented by poisonous plants and are not consumed by grazers because the lack of palatability (Aguirre and Huss, 1987). There are range condition guides created by the Mexican federal government agency COTECOCA (an agency devoted to establish the carrying capacity of rangelands in Mexico) to provide range managers with scientific names and desirability categories of plant species for all the rangelands of the country (Aguirre-Murrieta et al. 1973).

Species composition for a given pasture can be estimated by using the relative density, frequency, and/or dominance of the species present in the pasture. Also, production and ecological importance values of the species can be used to determine species composition. In this study, species composition (SC) was assessed considering their ecological importance value (IV), based on their relative densities and frequencies. By using COTECOCA's range condition guides, the species were grouped into desirable

(D), intermediate (I), and undesirable (U) species. The IV of the desirable species (IVD) was multiplied by 1.0, the IV of the intermediate species (IVI) by 0.5, and the IV of undesirable (IVU) species by 0. The products were summed and then divided by 100 to give a botanical composition contribution with values between 0 and 1.0.

$$SC = \frac{IVD + (IVI * 0.5)}{100}$$

A number of 37 ranches were selected as study sites to gather data (Figure 10).

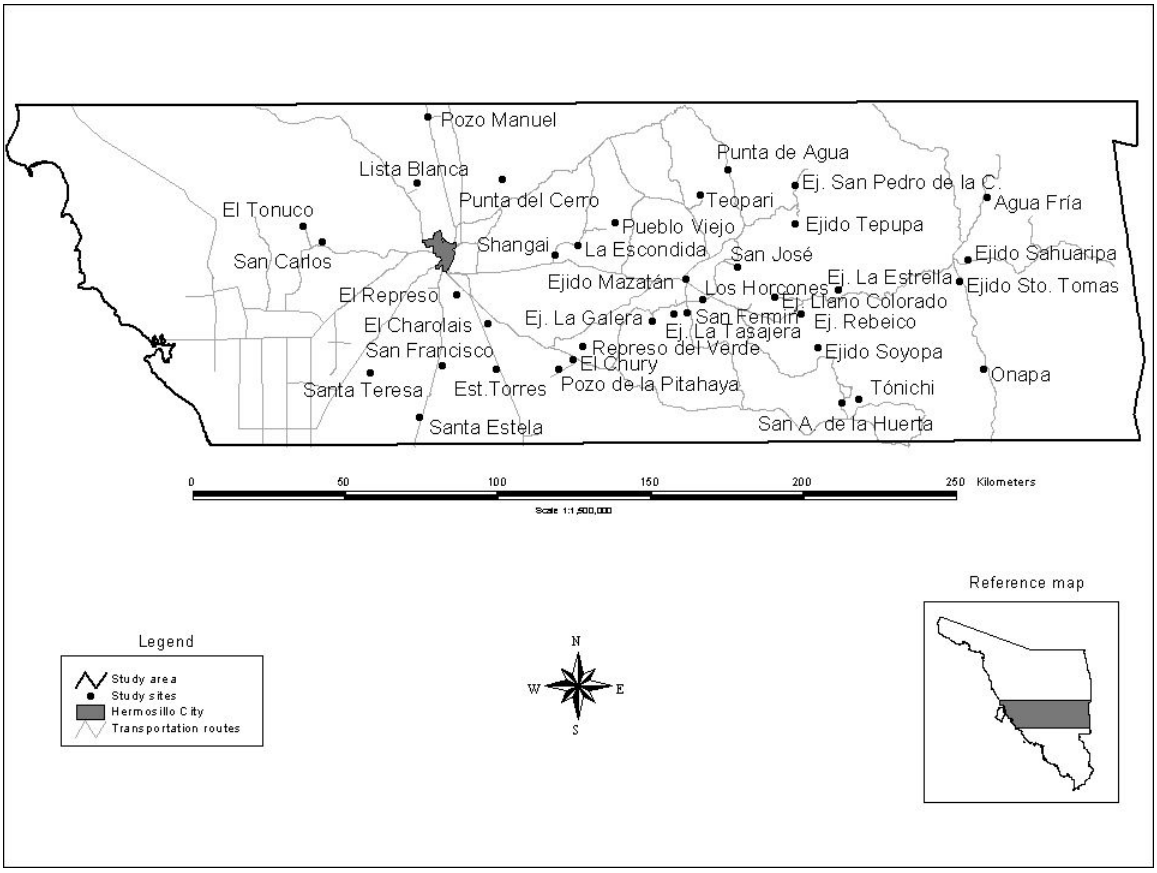

Figure 10. Geographic Distribution of Study Sites in the Study Area

Table 4 shows the UTM coordinates of the study sites.

Table 4. Geographic location of study sites.

No.	SITE	X COORDINATE	Y COORDINATE
1	SANTA TERESA	481411	3176362
2	SAN FRANCISCO	505078	3178674
3	SANTA ESTELA	497376	3161909
4	EL TONUCO	459441	3224278
5	SAN CARLOS	465894	3219179
6	PUNTA DEL CERRO	524445	3239522
7	POZO MANUEL	500356	3260122
8	EL REPRESO	509615	3201998
9	E. ESTACION TORRES	522575	3177495
10	LISTA BLANCA	496600	3238314
11	EL CHAROLAIS	520026	3192372
12	EL POZO DE LA P.	542986	3177479
13	EL CHURY	547936	3180877
14	LA ESCONDIDA	549550	3218146
15	PUEBLO VIEJO	561578	3225554
16	E. TEPUPA	620381	3225043
17	SAN PEDRO CUEVA	620525	3237548
18	E. MAZATAN	584620	3206939
19	E. LA GALERA	573535	3193383
20	E. LA TASAJERA	580884	3195537
21	REPRESO DEL VERDE	550961	3185008
22	AGUA FRIA	683262	3233656
23	E. SAHUARIPA	676787	3213176
24	ONAPA	682023	3177603
25	PUNTA DE AGUA	598325	3242728
26	EL SHANGAI	541988	3214755
27	EL TEOPARI	589308	3234546
28	E. REBEICO	622445	3195681
29	LLANO COLORADO	613839	3201318
30	SAN FERMIN	585090	3196029
31	SAN JOSE	601472	3210916
32	S. ANTONIO HUERTA	635641	3166720
33	C. TONICHI	641347	3167896
34	SANTO TOMAS	674244	3206358
35	E. LA ESTRELLA	634595	3203425
36	E. SOYOPA	627863	3184880
37	LOS HORCONES	590223	3200592

After scouting a study site, a squared plot of 1 hectare with buffelgrass was established as a representative area in which to collect data. Selected area was georeferenced using a Global Positioning System (GPS) receiver recording the geographic position (in degrees) and elevation above sea level (in meters). Slope and aspect were also determined for the plot using a Brunton compass. Given the average crown size of buffelgrass plants and following the criterion used by Bonham (1989), square quadrats 1-meter per side, were utilized as sampling units. The number of quadrats to measure buffelgrass ecological attributes was determined using the equation:

$$n = \frac{t^2 \, s^2}{E^2}$$

where n = sample size; t = the "t" statistic; s = the variance; and E = the specified level of precision, which is the sampling error (Brooks et al., 1993). The resulting value for n was 30 at a $p = 0.01$ significance level, with $E = 0.01$.

Thus, thirty 1 m^2 quadrats were sampled in each plot along three parallel transects, 30 m apart. Transects followed a perpendicular direction to the slope, presenting 10 quadrats per transect with a separation of 10 m between them (Figure 11).

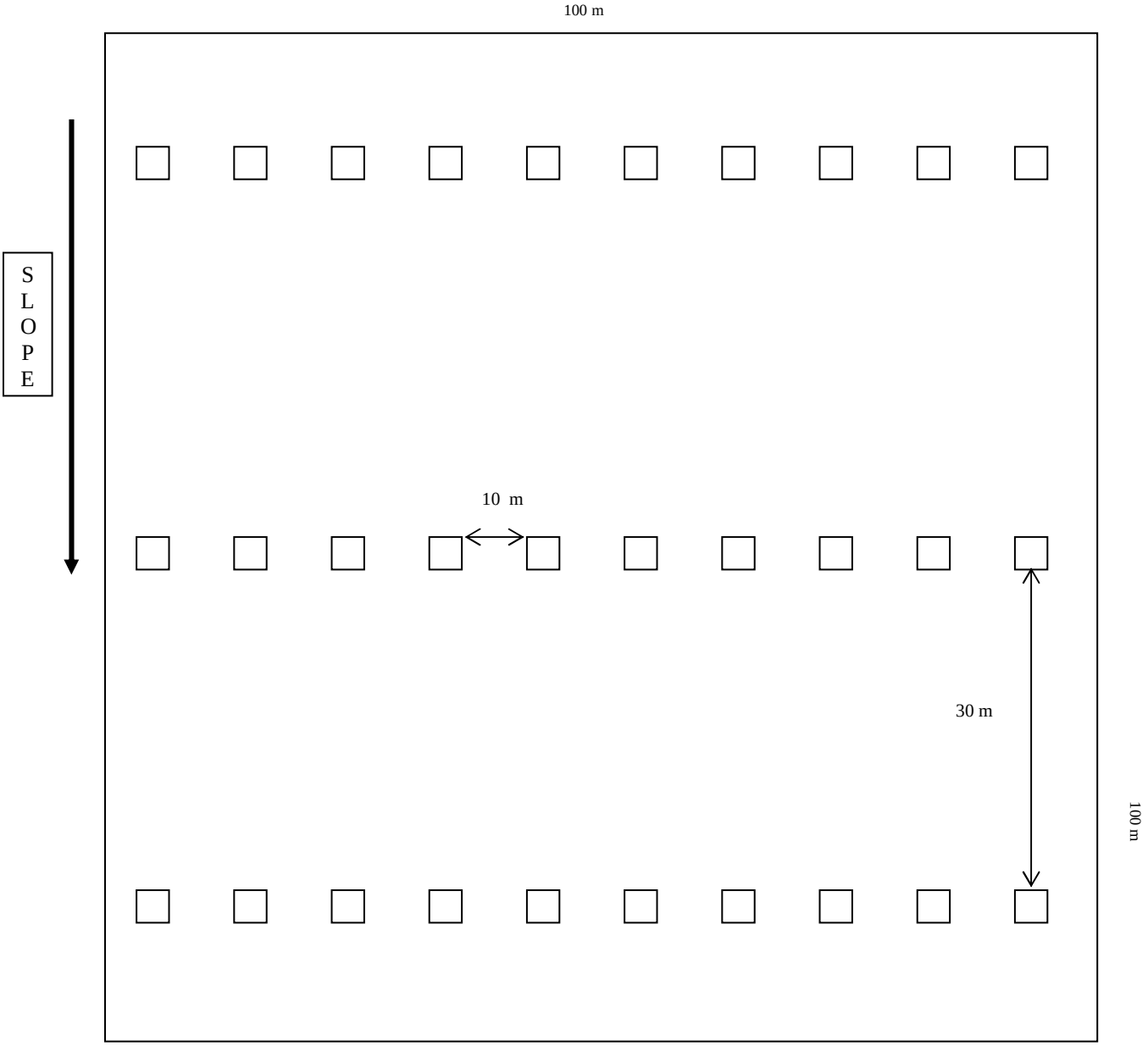

Figure 11. Distribution of sampling units within the study plots

In each 1 m^2 quadrat, species density was determined by counting the number of individuals inside the quadrat, and species cover (%) was estimated by considering the area of the quadrat occupied by each species. The basal diameter of every buffelgrass plant was measured and used to compute basal area according to the equation utilized to calculate the area of a circle (Πr^2); thus, the diameter measurements were divided by 2 to obtain the radius, the results squared and then multiplied by 3.1416. Only buffelgrass plants with more than 50% foliage cover or basal areas inside the quadrat were considered for sampling. At the same time, density and cover were recorded for other perennial species present in the quadrat. In addition, some soil and microenvironmental characteristics were recorded in the 1 m^2 quadrats as explained below; these included: soil surface micro relief, soil erosion features, surface crust development, litter and cryptogam cover, and percent of gravel or stone present within the quadrat. A field data sheet form is shown on Figure 12.

FIELD DATA FORM

RANCH_____ COUNTY_____ AGE ____.
AREA_____LOCATION:_____LAT_____LO___ ___ ALTITUDE_____SLOPE_____.
EXPOSITION _____ TRANSECT_____ SOIL SAMPLE_____DATE_____ .

No	SP	D	C	DC	MR	I	S	Cr	ER	BS

DC – Loose, Soft, Firm, Crusted **MR** – Smooth, Slight, Strong **I** – Loose litter (0.5), Incorporated (1.0)
S – Litter transp. (0.5), Local (1.0) **Cr** – Cryptogams (0-5) **ER** – Rills (0.1), flow lines (0.05)

Figure 12. Paper sheet used to record field data.

Above Ground Annual Net Production: In determining net production of buffelgrass plants in the study sites, the model obtained in the previous section was used, relating ecological data for each study site with basal diameter measured for buffelgrass plants included in the sampled quadrats to estimate aboveground biomass.

Soil Component

The soil component value (0 to 1.0) results from adding the values for surface crust development (maximum = 0.2), micro-relief of the soil surface (maximum = 0.1), litter and cryptogamic cover (maximum = 0.2), and erosion features (maximum = 0.5).

Surface Crust Development

A soil with a hard crusted surface will have lower infiltration of water than soils with a loose or friable surface (McIvor et al., 1995). Taking the study done by McIvor et al. (1995) as a reference, in this experiment soil surface crust development was visually estimated for each of the thirty sampling plots distributed along transects established in the study sites. Four categories were considered for surface crust development:

Loose: loose deposit of soil on the surface

Soft: surface stable but friable

Firm: surface hard but not crusted

Crusted: surface crusted with evidence of dispersed clay

The contribution of surface crust development (SCD) to the soil component in the 30 sampling plots of the study sites, was calculated by multiplying the proportion of the 30

plots with loose (Ls) and soft (Sf) by 0.2, the proportion with firm (Fm) by 0.1, and the proportion with crusted (Cr) by 0 and summing the products:

$$SCD = (\%Ls * 0.2) + (\%Sf * 0.2) + (\%Fm * 0.1) + (\%Cr * 0)$$

Soil Surface Micro-Relief

Soil roughness is positively related to water retention and infiltration, given the fact that in rough surfaces more water is held compared to smooth surfaces where water is rapidly shed. Rough surfaces may also provide more suitable germination sites (McIvor et al., 1995). In this study, soil surface micro-relief was visually estimated on each sampling plot. Three categories were recognized and given the following values: smooth (0), slight (0.05), and strong micro-relief development (0.1). The contribution of the soil surface micro-relief to the soil component was calculated by following the same mathematical operations used for surface crust development:

$$MR = (Sm * 0) + (Sl * 0.5) + (Sr * 0.1)$$

where: *MR* = Soil Surface Micro-Relief

Sm = Proportion of the sampling plots with smooth micro relief

Sl = Proportion of the sampling plots with slight micro relief

Sr = Proportion of the sampling plots with strong micro relief

Litter and Cryptogam Cover

Surface litter provides habitat and a food source for microorganisms, mesofauna and small animals, which can improve the physical condition of the soil surface. In combination with cryptogam cover, litter protects the soil surface from rain drop impact and slows the flow of water over the surface allowing more time for infiltration; it also provides soil nutrients when decomposed by soil micro-organisms (McIvor et al., 1995). Litter and cryptogam covers were visually estimated for the sampling plots. The proportion of the soil surface covered by litter was estimated by considering whether the litter is loose on the surface or partially incorporated, and the source (local or transported litter). These observations were combined to estimate the litter amount using the equation:

$$L = \frac{I(\%\,cover)S}{500}$$

where I = 0.5 for loose litter and 1.0 for partially incorporated and S = 0.5 for litter transported from surrounding areas and 1.0 for locally deposited litter (McIvor et al., 1995).

Cryptogams (algae, fungi, lichens, liverworts, mosses) on bare soil were recorded on a scale from 0 (no cryptogams present) to 5 (strong development). Cryptogam contribution is calculated as the product of the proportion of bare ground and cryptogam rating, and added to the litter value.

$$LCC = L + (B * Cp)$$

where *LCC* = Litter and cryptogam cover

L = Litter cover

B = Proportion of bare ground

Cp = Cryptogam rating

Erosion Features

There exist several soil erosion indicators defined by features that can be evaluated independently. In this study, four erosion features were considered to define the soil component for the sampling plots and their contribution was calculated by starting with a value of 0.5 and subtracting for each feature, as established by McIvor et al. (1995).

1. Rills (subtract 0.1), scarps (subtract 0.1) or flow lines (subtract 0.05) present.
2. Pedestals: Four categories were considered in this study (after Klemmedson, 1956):
    - Class 1. Plant crown on or near level with the soil surface (subtract 0)
    - Class 2. Plant crown above the soil surface; around part of its perimeter breaking away and tending to occur on the downhill side of the clumps (subtract 0.02)
    - Class 3. Plants on a soil pedestal above the adjacent soil surface on all sides (subtract 0.1)
    - Class 4. Grass on top of the pedestal dead or nearly so; pedestal disintegrating (subtract 0.2)
3. Loose or partially stabilized soil material deposited by water present (subtract 0.05)

4. The proportion of the area where the topsoil has apparently been removed by sheet erosion is estimated (subtract % sheet eroded/200).

Pasture Management Index (PMI).

The management of grazing lands is an important factor that affects the trend in health condition of the system and rates of forage production. For this reason it is imperative to have, at least, an approximate estimation of the management activities to make decisions about future management. However, there are no methods to qualitatively and quantitatively measure this factor. Thus, for this study, I developed a Pasture Management Index with emphasis on factors that influence buffelgrass annual production.

This index has values ranging from 0 to 1.0, resulting from the summation of values assigned to different activities developed in the pasture; the criteria to give a weighted value to those activities, was based on my experience and the importance the ranchers give to them:

Herd management . . . . . .0 - 0.2

Infrastructure condition . . . . . .0 - 0.2

Pasture maintenance . . . . . 0 - 0.2

Watering infrastructure . . . . . 0 - 0.2

Pest control (insects, weeds) . . . . . 0 - 0.1

Plant diseases control . . . . . .0 - 0.1

Herd management refers to the activities and criteria the ranchers use to feed the animals in the pasture during a year. These activities and criteria include the grazing systems and stocking rates, basically.

According to Coronado-Quintana (1994), the infrastructure condition is positively related to rangeland condition in Sonoran ranches. This means that with better infrastructure it is possible to have rangelands in better condition than otherwise.

Another very important activity to preserve a pasture in good health condition is the maintenance. Some actions to maintain a pasture in good condition could be the replantation of low-density pastures and improving soil conditions by fertilization and cultivation.

Water is probably the most important component in the well functioning of the pastures. Thus, ranchers and range managers have the obligation of planning the construction, distribution, and administration of appropriate watering infrastructure (i.e. stock ponds) to ensure the availability of this resource to the animals.

Buffelgrass pastures are susceptible to be attacked by insect pests and/or invaded by undesirable plants. These kinds of problems can be solved by the application of appropriate chemical, mechanical, or cultural control methods. Most of the Sonoran ranchers use prescribed fires as the more common practice to repress the presence of plant and insect pests.

Another serious problem that can affect buffelgrass pastures is the presence of plant diseases. Unfortunately, the producers in the study area do not give special interest to this problem and nobody performs any kind of practice to prevent or control plant diseases in

their pastures. Prescribed fires can help to control pathogens that cause plant diseases in buffelgrass pastures.

The *Pasture Condition Index* (PCI) is finally calculated by averaging the vegetation, soil, and pasture management components.

RESULTS AND DISCUSSION

Factors that Affect Above Ground Annual Production

Resulting values for climate data, plant attributes, buffelgrass production, and soil characteristics for the eight preliminary study sites, are shown in Tables 5a-5c. It is evident that there exist a gradient for the precipitation factor that increases from the coast to the high sierras (i.e. from Costa de Hermosillo to Cajón de Onapa); the opposite occurs with the temperature factor, which decreases following the same altitudinal gradient (Table 5a).

Table 5a. Climatic values for eight preliminary study sites.

No.	SITE	PPT	TEMP
1	Costa de Hermosillo	260.47	22.41
2	El Shangai	388.74	23.04
3	Rancho Viejo	390.09	22.95
4	Las Guásimas	569.69	22.54
5	Rebéico	649.26	22.61
6	Sahuaripa	705.30	23.03
7	Cajón de Onapa	717.82	21.76
8	Represo del Verde	371.83	21.84

PPT = total annual precipitation in mm
TEMP = annual mean temperature in Celsius degrees

There is a large variability in herbage production in buffelgrass plants in a given pasture and in different pastures; Table 5b shows the variability in above ground production for the eight pastures taken as preliminary study sites.

Table 5b. Buffelgrass plant attribute values for eight preliminary study sites.

No.	SITE	H	CA	BA	P
1	Costa de Hermosillo	51.16	2248.2	152.7	325.56
2	El Shangai	33.92	990.14	22.24	18.99
3	Rancho Viejo	36.32	1145.99	64.53	34.00
4	Las Guásimas	34.84	602.56	90.79	26.00
5	Rebéico	27.00	401.28	72.85	25.91
6	Sahuaripa	82.11	2843.69	375.59	282.73
7	Cajón de Onapa	54.84	1368.20	182.43	79.71
8	Represo del Verde	ND*	ND	96.01	145.32

H = mean height in cm
CA = mean crown area in square cm
BA = mean basal area in square cm
P = mean herbage production in grams
* no data

Also, soil characteristics are different in the study sites (table 5c).

Table 5c. Soil characteristics values for eight preliminary study sites

					ppm (mg/Kg soil)				Meq/100g	% EXCHANGEABLE CATIONS								TEXTURE ANALYSIS		
No	SITE	DEPTH	N-NO3	P	Ca	Mg	Na	K	CEC	Ca	Mg	Na	K	% SAT	pH	E.C.	%O.M.	% SAND	% SILT	% CLAY
1	Costa de Hermosillo	30.0	25.20	24.75	1008	119	28	374	7.11	70.88	13.92	1.69	13.50	17.30	7.42	1.53	0.14	79.82	16.0	4.18
2	El Shangai	30.0	12.20	7.25	2144	159	30	378	13.15	81.52	10.11	0.99	7.38	27.60	7.52	0.60	1.61	64.82	23.0	12.18
3	Rancho Viejo	30.0	2.20	9.52	3107	83	26	159	16.75	92.77	4.12	0.66	2.45	27.00	7.68	0.59	0.56	65.82	21.0	13.18
4	Las Guasimas	30.0	17.15	2.17	2634	122	24	99	14.54	90.57	7.02	0.69	1.72	31.00	7.50	0.47	1.04	75.82	14.0	10.18
5	Rebeico	30.0	51.90	6.83	1287	380	24	210	10.24	62.84	30.91	1.02	5.24	32.10	7.47	1.06	1.13	64.82	20.0	15.18
6	Sahuaripa	30.0	3.45	9.07	1395	253	29	331	10.06	69.33	20.25	1.25	8.41	23.30	7.45	0.55	1.15	64.82	18.0	17.18
7	Cajon de Onapa	30.0	5.35	9.77	883	153	27	213	6.35	69.53	20.08	1.84	8.58	25.60	7.40	0.67	0.93	69.82	17.0	13.18
8	Represo del Verde	30.0	12.95	7.03	4059	807	85	146	27.76	73.10	24.22	1.33	1.35	30.70	6.87	0.80	1.13	65.74	16.0	18.26

Buffelgrass above ground biomass production is not significantly correlated to soil characteristics, and climate. Correlation analyses show only significant associations between production and plant attributes. Resulting values are shown in the following table:

Table 6. Correlation analyses for different buffelgrass attributes

VARIABLES	HEIGHT	CROWN AREA	BASAL AREA	PRODUCTION
HEIGHT	1.0000	0.7382**	0.7181**	O.5884**
CROWN AREA	0.7382**	1.0000	0.7260**	0.8275**
BASAL AREA	0.7181**	0.7260**	1.0000	0.5865**
PRODUCTION	0.5884**	0.8275**	0.5865**	1.0000

** Correlation is significant at the 0.01 level (2-tailed).

As shown in table 6, there are meaningful statistical relationships (p = 0.01) between production and crown cover area (r = 0.83), plant height (r = 0.59), and basal area (r = 0.59). However, in this study, plant height and crown cover areas, were not used in the regression model to estimate production, because in Sonora, most of buffelgrass pastures are continuously grazed and have no resting periods during the entire year. Thus, the only possible plant attribute to measure and relate to production is basal area.

Basal area measurements resulted in some values numerically distant from the rest of the data; those values are called outliers and can indicate faulty data, erroneous measurement procedures, or it can simply be the case that some values happen to be a long way from the mean of the data. The latter case is the one that applies to my measurement given the fact that after trying different statistical transformations, the

outlier values remain showing objectionable results. So, after computing regression model and eliminating outlier points or residuals, as recommended by Valdez-Zamudio and Figueroa-Preciado (2000), the best fitting model between basal area and herbage production was given by the equation:

$$\boldsymbol{Y = 4.6735 + 0.7191*BA}$$

Were ***Y*** represents plant production or relative yield (grams) and ***BA*** is the basal area (cm^2) for buffelgrass plant. The resulting model has a $r^2 = 0.82$ ($p = 0.002$).

It is important to mention that, in terms of mathematics, the dependent variable (*Y*) will have a value of 4.6735 even if *BA* has a value of zero. This is because the model was created with measurements higher than zero. Thus, in the real world, it doesn't make sense to assume you have above ground biomass plant production if there are not buffelgrass plants to consider. In other words, it is not correct to apply the model in areas where it is not possible to measure basal area in buffelgrass plants. Figure 13 shows the regression line relating basal area and buffelgrass production.

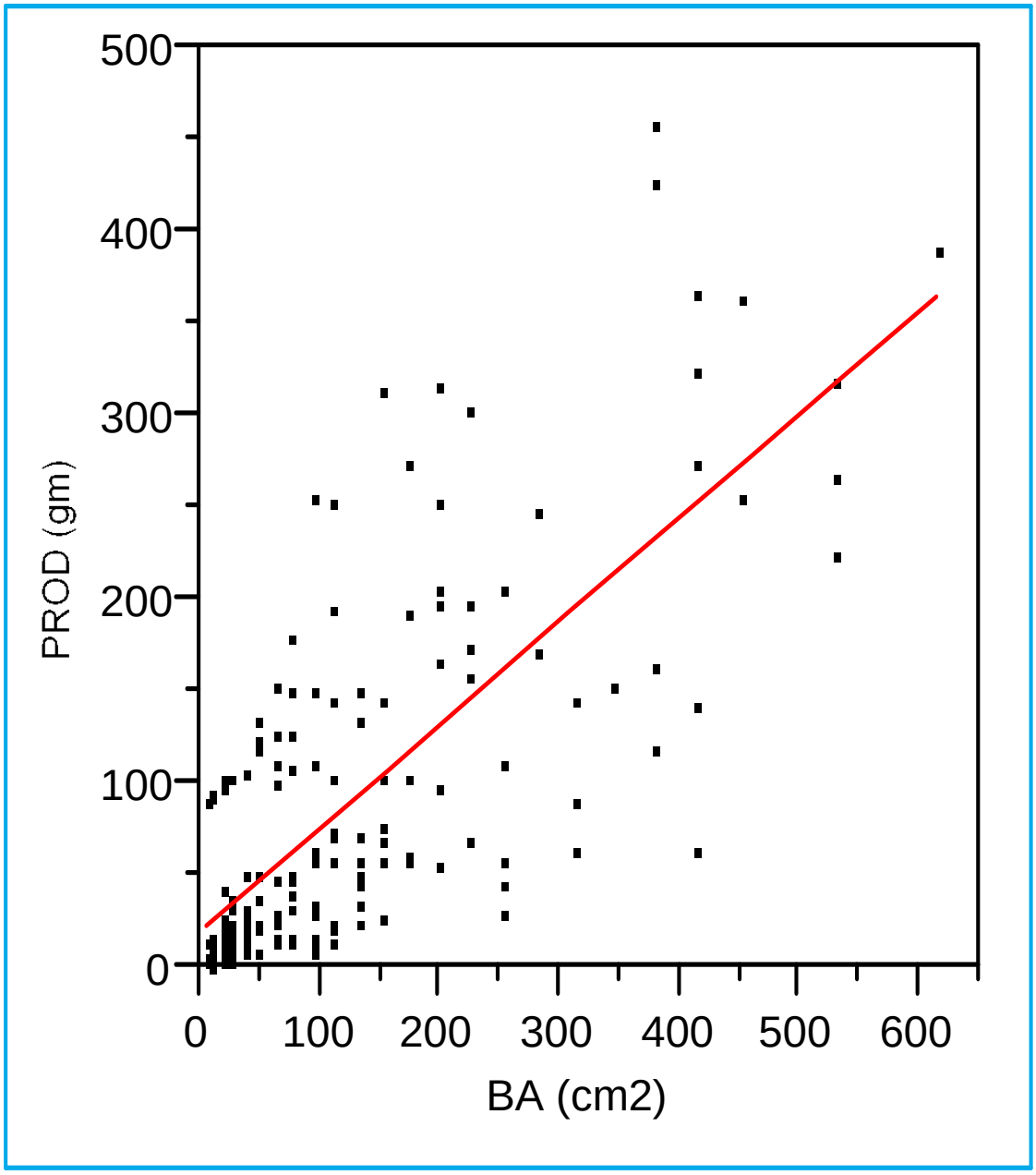

Figure 13. Regression line and equation after relating buffelgrass basal area and plant yield

In order to validate the model equation, 30 buffelgrass plants in a new site within the study area were sampled. As explained before, observed production values were compared to the values resulting from equation computation by realizing a means comparison, using the Student's *t* and DHS statistical tests (Sall and Lehman, 1996). The analyses show that there is no significant statistical difference between the two means ($p = 0.01$), concluding that the regression equation is valid to estimate production for buffelgrass pastures within the study area, based on the basal area of the plants.

These results are in agreement with those from Christie (1978) and McIvor et al. (1995) who concluded that, in bunch grasses, there exist a linear relationship between aboveground annual production (referred by them as relative yield) and plant attributes such as basal area. They simulate relative yield by a regression equation of the form:

$$\boldsymbol{RY = \beta_o + \beta * BA}$$

Where $\boldsymbol{RY}$ is the relative yield for the species, $\boldsymbol{\beta_o}$ is the point where the regression line intercepts the Y axis, $\boldsymbol{\beta}$ is the slope of the regression line and $\boldsymbol{BA}$ represents the basal area for the same species.

Modeling Suitable Conditions for Buffelgrass Pastures in Central Sonora

Suitability for buffelgrass pastures, in this study, was represented by PCI values. As mentioned before, PCI is estimated based on three components: vegetation component, soil component and management index. Resulting values for each one of those components are displayed on tables 7, 8, and 9, respectively.

Table 7. Vegetation component values for study sites

No.	SITE	RELATIVE YIELD	SPP COMPOSITION	VEG COMPONENT
1	SANTA TERESA	0.0365	0.5210	0.2788
2	SAN FRANCISCO	0.1802	0.7337	0.4570
3	SANTA ESTELA	0.2400	1.0000	0.6200
4	EL TONUCO	0.1733	0.9544	0.5638
5	SAN CARLOS	0.1785	0.8826	0.5305
6	PUNTA DEL CERRO	0.1332	0.7676	0.4504
7	POZO MANUEL	0.4945	0.9496	0.7220
8	EL REPRESO	0.2299	0.8973	0.5636
9	E. ESTACION TORRES	0.0000	0.0000	0.0000
10	LISTA BLANCA	0.5654	1.0000	0.7827
11	EL CHAROLAIS	0.1613	0.9590	0.5601
12	EL POZO DE LA P.	0.8219	1.0000	0.9109
13	EL CHURY	0.3873	1.0000	0.6936
14	LA ESCONDIDA	0.4905	0.9387	0.7146
15	PUEBLO VIEJO	0.3545	0.9760	0.6652
16	E. TEPUPA	0.9626	1.0000	0.9813
17	SAN PEDRO CUEVA	0.3202	0.9454	0.6328
18	E. MAZATAN	0.3883	0.9744	0.6813
19	E. LA GALERA	0.5263	0.8695	0.6979
20	E. LA TASAJERA	0.6380	1.0000	0.8190
21	REPRESO DEL VERDE	0.5096	0.9739	0.7418
22	AGUA FRIA	1.0000	0.9812	0.9906
23	E. SAHUARIPA	0.0789	0.2448	0.1619
24	ONAPA	0.2878	1.0000	0.6439
25	PUNTA DE AGUA	0.2174	0.8204	0.5189
26	EL SHANGAI	0.3978	0.9622	0.6800
27	EL TEOPARI	0.5169	0.9090	0.7129
28	E. REBEICO	0.6016	1.0000	0.8008
29	LLANO COLORADO	0.5616	0.9597	0.7607
30	SAN FERMIN	0.5523	0.9077	0.7300
31	SAN JOSE	0.5074	0.9303	0.7188
32	S. ANTONIO HUERTA	0.7060	1.0000	0.8530
33	C. TONICHI	0.3881	0.9467	0.6674
34	SANTO TOMAS	0.5948	0.8604	0.7276
35	E. LA ESTRELLA	0.4267	0.8395	0.6331
36	E. SOYOPA	0.4823	0.9789	0.7306
37	LOS HORCONES	0.1164	0.9459	0.5312

Table 8. Soil component values for study sites

No.	SITE	Crust Dev.	Micro Rel.	Litter /Crypt.	Eros. Feat.	SOIL COMP.
1	SANTA TERESA	0.1000	0.0067	0.0129	0.4500	0.5695
2	SAN FRANCISCO	0.1730	0.0015	0.0748	0.4967	0.7460
3	SANTA ESTELA	0.1000	0.0267	0.0374	0.4967	0.6608
4	EL TONUCO	0.1600	0.0883	0.0277	0.4967	0.7727
5	SAN CARLOS	0.1000	0.0017	0.0707	0.4883	0.6607
6	PUNTA DEL CERRO	0.1267	0.0667	0.0530	0.4617	0.7081
7	POZO MANUEL	0.1000	0.0000	0.0930	0.5000	0.6930
8	EL REPRESO	0.1100	0.0267	0.0818	0.4783	0.6968
9	E. ESTACION TORRES	0.0833	0.0050	0.0203	0.4383	0.5469
10	LISTA BLANCA	0.1600	0.0433	0.0778	0.4367	0.7178
11	EL CHAROLAIS	0.1267	0.0417	0.0663	0.4800	0.7147
12	EL POZO DE LA P.	0.1000	0.0000	0.0945	0.4983	0.6928
13	EL CHURY	0.1267	0.0383	0.0670	0.4950	0.7270
14	LA ESCONDIDA	0.1033	0.0933	0.0618	0.4967	0.7551
15	PUEBLO VIEJO	0.1033	0.0767	0.1443	0.4700	0.7943
16	E. TEPUPA	0.1000	0.0783	0.1082	0.4983	0.7848
17	SAN PEDRO CUEVA	0.1000	0.0767	0.0646	0.5000	0.7413
18	E. MAZATAN	0.1000	0.1000	0.0340	0.4883	0.7223
19	E. LA GALERA	0.1133	0.0867	0.0480	0.4800	0.7280
20	E. LA TASAJERA	0.1167	0.0917	0.1048	0.4950	0.8082
21	REPRESO DEL VERDE	0.1200	0.0300	0.0550	0.4767	0.6817
22	AGUA FRIA	0.1000	0.0367	0.0783	0.5000	0.7150
23	E. SAHUARIPA	0.1067	0.0533	0.0774	0.4950	0.7324
24	ONAPA	0.1067	0.0367	0.0754	0.5000	0.7188
25	PUNTA DE AGUA	0.1000	0.0150	0.0837	0.4900	0.6887
26	EL SHANGAI	0.1000	0.0517	0.0616	0.4617	0.6750
27	EL TEOPARI	0.1133	0.0717	0.0211	0.4617	0.6678
28	E. REBEICO	0.1000	0.1000	0.0493	0.5000	0.7493
29	LLANO COLORADO	0.1000	0.0617	0.0778	0.5000	0.7395
30	SAN FERMIN	0.1000	0.0600	0.0472	0.4717	0.6789
31	SAN JOSE	0.1000	0.0033	0.0931	0.4983	0.6947
32	S. ANTONIO HUERTA	0.1033	0.0833	0.0661	0.4967	0.7494
33	C. TONICHI	0.1000	0.0217	0.0578	0.5000	0.6795
34	SANTO TOMAS	0.1000	0.0967	0.0760	0.5000	0.7727
35	E. LA ESTRELLA	0.1000	0.0917	0.0537	0.5000	0.7454
36	E. SOYOPA	0.1000	0.0967	0.0619	0.5000	0.7586
37	LOS HORCONES	0.1000	0.0633	0.0535	0.5000	0.7168

Table 9. Pasture Management Index values for the studied pastures

No.	SITE	HM	IC	PM	WS	PC	PDC	PMI
1	SANTA TERESA	0.00	0.05	0.00	0.00	0.00	0.00	0.05
2	SAN FRANCISCO	0.15	0.15	0.10	0.20	0.05	0.00	0.65
3	SANTA ESTELA	0.05	0.15	0.10	0.10	0.00	0.00	0.40
4	EL TONUCO	0.15	0.15	0.10	0.20	0.05	0.00	0.65
5	SAN CARLOS	0.15	0.15	0.10	0.20	0.05	0.00	0.65
6	PUNTA DEL CERRO	0.00	0.05	0.00	0.10	0.00	0.00	0.15
7	POZO MANUEL	0.15	0.15	0.10	0.10	0.05	0.00	0.55
8	EL REPRESO	0.00	0.05	0.00	0.10	0.00	0.00	0.15
9	E. ESTACION TORRES	0.00	0.05	0.00	0.00	0.00	0.00	0.05
10	LISTA BLANCA	0.10	0.05	0.00	0.10	0.05	0.00	0.30
11	EL CHAROLAIS	0.10	0.05	0.00	0.10	0.00	0.00	0.25
12	EL POZO DE LA PITAHAYA	0.15	0.15	0.10	0.20	0.05	0.00	0.65
13	EL CHURY	0.15	0.15	0.10	0.20	0.05	0.00	0.65
14	LA ESCONDIDA	0.05	0.10	0.10	0.10	0.00	0.00	0.35
15	PUEBLO VIEJO	0.20	0.15	0.10	0.20	0.05	0.00	0.70
16	E. TEPUPA	0.00	0.05	0.00	0.10	0.00	0.00	0.15
17	SAN PEDRO DE LA CUEVA	0.00	0.05	0.00	0.10	0.00	0.00	0.15
18	E. MAZATAN	0.00	0.05	0.00	0.00	0.05	0.00	0.10
19	E. LA GALERA	0.00	0.05	0.00	0.00	0.00	0.00	0.05
20	E. LA TASAJERA	0.00	0.05	0.00	0.00	0.00	0.00	0.05
21	REPRESO DEL VERDE	0.15	0.15	0.10	0.20	0.05	0.00	0.65
22	AGUA FRIA	0.05	0.05	0.00	0.00	0.05	0.00	0.15
23	E. SAHUARIPA	0.00	0.05	0.00	0.00	0.00	0.00	0.05
24	ONAPA	0.00	0.05	0.00	0.10	0.00	0.00	0.15
25	PUNTA DE AGUA	0.00	0.05	0.00	0.10	0.05	0.00	0.20
26	EL SHANGAI	0.10	0.15	0.10	0.10	0.05	0.00	0.50
27	EL TEOPARI	0.10	0.15	0.10	0.10	0.05	0.00	0.50
28	E. REBEICO	0.00	0.05	0.00	0.00	0.00	0.00	0.05
29	LLANO COLORADO	0.00	0.10	0.10	0.10	0.05	0.00	0.35
30	SAN FERMIN	0.10	0.15	0.10	0.10	0.00	0.00	0.45
31	SAN JOSE	0.05	0.05	0.00	0.10	0.00	0.00	0.20
32	S. ANTONIO HUERTA	0.00	0.05	0.00	0.00	0.00	0.00	0.05
33	C. TONICHI	0.00	0.05	0.00	0.00	0.00	0.00	0.05
34	SANTO TOMAS	0.00	0.05	0.00	0.00	0.00	0.00	0.05
35	E. LA ESTRELLA	0.00	0.10	0.10	0.10	0.00	0.00	0.30
36	E. SOYOPA	0.05	0.10	0.10	0.10	0.05	0.00	0.40
37	LOS HORCONES	0.00	0.05	0.00	0.00	0.00	0.00	0.05

HM =Herd management (stocking rates, grazing systems); maximum value: 0.20
IC = Infrastructure condition; maximum value: 0.20
PM = Pasture Maintenance (replanting); maximum value: 0.20
WS = Water administration and distribution; maximum value: 0.20
PC = Pest control; maximum value: 0.10
PDC = Plant diseases control; maximum value: 0.10
PMI = Pasture Management Index; maximum value: 1.00

PCI values are displayed on table 10.

Table 10. Pasture Condition Index values for study sites

No.	SITE	VEG COMPONENT	SOIL COMPONENT	PMI	PCI
1	SANTA TERESA	0.2788	0.5695	0.05	0.30
2	SAN FRANCISCO	0.4570	0.7460	0.65	0.62
3	SANTA ESTELA	0.6200	0.6608	0.40	0.56
4	EL TONUCO	0.5638	0.7727	0.65	0.66
5	SAN CARLOS	0.5305	0.6607	0.65	0.61
6	PUNTA DEL CERRO	0.4504	0.7081	0.15	0.44
7	POZO MANUEL	0.7220	0.6930	0.55	0.66
8	EL REPRESO	0.5636	0.6968	0.15	0.47
9	E. ESTACION TORRES	0.0000	0.5469	0.05	0.20
10	LISTA BLANCA	0.7827	0.7178	0.30	0.60
11	EL CHAROLAIS	0.5601	0.7147	0.25	0.51
12	EL POZO DE LA PITAHAYA	0.9109	0.6928	0.65	0.75
13	EL CHURY	0.6936	0.7270	0.65	0.69
14	LA ESCONDIDA	0.7146	0.7551	0.35	0.61
15	PUEBLO VIEJO	0.6652	0.7943	0.70	0.72
16	E. TEPUPA	0.9813	0.7848	0.15	0.64
17	SAN PEDRO CUEVA	0.6328	0.7413	0.15	0.51
18	E. MAZATAN	0.6813	0.7223	0.10	0.50
19	E. LA GALERA	0.6979	0.7280	0.05	0.49
20	E. LA TASAJERA	0.8190	0.8082	0.05	0.56
21	REPRESO DEL VERDE	0.7418	0.6817	0.65	0.69
22	AGUA FRIA	0.9906	0.7150	0.15	0.62
23	E. SAHUARIPA	0.1619	0.7324	0.05	0.31
24	ONAPA	0.6439	0.7188	0.15	0.50
25	PUNTA DE AGUA	0.5189	0.6887	0.20	0.47
26	EL SHANGAI	0.6800	0.6750	0.50	0.62
27	EL TEOPARI	0.7129	0.6678	0.50	0.63
28	E. REBEICO	0.8008	0.7493	0.05	0.53
29	LLANO COLORADO	0.7607	0.7395	0.35	0.62
30	SAN FERMIN	0.7300	0.6789	0.45	0.62
31	SAN JOSE	0.7188	0.6947	0.20	0.54
32	S. ANTONIO HUERTA	0.8530	0.7494	0.05	0.55
33	C. TONICHI	0.6674	0.6795	0.05	0.47
34	SANTO TOMAS	0.7276	0.7727	0.05	0.52
35	E. LA ESTRELLA	0.6331	0.7454	0.30	0.56
36	E. SOYOPA	0.7306	0.7586	0.40	0.63
37	LOS HORCONES	0.5312	0.7168	0.05	0.43

Vegetation Component

In order to determine the vegetation component values, it was necessary to compute production and plant species composition for the study sites, since this component was determined by averaging the values of those parameters.

Production

Above ground annual production per plant was estimated by applying the model described before (Y = 4.6735 + 0.7191*BA). We can see on Table 5 that there is a wide variability in forage production in the studied pastures.

According to a correlation analysis, two factors affect buffelgrass production in a significant way ($p = 0.05$) in central Sonora: plant density and pasture management index (PMI). Density is negatively related to buffelgrass production, while PMI has a positive relation to biomass production for the species. Thus, it is important to know the appropriate population density for buffelgrass pastures in a given area, to get the most promising forage production.

There is a positive significant response of biomass production in buffelgrass to pasture management index. Obviously, this relationship indicates that, even in optimal climatic and soil conditions, mismanagement of buffelgrass pastures will provoke failures and probably serious ecological problems such as soil loss, and changes in plant diversity in areas dedicated to these activities. This is evidence that buffelgrass pastures can be established and preserved for long periods of time if appropriate management activities are performed in the grazing allotments.

Species Composition.

Species composition values presented on Table 5, are mostly given by buffelgrass populations which clearly dominate the plant communities included in the study sites. This is given by the fact that original vegetation in actual areas was totally cleared before establishing the pastures. Some sites like Santa Teresa, however, showed a good percent composition of woody species probably as a result of a selective deforestation performed before establishing the buffelgrass pastures. In some cases, high percentages in plant composition for other species than buffelgrass could be the result of successional changes, range mismanagement or local climate change. Milchunas et al. (1994) described that forage production difference over 50 years has been mostly explained by precipitation that to long term effects of grazing treatments. Studies made in Eastern Montana by White et. al. (1978), show that severe droughts has been responsible for changes in botanical composition in rangelands.

Soil Component

Crust Development.

Resulting values for soil component are shown on Table 6. It is possible to observe in this table that, in general, study sites have soil surfaces ranging from loose deposits to firm surfaces, but without showing clayed crusts which is an undesirable soil characteristic. Surfaces in some soils are firm probably due to the trampling effect by cattle.

Soil Micro-relief.

Micro-relief values for all sites range between slight and strong micro-relief development. This indicates that, in general, study sites have an acceptable soil roughness to assure water retention and infiltration, and probably having a good number of germination micro-sites. Soil micro-relief is given basically by rocks and gravel and, in few cases, by cattle trampling.

Litter and Cryptogams.

In relation to organic layers covering the soil surface, we can also see in Table 6 that most of the sampled pastures have litter deposits covering over than 60% of their areas. In general, it is local litter, not incorporated to the soil, a common characteristic of desert regions. Thus, we can say that soil surface in buffelgrass pastures from the study area, are well protected from raindrops impact and have good rain water retention. This reduces the erosion caused by rain by slowing the flow of water over the surface and allowing more time for water infiltration.

In relation to cryptogrammic crusts, only 10 study sites presented at least one sampling plot with that kind of plant formations, with ranges of 4 or less in a scale of 0-5. It is presumable that cryptogrammic crusts are formed by the blue-green algae *Microcoleus vaginatus* (Belnap and Gardner, 1993).

Erosion Features.

The indicators of soil erosion in the studied pastures, show an acceptable situation since, the mean value for all the study sites is over 0.49, being a value of 0.50 for places

without erosion (Tongway and Smith, 1989). However, in the cases where the erosion is present, flow lines are the most common erosion features, but litter cover and smooth slopes of the land, do not allow the flow lines to progress in deeper and wider formations when rain events occur. Then, it is thought that, in general, soil erosion caused by water is not a problem in buffelgrass pastures of central Sonora. This is probably the result of having a good percentage of plant and litter cover and to the acceptable soil surface micro-topography.

Pasture Management Index

Pasture management index was obtained by summing different parameters (Table 7).

Herd Management.

We can see that majority of the study sites present low values for the parameters used to compute this index; only in one of the sites (Pueblo Viejo) the appropriate herd management practices (i.e. stocking rates) are used. This is a very important component of the PMI that affects the health and productivity of the rangelands in particular, as well as the natural resources in general.

In a Colorado grazing study, Torell et al. (1991) found that rangeland productivity deterioration was related directly to grazing pressure. Rangeland productivity increased slightly under a light grazing treatment, decreased under a heavy use rate, and remained relatively constant at a moderate rate.

In Mexico, ranchers increase the applied stocking rate when they perceive a good

rainfall year and greater forage availability (Rowan et al., 1994). In other studies, Rowan and White (1994) found a strong relationship between perceived rainfall effects and adjustments to stocking rates. An expected drought by ranchers induced them to a decrease in stocking rate over time. Yates (1981) assesses that there is a trend for grassland carrying capacity to decline. He based his judgment on the studies made by COTECOCA, during the early 1970's, where this commission found that most ranches were stocking more animals than recommended. It is also possible, that ranchers in Sonora, adjust their stocking rates based on their perception of future forage production and range condition Maybe, the tendency to observe low stocking rates could be associated to poor rangeland condition.

In relation to the grazing systems used, about 50% of the sample sites lack of this kind of practices. Ranchers allow the animals to graze yearlong without putting the pastures to rest and, in some cases without having pasture divisions.

Infrastructure Condition.

According to Coronado-Quintana (1994), infrastructure condition is positively related with rangeland condition. However, it was observed that the majority of the ranches included in this study, did not show infrastructures in good or excellent condition. Only a few private ranches presented infrastructure in acceptable condition.

Pasture Maintenance.

Planning and performing maintenance activities in buffelgrass pastures preserve and/or increase condition. Some of these activities include fertilization, irrigation, soil plowing, and reseeding. As mentioned by Wiedenfeld et al. (1985) and Cabanillas-Cruz (1996), buffelgrass yields can be increased with nitrogen applications. Irrigation can also increase production in buffelgrass plants (Cabanillas-Cruz, 1996). Ibarra et al. (2000) found that soil plowing and reseeding is a good alternative to rehabilitate deteriorated buffelgrass pastures. Reseeding is used in areas where plants die as a result of animal trampling and/or overgrazing. In this study, only two of the 37 sites (San Francisco and Santa Estela, both private ranches), shown soil plowing and reseeding activities with acceptable results.

Water Administration and Distribution.

The amount of water supplied and the number of watering points on grazing pastures is important in controlling the movement, distribution, and concentration of grazing animals. Thus, a good management of water resources can lead to have a uniform grazing pattern on the pastures, avoiding the overgrazing of areas close to watering points and decreasing the effects of cattle trampling in restricted areas inside the pastures (Vallentine, 1990). It is recommended to locate water points no more than one mile from forage supplies (Vallentine, 1990). Unfortunately, no one of the study pastures show a water distribution pattern to control cattle distribution and/or grazing uniformity.

Pest Control.

Practices such as weed/brush control programs are generally done on perception of current pasture condition (Rowan et al., 1994, and Rowan and White, 1994). Even when Miranda-Zarazua and Ramirez-Moreno (1995) mention different methodologies to control invasions by perennial plant species in buffelgrass pastures, most of the study ranches do not use any method to have their grazing areas clean of weeds or undesirable plants. However, when a control activity is performed, usually the ranchers use the manual method, in other words, they cut invader brushes by hand. Sometimes they also use the prescribed burn method (Ibarra et al., 1996).

In relation to insect pests, buffelgrass is attacked by a sucker insect named “mosca pinta” or spittlebug (*Aeneolamia albofasciata* Lall.), which can be controlled by chemical methods, prescribed fires and cattle grazing (Miranda-Zarazúa and Ramirez-Moreno, 1995). Martin-Rivera et al. (1996) recommend prescribed burning to disrupt the life cycle of the insect by removing dead plant material and litter. Commonly, buffelgrass pastures of the region are overgrazed in such a way that pest populations are naturally controlled by cattle grazing. However, when this problem is present, ranchers use prescribed burning to solve it. This practice has been only seen in private pastures.

Plant Diseases Control

The most common disease known for buffelgrass is named “salivazo”, which consists in a mass of substances similar to saliva. This “spit” is formed by the insect called spittlebug (*Aeneolamia albofasciata* Lall.) and, when covers most of the leaf area of the

grass, it interferes the photosynthetic process and affects the respiration of the plant reducing biomass production and, consequently, forage yield.

Any method recommended to control spittlebug populations can help to solve the problems caused by the presence of “salivazo” (Miranda-Zarazúa and Ramirez-Moreno, 1995; Ibarra et al., 1996; Martin-Rivera et al., 1999). Only private ranchers use prescribed burning to control spittlebug and “salivazo” in rare occasions in study pastures.

It is important to mention that, there are significant differences ($p = 0.01$) when comparing PMI means between private ranches and ejidos. In other words, better management practices can be found in sites exploited under private properties than in the ejido. Because of low cultural and economic status of the members, the ejido has been judged as a land tenure system that has more disadvantages than private properties in terms of proper management of natural resources.

Modeling results

Pasture Condition Index (PCI) was obtained by averaging vegetation, soil, and pasture management components. The results for this index are given on Table 8. Pasture condition index does not reflect a significant relationship with geographical location of rangelands. In other words, similar values can be found in sites far apart in terms of elevation, longitudinal and/or latitudinal distances. Same pattern is shown in relation to land tenure (i.e. ejido and private property).

There is a negative significant correlation (p = 0.01) between PCI and total sodium and N-NO_3 content in the soil. There are not informative studies in relation to the effect of sodium on buffelgrass establishment and growth. Some researchers found that sodium is toxic to some plant species and, also, affects the hydraulic conductivity of the soils (Soil Survey Division Staff, 1993).

There exists a negative relationship (p = 0.05) between N-NO3 and soil pH. This indicates that soils rich in N-NO3 will tend to be more acidic, a situation not desirable for buffelgrass to survive. Thus, my results confirm the studies realized by Ibarra-Flores et al. (1995a). They found that the amount of nitrogen in soils is low where the grass growths healthy, and high where the plant dies. On the other hand, this is contrary to that concluded by Wiedenfeld et al. (1985) and Cabanillas-Cruz (1996), who found that buffelgrass yields could be increased with nitrogen applications.

Ibarra-Flores et al. (1995a) mention that low available soil phosphorus may limit buffelgrass production. However, the results of this study can not validate what these authors found because soil phosphorus and buffelgrass production did not show statistical significant relationship. Same authors, also confirm a negative relationship between soil organic matter and buffelgrass habitat suitability, although this research did not show any significant statistical relationship.

Calcium and potassium are elements poorly or not related to the majority of the variables involved in this study and especially to PCI.

Coronado-Quintana (1994) stated that the main factor associated with rangeland condition in Sonora, is annual precipitation. According to Martin et al. (1995), live

biomass production for buffelgrass increased almost eight times from a summer of below average precipitation to a summer of above average precipitation in the Sonoran Desert. However, according to this study, PCI was not significantly correlated to this factor, depending probably on management practices.

In relation to mean annual temperature, the correlation analysis resulted in a negative value when related to PCI ($p = 0.05$). This indicates that suitable places for buffelgrass to grow could be desertic but not in extreme aridity.

PCI was negatively correlated with aspect factor at 0.05 level. This indicates that suitability for buffelgrass pastures, could decline when the aspect of the land show a tendency to face to the west. Probably this pattern is related to the fact that driest slopes face south-southwest (SSW) or southwest (SW) rather than S, and the coolest and wettest slopes face north-northeast (NNE) or northeast (NE) rather than N (Shreve, 1915; Ayyad and Dix, 1964; Geiger, 1965; Haase, 1969).

Another factor statistically related to the PCI ($p = 0.05$) is the pasture age. Probably this positive relationship demonstrates that, as the time passes, the components of the PCI such as vegetation and soil attributes tend to be improved in terms of suitability for buffelgrass, and/or the ranchers get more experience in managing the pastures.

Slope is a factor that was not correlated to any of the other variables considered in this study. However, it is well known that steep lands are not appropriated to be used for grazing cattle since the animals spend too much energy when moving upslope. Another reason is the fact that steeper lands dedicated to range activities, experience greater erosion effects caused by rainwater action.

Table 11 shows resulting values for independent variables. These are: soil nitrogen content (ppm), soil phosphorus (ppm), cation exchange capacity (mEq/100g soil), exchangeable cations (mEq/100g), percent exchangeable cations, percent saturation, soil pH, electrical conductivity (mmhos/cm), percent of soil organic matter, soil texture, precipitation values (mm), temperature (°C), altitude (meters above sea level), slope (degrees), aspect (unitary units ranging from 1 to 8), and pasture age (years).

Table 11. Variables included in the statistical analyses.

No.	SITE	PCI	D	BA	PC	SC	CD	MR	LC	EF
1	SANTA TERESA	0.30	2667	126.74	0.04	0.52	0.10	0.0067	0.01	0.45
2	SAN FRANCISCO	0.62	14000	117.23	0.18	0.73	0.17	0.0015	0.07	0.50
3	SANTA ESTELA	0.56	28333	66.08	0.24	1.00	0.10	0.1267	0.04	0.50
4	EL TONUCO	0.66	9000	191.29	0.17	0.95	0.16	0.0883	0.03	0.50
5	SAN CARLOS	0.61	12000	140.46	0.18	0.88	0.10	0.0017	0.07	0.49
6	PUNTA DEL CERRO	0.44	26333	26.47	0.13	0.77	0.13	0.0667	0.05	0.46
7	POZO MANUEL	0.66	17667	292.73	0.49	0.95	0.10	0.0000	0.09	0.50
8	EL REPRESO	0.47	15000	145.70	0.23	0.90	0.11	0.0267	0.08	0.48
9	E. ESTACION TORRES	0.20	0	0.00	0.00	0.00	0.08	0.0050	0.02	0.44
10	LISTA BLANCA	0.60	41667	125.31	0.57	1.00	0.16	0.0433	0.08	0.44
11	EL CHAROLAIS	0.51	11000	137.99	0.16	0.96	0.13	0.0417	0.07	0.48
12	EL POZO DE LA P.	0.75	36333	230.39	0.82	1.00	0.10	0.0000	0.09	0.50
13	EL CHURY	0.69	24000	155.12	0.39	1.00	0.13	0.0383	0.07	0.50
14	LA ESCONDIDA	0.61	40667	107.80	0.49	0.94	0.10	0.0933	0.06	0.50
15	PUEBLO VIEJO	0.72	34667	86.48	0.35	0.98	0.10	0.0767	0.14	0.47
16	E. TEPUPA	0.64	47333	203.88	0.96	1.00	0.10	0.0783	0.11	0.50
17	SAN PEDRO CUEVA	0.51	20000	153.66	0.32	0.95	0.10	0.0767	0.06	0.50
18	E. MAZATAN	0.50	34333	99.06	0.39	0.97	0.10	0.1000	0.03	0.49
19	E. LA GALERA	0.49	21667	249.80	0.53	0.87	0.11	0.0867	0.05	0.48
20	E. LA TASAJERA	0.56	69667	74.09	0.64	1.00	0.12	0.0917	0.10	0.50
21	REPRESO DEL VERDE	0.69	21667	240.84	0.51	0.97	0.12	0.0300	0.06	0.48
22	AGUA FRIA	0.62	78667	115.35	1.00	0.98	0.10	0.0367	0.08	0.50
23	E. SAHUARIPA	0.31	4333	179.19	0.08	0.24	0.11	0.0533	0.08	0.50
24	ONAPA	0.50	45667	40.93	0.29	1.00	0.11	0.0367	0.08	0.50
25	PUNTA DE AGUA	0.47	21000	87.93	0.22	0.82	0.10	0.0150	0.08	0.49
26	EL SHANGAI	0.62	74000	30.18	0.40	0.96	0.10	0.0517	0.06	0.46
27	EL TEOPARI	0.63	128000	14.64	0.52	0.91	0.11	0.0717	0.02	0.46
28	E. REBEICO	0.53	55667	93.23	0.60	1.00	0.10	0.1000	0.05	0.50
29	LLANO COLORADO	0.62	47333	105.52	0.56	0.96	0.10	0.0617	0.08	0.50
30	SAN FERMIN	0.62	46000	107.15	0.55	0.91	0.10	0.0600	0.05	0.47
31	SAN JOSE	0.54	34333	139.34	0.51	0.93	0.10	0.0033	0.09	0.50
32	S. ANTONIO HUERTA	0.55	94667	54.34	0.71	1.00	0.10	0.0833	0.07	0.50
33	C. TONICHI	0.47	24333	152.93	0.39	0.95	0.10	0.0217	0.06	0.50
34	SANTO TOMAS	0.52	56333	90.34	0.59	0.86	0.10	0.0967	0.08	0.50
35	E. LA ESTRELLA	0.56	25333	163.30	0.43	0.84	0.10	0.0917	0.05	0.50
36	E. SOYOPA	0.63	51667	76.13	0.48	0.98	0.10	0.0967	0.06	0.50
37	LOS HORCONES	0.43	10333	98.58	0.12	0.95	0.10	0.0633	0.05	0.50

Table 11. Continued

No.	SITE	MAP	MAT	AI	ALT	SLP	ASP	PA	PMI	N-NO3	P	Ca
1	SANTA TERESA	291	22.7	8.9	200	3	7	3	0.05	7.30	24.04	1917
2	SAN FRANCISCO	361	23.1	10.9	26	4	6	3	0.65	0.40	19.42	1536
3	SANTA ESTELA	350	22.9	10.6	156	2	3	8	0.40	34.05	28.52	1126
4	EL TONUCO	302	22.8	9.2	122	4	2	17	0.65	2.20	10.70	8329
5	SAN CARLOS	312	22.9	9.5	91	4	2	11	0.65	1.55	14.24	1430
6	PUNTA DEL CERRO	400	23.5	11.9	321	4	7	7	0.15	42.00	12.18	9816
7	POZO MANUEL	392	22.3	12.1	485	4	2	17	0.55	0.95	8.52	509
8	EL REPRESO	346	23.6	10.3	266	2	3	10	0.15	1.55	16.48	1811
9	E. ESTACION TORRES	382	23.3	11.5	213	2	7	4	0.05	69.40	14.80	1772
10	LISTA BLANCA	375	22.9	11.4	390	3	3	6	0.30	2.20	22.60	1617
11	EL CHAROLAIS	372	23.1	11.2	330	2	6	14	0.25	5.35	17.64	717
12	EL POZO DE LA P.	377	21.4	12.0	416	5	8	7	0.65	5.35	15.90	886
13	EL CHURY	384	21.3	12.3	411	2	4	27	0.65	10.05	20.70	535
14	LA ESCONDIDA	375	23.1	11.3	460	5	7	4	0.35	10.05	21.3	1730
15	PUEBLO VIEJO	423	22.7	12.9	444	2	3	17	0.70	1.55	4.51	9875
16	E. TEPUPA	606	22.8	18.5	525	2	1	12	0.15	2.20	12.7	1988
17	SAN PEDRO CUEVA	580	22.7	17.7	391	2	4	11	0.15	6.65	10.70	4194
18	E. MAZATAN	541	21.9	17.0	549	5	3	14	0.10	93.05	13.2	1361
19	E. LA GALERA	533	22.6	16.4	424	4	4	9	0.05	13.70	4.93	9884
20	E. LA TASAJERA	535	22.4	16.5	475	3	2	6	0.05	2.20	5.35	9915
21	REPRESO DEL VERDE	396	21.6	12.5	392	4	3	5	0.65	12.95	7.03	4059
22	AGUA FRIA	683	22.5	21.0	956	5	4	8	0.15	1.55	39.6	5344
23	E. SAHUARIPA	705	22.9	21.4	683	4	3	4	0.05	18.35	20.05	1820
24	ONAPA	805	21.3	25.7	664	4	5	6	0.15	5.35	10.7	2057
25	PUNTA DE AGUA	521	22.3	16.1	750	3	6	8	0.20	15.90	9.31	1247
26	EL SHANGAI	394	23.0	12.0	420	2	7	5	0.50	7.30	7.03	9907
27	EL TEOPARI	513	21.6	16.2	643	2	2	3	0.50	4.70	7.03	671
28	E. REBEICO	675	23.2	20.3	472	4	3	7	0.05	14.45	8.36	1727
29	LLANO COLORADO	652	23.0	19.8	663	3	4	8	0.35	6.65	11.7	3268
30	SAN FERMIN	540	22.3	16.7	473	2	1	4	0.45	3.45	15.9	4052
31	SAN JOSE	545	22.7	16.7	675	2	8	5	0.20	12.2	14.8	3278
32	S. ANTONIO HUERTA	638	24.2	18.6	273	6	4	10	0.05	5.35	16.5	1709
33	C. TONICHI	611	24.8	17.5	248	2	7	6	0.05	2.80	8.40	9897
34	SANTO TOMAS	719	21.8	22.6	508	2	7	16	0.05	6.00	11.7	1985
35	E. LA ESTRELLA	686	23.9	20.2	551	6	5	5	0.30	10.05	11.2	9961
36	E. SOYOPA	626	22.8	19.1	273	4	5	15	0.40	5.35	9.30	3357
37	LOS HORCONES	545	22.2	16.9	583	2	6	10	0.05	19.15	7.91	9889

Table 11. Continued

No.	SITE	Mg	Na	K	CEC	%Ca	%Mg	% Na	%K	%SAT	pH
1	SANTA TERESA	463	70	423	14.832	64.62	26.01	2.01	7.31	22.3	6.73
2	SAN FRANCISCO	255	41	154	10.378	74.00	20.47	1.71	3.81	18.7	6.85
3	SANTA ESTELA	323	85	839	10.842	51.93	24.83	3.40	19.5	20.3	6.36
4	EL TONUCO	273	71	134	44.572	93.43	5.10	0.69	0.77	21.3	7.65
5	SAN CARLOS	238	28	190	9.742	73.40	20.35	1.25	4.99	20.7	7.16
6	PUNTA DEL CERRO	261	71	237	52.172	94.07	4.17	0.59	1.16	24.3	7.10
7	POZO MANUEL	108	38	148	3.985	63.86	22.68	4.14	9.51	16.0	6.52
8	EL REPRESO	212	38	188	11.469	78.95	15.41	1.44	4.20	22.7	7.14
9	E. ESTACION TORRES	551	236	512	15.79	56.11	29.07	6.52	8.30	26.0	6.47
10	LISTA BLANCA	85	33	144	9.305	86.69	7.61	1.54	3.96	21.7	7.76
11	EL CHAROLAIS	261	54	212	6.537	54.84	33.27	3.58	8.31	19.3	6.44
12	EL POZO DE LA P.	240	53	152	7.05	62.84	28.37	3.26	5.53	17.7	7.33
13	EL CHURY	145	32	223	4.604	58.32	26.24	3.02	12.4	19.3	6.33
14	LA ESCONDIDA	228	34	260	11.365	76.11	16.72	1.30	5.87	24.0	6.35
15	PUEBLO VIEJO	201	54	355	26.102	80.34	14.14	0.75	4.77	24.3	6.87
16	E. TEPUPA	123	40	214	11.688	85.04	8.77	1.49	4.70	23.7	6.75
17	SAN PEDRO CUEVA	443	45	486	26.102	80.34	14.14	0.75	4.77	29.3	7.80
18	E. MAZATAN	294	67	178	10.002	68.04	24.49	2.91	4.56	23.0	6.29
19	E. LA GALERA	189	44	255	51.84	95.33	3.04	0.37	1.26	26.7	7.16
20	E. LA TASAJERA	203	33	141	55.771	95.76	3.27	0.28	0.69	31.0	7.11
21	REPRESO DEL VERDE	807	85	146	27.763	73.10	24.22	1.33	1.35	30.7	6.87
22	AGUA FRIA	1777	41	283	42.434	62.97	34.90	0.42	1.71	30.7	7.19
23	E. SAHUARIPA	797	62	236	16.616	54.77	39.97	1.62	3.64	26.0	6.18
24	ONAPA	249	37	415	13.585	75.71	15.27	1.18	7.83	22.0	6.45
25	PUNTA DE AGUA	157	35	137	8.046	77.49	16.26	1.89	4.36	19.7	5.94
26	EL SHANGAI	428	36	383	54.24	91.32	6.58	0.29	1.81	22.7	7.32
27	EL TEOPARI	169	54	264	5.675	59.12	24.81	4.14	11.93	21.7	6.39
28	E. REBEICO	1459	77	391	22.13	39.02	54.94	1.51	4.52	35.7	5.77
29	LLANO COLORADO	551	32	612	22.64	72.17	20.28	0.61	6.93	28.7	7.33
30	SAN FERMIN	173	36	185	22.332	90.72	6.46	0.70	2.12	21.7	7.40
31	SAN JOSE	308	42	867	21.363	76.72	12.02	0.86	10.4	25.7	6.59
32	S. ANTONIO HUERTA	200	51	234	11.034	77.44	15.12	2.01	5.42	27.0	6.91
33	C. TONICHI	308	27	377	53.136	93.13	4.83	0.22	1.82	26.3	6.87
34	SANTO TOMAS	380	38	603	14.535	66.01	22.06	1.15	10.8	26.0	7.20
35	E. LA ESTRELLA	848	62	443	58.277	85.46	12.13	0.46	1.95	55.3	7.33
36	E. SOYOPA	919	88	455	25.993	64.57	29.46	1.47	4.49	36.0	7.04
37	LOS HORCONES	543	65	519	55.583	88.96	8.14	0.51	2.39	37.7	7.40

Table 11. Continued

No.	SITE	EC	%OM	%SND	%CLY	%LOAM	SOIL TYPE	VARIABLES
1	SANTA TERESA	0.47	0.28	72.46	11.9	15.64	Yermosols	
2	SAN FRANCISCO	2.9	0.31	84.46	6.9	8.64	Regosols	PCI = Pasture Condition Index (value 0 – 1.0)
3	SANTA ESTELA	1.02	0.17	70.46	8.9	20.64	Yermosols	D = Density (plants/ha)
4	EL TONUCO	0.28	0.14	80.46	5.9	13.64	Regosols	BA = Basal Area (cm^2)
5	SAN CARLOS	0.49	0.28	83.46	5.9	10.64	Yermosols	PC = Productive Capacity (gr)
6	PUNTA DEL CERRO	1.50	0.48	75.46	12.9	11.64	Regosols	SC = Species Composition (%)
7	POZO MANUEL	0.39	0.41	84.46	4.9	10.64	Regosols	CD = Crust Development (value 0 – 0.2)
8	EL REPRESO	0.43	0.17	79.46	6.9	13.64	Litosols	MR = Micro Relief (value 0 – 0.1)
9	E. ESTACION TORRES	1.70	0.34	65.46	17.9	16.64	Yermosols	LC = Litter / Cryptogams (value 0 – 0.2)
10	LISTA BLANCA	0.28	0.45	82.46	3.9	13.64	Regosols	EF = Erosion Features (value 0 – 0.5)
11	EL CHAROLAIS	0.65	0.24	82.45	5.9	11.65	Yermosols	MAP = Mean Annual Precip. (mm)
12	EL POZO DE LA P.	0.43	0.38	83.46	7.9	8.64	Regosols	MAT = Mean Annual Temp. (T^0)
13	EL CHURY	0.61	0.31	85.46	4.9	9.64	Regosols	AI = Aridity Index
14	LA ESCONDIDA	0.59	1.11	73.46	8.9	17.64	Regosols	ALT = Altitude (masl)
15	PUEBLO VIEJO	0.48	0.78	71.46	10.9	17.64	Xerosols	SLP = Slope (degrees)
16	E. TEPUPA	0.45	0.33	79.46	7.9	12.64	Regosols	ASP = Aspect (value 1 – 8)
17	SAN PEDRO CUEVA	0.42	0.63	66.46	27.9	5.64	Regosols	PA = Pasture Age (years)
18	E. MAZATAN	3.20	0.99	77.46	6.9	15.64	Xerosols	PMI = Pasture Management Index (value 0 – 1.0)
19	E. LA GALERA	0.50	0.84	76.46	10.9	12.64	Regosols	N-NO3 = Total Nitrates (ppm)
20	E. LA TASAJERA	0.64	1.40	54.74	18.26	27.00	Xerosols	P = Total Phosphorus (ppm)
21	REPRESO DEL VERDE	0.80	1.13	65.74	18.26	16.00	Regosols	Ca = Total Calcium (ppm)
22	AGUA FRIA	0.25	0.96	71.46	10.26	18.28	Feozems	Mg = Total Magnesium (ppm)
23	E. SAHUARIPA	0.55	1.57	54.46	26.26	19.28	Regosols	Na = Total Sodium (ppm)
24	ONAPA	0.49	0.93	77.46	10.26	12.28	Regosols	K = Total Potasium (ppm)
25	PUNTA DE AGUA	0.86	1.16	79.74	8.26	12.00	Luvisols	CEC = Cation Exchange Capacity (meq/100g soil)
26	EL SHANGAI	0.53	0.96	71.46	10.26	18.28	Regosols	% Ca = % Calcium
27	EL TEOPARI	0.28	0.60	85.46	9.26	5.28	Regosols	% Mg = % Magnesium
28	E. REBEICO	0.49	0.36	33.48	52.52	14.00	Cambisols	% Na = % Sodium
29	LLANO COLORADO	0.71	2.32	56.46	7.26	36.28	Cambisols	% K = % Potasium
30	SAN FERMIN	0.34	1.08	88.46	11.26	0.28	Regosols	% SAT = % Soil Saturation
31	SAN JOSE	0.80	1.22	84.46	4.26	11.28	Regosols	pH = pH
32	S. ANTONIO HUERTA	0.36	1.67	71.46	8.26	20.28	Litosols	EC = Electrical Conductivity (mmhos/cm)
33	C. TONICHI	0.49	1.31	75.74	10.26	14.00	Luvisols	% OM = % Soil Organic Matter
34	SANTO TOMAS	0.29	1.91	73.46	11.26	15.28	Regosols	% SND = % Sand
35	E. LA ESTRELLA	0.37	1.62	41.48	34.52	24.00	Cambisols	% CLY = % Clay
36	E. SOYOPA	2.70	1.95	58.46	25.26	16.28	Cambisols	
37	LOS HORCONES	0.74	1.67	56.46	24.26	19.28	Xerosols	

Correlation analysis demonstrates that only few variables were significantly correlated to PCI at the 0.05 level. These variables are mean annual temperatures, aspect, pasture age, nitrogen and sodium content. However, it is important to mention that, when performing stepwise regressions, non significant related variables can interact with other significant or not significant variables to produce a significant response on the dependent variable. A stepwise regression is represented by the equation:

$$PCI = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots \beta_m X_m$$

In this study, the resulting equation after computing stepwise regressions ($p = 0.10$) is:

$$PCI = 1.453 + 0.005865PA - 0.00291N_2 - 0.0404MAT$$

Where *PA* corresponds to pasture age, N_2 is total nitrogen content, and *MAT* represents mean annual temperature values.

In theory, we would expect a higher PCI in favor of private property, but the results obtained in this project, could not confirm that expectance. Same criteria could be applied to relate pasture management index with PCI. Although private ranches presented higher values in PMI in relation to those with communal type property, this index did show a positive relationship to PCI but not statistically significant.

CONCLUSIONS

The conclusions of the study are:

1. Basal area is a reliable parameter to estimate production in buffelgrass plants. The validated model confirms the studies done by other authors (Christie; 1978; McIvor, Ash, and Cook, 1995) and could be a useful tool to determine successfulness for buffelgrass pastures. The best fitting model between basal area and herbage production was given by the equation:

$$Y = 4.6735 + 0.7191*BA$$

2. Plant production in buffelgrass is negatively affected by population density. Thus, it could be very important to know the response of buffelgrass plants to different forms and intensities of population pressures.
3. Pasture condition index does not reflect a significant relationship with geographical location of rangelands.
4. Pasture condition index does not reflect a significant relationship in relation to land tenure.
5. Suitability for buffelgrass pastures, could decline when the aspect of the land show a tendency to face to the west.
6. As pastures get older, the components of the PCI such as vegetation and soil attributes tend to be improved in terms of suitability for buffelgrass, and/or the ranchers get more experience in managing the pastures.

7. After computing stepwise regressions (p = 0.10) with 35 independent variables, only three were statistical significant related to PCI: pasture age, total nitrogen content, and mean annual temperature.
8. Suitability rates for buffelgrass pastures in central areas in Sonora, Mexico, can be defined by the mathematical expression:

$$PCI = 1.453 + 0.005865PA - 0.00291N_2 - 0.0404MAT$$

Where *PA* corresponds to pasture age, N_2 is total nitrogen content, and *MAT* represents mean annual temperature values.

9. There exist a positive correlation between pasture management and buffelgrass plant production. This relationship leads us to conclude that pasture management is an important factor to consider in any study related to buffelgrass pasture production and in any decision making about pasture managing and administration. This is evidence that buffelgrass pastures can be established and preserved for long periods of time if appropriate management activities are performed in the grazing allotments. Pasture mismanagement (i.e. overgrazing) causes buffelgrass failure.
10. This research is an important contribution to range management in Mexico because it can help to decide on suitable areas to establish buffelgrass pastures avoiding the impact of inappropriate sites for that kind of land use conversion. In addition, this study can be useful to define the tendencies of buffelgrass pastures after monitoring the grasslands status at different periods of time.

11. The PCI suitability model must be used by range managers (owners and/or technicians) to identify actions to improve pasture conditions.
12. The PCI suitability model can be improved with more information obtained at different periods of time.

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