Effects of Clearcutting on Forage Production, Quality and Decomposition in the Caatinga Woodland of Northeast Brazil: Implications to Goat and Sheep Nutrition

Robert D. Kirmse
Utah State University

EFFECTS OF CLEARCUTTING ON FORAGE PRODUCTION, QUALITY AND DECOMPOSITION IN THE CAATINGA WOODLAND OF NORTHEAST BRAZIL: IMPLICATIONS TO GOAT AND SHEEP NUTRITION

by

Robert D. Kirmse

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ABSTRACT

Effects of Clearcutting on Forage Production, Quality, and Decomposition in the Caatinga Woodland of Northeast Brazil: Implications to Goat and Sheep Nutrition

by

Robert D. Kirmse, Doctor of Philosophy

Utah State University, 1984

Major Professor: Dr. Frederick D. Provenza
Department: Range Science

Clearing of trees from the so-called caatinga woodland that characterizes the vegetation of the semi-arid region of northeast Brazil offers possibilities for increasing forage production. This research analyzed the first-year effects of clearing caatinga on dry season forage for goats and sheep. In addition, factors affecting litter decomposition on cleared and uncleared caatinga were assessed to evaluate the viability of deferring grazing of forages during the wet season for use later in the dry season.

Removing the trees resulted in a sixfold increase in production of herbaceous vegetation, however, 88 percent of the increased yield on the cleared areas was in the form of stems from herbaceous vegetation. Seventy-two percent of the stems were unpalatable to goats and sheep because of the massive size of those stems. Leaf litter from trees was an important component of the diets of goats and sheep during the dry

season and clearing reduced production of this forage threefold.

Clearing resulted in increased decomposition of leaf litter. Changes in microclimate played only a minor role in this difference. The reduction in the amount of leaf litter from trees relative to litter from herbs had the greatest effect on decomposition rates of dry season forage because tree litter decomposed less rapidly than did herbaceous litter. The slow decomposition of leaf litter during the dry season suggests that deferment of cleared or uncleared caatinga for use as forage in the latter part of the dry season is feasible.

An analysis of the diets of esophageally fistulated goats and sheep indicated that clearing may be a viable alternative for improving the amount and the in vitro dry matter digestibility of the forage consumed during the dry season the first-year post-treatment. These increases were attributed to an absolute greater abundance of preferred herbaceous forages (i.e., foliage and leaf litter) and to the persistent green foliage on coppicing woody plants. Dietary nitrogen appeared to limit intake, and clearing did not improve availability of this nutrient to sheep and goats at the higher levels of grazing pressure applied in this study. Other ecosystem considerations such as watershed protection and long-term community stability must also be considered in decisions to remove the tree canopy of the caatinga.

(165 pages)

CHAPTER I

INTRODUCTION

Significance and Statement of the Problem

Caatinga is the general vegetation type of the semi-arid northeastern part of Brazil. This vegetation type covers approximately 830,000 km^2 of the region referred to as the Northeast and constitutes about 10 percent of the total surface area of Brazil. The vegetation of Ceara state, the location of this research program, is primarily caatinga except for a thin strip of more humid littoral vegetation along the coast of the Atlantic ocean and occasional inland mountain ranges. Generally, caatinga is composed of deciduous trees and shrubs with an understory of annual herbs. More specifically, however, caatinga refers to a wide range of woody vegetation types that have not been completely classified, and species composition and densities vary greatly within small areas and from one district to the next (Bucher 1982).

The climate of the Northeast is characterized by distinct wet and dry seasons. The dry period begins about July and can last 6 to 11 months. Rainfall distribution is highly erratic and it is not unusual for a season's total precipitation to fall within a few days in sudden downpours. During the dry season the herbaceous vegetation withers and the woody species lose their leaves.

This harsh environment imposes severe limitations for agricultural endeavors. Shallow soils, combined with periodic droughts, make cultivation a tenuous prospect (Christiansen-Weniger 1977). Cotton, corn, and beans are the major crops cultivated by small land holders; however, production of sheep and goats under extensive grazing programs is an integral component of the mixed-farming system of the region (Gutierrez et al. 1981) and provides a source of dietary protein and a cash reserve for subsistence farmers (Primov 1982). The 9 million goats and 6 million sheep in northeastern Brazil represent 92 and 30 percent, respectively, of the total number of these animals for the entire country (Anuario Estatistico do Brasil 1981). These small ruminants are dependent on vegetation from the native ranges for survival and production. The seasonality of rainfall and periodic droughts, however, place severe constraints on the dry season forage supply and resultant production of these small ruminants.

Various management methods have been proposed for improving livestock nutrition during this critical time of the year. Cutting and burning of the woody vegetation is the most common management practice for increasing forage production in the caatinga (Johnson 1971, Christian-Weniger 1977, Mason 1980, Gutierrez et al. 1981). This practice is supported by the Brazilian rural extension service (EMBRATER) and the Banco do Nordeste do Brasil which provides loans for agricultural development in the Northeast (BNB 1982). EMBRATER/EMBRAPA (1980) and EMBRAPA (1982) maintain that clearing increases the carrying capacity by 50 percent. The prevalent belief in the Northeast is that a reduction in woody plant density increases livestock production by favoring the production of annual vegetation. An increase in herbaceous vegetation after reducting the tree canopy has been documented in similar climatic zones of the world as well as in Northeast Brazil (Araujo Filho et al. 1982). Little quantitative information exists, however, on how clearing affects the quality and quantity of the dry season forage for the grazing animal. Additionally, most of the available forage during the dry season on caatinga rangelands is in the form of leaf litter and no information is available on its value, persistence, decomposition, and palatability to livestock.

Purpose and Objectives

This study addressed a management question: does clearing of the woody plants on caatinga rangelands result in improved forage conditions for livestock production? The study was designed to answer this question by assessing the relative production, nutritive value and decomposition of native forages growing on cleared and uncleared sites. Specific emphasis focused on changes in the quantity and quality of the dry season forage reserves during the first year after clearing.

The specific objectives were:

1. To determine the production of forage in response to clearcutting, and the nutritive value of this vegetation for goats and sheep during different times of the year.
2. To determine the value of the dry season forage reserves to goats and sheep as influenced by clearcutting and grazing pressure.
3. To determine the effects of clearcutting on leaf litter production and decomposition.

The experiments and results for each of these objectives are presented independently to quickly facilitate publication, as a result there is a certain degree of overlap.

CHAPTER II

LITERATURE REVIEW

Effects of Clearcutting on Forage Quantity

In their review of the literature, Eiten and Goodland (1979) were unable to find published studies on vegetation responses to clearcutting caatinga. Since their review I have found only one published study by Araujo Filho et al. (1982) on herbage response to clearing caatinga in Ceara state. This study found a fivefold increase in herbaceous yields, and a fourfold increase in carrying capacity. The caatinga is highly diverse, however, and the sites studied by Araujo Filho et al. (1982) near Quixada, Independencia, Iraucuba, and Alto Santo are different from the caatinga near Sobral.

The general purpose of brush clearing in semi-arid areas of the world is to increase forage production. This increase is usually expressed in terms of increased dry matter yields from the herbaceous vegetation. The greater yields are generally attributed to reduced competition for the basic resources required by plants. Powell and Box (1979) noted that brush control technology in Texas has advanced to a degree that the producer is reasonably assured of increased herbage production, assuming favorable growing conditions. This is not be the case for Northeast Brazil or other semi-arid areas of the lesser developed world where limited research information is available. The following review of research pertaining to scrub-woodlands of the world provides background on herbaceous responses to brush clearing in semi-arid environments and guidance for areas in which research is critically needed.

The response of herbaceous plants to reductions in the density of the woody species has been extensively studied in the semi-arid woodlands of western United States. Control of honey mesquite (Prosopis glandulosa) and huisache (Acacia fornesiana) in south Texas resulted in from 14 to greater than 200 percent increases in herbage yield (Box and White 1969, Scifres et al. 1976, Scifres et al. 1982, Jacoby et al.1982). Herbel and Gould (1970) obtained a fivefold increase in perennial grass production with the control of mesquite dominated rangeland in New Mexico. Reducing the density of the overstory on pinyon-juniper chaparral of Colorado, Arizona, New Mexico and Utah has resulted in a variety of responses in herbaceous production. Researchers have reported no increases on poor sites with low woody plant density, and greater than 600 percent increases in the native herbaceous vegetation on productive sites (Arnold et al. 1964, O'Rourke and Ogden 1969, Aro 1971, Clary 1974, Clary and Jameson 1981). Reductions in the density of blue oak (Quercus douglasii) in the woodlands and savannas of California have resulted in increases in herbage production ranging from 100 to 650 percent (Johnson et al. 1959, Murphy and Crampton 1964, Burgess and Leonard 1979).

Studies in semi-arid tropical woodlands of Africa and Australia have also shown increases in herbaceous plant yields with woody canopy reductions. For example, Pratt and Gwynn (1977) cited unpublished work by Bunderson in the Commiphora woodland of Kenya where a reduction in the density of the woody vegetation resulted in a 77 percent increase in herbage yields. A reduction in the density of a Tarchonanthus/Acacia thicket in the Rift Valley of Kenya resulted in a

219 percent increase in production of herbaceous vegetation (Pratt and Knight 1971). Pratchett (1978) found a 16 percent increase in herbage growth after clearing a semi-arid woodland in Botswana. Barnes (1979) reported increases ranging from 134 to 443 percent after clearing semi-arid savannas of east and southern Africa. Reduction in the Brachystesia/Isoberlinia woodland canopy of Zimbabwe resulted in a 210 percent (four year average) increase in grass production (Ward and Cleghorn, 1964). Herbicidal control of the woody vegetation in an Acacia/Commiphora brushveld community in South Africa resulted in 50 to 500 percent increases in grass yields (Van Niekerk et al. 1978). Thinning of trees and shrubs in a Eucalyptus populnea shrub woodland in Australia resulted in a maximum herbage increase of 217 percent and there was an inverse curvilinear relationship between tree and shrub biomass and herbage production (Walker et al. 1972). They found that trees had a greater effect on herbage production than did shrubs. Beale (1973) also found an inverse curvilinear relationship (concave) between basal diameter of trees and herbage production in a mulga (Acacia aneura) scrub type in Australia.

Some broad generalities and research priorities can be derived from the review of these works:

1. Herbage response to brush clearing is highly variable from one semi-arid community to another and from one year to the next. The factors that most affect response are degree of canopy cover (O'Rourke and Ogden 1969), site potential (O'Rourke and Ogden 1970, Dwyer 1975, Clary et al. 1974), competition for available soil moisture and nutrients, availability of seeds from native herbaceous vegetation

(Clary 1971, Dwyer 1975), amount of current year's rainfall (Ward and Cleghorn 1964, Burgess and Leonard 1967, O'Rourke and Ogden 1969), and the time since clearing.

2. Grasses tend to increase in greater proportion than forbs (Clary and Jameson 1981), and, in a study conducted in Texas (Scifres et al. 1982), warm- season grasses increased relative to cool-season grasses. Changes in the botanical composition of the herbaceous layer have implications for the nutrition of the grazing animal as well as for decomposition rates. No consistent trend in forage quality is evident from the few studies that report changes in botanical composition. This is probably due to the limited availibility of research information.

3. Livestock management recommendations based only on total herbaceous yields may neglect the potential importance of browse. Scifres (1980) maintains that brush management has traditionally been practiced to favor "desirable" over "less desirable" species by minimizing competition between them. For most classes of domestic livestock trees and shrubs are generally considered to be of lower feed value than grasses and forbs. Powell and Box (1979) pointed out that a negative attitude existed toward shrubs early in the twentieth century. They noted, however, that this philosophy began to change in the 1960's. Interest in the value of trees and shrubs as dry season forage reserves on semi-arid rangelands is growing (eg., Kelly 1977, Beale 1973, Le Houerou 1980, Torres 1983), but research data are scarce.

4. Studies on the effect of brush removal on livestock nutrition are critically deficient. Increases in herbage production do not necessarily cause improved animal nutrition.

5. I was unable to locate studies that consider the effects of clearing on the decomposition rates of the leaf litter (herbaceous or tree) during the dry season in semi-arid woodlands. In areas with heavy trampling, high winds, and deciduous species, decomposition rates may deplete this critical dry season forage reserve.

Effects of Clearcutting on Forage Quality

An increase in total herbaceous biomass as a result of brush control does not necessarily result in improved livestock production. This is especially true if the increase in dry matter yields is of low nutritional quality for or poorly palatable to the grazing animal (Beaty and Engel 1980).

Powell and Box (1979) observed that almost anything that affects plant growth will influence nutritional quality. Changes in the microclimate affect plant growth and tree canopies moderate microclimate. Due to the effects of crown cover, maximum temperatures are lower, minimum temperatures are higher and wind speeds are reduced as compared with open areas (Barry and Chorley 1982). Pratchett (1978) found brush cover reduced noontime temperatures by 2-3°C. Relative humidity is also moderated, and was 3-10 percent higher under a birch-beech-maple forest compared with an open area during summer (USDA yearbook 1941,as reported by Barry and Chorley 1982).

Shading by tree or shrub canopies is an important feature in woodland microclimates. In dense hardwood forests of the United States, 80 percent of the incoming short-wave radiation may be intercepted by crown cover, and in tropical forests in Africa as little as 7.6 to 0.1 percent of the total short-wave radiation reaches the forest floor (Barry and Chorley 1982). Because leaves are a major interceptor of short-wave radiation in a forest, a deciduous forest in a leafless state may intercept less than 30 percent of the incoming radiation (Barry and Chorley 1982).

Changes in microclimate as well as reduced competition for available soil moisture and nutrients from the woody species have direct and indirect effects on the nutritive value of the herbaceous vegetation. Direct effects involve chemical and morphological modifications of the herbaceous plants and indirect effects include changes in the botanical composition of the community.

The maturation rates of annual and perennial plants are accelerated with increased temperatures and solar radiation (McCloud and Bula 1973, Ford et al. 1979). Beaty et al. (1978) and Cook and Harris (1950) observed increases in the proportions of stems to leaves with maturation. The leaf:stem ratios of herbaceous vegetation are generally accepted as an index of forage quality and leaves are generally higher in nutritive value (Van Soest 1982) and are more palatable than stems (Arnold 1964).

The nutritive value of forage is a consequence of the conditions of plant growth (Van Soest 1982). In xeric conditions, plants tend to produce relatively more soluble than structural carbohydrates (Van Soest 1982). Most researchers working with tropical grasses have found a decrease in digestibility with increased temperatures (Deinum et al. 1968, Minson 1971, Wilson et al. 1976, Deinum and Dirven 1975). Minson and Wilson (1980), in a review of controlled environment studies of tropical and temperate grasses, found an average decrease in dry matter digestibility (DMD) of 0.6 percentage units for each degree Celsius increase in ambient temperature. Wilson (1982) concluded that temperature is the most important environmental factor affecting nutritive quality.

Deinum and Dirven (1975) believe the decline in digestibility generally found with increasing temperatures is a result of increased cell wall (CW) content. Van Soest (1982) maintains the decrease in digestibility with increasing temperatures is caused by two factors. First, an increase in temperature accelerates the enzymatic activity associated with lignin biosynthesis such that the cell wall becomes more highly lignified. Second, high temperatures increase metabolic activity so that the cellular contents (nitrate, protein, and soluble carbohydrate) are depleted at the expense of the structural material. Higher temperatures have also been shown to decrease the leaf:stem ratio (Stobbs 1975) which would increase the total amount of cell wall in a plant and decrease its digestibility (Wilson et al. 1976).

Most of the literature on the influence of temperature on forage quality concerns grasses, and the herbaceous community in the caatinga is composed primarily of forbs. Wilson and Minson (1980) determined that the digestibilities of legumes are less affected by temperature than those of grasses. Anatomical differences in the number of vascular bundles and sites for lignification may be factors contributing to this difference. I have found no published information on the effect of temperature on forbs, however, Van Soest (1982) discussed the results of a controlled temperature experiment conducted on alfalfa by Faix

(1974). There was no change in the digestibility of the leaves of alfalfa, which Van Soest attributed to their lack of structural function. Stems, on the other hand, decreased in digestibility in response to increased temperature.

The amount of solar radiation also influences the chemical composition of herbaceous vegetation. Field studies that assess the effects of shading, however, generally have confounded solar radiation and temperature. Van Dyne and Heady (1965), working on an annual grass range in California, found lower lignin in plants growing with full sunlight than in plants growing under shade. In their review of environmental factors influencing forage quality, Laycock and Price (1970) gave examples of decreased lignin and increased soluble carbohydrate percentages of plants grown in full sunlight as compared with those grown under shade. Plants growing in shade tend to be higher in crude protein than those growing in full sunlight (Fisher et al. 1959 as cited in Powell and Box 1979, McEwen and Dietz 1965, Holland and Morton 1979, Grossman et al. 1980).

Van Soest (1982) offers a possible explanation for these differences in forage quality as influenced by different levels of solar radiation. He explains that greater sunlight intensities accelerate the anabolism of non-structural carbohydrates, amino acids and organic acids. The lower percentages of CWC reported under full sunlight are probably the result of a greater proportional accumulation of cellular contents over structural material. Van Soest (1982) also believes that the lower crude protein content under full sunlight may be due to an accelerated rate of nitrate reduction for amino acid synthesis.

Wilson (1982) citing work on a tropical grass by Wong (1978) suggests that the stem elongation characteristic of grasses growing under shaded conditions could also contribute to lower forage digestibility. Allden and Whittaker (1970), however, found that bite size and forage intake increase with increasing tiller length.

Assessment of Forage Quality

The nutritive value, or quality, of a forage refers to its digestible nutrient and energy availability to a particular animal. Chemical analyses of hand-harvested samples representative of the average available forage on a pasture are a gross indication of the chemical composition of the plant community but may not be a good predictor of its nutritive quality to the grazing animal. Because animals select forages of higher nutritive value than the average quality of the forage on offer (Weir and Torell 1959, Arnold 1964, Van Dyne et al. 1980), a more accurate measure of pasture quality involves assessing the actual diet selected by the animal. This type of information is generally lacking on the world's rangelands (Van Dyne et al. 1980) and is particularly scarce for brush management studies. Knowledge of the specific plant species and parts in the diet is required to help explain modifications in feeding behavior and the chemical composition of diets. More importantly, however, an assessment of diets provides an indication of the most important plant species for which to manage. An understanding of the potential change in the nutritional quality of diets as influenced by brush control is essential for planning efficient livestock production.

The animal performance variables most commonly measured in grazing research on rangelands is weight change (Dahl 1982) which is a reflection of the quality and quantity of forage ingested (t'Mannetje et al. 1976). Intake is an equally important variable but is less often determined because of the cost and difficulty involved. The assessment of intake is desirable because of the positive linear relationship between herbage consumption and livestock gain (Matches et al. 1981, Hodgson 1981). The amount of feed ingested is a basic aspect of nutrition as it determines the nutrients available to an animal for maintenance and production (Van Soest 1982, Minson et al. 1976).

The nutritional quality of a forage influences intake and animal gain by its effect on rumen function (Zimmerman, 1980). The chemical composition of a diet is an important parameter, therefore, in explaining intake and animal weight response. The most significant and commonly used measures of diet quality are forage digestibility, crude protein, neutral detergent fiber (cell wall constituents), and lignin.

Energy is probably the most limiting nutrient for animal production on native rangelands (NAS 1975). Dry matter digestibility (DMD) can be used as an index of energy available for metabolism on grass pastures because of the good linear relationship between DMD and digestibile energy (Moir 1961, Minson et al. 1976, Rittenhouse et al. 1971). I am not, however, aware of similar published relationships for forb and browse pastures.

There is also a good relationship between DMD and forage consumption whereby low digestibilities depress intake (Blaxter et al. 1961). Owen-Smith (1982) suggests, however, that the rate of digestion, which is primarily controlled by the plant cell wall (CW)content, may be more important than the total digestibility of a forage for its nutritional value to a ruminant. Van Soest (1982) also maintains that the content of cell wall, as expressed by the neutral detergent fiber (NDF) assay, and its degree of lignification are the most important factors determining nutritive value. Generally the correlation between plant cell wall and intake (r=-0.83) is higher than the correlation between digestibility and intake (Osbourne et al. 1974).

McCammon-Feldman (1980) and Van Soest (1982) present convincing evidence that the amount of cell wall in a forage and its effect on the time required for rumination is an especially critical factor for limiting forage consumption by small ruminants. They argue that, relative to large ruminants, small animals such as sheep and goats probably must ruminate each gram of cell wall longer to reduce the size of particles enough to pass through their smaller sorting and filtering mechanisms. The longer retention time and limited rumen capacity of the small ruminant apparently restricts the amount of forage consumed. They also point out that small ruminants require a proportionally greater amount of energy per unit of body size than large ruminants and are therefore less capable of meeting energy requirements on high fiber diets. Sheep and goats, therefore, must be able to select forages containing either low cell wall or highly digestible cell wall, or both, in order to meet energy requirements.

Crude protein (CP), another important nutrient entity, is a principal constituent of animal tissue and is therefore continuously required for cell function (NAS 1981). Low levels of CP can limit intake by depressing rumen function (NAS 1981). Rumen bacteria require a minimum of 6-8 percent crude protein for efficient fermentation of plant material (Van Soest 1982). The NAS (1981) has set this minimum level at 6 percent for goats. Barton et al. (1976) determined that protein was a good predictor (r=0.90) of *in vitro* dry matter digestibility of tropical grasses.

Effects of Clearcutting on Leaf Litter Production and Decomposition

Pfister (1983) observed that the disappearance of leaf litter through the dry season on a native caatinga site was caused by weathering, decomposition, trampling, and consumption by livestock. An understanding of the relative rates of weathering and decomposition of leaf litter on both cleared and uncleared caatinga is required to determine potential advantages or disadvantages to clearing for dry season forage reserves. This information will also help direct management decisions on grazing methods to minimize waste of feed reserves (Malechek 1982).

Decomposition rates are affected by the microclimatic changes discussed earlier. Clearing of forests is generally believed to increase the rates of organic matter decomposition because of increases in temperature and humidity (Spurr and Barnes 1980, Binkley 1984). Very little information is available on microclimatic modifications or decomposition rates as influenced by clearing semi-arid woodlands. A review of the literature indicated that most research on litter decomposition has been conducted in more mesic areas of the world (Meentemeyer 1977). Based on these studies moisture is the most important factor affecting decomposition. Moser and Olsen (1953) and Bocock et al. (1960) found that as litter dries the activity of decomposer organisms slows, and Fogel and Cromack (1977) found a direct relationship between decomposition rate and the water content of litter. Witkamp and Van Der Drift (1961) maintain that moisture and temperature are the most important factors influencing litter decompositon.

Differences in chemical composition (i.e., substrate quality) between woody and herbaceous foliage can also result in different rates of decompositon, and reducing the overstory canopy alters the balance of woody to herbaceous foliage. In southeastern Rhodesia, Kelly and Walker (1976) observed that leaf litter from trees was more persistant than grass litter. Edwards (1977) and Heath et al. (1966) noted that fibrous leaves decompose less rapidly than 'soft' leaves. No quantitative information is available, however, for plant species in the caatinga.

Another consideration relative to decomposition rate is the difference in chemical composition of the annual vegetation found under the canopy versus that growing in the cleared areas. As noted above, herbaceous vegetation growing under shade has been reported to have a different chemical composition than that growing infull sunlight (McEwen and Dietz 1965, Van Dyne and Heady 1965, Holland and Morton 1979, Grossman et al. 1980). Although they were studying tree leaf litter, Witkamp and Van der Drift (1961) observed a difference in form and structure of sun and shade leaves that influenced the relative rates of decomposition.

When attempting to speculate on forage decomposition under cleared and uncleared caatinga, and the potential effects on sheep and goat nutrition, several conflicts are apparent. Nitrogen is an important factor especially in the initial phases of plant decomposition (Bocock, 1964, Anderson 1973(b), Hunt 1977). The annual forbs, favored by clearing the woody canopy, should be nutritious during the wet season, partially because they contain relatively high nitrogen levels. As a result of higher nitrogen levels, however, these forbs may also be subject to more rapid decay than tree leaves which are relatively lower in nitrogen and higher in polyphenols.

Tannins and lignins are the two most common polyphenols produced by trees, and both retard the decomposition process (Edwards and Heath 1963, Basaraba and Starkey 1966). Lignin apparently inhibits the abilities of microorganisms to digest cell wall cellulose and cell contents (Van Soest 1982). Tannins may inactivate digestive enzymes by binding with amino acids (Rhodes 1979). Although polyphenols may decrease the decomposition rates of tree foliage, they may also decrease the palatability and nutritional value of the leaves; at present the ecological role of tannins is poorly understood.

Lignification of grasses generally increases with higher temperatures but decreases with increasing light. Clearing the caatinga may result in higher temperatures and insolation. I do not know how annual forbs react to microclimatic changes, nor do I know if the effects of temperature or light take precedence. If temperature is the most important microclimatic influence as Deinum and Dirven (1973) maintain, lignin levels could rise in herbaceous vegetation on the cleared areas. Although higher levels of lignification would retard decomposition rates (Van Cleve 1974, Fogel and Cromack 1977) it would also decrease forage quality.

CHAPTER III

STUDY AREA

The EMBRAPA (Brazilian Federal Agricultural Research Agency) National Goat Research Center (CNPC) in the municipality of Sobral, in the state of Ceara is the location of this study. The research center is 3.5°south latitude, 41°west longitude at an elevation of approximately 78 m. The 30 year average precipitation in Sobral is 750mm. There were 705 mm of rainfall measured during this study (Fig. 1). Temperatures are consistently high with little seasonal variation. The average daily temperatures for the Northeast range from 22°C during the rainy season to 28°C during the dry season (Anuario Estatistico do Brasil 1972). Appendix Figures 24 and 25 present temperatures and relative humidities recorded on cleared and uncleared portions of the research area during the period of April, 1982 through March 1983. The relative humidity on native caatinga during the dry season ranges from a high of about 90 percent during early morning hours to about 35 percent in the afternoon.

The research site was dominated by a relatively old (in terms of caatinga vegetation) mixed species stand of pau branco (Auxemma oncocalyx), sabia (Mimosa caesalpiniaefolia), and catingueira (Caesalpinia pyramidalis). Based on observations of local residents, the trees had not been cut for at least 50 years. I attempted to confirm this observation by counting tree rings, however, there were no clearly defined rings for determining age of the stand. At the initiation of the study the tree canopy was nearly 80 percent (visual

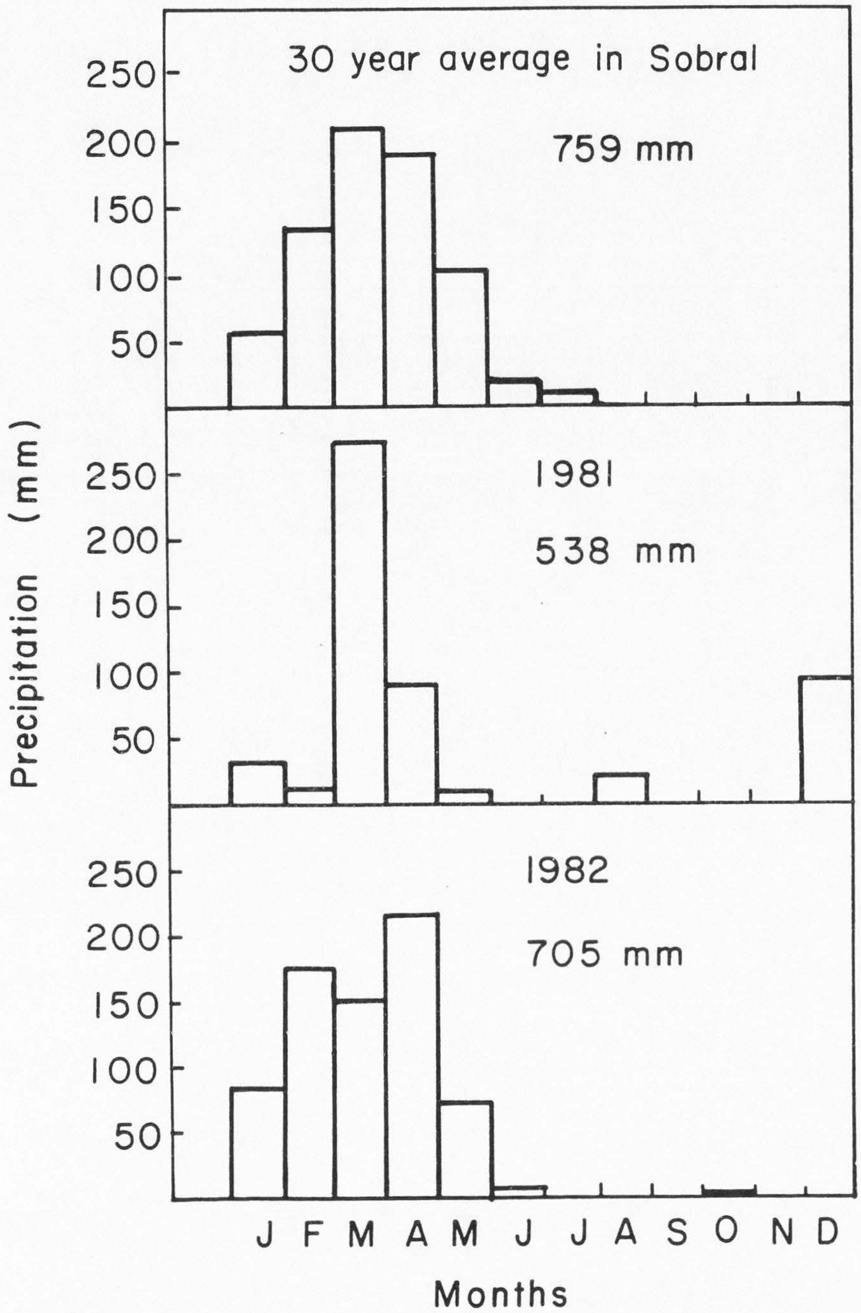

Figure 1. The 30 year average rainfall in Sobral, Ceara, and the 1981 and 1982 rainfall on the research area in the caatinga woodland near Sobral.

estimation) with approximately 2,570 trees per hectare. The most important trees and their densities are listed in Appendix Table 5. Descriptions of the major trees of the area are provided by Kirmse et al. (1983). Some of the major herbaceous species and their relative frequencies before and after clearing are listed in Appendix Table 6.

Mr. Augmar Ramos, EMBRAPA soil scientist, found four soil types represented on the research area (Appendix figure 26). Mr. Ramos noted that great soil variation is typical of the Northeast. Despite the variety of soils on the study area the A horizon is uniformly shallow 19.8 cm $\pm$5.4 cm (mean $\pm$ SD) and water storage is low. There is a pronounced clay concentration in the B horizon. The regolith or C horizon is also shallow, from 22 to 56 cm. Bedrock is gneiss of precambriam origin. Topography is gently undulating and surface drainage is rapid.

A homogeneous 6.48 hectare exclosure was established within a 45 hectare pasture. The exclosed area (Fig. 2.) was divided into 3 blocks, measuring 1.44 ha each. Half of each block was cleared providing three replications of two treatments (cleared versus uncleared). The clearing was conducted from December 16, 1981 to January 20, 1982 in the traditional fashion for harvesting firewood. Trees were cut at approximately 40 cm and all firewood (271 $m^3 \cdot ha^{-1}$) was removed from the site. Following removal of the utilizable wood, the slash was piled and burned. The research area was fenced to exclude grazing, and each treatment replication was split (fenced) to provide a grazed and ungrazed paddock. A cleared and an uncleared area were reserved within the exclosure as animal adaptation areas for the nutrition studies.

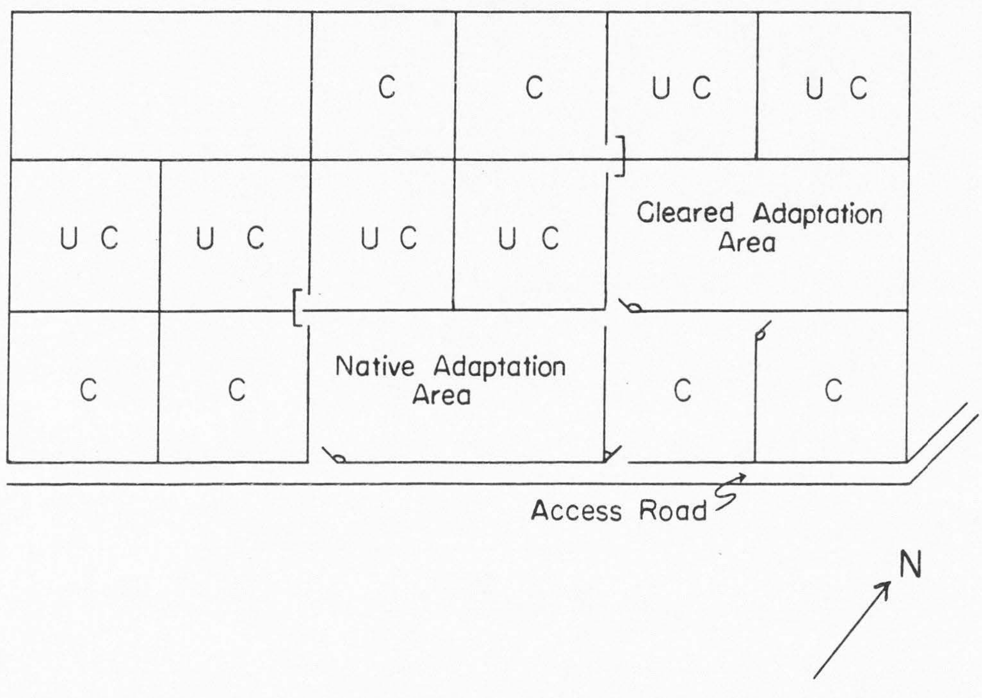

Figure 2. Study area. C represents the cleared paddocks and UC represents the uncleared.

CHAPTER IV

EFFECTS OF CLEARCUTTING CAATINGA WOODLAND ON FORAGE PRODUCTION AND QUALITY IN NORTHEAST BRAZIL

Introduction

Cutting and burning of woody vegetation in the caatinga is the most common range improvement practice in Northeast Brazil (Johnson 1971, Christiansen-Weniger 1977, Mason 1980, Gutierrez et al. 1981). As in other areas of the world, brush management has traditionally been practiced to favor "desirable" over "less desirable" species by minimizing competition for sunlight, moisture and nutrients (Scifres 1980). The prevalent belief in the Northeast is that clearing increases livestock carrying capacity by increasing the production of annual vegetation. While most studies in semi-arid woodlands have reported impressive increases in yields of herbaceous vegetation following a reduction in the overstory canopy (e.g., Pratt and Knight 1971, Walker et al. 1972, Pratchett 1978, Van Niekerk et al. 1978, Barnes 1979), high forage yields do not necessarily result in improved animal production (Beaty and Engel 1980). This is especially true when the increase in dry-matter production is concentrated in the stem component of the plant or when the nutritive value of the plant community is reduced.

McKell (1980) suggested that the large increases in herbaceous yields following reductions in the woody canopy have caused browse plants to be considered undesirable competitors. In Northeast Brazil, removing the woody vegetation to favor herbaceous production is endorsed by the Brazilian rural extension service (EMBRATER/EMBRAPA 1980) and the Banco do Nordeste do Brasil (BNB 1982) which provides loans for agricultural development. Although information is critically lacking on the fodder value of shrubs and trees, there is growing interest in the potential value of woody perennials for livestock nutrition in the semi-arid tropics (Le Houerou 1980). In woodlands such as the caatinga that are dominated by an annual herbaceous understory, the value of browse may take on a more important role as a dry season fodder since the dry grasses and forbs are low in nutritional value and deteriorate rapidly (McKell 1980, Malechek and Provenza 1983). Woody perennials are also well adapted to arid environments and their productivity is less adversely affected by drought than is the annual herbaceous vegetation (Malechek 1982, Smith and Silcock 1984, Jacoby 1984).

This study investigated the potential advantages and disadvantages of reducing the woody caatinga canopy on small ruminant nutrition. specific objectives are to determine the effect of clearing on 1) herbage standing crop through the season, 2) chemical composition of the clipped annual herbaceous vegetation, 3) nutritive value of the forage to goats and sheep through the season, and 4) botanical composition of goat and sheep diets.

Methods

Herbage response

Determinations of herbaceous standing crops began with the onset of the rains in March 1982 and were repeated on a monthly basis through the dry season which ended in December 1982. All vegetation sampling was done on the ungrazed section of the research area (Fig. 2). Variability in the standing crop was higher on the cleared area than on the uncleared area, and the degree of variability changed through the seasons, generally decreasing in the dry season. As a consequence, variable sample numbers were used for the two treatments and through the season. At each monthly interval, 10 to 20 quadrats (50 by 60 cm) were harvested at random within each cleared replicated paddock, and 10 quadrats were sampled within each uncleared plot. All herbaceous vegetation that projected within the quadrat (including those rooted outside) was clipped at ground level, sacked separately, and dried in a forced air oven at 65°C for 48 hours. In the laboratory the vegetation was separated into leaf and stem and weighed. An unbalanced analysis of variance (statistical package Rummage, Bryce 1980) was used to analyze the data.

Because the research area was small it precluded the use of destructive methods to determine leaf litter production from woody plants. Since the woody species are deciduous and because the research area was not grazed, it was possible to sample leaf production from the ground after abscission. Sampling leaf litter, rather than green foliage on the stem, is preferred because this is the form in which browse is most readily available and utilizable by livestock in the caatinga.

Sampling of leaf litter from woody species began at the onset of leaf fall in July of 1982 and continued on a monthly basis through the end of the dry season in December of 1982. Sample procedures involved collecting all the present-year leaf litter from 10 randomly placed quadrats (50 x 60 cm) on each ungrazed paddock. The litter samples were separated by species, dried as above and weighed.

Chemical composition

Samples of the leaf and stem fractions of the herbaceous vegetation clipped during the March, May, and July collection periods were pooled by month and treatment, across replications. These samples represented the average herbaceous foliage and stem on offer to livestock. These leaf and stem components were analyzed separately to avoid the confounding effect different leaf:stem ratios may have on the results (Bailey 1973). The samples were ground through a 20 mesh $\cdot$ cm^{-1} screen and analyzed for crude protein (AOAC 1975), fiber and *in vitro* dry matter digestibility (Goering and Van Soest 1970).

Diet quality

Chemical analyses of clipped samples representative of the average available on a pasture provide a gross indication of the changes clearing may have on the chemical composition of the plant community. Grazing animals, however, select forages of higher nutrient quality than the average of that on offer (Weir and Torell 1959, Arnold 1964, McCammon-Feldman 1980, Van Dyne et al. 1980). A more accurate measure of the nutritional quality of the forage produced on cleared and uncleared caatinga is, therefore, an assessment of the quality of the diet selected by the animal.

Indigenous goat and sheep wethers fitted with esophageal fistulas (Van Dyne and Torell 1964), were used to collect representative diets from the cleared and uncleared paddocks of the research area (Fig.2). The goats were the common SRD (sem raca definida-- without definite race or breed) and the sheep were typical of the woolless type of the region.

Extrusa collections began in early March (early wet season) and were repeated monthly until December (late dry season). The fistulates were placed on adaptation paddocks (Fig. 2), that were representative of the plant communities on the research paddocks, two days prior to each collection period. Collections involved sampling diets from each of the paddocks (one day per block). The animals were fasted the night prior to the collection. A sampling day (block) consisted of a 30-minute collection in the early morning with four sheep and four goats assigned to each treatment. The paddocks were ungrazed except for the 30-45 minute collection periods each month. Between collection periods the experimental animals were kept in an adjacent pasture with similar forage.

The extrusa samples were hand-mixed and composited by species of animal, within treatment blocks, for each sample period. Part of each sample was dried at 40°C for 3 days and part was frozen at -17°C. Based on previous findings (Jim Pfister, personal communication), drying at 40°C resulted in biased fiber and digestibility values as a result of Maillard reactions (Van Soest 1982), particularily for the wet season samples. Sufficient sample material was frozen from the April, June, August, and October collection periods to be freeze dried and analyzed for fiber and in vitro organic matter digestibility.

The crude protein content of the extrusa material was determined by a modified Kjeldahl procedure (AOAC 1975). A modified sequential extraction procedure was used for the analysis for neutral-detergent fiber (NDF) and lignin (Robertson and Van Soest 1980). In vitro organic matter digestibility (IVOMD) was determined using the method of Tilley and Terry (1963) as modified by Moore (Harris 1967). The inoculum for goat and sheep samples was obtained from a ruminally fistulated sheep maintained on a diet of alfalfa hay.

Botanical composition of diets

The extrusa from three of the collection periods representing mid-wet (May), mid-dry (October) and late-dry (December) seasons were analyzed for botanical composition. The microscope point technique (Harker et al. 1964), was used for the analysis. Fifty grams of oven-dried material was spread evenly in a 15 x 30 cm tray. The tray was passed under a binocular microscope equipped with a base board and a movable guide rail that established sampling locations within the tray. Readings were made with 15 x magnification at the point of intersect of a cross hair at each of 100 pre-determined coordinates. Plant species and plant parts, as well as unknown species, were recorded. The percent of diet contributed by each plant species was calculated by the formula;

$$\text{Percent in Diet} = \frac{\text{no. hits per species} \times 100}{\text{no. of recognizable hits}}$$

Experimental design

The experimental design for the analysis of the diet quality and botanical composition data was a factoral with treatment (cleared and uncleared) and animal type (goat and sheep). The experiment for diet quality was repeated on four dates. This study focused on comparing cleared and uncleared treatments and not on differences between sheep and goats. In general statistically significant differences between sheep and goats did not exist for the nutritional parameters that I measured. I discussed significant differences where they exist.

Results and Discussion

Herbage response

Removal of the woody canopy resulted in a sixfold increase in standing herbaceous vegetation (Fig 3). Due to the large number of herbaceous species (more than 40) and the asychrony of their phenologies, peak standing crop does not equal total production (Odum 1960). The increased production (standing crop) presumably a result of less competition for soil moisture, nutrients and sunlight on the cleared paddocks corresponds with the findings of researchers in other semi-arid tropical woodlands of the world and with the five-fold

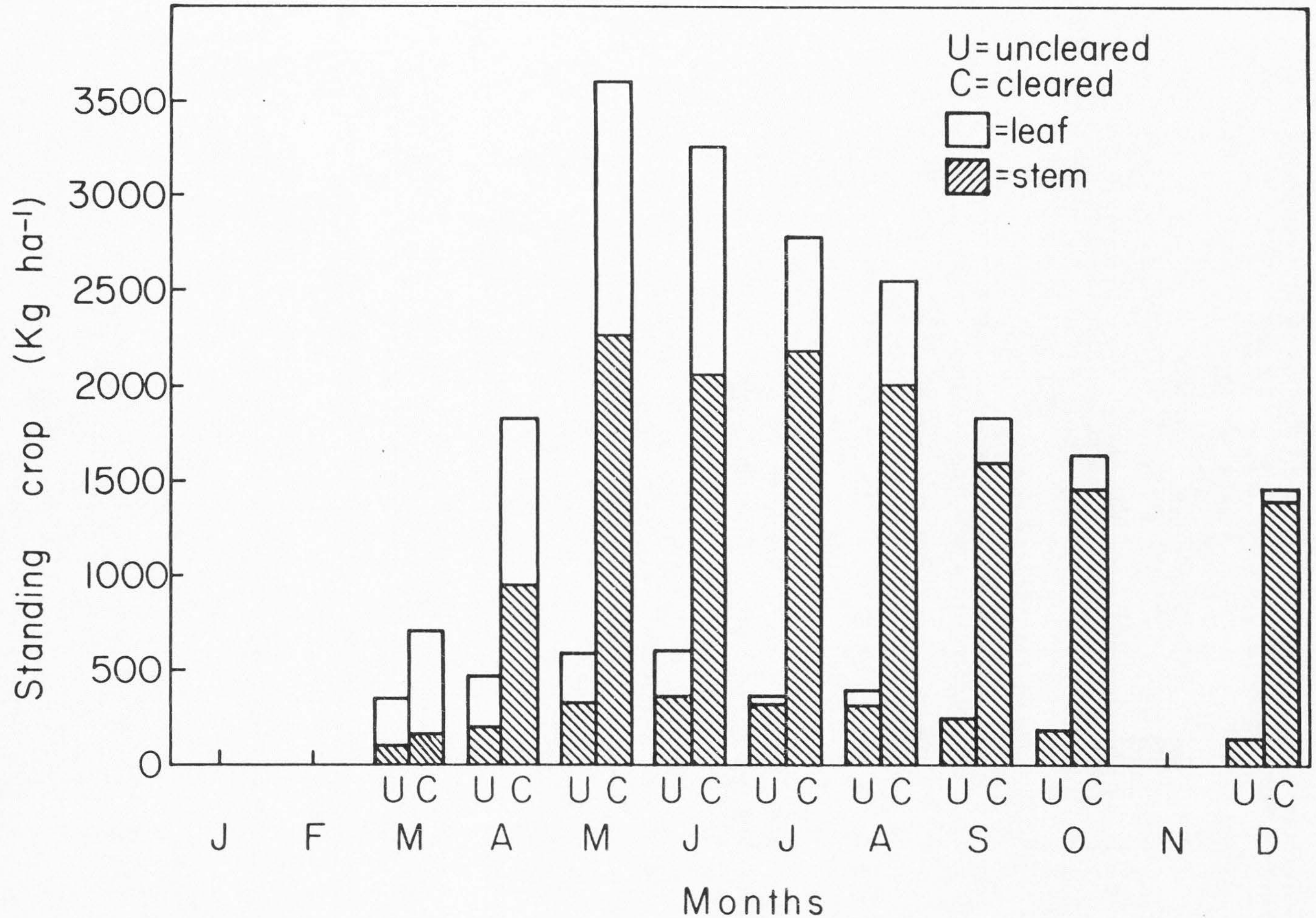

Figure 3. Herbaceous vegetation standing crop on cleared and uncleared caatinga, 1982.

increase on another "native" caatinga site in Northeast Brazil (Araujo Filho et al. 1982).

A major portion (> 88 percent) of this increase, however, was in the form of stem on annual herbs (Appendix Table 7). At peak standing crop the leaf:stem ratio was considerably higher on uncleared than on cleared caatinga. There was a fivefold increase in the average diameter of herbaceous stems on the cleared versus the uncleared areas (Appendix Table 8). Basal diameters of stems of the two major forbs (Blainvillea rhomboindea and Wissadula spp.) averaged 2.5 mm $\pm$ 1 (std. dev.) on the uncleared paddocks and 10.6 mm $\pm$ 4.3 (std. dev.) on the cleared paddocks.

Clearing increased the production of grasses relative to forbs (Appendix Table 9). In the uncleared areas grasses represented 1.3 percent by weight of the herbaceous vegetation while on cleared areas grasses yielded 27 percent of the total herbaceous production. The annual Brachiaria mollis largely accounted for this increase in grass weight. In semi-arid woodlands of the United States, Clary and Jameson (1981) also observed a proportionally greater increase of grasses than forbs after reductions in tree canopy.

Peak standing crop of leaf litter from woody plants ($\pm$ std. error) on the uncleared area was 3,327 kg•ha^{-1} $\pm$ 172 and occurred in September (Table 1). The peak for the cleared area was significantly less (1077 kg•ha^{-1} $\pm$172) and occurred in December. Leaf fall on the cleared areas was from the trees that coppiced and retained their leaves longer into the dry season.

On the uncleared areas in September leaf litter from woody species

Table 1. Herbaceous and tree leaf litter ($Kg \cdot ha^{-1}$) on ungrazed cleared and uncleared caatinga during the dry season, 1982.

Month	Uncleared		Cleared	
	Herbaceous	Tree	Herbaceous	Tree
July	113 ± 39[1]	1065 ± 140	325 ± 39	63 ± 40
August	11 ± 48	2336 ± 172	243 ± 34	285 ± 121
September	60 ± 48	3327 ± 172	347 ± 48	940 ± 172
October	48 ± 48	2970 ± 172	231 ± 48	890 ± 172
December	43 ± 48	2715 ± 172	240 ± 48	1077 ± 172

[1]Mean ± std. error, N = 45 in July and 30 in the other months on the uncleared paddocks; 45 in July, 60 in August and 30 in the other months on the cleared paddocks.

represented 91 percent of the available forage. Herbaceous standing crop (mostly stem) represented only 7 percent and the remaining 2 percent was herbaceous litter. Summing the peak standing crops of the herbaceous vegetation on the uncleared areas with the total woody leaf litter results in a total herbage biomass yield of 3,923 $kg \cdot ha^{-1}$. Likewise, summing the peak yields on the cleared areas results in a total herbage yield of 4,677 $kg \cdot ha^{-1}$, which in light of the standard errors are not significantly different.

Chemical composition

Herbaceous foliage from cleared areas had less ($P<0.01$) crude protein than did the leaves of herbs growing on uncleared areas (Table 2). Other researchers have also found a decrease in crude protein levels in full sunlight relative to shaded conditions (Fisher et al. 1959, McEwen and Dietz 1965, Grossman et al. 1980). This may be due to a faster maturation rate resulting from increased temperature and solar radiation (McCloud and Bula 1973 , Ford et al. 1979). During the growing season (April) the air temperatures on the cleared areas were 3.8 ^{o}C higher than those on the uncleared areas (Appendix Figure 24). The lower crude protein levels found in this study are probably due to a dilution effect by cell wall components that increase with higher temperatures (Van Soest 1982).

The fiber components and IVDMD of the foliage did not show significant differences due to clearing. Clearing apparently had a greater effect on leaf:stem ratios than on fiber, and reduced leaf:stem ratios would increase the total cell wall content of the sun-grown

TABLE 2. Chemical composition and leaf:stem ratios of the herbaceous vegetation [1] growing on the cleared and uncleared paddocks.

	UNCLEARED		CLEARED	
	Leaf	Stem	Leaf	Stem
Crude Protein (%)	12.5c	3.5a	9.3b	3.8a
NDF (%)	42.3a	67.7b	47.4a	69.3b
Cellulose (%)	15.3a	33.9b	17.8a	33.5b
Hemicellulose (%)	12.7a	16.9b	16.5b	19.3b
Lignin (%)	12.4ab	16.4b	11.5a	15.8b
IVDMD (%)	38.2b	25.1a	42.5b	29.0a
Leaf:stem[2]	0.72		0.51	

[1]Primarily forbs (Values averaged for March, May, July).

[2]Ratio at peak standing crop.

[ab] means in the same row, followed by a different letter, are significantly different (LSD, $P<0.05$).

plants. The decrease in leaf:stem from 0.72 to 0.51 after clearing might be attributed to more rapid rates of maturity associated with reduced competition for soil moisture and nutrients as well as changes in sunlight and temperature regimes.

Quality of herbaceous forage declined from the early growing season (March) through senescence (July). The crude protein content of the foliage declined from 13.6 percent in March to 9.3 percent in July ($P<0.05$) on the uncleared areas (Fig. 4). The decline from 12.0 to 5.3 percent on the cleared area was more pronounced. The decline in crude protein levels in the stem fraction was minimal probably because it began with a low level. Digestibilities were also significantly reduced over the season but the magnitude of the decline between cleared and uncleared areas was not significantly different (Fig. 5).

Diet quality

Protein. The decline in the crude protein (CP) contents in the diets of goats and sheep presented in Figure 6 characterizes the dynamic nature of forage in the caatinga. Crude protein levels declined from a high of 15 percent in March (early growing season) to a low of 7.3 percent in December (late dry season). These values were higher than those for hand harvested material (Table 2) and reflect the ability of animals to select for a higher plane of nutrition than the average on offer.

Pfister (1983), studying an adjacent uncleared area the previous year, also found seasonal variations in CP, but to a lesser extent (18 percent in May to 12 percent in December). The high levels of CP observed by Pfister through the dry season were probably a result of

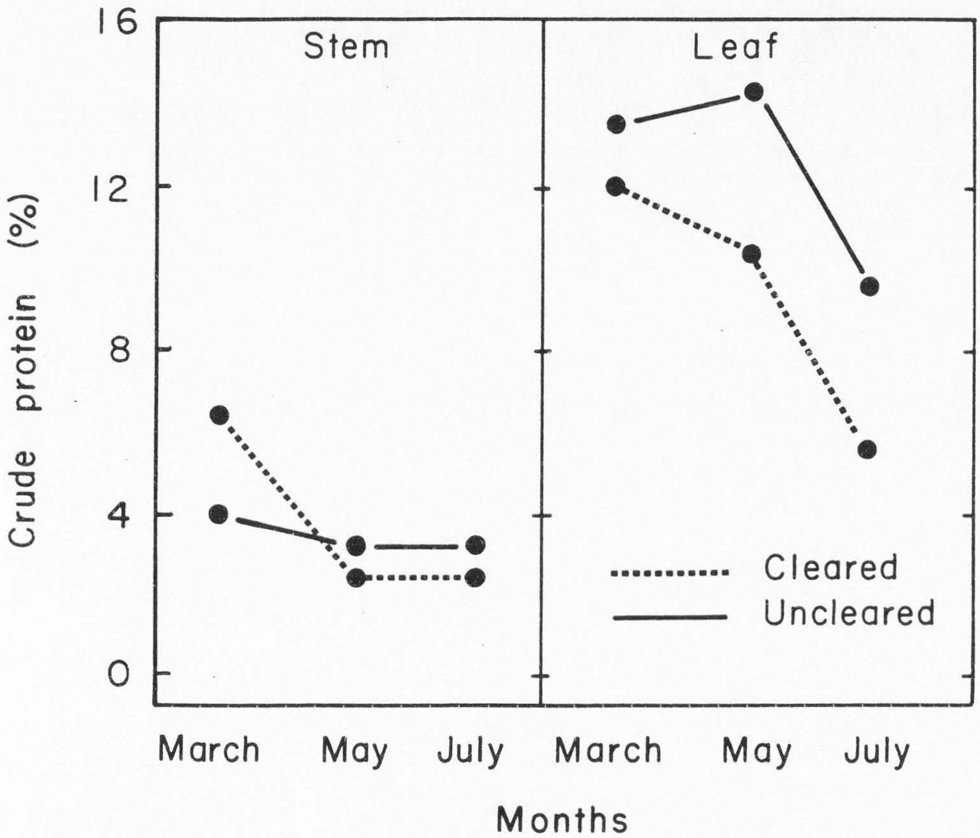

Figure 4 Crude protein content of leaf and stem components of the herbaceous vegetation growing on cleared and uncleared caatinga, 1982

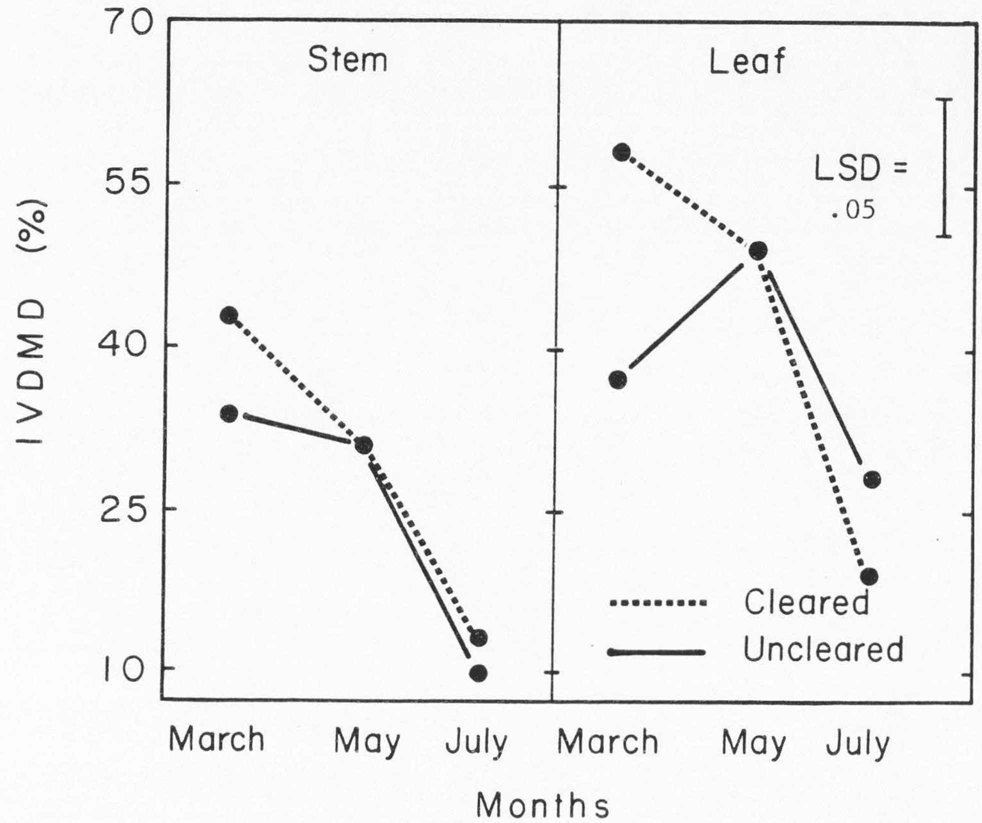

Figure 5. In vitro dry matter digestibility of leaf and stem components of the herbaceous vegetation growing on cleared and uncleared caatinga, 1982

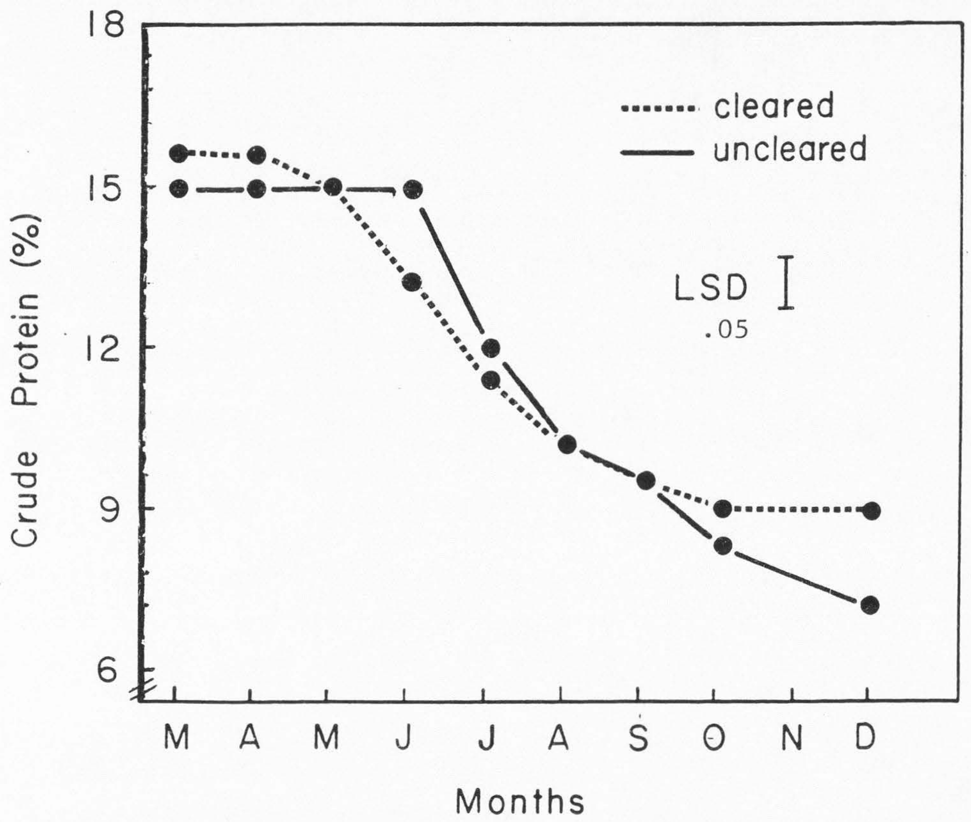

Figure 6. Seasonal crude protein contents in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

the mid-dry season rains that occurred in August and December 1981, which were sufficient to cause the major woody species to produce new foliage. No such rainfall event occurred during this study (1982). Pfister (1983) also found that the leaf litter from the major tree species of the caatinga retain relatively high levels of CP and suggested that this allowed goats and sheep to maintain adequate levels of protein in their diets.

The cleared and uncleared paddocks showed similar trends until the latter part of the dry season. Only in December were the animals grazing on the cleared paddocks able to maintain significantly ($P < 0.05$) higher levels of CP than those grazing on uncleared paddocks. This was probably a result of the additional protein they obtained by consuming the persistent green foliage from the trees that coppiced. Goats generally maintained diets higher ($P<0.05$) in crude protein than sheep. Clearing did not increase the level of crude protein in the diets of goats but it did significantly increase ($P<0.05$) crude protein in the diets of sheep (Appendix Table 10).

Rumen bacteria require a minimum of 8 percent CP from the forage for efficient fermentation of plant material (Van Soest 1982). These levels were maintained on the cleared paddocks the first year after clearing. Maintenance levels were also maintained through October on the uncleared paddocks but dropped to 7.3 percent by December.

Digestibility. IVOMD also varied seasonally (Fig. 7). Values averaged 67 percent during the early growing season and declined to 51 percent in August. The increase of four percentage units from August to October was significant ($P < 0.05$). A possible explanation for the

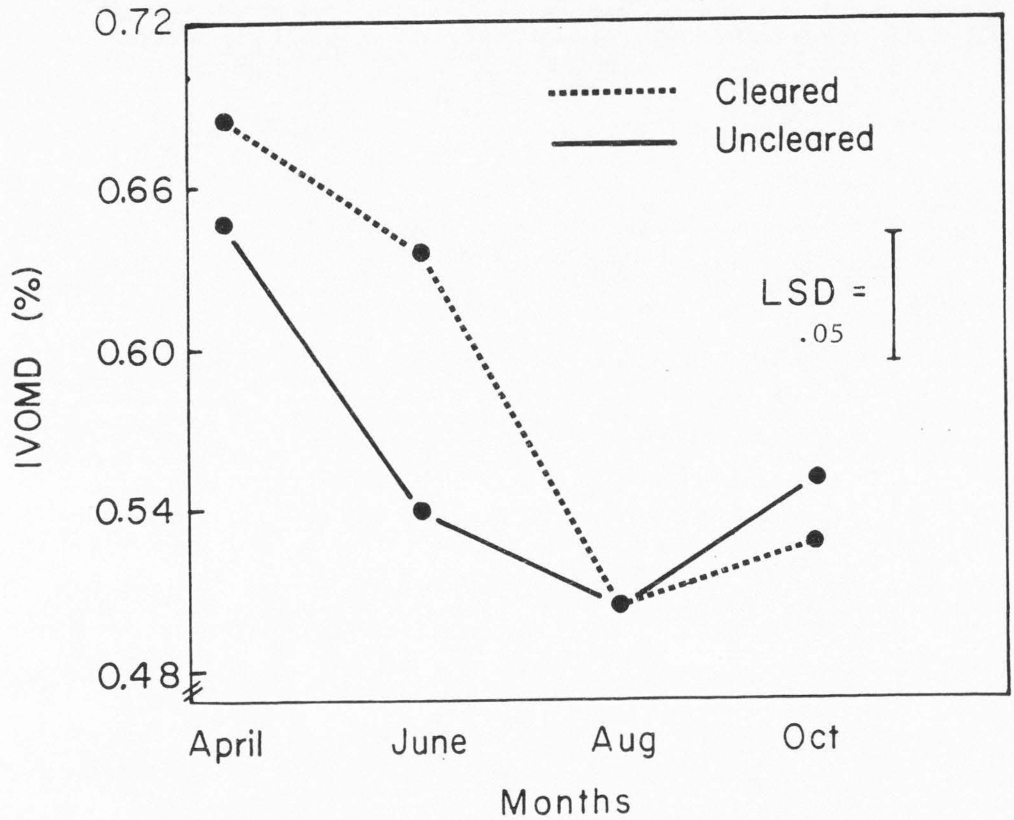

Figure 7. Seasonal *in vitro* organic matter digestibilities in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982

low levels in August may be that large quantities of seeds were consumed (non-systematic observation of seeds in the extrusa). Streeter et al. (1968) found a decrease in digestibilities when large quantities of seeds were ingested, attributing it to the lignin content of the seed coat.

Digestibilities tended to be higher on the cleared areas, but only in the month of June were goats and sheep able to maintain significantly higher ($P < 0.05$) digestibilities on the cleared than on the uncleared paddocks. This was probably due to the greater amounts of highly digestible herbaceous foliage available on the cleared areas (Fig. 3).

NDF and lignin. The neutral detergent fiber and lignin components of goat and sheep diets increased as forage matured (Figures 8 and 9). Both were inversely correlated with IVDMD; however, lignin was better correlated ($r^2 = -0.93$ for uncleared and -0.96 cleared) than NDF ($r^2 = -0.54$ for uncleared and -0.91 for cleared). There was a general trend for higher levels of NDF and lignin on uncleared than on the cleared paddocks. Cell wall constituents are generally highly correlated with the retention time in the rumen and therefore dry matter intake would be expected to be lower on uncleared areas (McCammon-Feldman 1980). The lignin values in August on the cleared paddocks may reflect the high levels of seed consumption.

Botanical composition of diets

Generally herbaceous foliage decreased in the diets as the vegetation matured, and stem increased (Fig. 10). Goats consumed more stem than sheep. Field observations also confirmed that goats avidly

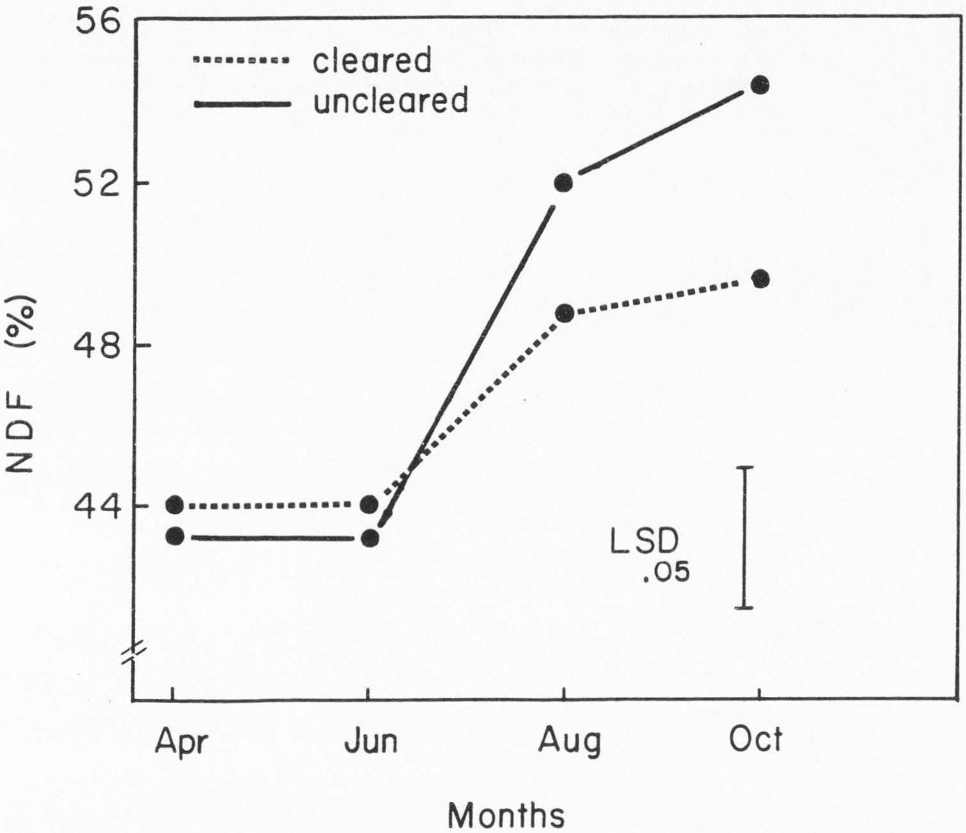

Figure 8 Seasonal neutral detergent fiber in diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

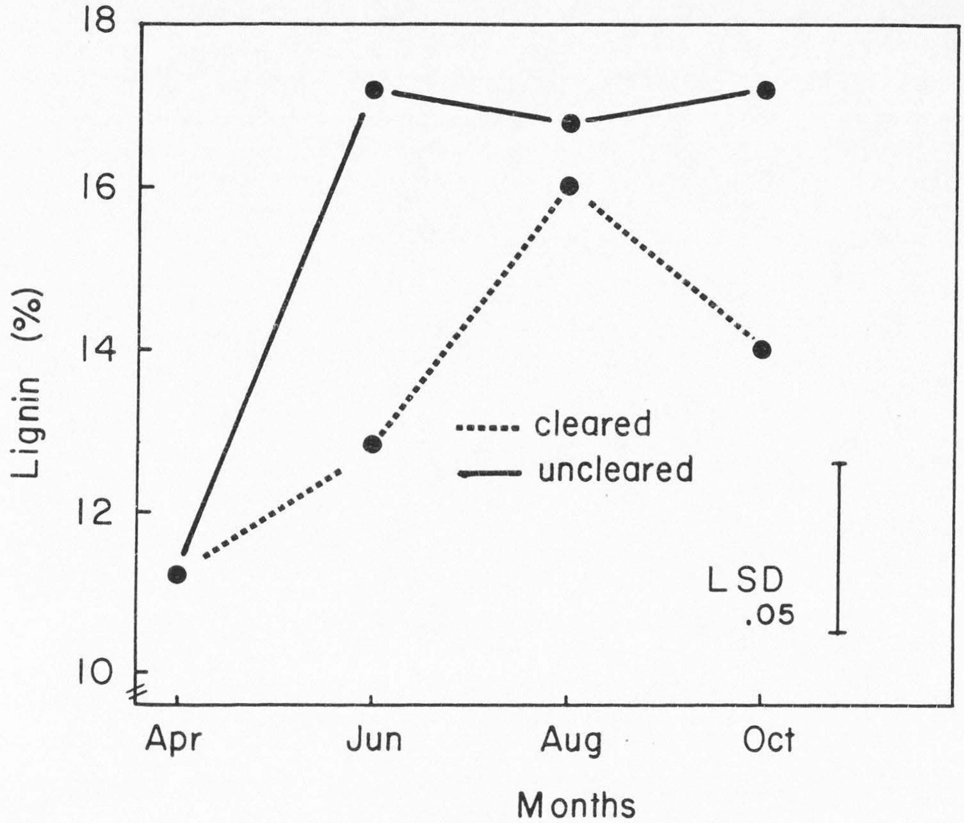

Figure 9. Seasonal lignin contents in the diets of goats and sheep grazing on cleared and uncleared caatings, 1982

seek herbaceous stems. The fact that the stem content in the diet was not higher on the cleared than the uncleared paddocks, while its availability was much greater (Fig. 3), indicates that goats and sheep do not fully utilize this element of the increased herbaceous growth on cleared paddocks. There are two possible explanations for this. The stem materials on the cleared areas may have been less palatable than the stems on the uncleared areas, or there may have been greater possibilities for selective grazing on the cleared areas.

The availability of persistent green foliage on the trees that coppiced was an integral part of the diets in December on the cleared paddocks (Fig. 10). This is probably the reason for the higher levels of crude protein in the diets of animals on the cleared paddocks at the end of the dry season (Fig. 6). These data are in agreement with Pfister's (1983) findings that leaf litter is utilized by goats and sheep as dry season fodder. *Auxemma oncocalyx* foliage, which was the most prevalent litter available on this caatinga site (Appendix Table 11), was the least utilized by livestock. Of the more prevalent woody species, the leaf litter of *Mimosa caesalpiniaefolia*, *Caesalpinia pyramidalis*, and *Bauhinia forficata* were most acceptable to goats and sheep as forage (Appendix Tables 12 and 13).

Conclusion

This study confirmed an expected increase in herbaceous production following the removal of the woody overstory. It also revealed that this increase in yield came mostly from low quality stem tissue. The large supply of leaf litter from woody species that is typical of the

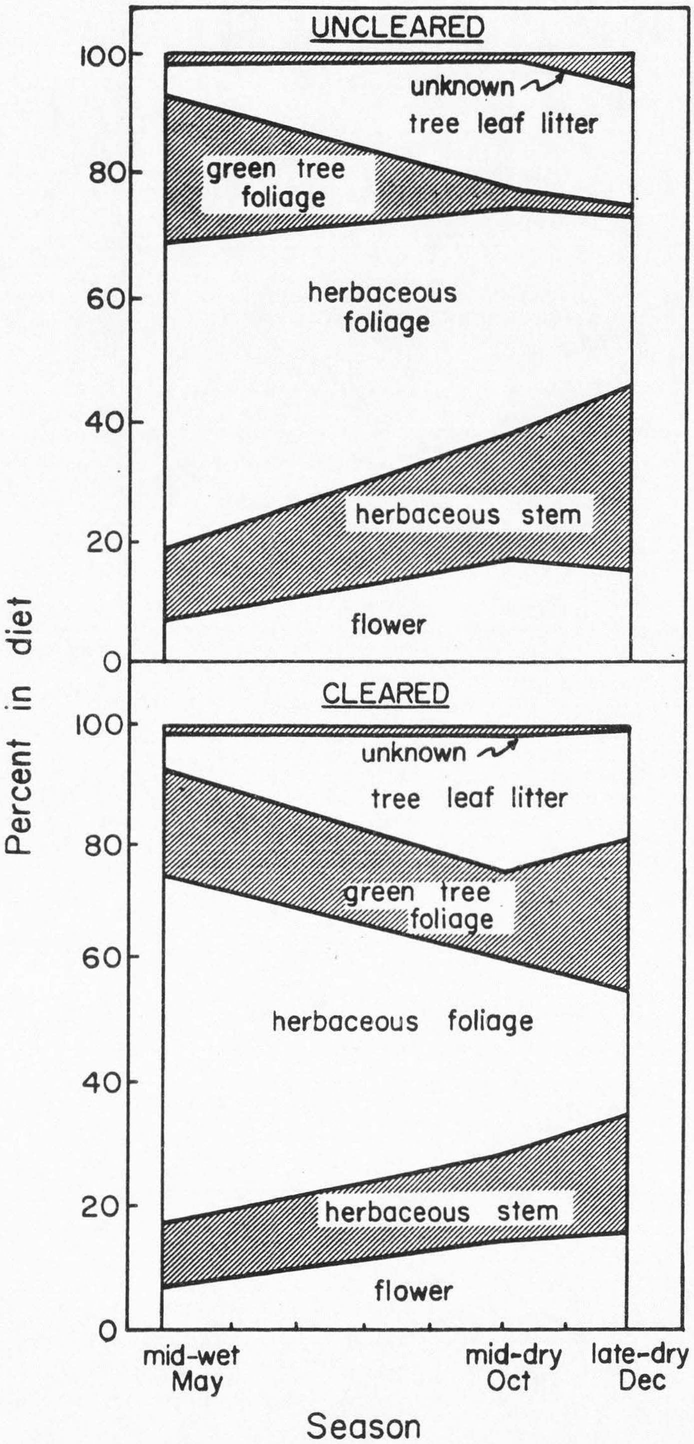

Figure 10. Plant parts in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

uncleared areas during the dry season is replaced by persistent green foliage on coppicing trees the first year after clearing. This green material provided a quality component to the diets that was not available on the uncleared paddocks.

Observations of successional stages following clearing in the Northeast indicate, however, that this persistent green foliage may only be a short-term phenomenon. Adult deciduous trees characteristically lose their leaves earlier than juvenile trees of the same species, and heavy pruning or cutting stimulates a reversal to juvenility (Kozlowski 1971). For the deciduous species of the caatinga this reversal to juvenility appears to be short-lived.

The improvements in goat and sheep nutrition on cleared areas suggest that clearing may be a desirable practice for improving production. Long-term effects on ecosystem productivity must also be considered, however. Woody perennials are generally believed to afford semi-arid landscapes with a degree of resilience by way of nutrient cycling and protection from erosion. In climatic regimes of highly variable rainfall and periodic droughts, such as occur in Northeast Brazil, woody perennials may also provide more forage on an annual basis over time than herbaceous species which are more sensitive to drought.

CHAPTER V

EFFECTS OF GRAZING PRESSURE AND CLEARING ON THE NUTRITIONAL VALUE OF DRY SEASON FORAGE RESERVES IN A CAATINGA WOODLAND IN NORTHEAST BRAZIL.

Introduction

Caatinga, an indian word meaning white forest (Ferri 1980), is the name used to refer to the semi-arid deciduous woodland that dominates Northeast Brazil. This title is appropriate because of the 'bone dry' aspect the trees assume during the long severe dry season. During this time the annual herbaceous vegetation is dry and most of the available forage is leaf litter. Small ruminant production, which is an integral part of the mixed farming system of the Northeast (Gutierrez et al. 1981), is critically limited by the prolonged nutritional stress of the dry season. Pfister et al. (1983) noted that goats and sheep can lose as much as 30-35 percent of their body weight during this period.

Livestock producers of the Northeast recognize the need to improve dry season forage conditions but the development of technology must be within the means of the small farmer (Nolan 1983). Economic and climatic constrants critically limit the potential means of improving forage supplies for the dry season. Grazing systems that defer use of the forage produced in the wet season until the dry season are usually the only economically viable management practices in semi-arid rangelands (Stobbs and Minson 1980), and may be an option for the caatinga. Information is required on the nutritional quality of range cured fodder, however, before initiating grazing systems that defer dry season forage reserves. The objectives of this study were, therefore, to investigate the nutritional quality of forage that was deferred from use until the middle of the dry season on cleared and uncleared caatinga.

Methods

The research paddocks are the same as previously described (Fig.2). They were protected from grazing prior to this study. On October 8, 1982, which corresponded with the mid-dry season when forage was mature and the vegetation virtually dormant, 24 indigenous goat and sheep castrates were placed on the six treatment paddocks (two goats and two sheep per paddock), and were not removed until November 25. This study was conducted under an increasing gradient of grazing pressure to accentuate possible differences in forage reserves on cleared and uncleared caatinga. At low grazing intensities highly variable factors (e.g., animal variation, yearly variables) could mask the effects of the factor under investigation (Gammon 1978).

The experimental stocking rates were derived from EMBRATER/EMBRAPA's (1980) recommended rate of 1.7 ha per 35 kg animal per year for native caatinga. This initial rate of stocking was obtained by placing 4 animals in a 0.32 ha paddock for 17 days. Higher grazing pressures were obtained by allowing the animals to continue grazing on these paddocks as per the schedule below. The 3-day periods at which nutritional and vegetation data was collected are indicated for each level of grazing pressure.

1. October 6-8, previously ungrazed.
2. October 23-25, two week's grazing of 2 sheep and 2 goats on each 0.32 ha paddock (equivalent to 1.7 ha per 35 kg small ruminant per year).
3. November 8-10, four week's grazing of 2 sheep and 2 goats on each 0.32 ha paddock (equivalent to 0.8 ha per 35 kg small ruminant per year).
4. November 23-25, six week's grazing of 2 sheep and 2 goats on each 0.32 ha paddock (equivalent to 0.5 ha per 35 kg animal per year).

The experimental sheep used in this study were criola ancestry and the goats were SRM (*sem raca definida* -- without definite race) goats.

Animal weights and intake

The 12 goats and 12 sheep used to provide the grazing pressure were monitored for weight gain or loss. Each animal, which had been assigned at random to the research paddocks, was weighed at the onset of the experiment on October 8 and at two-week intervals corresponding with the four grazing pressure gradients. The animals were weighed for the last time two weeks after the last fecal collection period. By the last weighing the animals had been on the paddocks a total of two months. The animals were penned overnight (14 hrs) without feed or water before weighing. Individual animals were weighed in random order between 6 and 7 a. m.

Total fecal collections were used to assess intake on the same 24 animals. Collection of feces, from canvas bags attached by harnesses to the animals, were made each 12 hours for four days at each collection period. The feces were dried in a forced air oven at 105°C for 48 hours and weighed. They were subsampled and composited by animal over the four day period to determine dry matter and ash. The mean fecal output per day and the mean digestibility of the corresponding extrusa collections were used to calculate organic matter intake (OMI) as follows:

$$OMI = \frac{\text{Fecal organic matter output X 100}}{\text{100 - Digestibility}}$$

Intake was calculated on an organic matter basis due to the high ash content of these forages (Cordova et al. 1978).

Diet quality

Eight esophageally fistulated goats and 8 sheep were used to collect samples of diets for nutritional analysis. Extrusa samples were collected from animals in the cleared and uncleared paddocks for three days (one day per replication) each two weeks; the early morning collections lasted approximately 30 minutes. The sequence of sampling was randomized; however, the same group of 8 animals foraged in the same paddock to which they were originally assigned. Reserve animals were available to replace those that had complications with the cannula.

The samples were hand-mixed and composited by species of animal within treatment for each sample period. The extrusa samples were dried at 40°C for 3 days, and then analyzed for crude protein (CP), _in vitro_ dry matter digestibility (IVDMD), neutral detergent fiber (NDF), and lignin. Crude protein was determined by a modified Kjeldahl procedure (AOAC 1975). IVDMD was determined using the procedure of Tilley and Terry (1963) as modified by Goering and Van Soest (1970). The Goering and Van Soest (1970) detergent procedure was used for the determination of NDF and lignin.

Unlike the wet season extrusa samples that required freeze-drying (Chapter IV), the IVDMD and NDF analysis of air dried samples collected during the dry season were probably not affected by Maillard reactions (Pfister, in press). Pfister found only a 1 percent difference in digestibilities between air dried and freeze dried samples. This lack of difference was probably a result of low soluble carbohydrate concentrations at this time of year and a lack of moisture required for non-enzymatic browning reactions to occur (Van Soest 1982).

Botanical composition of diets

Extrusa samples that were composited by collection period, species of animal, and treatment were analysed botanically using a microscope point method as described by Harker et al. (1964). Two hundred points were sampled using a binocular microscope set at 15 x magnification. The percent of diet contributed by each plant species or was calculated using the formula:

$$\text{Percent in Diet} = \frac{\text{no. hits per species} \times 100}{\text{number of recognizable hits}}$$

Available forage

At the beginning of this study on October 6, and at two week intervals corresponding with the extrusa collections, the leaf litter and herbaceous components of the available forage were sampled. All standing herbaceous vegetation was clipped and all leaf litter (woody and herbaceous) was collected from within 10 (50 X 60 cm) quadrats randomly located within each pasture. On the uncleared paddocks this represented total forage available as all trees had shed their leaves. On the cleared paddocks this sampling did not constitute total available forage because three of the woody species (*Auxemma oncocalyx*, *Caesalpinia pyramidalis* and *Combretum leprosum*) had coppiced and retained green foliage through this period of collection. Observations on grazing behavior, coupled with diet data, indicated that although some of this green leafy material was grazed, its availability was not limiting. Palatibility, however, may have limited their use. Before leaves of these three species abscise and fall their palatabilities are relatively low. As they fall to the ground in November and December they contribute more to the forage pool.

Experimental design

The statistical design for the analyses of the diet quality, intake, weight response and botanical composition data was a randomized block factorial with treatment (cleared and uncleared) and animal type (goat and sheep). The experiment was repeated at four grazing pressures. This study focused on the comparison of cleared and uncleared caatinga and not on differences between goats and sheep.

Generally, statistically significant differences between sheep and goats did not exist for the nutritional parameters measured. Where significant differences exist, they are discussed in the text. An LSD bar is presented on figures only if the overall F test was significant.

Results and Discussion

Intake

The amount of forage that sheep and goats consumed declined as grazing pressure increased (Fig. 11). Others have also reported decreases in intake with increasing levels of utilization (Handl and Rittenhouse 1972, Vavra et al. 1973, Malechek et al. 1978). Arnold (1970) suggested that the decreasing rates of intake associated with declining forage supplies may be caused by animals spending a proportionately greater amount of time searching for favored plant species and parts that are increasingly hard to find. A decline in the nutritional quality of the forage at higher levels of utilization may also limit intake as it influences the rate of passage. Clearing significantly ($P < 0.05$) reduced this drop in intake but did not alter the general trend.

The average intakes of goats and sheep on uncleared paddocks that were previously ungrazed were 1.9 percent and 2.4 percent of body weight (BW), respectively. Sheep consistantly consumed more ($P<0.05$) than goats (Appendix Table 14). These values correspond to the range of intakes reported for sheep by Cordova et al. (1978) and Van Dyne et

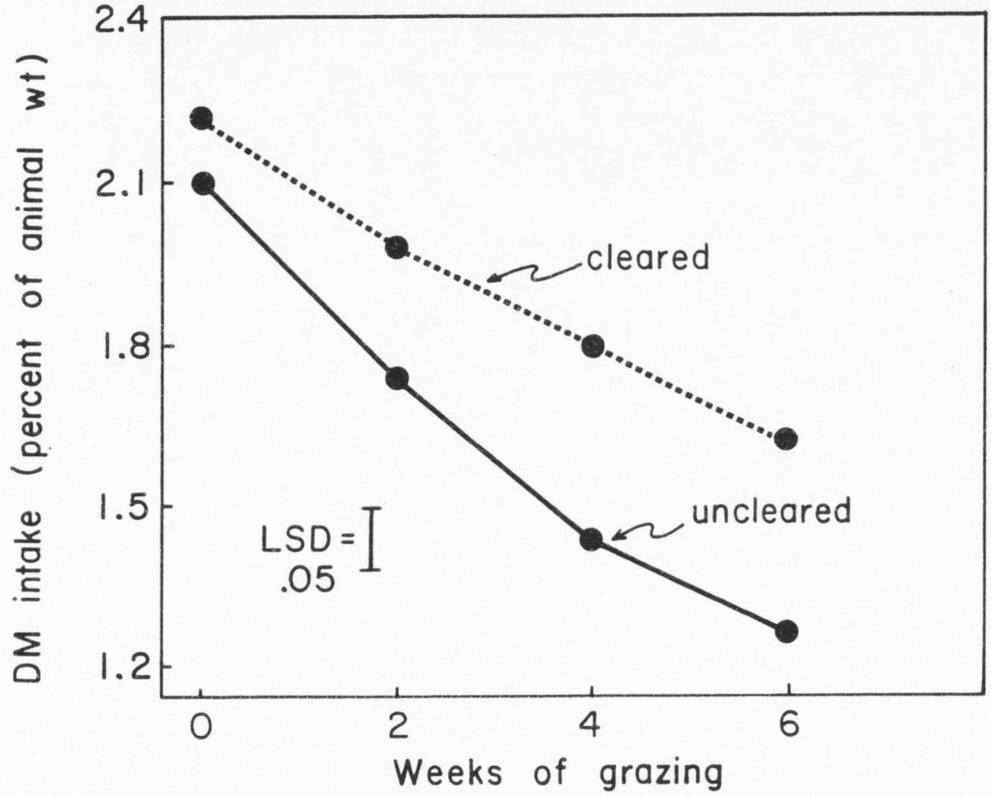

Figure 11. Dry matter intake of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982

al. (1980), for goats as reported by McCammon-Feldman (1980) and for goats and sheep grazing in the uncleared caatinga as reported by Pfister (1983). The levels of intake are generally lower than those recommended for goats (NRC 1981) and sheep (NAS 1975) for maintenance and activity.

Diet quality

Digestibility. Digestibilities decreased as grazing pressure increased (Fig. 12) probably because animals were forced to consume forage that were previously rejected when forage was abundant (Heady 1961). The mean digestibility of the combined diets of goats and sheep grazing on cleared and uncleared caatinga during the dry season was 60 percent. After two weeks of grazing, which was equivalent to a stocking rate of 1.7 ha per 35 kg animal per year, the mean digestibility dropped to 51 percent. This decrease in digestibilities was closely correlated with reduced intake levels ($r = 0.97$) on both treatments. Blaxter et al. (1961) also found a strong correlation between digestibility of forage and herbage consumed by sheep. Poorly digestible diets may depress herbage intake by limiting the rate of passage of digesta from the rumen and therefore affect fill (Jones 1972, Van Soest 1982).

As with intake, differences in the digestibilities of the diets of animals grazing on cleared and uncleared paddocks were manifested only as forage availability declined (Appendix Table 15). As grazing pressure increased, the animals on the cleared paddocks maintained diets that were significantly ($P < 0.05$) more digestible than those on the uncleared. Possibly the greater amounts of herbaceous forages or

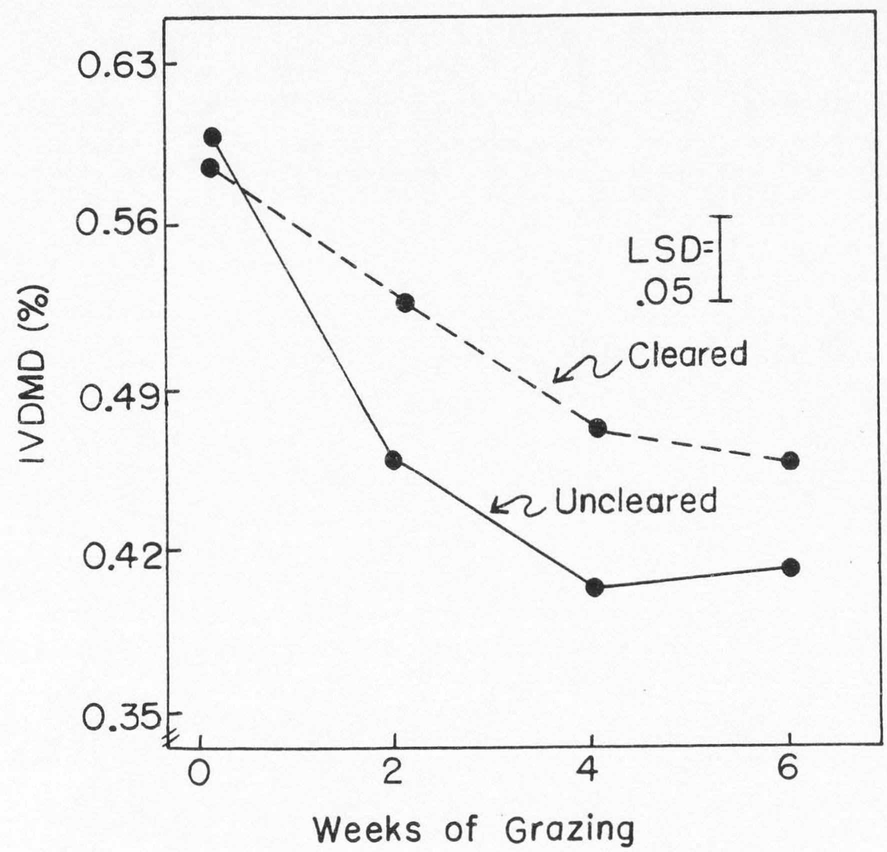

Figure 12. In vitro dry matter digestibility of the diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982

the green coppice leaves in the diets of the animals grazing on the cleared paddocks accounted for the higher level of digestibility.

NDF and lignin. Neutral detergent fiber increased significantly after the first two weeks of grazing then stabilized (Fig.13). Although there was a general tendency for lower fiber levels in the diets of animals grazing the cleared paddocks, this difference was not significant ($P > 0.05$). Goats generally had diets higher in NDF ($P<0.05$) than sheep. The species by treatment interaction was also significant ($P<0.05$) whereby clearing did not change the cell wall content of the goat diet but reduced it in the diets of sheep (Appendix Table 18).

The lignin contents of the diets generally increased as available forage decreased on uncleared paddocks (Fig.14). There was an initial decrease in lignin in the diets of animals on the cleared paddocks, however, after the first two weeks of grazing. This dip in lignin levels was possibly related to the reduced amount of tree foliage and increased amounts of herbaceous material in their diets at that time (Figure 16). As the tree leaf litter again gained importance in their diets, lignin levels increased.

The cell wall, and especially the lignified cell wall, is resistant to microbial and mechanical degradation in the rumen (Van Soest 1982). There is evidence that this fraction of plant tissue is the principal physical factor controlling rates of digestion and intake (McCammon-Feldman 1980, Owen-Smith 1982, Minson 1982). McCammon-Feldman (1980) pointed out that relative to large ruminants, small ruminants must ruminate each gram of cell wall longer to reduce the size of the

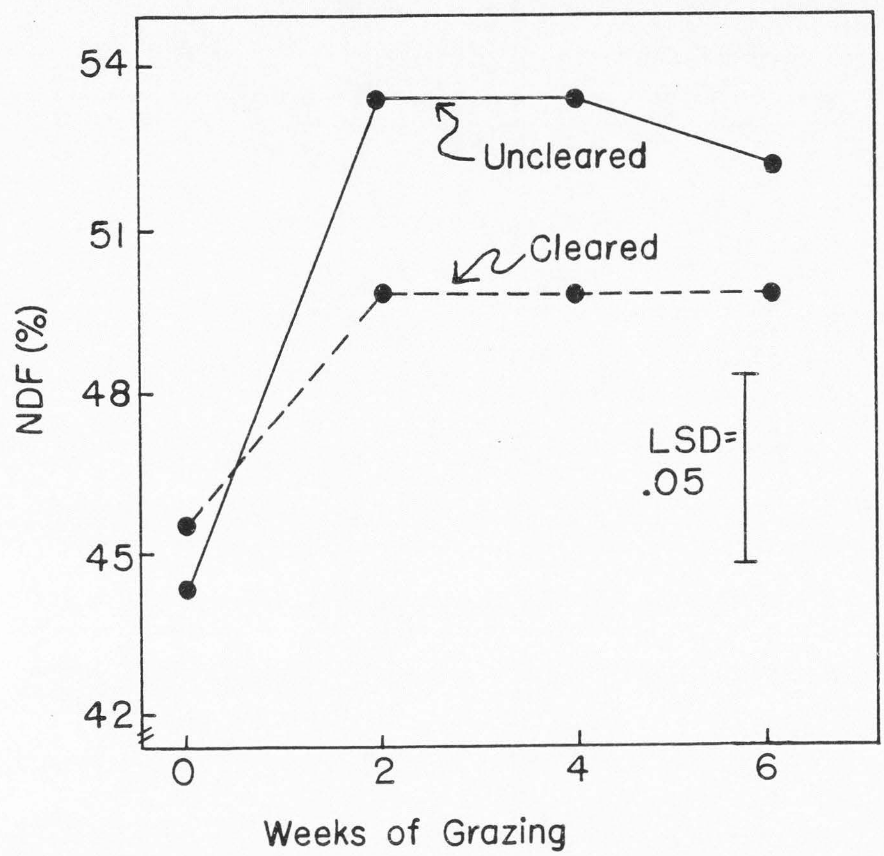

Figure 13. Neutral detergent fiber in the diets of sheep and goats grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

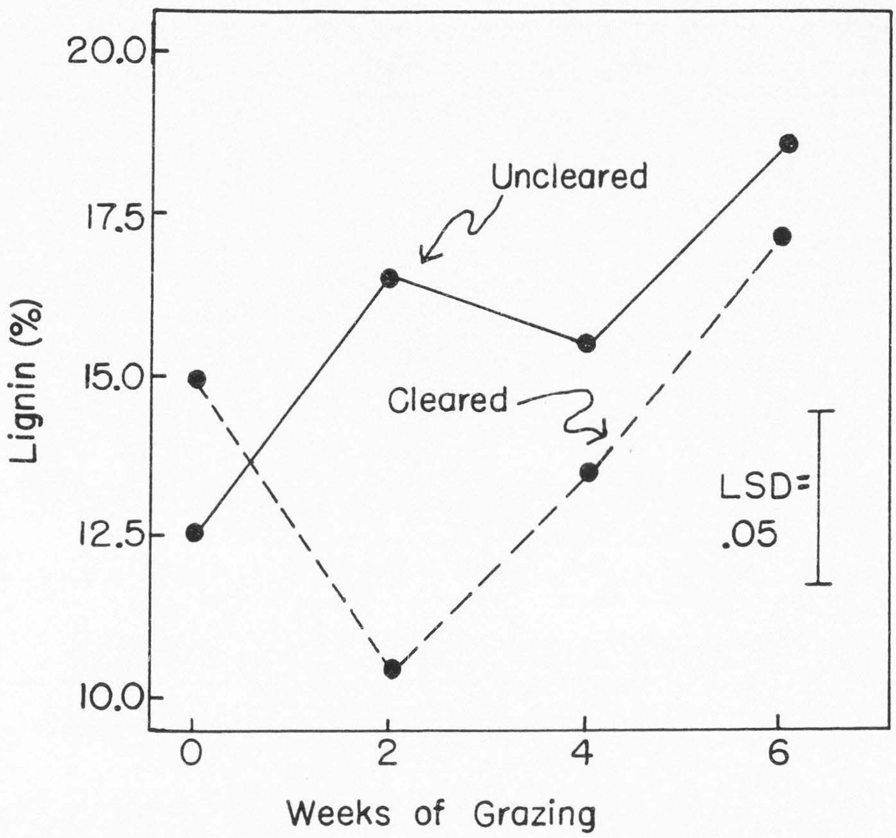

Figure 14. Lignin contents in the diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

particles enough to pass through the relatively small sorting and filtering mechanisms of the rumen and omasum. The forage consumption rates of goats and sheep should therefore be subject to strict control by the amount of cell wall.

The increase in the cell wall in the diets of goats and sheep grazing on cleared and uncleared paddocks over the first two weeks of grazing corresponds to this expected trend in forage intake. Dry matter intake dropped with increasing grazing pressure, however, while the cell wall contents of the diets leveled off and the coefficients of determination for NDF on intake dropped to 0.59 on cleared and 0.69 on uncleared paddocks. This apparent anomaly can be explained by the low concentration of crude protein in the diets at higher grazing pressures. Minson (1982) pointed out that as long as dietary protein in sufficiently available fiber plays a major role in intake limitation. However, when protein becomes insufficient (i.e., at levels less than 7-8 percent) then protein is the first limitation.

Crude protein. The levels of crude protein in the diets after two weeks of grazing (7.1 percent on uncleared and 7.5 percent on cleared) were marginal (Van Soest 1982), and may have restricted appetite and intake (Milford and Minson 1965). Crude protein levels continued to drop steadily with increasing grazing pressure (Fig. 15), and the pattern of decline was not significantly ($P > 0.05$) influenced by clearing. Apparently the disappearance of forage due to grazing, in combination with the natural degradation of the forage associated with maturity and decomposition, lead to a depletion of forage with adequate nitrogen.

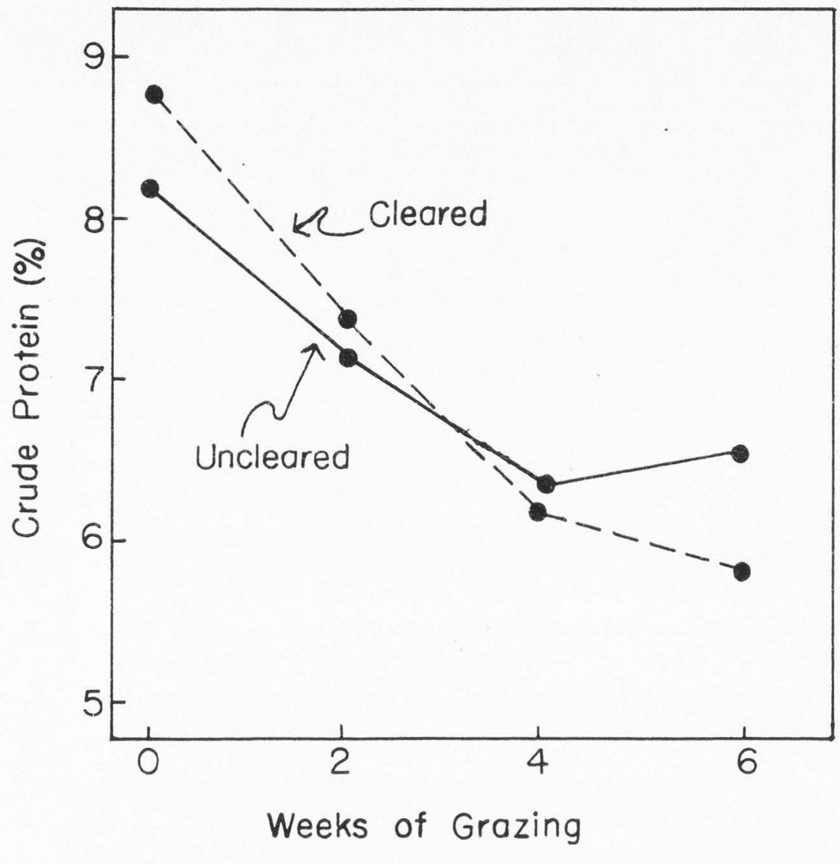

Figure 15. Crude protein contents of the diets of goats and sheep on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

These data suggest, in contrast to Pfister's (1983) findings , that insufficient nitrogen may limit the utilization of dry season forages by goats and sheep. The results that lead to these different conclusions may be due to the differences in project design. On my study the animals' ability to select for high protein diets may have been compromised by the small, relatively homogeneous pastures and by the heavy levels of forage utilization applied. By contrast, Pfister's study was conducted on a larger, more heterogeneous pasture that may have allowed the animals a greater opportunity for seletive grazing.

Large quantities of herbage were remaining on the paddocks throughout the study. If nitrogen is limiting the use of these poor quality forages, more efficient utilization may require protein supplementation to facilitate rumen function (Morris 1958 and 1966, Van Gylswyk 1970, Minson 1982).

<u>Botanical composition of diets</u>

The botanical composition data were summarized into plant parts in Figure 16. After the first two weeks of grazing, sheep and goats increased the amount of leaf litter from tree species in their diets. The amount of leaf litter in the diets was higher ($P < 0.05$) on the uncleared paddocks. The amount of tree leaf litter increased from 11 to 56 percent in the diets of goats on the uncleared paddocks after six weeks of grazing. Over the same period sheep increased their consumption of leaf litter from 29 to 55 percent. The increase in tree leaf litter in goat and sheep diets on uncleared paddocks corresponded with a decline in the amount of herbaceous foliage in the diets and a

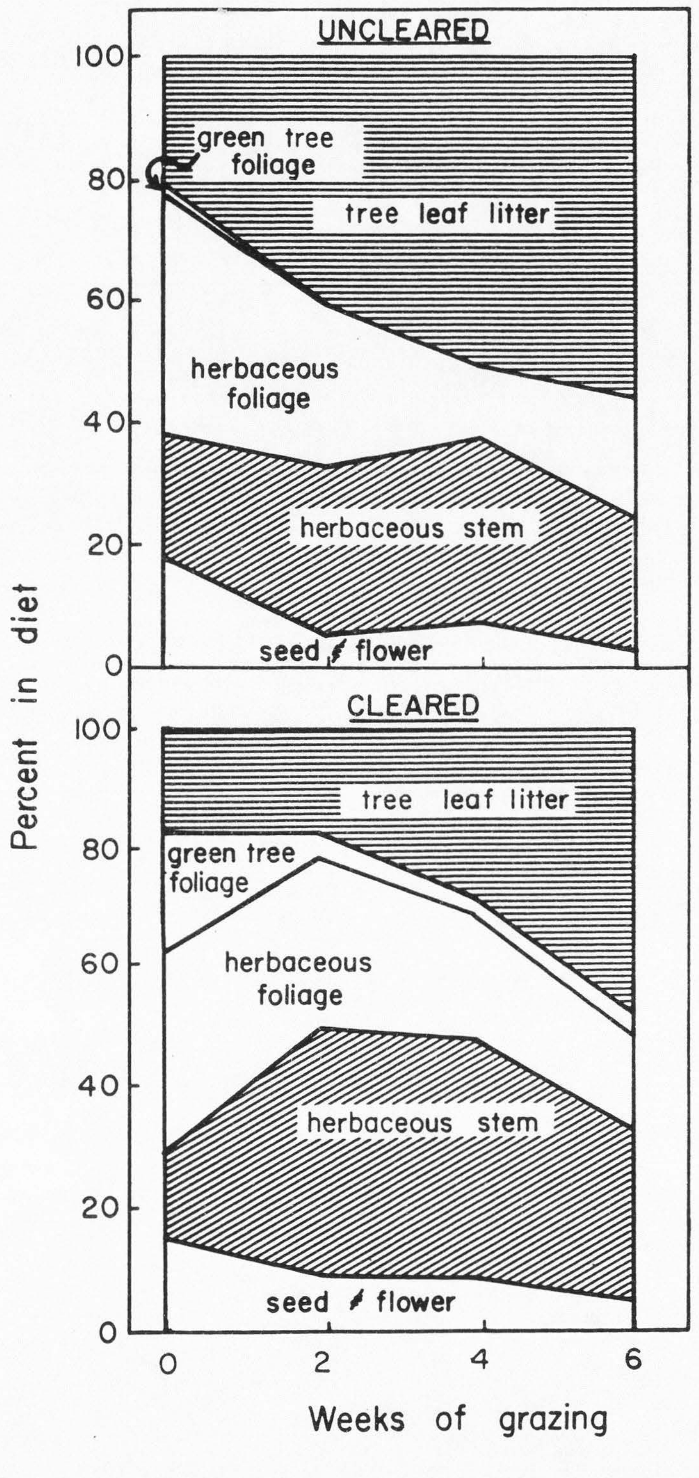

Figure 16. Plant parts in the diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

decreasing abundance of herbaceous vegetation on the paddocks. Although consumption of leaf litter by sheep and goats caused diet quality to decline, tree leaf litter provided the only source of dry season forage. Other researchers have also observed tree leaf litter to be an important source of dry season fodder (Hunt 1954, Dougall and Bogden 1958, Wilson et al. 1975, McArthur and Harrington 1978, Pfister 1983).

Herbaceous stems remained an important component of the diet throughout the study. Although there was a sixfold increase in production of herbaceous stem on the cleared areas there was no significant difference ($P > 0.10$) in the amount of stem consumed on cleared and uncleared caatinga. This is probably because of the corresponding fivefold increase in diameter of stems on the cleared area compared to those on the uncleared (Appendix Table 8).

Goats and sheep initially selected for high levels (20 percent of diet) of green foliage from the coppiced trees in the cleared areas (Fig. 16). After two weeks of grazing, however, sheep discontinued use of this green forage while goats continued a moderate level of use. This reduced consumption of green foliage from coppiced trees is probably because of the reduced availability of preferred species. The persistent green foliage used most by goats and sheep was from *Mimosa caesalpiniaefolia*, *Bauhinia forficata* and *Caesalpinia ferrea*. The remaining green foliage on the cleared paddocks was from the species with lower palatibilities, *Auxemma oncocalyx*, *Caesalpinia pyramidalis*, and *Combretum leprosum* (Appendix Tables 16 and 17).

Available forage

The relative amounts of the various forage components remaining on the cleared and uncleared research paddocks under progressively greater grazing pressures is presented in Figure 17. Although trace amounts of the herbaceous fraction were available throughout the study (Appendix Table 15), these data indicate that most of the herbaceous leaf litter and standing stem was utilized after the first two weeks of grazing on the cleared paddocks. This was followed by a gradual depletion in the remaining tree leaf litter. This roughly corroborates the data on botanical composition.

These data reveal that 100 percent of the standing herbaceous stem on the uncleared areas was consumed while only 28 percent of the stem on cleared areas was used. There were no significant ($P > 0.05$) decreases in the standing crop of stems recorded on the cleared areas in the succeeding periods, implying that this portion of the stem was unpalatable. The refusal of animals to make greater use of all the available stem on the cleared areas was attributed to the much more robust development of the stems on cleared paddocks (Appendix Table 8).

Tree leaf litter on the uncleared areas gradually declined as it was eaten by goats and sheep. This component of the available forage increased during the fourth week of grazing on the cleared paddocks, after which it also decreased (Fig. 17). This trend is explained by the shedding of the persistent green foliage from the coppice tree species *Auxemma oncocalyx*, *Caesalpinia pyramidalis* and *Combretum leprosum*.

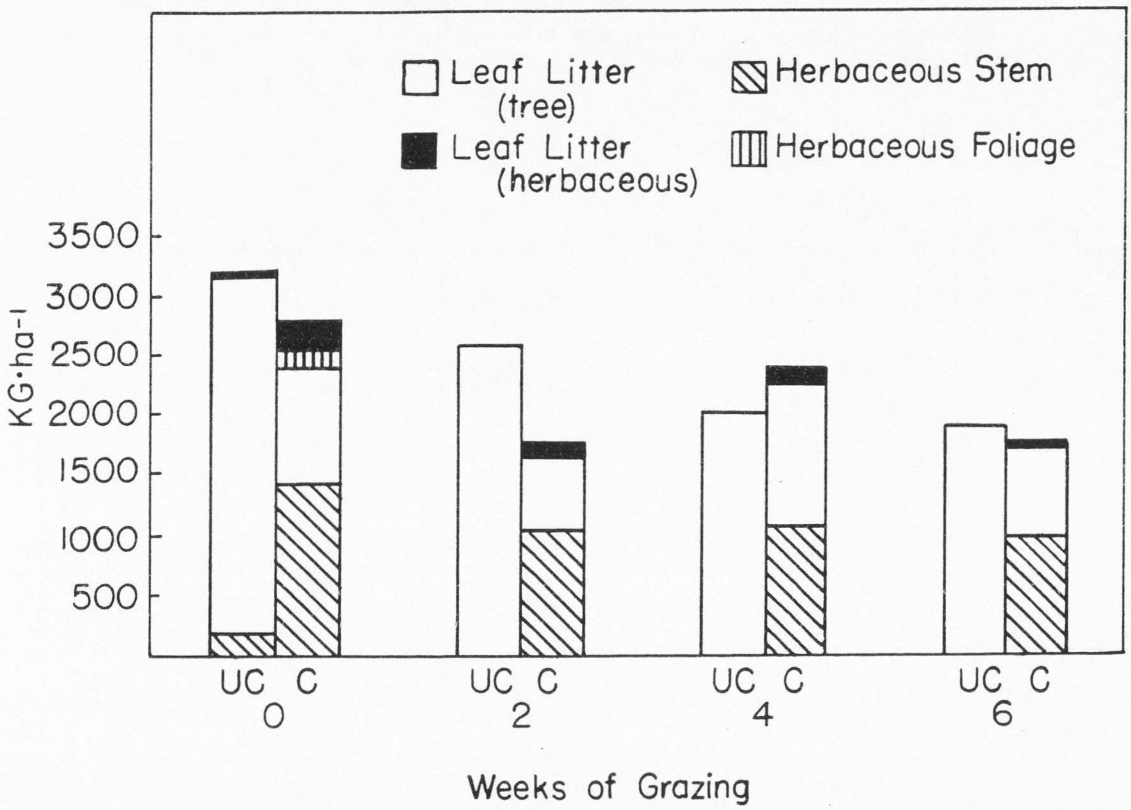

Figure 17. Standing crop and leaf litter remaining on cleared and uncleared caatinga uncer increasing levels of grazing pressure during the dry season, 1982.

Weight response

Diet quality and intake generally declined as grazing pressure increased. This trend is attributed to a declining forage supply and resultant reduction in the grazing animals' ability to select for higher quality forage. Similar results were observed by researchers in other rangelands (Blaser et al. 1959, Cook et al. 1965, Vavra et al. 1973, Bryant et al. 1970).

The animals in this study did not, however, exhibit corresponding losses in body weight (Table 3). Nor did the improvements in diet quality due to clearing result is significantly higher ($P<0.05$) weights for animals in cleared paddocks. The length of the experiment was likely too short to detect weight changes (Petersen and Lucas 1960, Baker 1982), probably because weight response lags behind changes in diet quality and intake and because changes in diets generally cause a change in gut fill (Corbett 1978). The increased cell wall content, the lower levels of crude protein, and the lower digestibilities of the diets of goats and sheep caused by higher levels of forage utilization would be expected to increase retention time of the digesta in the rumen (McCammon-Feldman 1980) and therefore increase rumen fill. An increase in gut fill would artificially show as an increase in animal weight. In addition, there were probably too few animals to significantly detect weight changes.

Table 3. Body weight (kg) of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
0	26.2 ± 4.2[1]	29.8 ± 4.4	27.7 ± 3.6	30.9 ± 2.3
2	27.0 ± 4.8	31.5 ± 4.1	29.9 ± 3.0	32.5 ± 1.8
4	26.9 ± 4.4	31.3 ± 4.8	30.0 ± 3.9	32.9 ± 2.2
6	25.2 ± 3.9	30.2 ± 4.5	28.7 ± 3.7	31.9 ± 1.7
8	24.8 ± 3.9	29.9 ± 5.0	27.2 ± 3.2	31.6 ± 2.0

[1]Mean ± std. dev., n = 6.

CHAPTER VI

EFFECTS OF CLEARCUTTING ON LITTER PRODUCTION AND DECOMPOSITION IN A CAATINGA WOODLAND IN NORTHEAST BRAZIL

Introduction

Lack of dry season forage is the major constraint to livestock production in the semi-arid caatinga woodland of Northeast Brazil. Rainfall during the wet season results in a flush of highly nutritious annual herbaceous vegetation during a 3-4 month period, but this forage is rapidly depleted during the dry season by grazing, trampling, and decomposition. The erratic nature of the yearly rainfall and periodic droughts have a critical impact on sheep and goat production and net farm income in the Northeast (De Boer 1983). Economic studies indicate that the development of strategies for better management of large fluctuations in forage reserves will have potentially important impacts on improving small farm productivity in the region.

The options for managing the caatinga for improving dry season forage reserves are critically limited by the inability of farmers to invest capital in range improvement projects. Possibly the only economically feasible option for minimizing weight loss during this stressful period is conservation of standing range forage by some form of grazing deferment during the rapid growth period (Stobbs and Minson 1980, Malechek 1982). This, however, may lead to poor quality forage during the dry season and could also result in excessive losses of potential feed to decomposer organisms. Swift et al. (1979) pointed out that only about 10-15 percent of the net primary production in tropical grasslands is consumed by herbivores. The remaining organic matter enters the decomposition subsystem directly as plant detritus.

Clearcutting of these woodlands is the predominant range improvement practice used by the small farmer (Gutierrez et al. 1981). This practice increases herbaceous standing crops 5 to 6-fold on caatinga rangelands (Araujo Filho et al. 1982, Chapter IV) Araujo Filho (personal communications) suggested that a combination of clearing to increase herbaceous production and deferment to reserve these forages for dry season use, is a management scheme worth investigating. In order to understand potential benefits and limitations of this scheme, information is required on the effects of clearing on decomposition.

Decomposition is predominantely a microbrial process and therefore anything that affects the populations and activities of microorganisms will influence the rates of organic matter catabolism (Swift et al. 1979). Clearcutting may affect rates of decomposition by changing microclimate, especially the litter layer temperature and moisture regimes. For more humid forests others have speculated that the removal of the overstory vegetation will result in higher biotic activity and organic matter decomposition rates due to increases in soil temperatures and moisture (Sanchez 1976, Pritchett 1979, Woodmansee 1984). Because of the generally high mean annual temperatures of the caatinga (22-28°C), moisture will probably be the most limiting factor to microbial activity. In their review, Swift et al. (1979) found that moisture was highly correlated with decomposition rates when temperature was not a limiting factor. Clearing the woodland could conceivably affect the moisture available to decomposer oraganisms by decreasing evapotranspiration rates or increasing dewfall (Geiger 1965, Barry and Chorley 1982).

The chemical composition of the plant material also influences microbial activity and the rates of litter decomposition (Swift et al. 1979). The lignified cell wall and crude protein contents of the dry matter are apparently important substrate qualities that influence the rates of decomposition. This study (Chapter IV) showed that the removal of the tree overstory modifies the chemical composition of the herbaceous stratum. Removal of the tree canopy also results in less tree leaf litter. If tree foliage is higher in lignified cell wall content than herbaceous vegetation as Wilson (1969) suggested, then tree leaves should decompose at a slower rate (Swift et al. 1979).

The intent of this study was to investigate the potential losses to decomposition of forage deferred from grazing until the dry season, and to examine how tree clearing might influence the decompositon process. The specific objectives were to : 1) Determine the relative production and decomposition of tree and herbaceous leaf litter on cleared and uncleared caatinga. 2) Determine the effect of changes in the chemical composition of herbaceous vegetation, as affected by clearing, on the rates of decomposition.

Methods

Litter production

The tree leaf litter and herbaceous leaf standing crop were measured at the onset of anthesis of the major herbaceous species in August. These measurements were repeated in September, October and December. Sampling involved collecting all of the present-year's tree and herbaceous leaf litter from 10 randomly placed quadrats (50 x 60 cm) on each of the six cleared and uncleared ungrazed paddocks (Fig. 2). Petioles were not removed from the tree foliage; however, on some species they were shed naturally. Leaf litter was separated into herbaceous and tree sources, dried at 105°C for 48 hours and weighed. For the purpose of this study, litter is defined as the present-year accumulation of herbaceous or tree foliage that is recognizable as to origin.

Litter decomposition

The direct method of confining representative samples of foliage in litter bags (Singh and Gupta 1977) was used to determine the relative rates of decomposition as influenced by clearing. Sufficient information is available for determining the use, advantages and limitations of the litter bag method (Bocock and Gilbert 1957, Bocock et al. 1960, Crossley and Hogland 1962, Witkamp and Olson 1963, Old 1969, Anderson 1973(a), Sniffling and Smith 1974, Wiegert and McGinnis 1975, Lousier and Parkinson 1976, Edwards 1977, Fogel and Cromack 1977, Christie 1979, Vossbrick et al. 1979, etc.). Generally these researchers found that the rates of decomposition in litter bags underestimate true rates. Four primary factors may account for these findings:

1. The litter in bags does not incorporate into the natural litter layer.
2. The microclimate of the litter bags is different from that of the natural litter.
3. The small mesh size (1-2 mm) restricts the effects of large arthropods.
4. Litter confined in bags tends to become compacted.

The general consensus, however, is that the litter-bag approach is good for assessing relative rates of weight loss as affected by changes in the agents of decomposition. The key advantage of litter bags for this study is to minimize fragmentation losses to trampling or herbivory such that the relocation of intact material is facilitated. I avoid, however, the common assumption that litterbags represent nature (Lousier and Parkinson 1976) and the absolute amount of decomposition (Ratliff 1980).

Six plant species, three herbaceous and three woody, were selected for this study based on their relative abundance in the community. The species selected were *Brachiaria mollis* a grass, *Wissadula* spp. a forb, *Blainvillea rhombordea* a forb, and the trees *Mimosa caesalpiniaefolia*, *Auxemma oncocalyx*, and *Caesalpinia pyramidalis*. The herbaceous foliage was collected at anthesis. The tree foliage was collected at the onset of leaf fall, in the form of litter. All plant materials were collected at random from the three cleared and uncleared ungrazed paddocks. Ten grams of air dried foliage from each species was placed in each 20 x 20 cm litter bag. The amount was based on the natural layering of the litter of approximately 10 g per 400 cm^2. The litter bags were made of 1 mm fiberglass mesh (Swift and French 1972).

In placing the litter bags in the field, I was careful to avoid disturbing the native litter while allowing the surface of the experimental litter to make contact with the mineral soil (Wiegert and Evans 1964, Gosz et al. 1973). A sufficient number of bags was placed in the field such that a bag from each species and treatment could be collected at five or six periods during the year. The collection of plant material and placement of litter bags is explained below:

1. To determine the effects that clearing had on the chemical composition (substrate quality) of the herbaceous vegetation and subsequent decomposition rates, representative foliage from the three herbaceous species was collected from the uncleared and cleared paddocks. A total of 220 bags was prepared, 110 with leaf material that had developed in full sunlight (from cleared areas) and an equal number from plants that had grown in the shade of the uncleared areas. Half of each group (sun and shade) was placed at random on the cleared paddocks and half on the uncleared paddocks. The grass matured one month earlier than the forbs. In order to follow the natural phenology of the community, therefore, these grass litter bags were placed in the field on April 20th, one month earlier than the placement of the forb litter bags.

2. To determine the relative decomposition rates of tree versus herbaceous foliage and grass versus forbs (substrate quality difference between species), fresh leaf litter from the trees

Auxemma oncocalyx, Mimosa caesalpiniaefolia, and Caesalpinia pyramidalis was collected from the ungrazed areas. Thirty litter bags were prepared for each of the tree species (90 bags), half of which were placed in the uncleared paddocks and half of which were placed on the cleared paddocks. The same herbaceous litter bags (grass and forbs) used for assessing the effects of substrate quality were used in this comparison. A second set of grass litter bags was placed in the field at the same time as the forbs (May 20) to enable a comparison of relative rates of weight loss without confounding differences in precipitation. Because all bags were placed on the cleared and uncleared paddocks as described above, the design for determining the effects of chemical composition on decomposition rates also allowed for the determination of the effects of the microenvironment.

3. To control for possible confounding by arthropod activity I determined the extent to which they influence herbaceous decomposition rates on cleared and uncleared sites. A specially designed litter bag containing a side of 15 mm mesh was used to monitor the rates of weight loss of the three herbaceous species. This larger opening allowed the soil animals (i.e., invertebrates) to enter (Edwards and Heath 1963, Madge 1969). Sufficient 'insect' bags were prepared to place one for each of the three herbaceous species on each of the six paddocks (Fig. 2). All bags were placed in the field at the same time and collected after a period of 91 days.

Litter bags were collected at periodic intervals. Collection dates were more frequent at the onset of the study in order to monitor the rapid weight loss of water soluble components observed by other investigators (e.g., Jenny et al. 1949, Wiegert and Murphy 1970, Bernard-Reversat 1972, Wood 1974). Litter bags were collected at 3 p.m., placed in a plastic bag and carried immediately to the laboratory where they were weighed to the nearest 0.1 g. They were dried in a forced air oven at 65°C for 48 hours and weighed again. The leaf material was pooled over replication and ground to pass a 40-mesh screen. The samples were ashed at 600°C overnight. Results were reported on an organic matter basis due to the wind-blown and rain-splashed soil contamination of the litter in the bags. The rates of decomposition were estimated by the difference in mass. As used here, decomposition includes losses to bacterial and fungal degradation, leaching, and removal or export by arthropods. A separate analysis of variance was run on each species using a randomized block design.

Chemical composition of litter

One pooled samples of fresh litter from the three herbaceous and three woody species were dried in a forced air oven at 65°C for 48 hours and ground to pass a 20-mesh screen. These were analyzed for neutral detergent fiber (NDF), lignin, crude protein (CP) and cutin. The crude protein content of the material was determined by a modified Kjeldahl procedure (AOAC 1975). The Goering and Van Soest (1970) procedures were used for the fiber determinations. Cutin was partitioned from crude lignin by the procedure of Van Soest and Wine (1968).

Results and Discussion

Litter production

The peak standing crop of tree leaf litter ($\pm$ std. error) on uncleared caatinga was 3327 kg•ha^{-1} $\pm$172 (Fig. 18) Few estimates of leaf litter production are available from similar semi-arid woodlands of the world with which to compare these results (Bray and Gorham 1964). Pfister (1983) measured 1501 kg•ha^{-1} on an adjoining caatinga site in 1981, but that pasture was grazed by goats and sheep and, therefore, does not represent peak standing crop.

As expected, removal of the tree canopy significantly reduced tree leaf litter production. All tree leaf litter on the cleared areas was from the trees that resprouted. These coppicing tree stumps retained green foliage longer into the dry season than did mature trees and the increasing amounts of litter on the cleared paddocks represent late dry season abscission. The declining amounts on the uncleared areas represent decomposition because all tree foliage was shed by the September sampling period. The tree leaf litter had an 18.4 percent loss in weight from September to December.

Higher amounts of herbaceous leaf litter were recorded on the cleared than on the uncleared paddocks. This reflected a sixfold increase in herbaceous yields due to clearing (Fig. 3, Chapter IV). Harvest data on the uncleared areas revealed a 28 percent decomposition rate from peak standing crop (September) to the end of the dry season (December). There was a 30 percent loss on the cleared areas for the same period. Although these decomposition rates from harvest data may be useful for management purposes, they are not representative of the

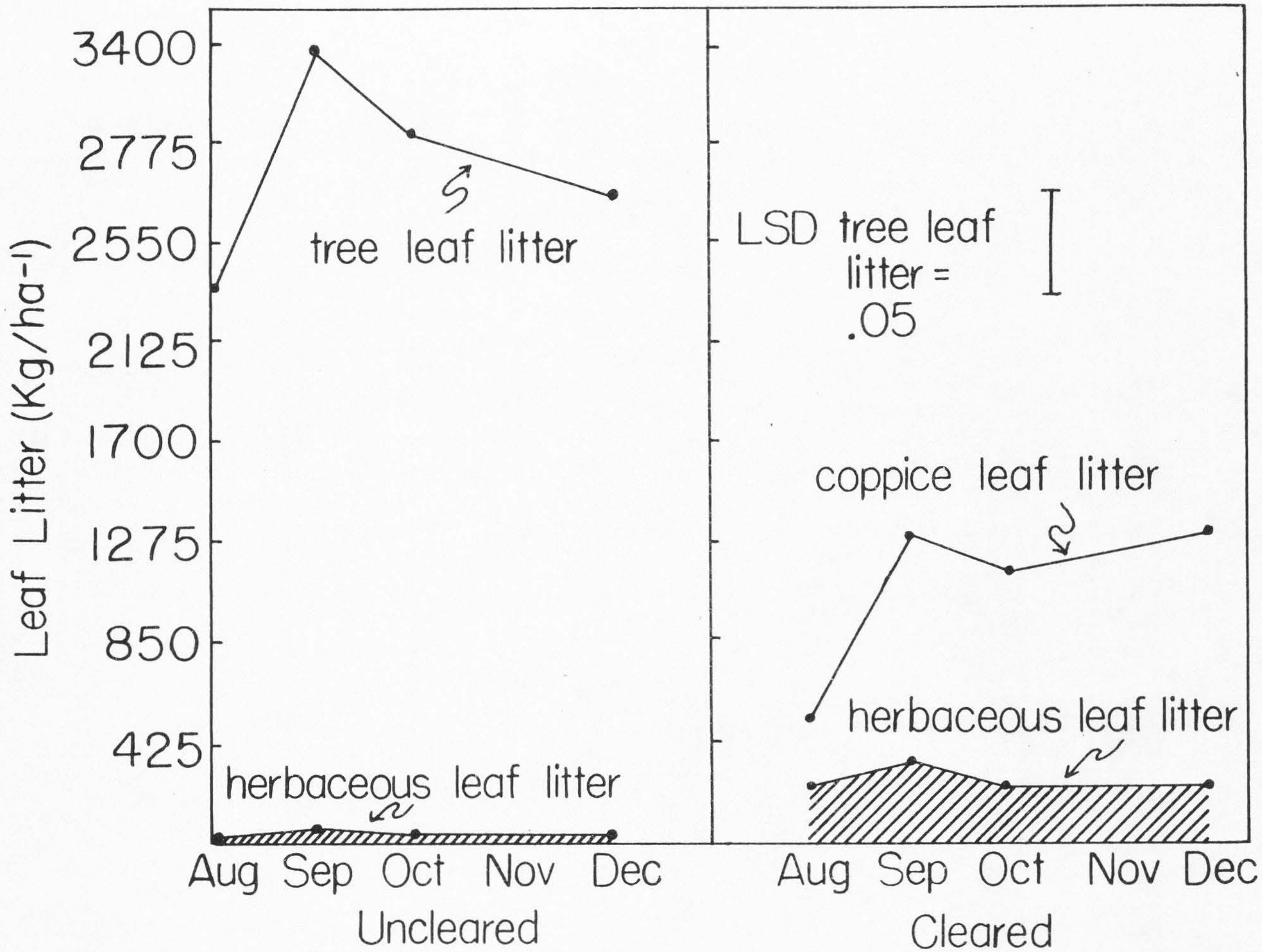

Figure 18. Herbaceous and tree leaf litter on cleared and uncleared caatinga during the dry season, 1982.

actual rates because they do not account for the decomposition that occurs in the litter that falls earlier than September, nor do they account for the potentially large amounts of soluble carbohydrates believed to be lost through leaching while still on the stem (Jensen 1974).

Factors affecting decomposition

Seasonal effects of clearing. The seasonal decompositon rates of the leaf litter from the three tree species on cleared and uncleared areas are shown in Figure 19. Corresponding data for the litter from the three herbaceous species are given in Figure 20. The period from June through December represented the dry season of 1982 (Fig. 21). The period from December through March was the beginning of the wet season of 1983.

The early weight loss (20-30 days) was the most rapid and was apparently a function of the leachable or water soluble substances in the litter. Singh and Gupta (1977) cited various studies that found similar weight losses. Soluble components are more easily assimilated and catabolized by the decomposer microflora than the more recalcitrant lignified cell wall material remaining during later stages of decomposition (Swift et al. 1979).

By mid-dry season there was a general trend for greater rates of decomposition of the tree litter on the cleared areas compared with that on the uncleared. This trend was less apparent for the herbaceous litter. For temperate forests clearing is speculated to have greatest effects on changes in decomposition rates by modifying microclimate (Spurr and Barnes 1980, Binkley 1984). Large differences in

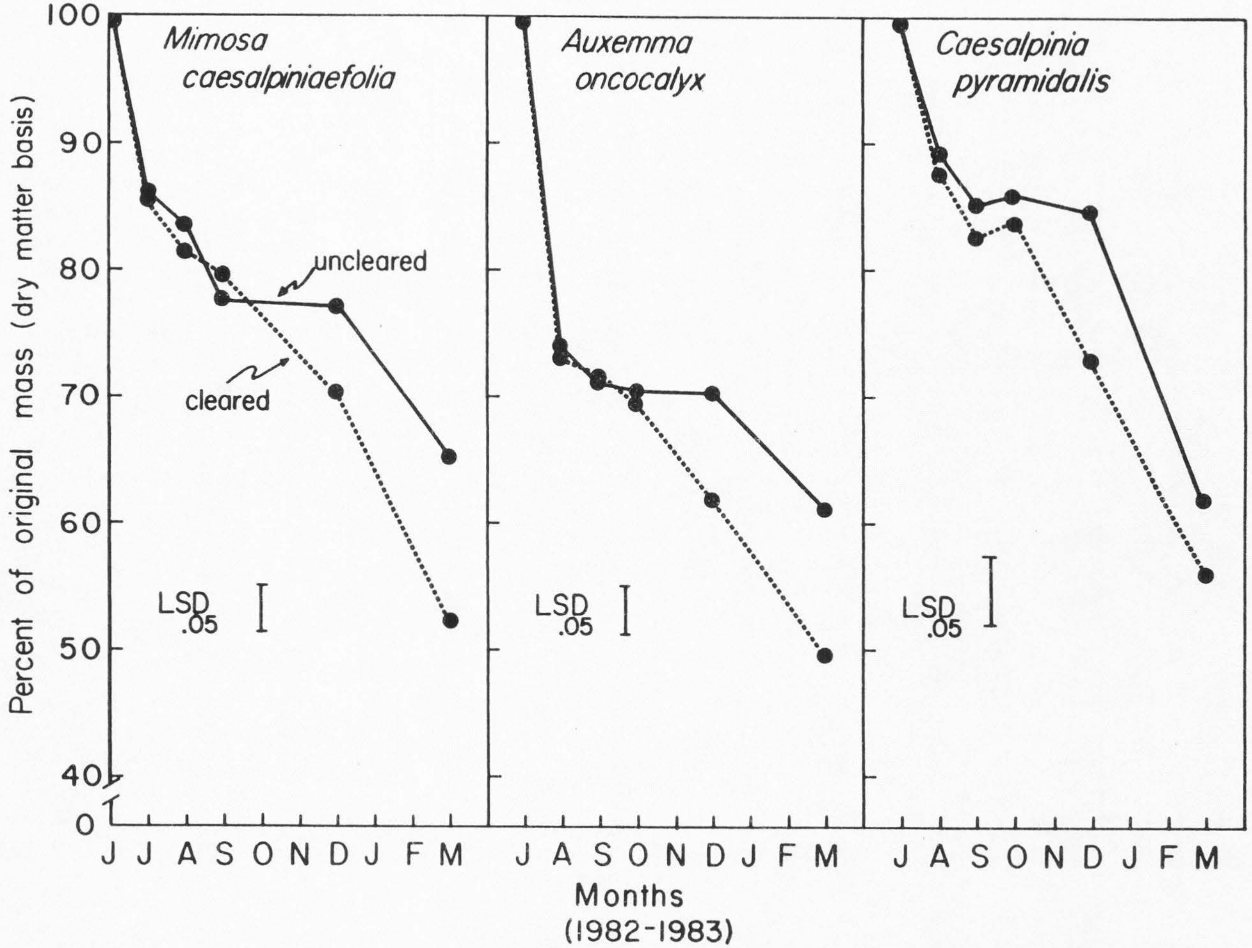

Figure 19. Seasonal decomposition rates of leaf litter from three woody species on cleared and uncleared caatinga, 1982 - 1983.

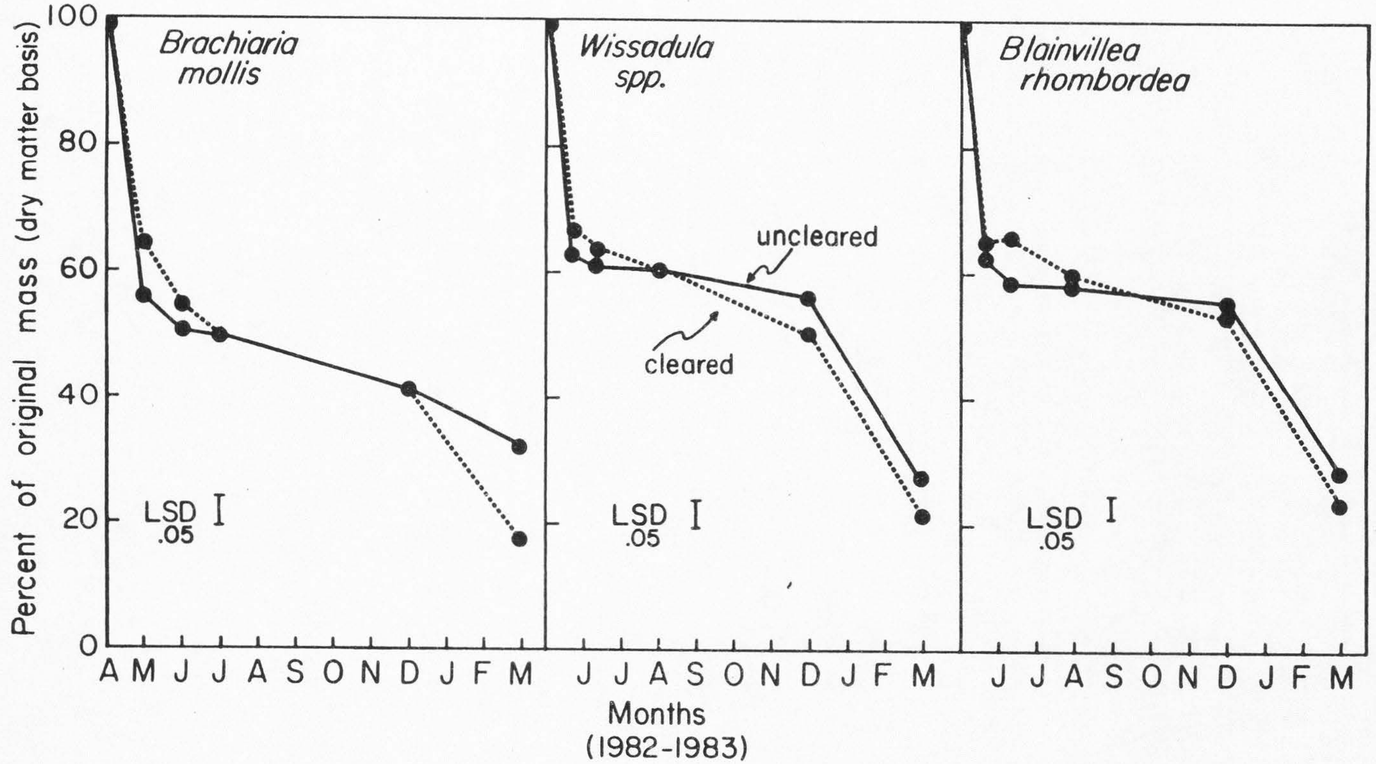

Figure 20. Seasonal decomposition rates of leaf litter from three herbaceous species on cleared and uncleared caatinga, 1982-1983.

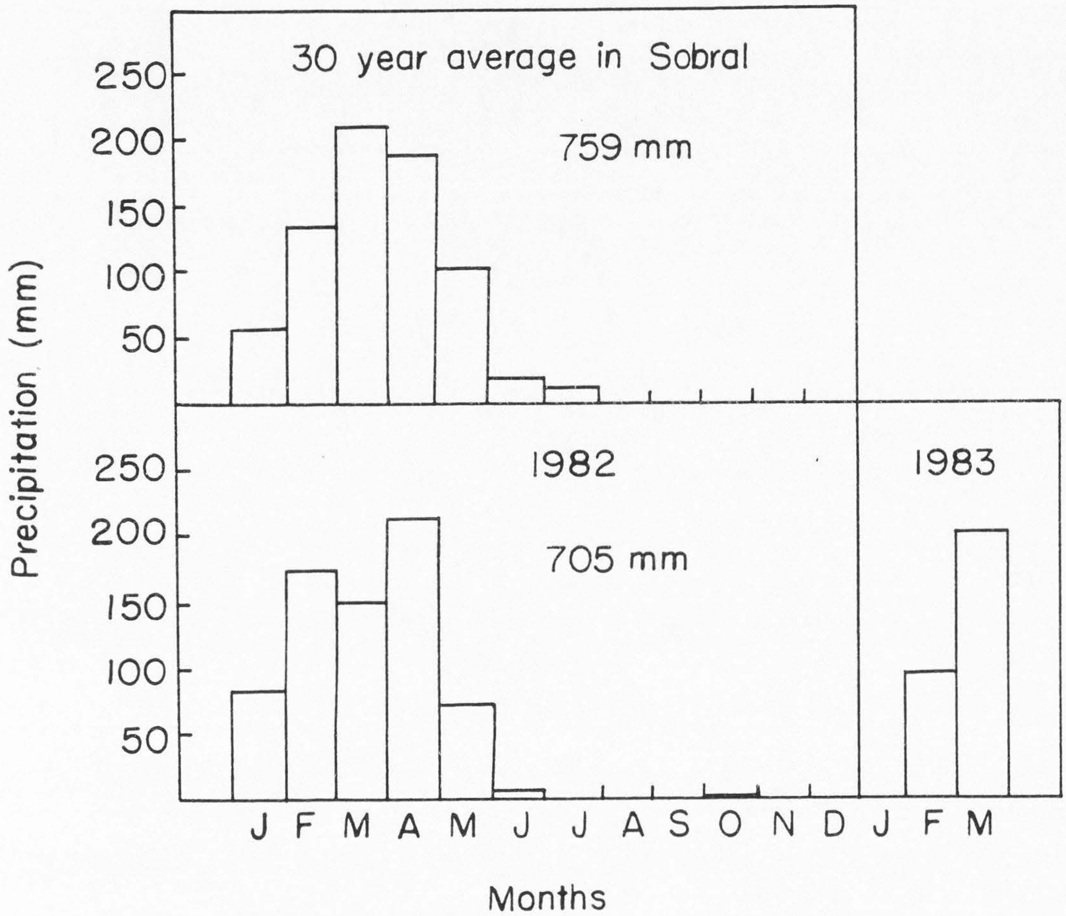

Figure 21. The thirty year average rainfall in Sobral and the rainfall recorded on the research area during 1982-1983.

temperatures and relative humidities, however, were not recorded on the cleared and uncleared research paddocks during the dry season (Appendix Figures 24 and 25). Clearing probably did not result in major microclimatic modifications during the dry season because the leafless trees provided less of a blanketing effect for radiation exchange than is generally expected in evergreen forests. Leaves intercept large quantities of short-wave radiation but when leafless a deciduous forest may intercept less than 30 percent of the incoming radiation (Barry and Chorley 1982). The removal of this open canopy would, therefore, influence the microclimate less than the removal of a closed evergreen canopy.

The increased rates of disappearance at the initiation of the 1983 rainy season (after December) for all plant species illustrate the importance of moisture to the decomposition process (Figures 19 and 20). Madge (1969) also observed very little decomposition in the dry season followed by more rapid rates in the wet season in a savanna in Nigeria.

Sun versus shade plants. Shade-grown plants decomposed less rapidly than those that developed in full sunlight (Table 4). The differences in decomposition rates for *Brachiaria mollis* and *Wissadula* spp. were significant ($P < 0.05$), while that for *Blainvillea rhombordea* was not. In their review of decomposition studies, Singh and Gupta (1977) found that litter higher in nitrogen (low C:N ratio) decomposed more rapidly than that low in nitrogen. Results from this study are apparently incongruent because, with the exception of the grass, the higher decomposition rates correspond with the lower

Table 4. Percent disappearance of herbaceous foliage grown under shade and full sunlight in a caatinga woodland of Northeast Brazil, 1982.

	WEIGHT LOSS [1]	
	SHADE[2]	SUN
Brachiaria mollis	50.9a	65.2b
Wissadula spp.	45.2a	47.4b
Blainvillea rhombordea	44.6a	45.6a

[1] Percent weight lost by December 1982, from original weight on a dry matter basis.

[2] Shade and sun refers to plant material that developed under the shade of the uncleared caatinga and that grown in full sunlight on the cleared areas, respectively.

ab Letter followed by a different letter in the same row is significantly different at $P<0.05$.

nitrogen levels (Appendix Table 19). Possibly, however, this only highlights the importance of the lignified cell wall content in depressing decomposition of plant tissue.

The shade grown foliage of the forbs tended to be higher in lignin than that grown in full sunlight (13 vs. 9 percent for shade vs. full sunlight-grown Wissadula spp. and 10 vs. 8 percent for shade vs. full sunlight-grown Blainvillea rhombordea). Temperatures were higher, however, on the cleared areas than on the uncleared areas during this period of rapid growth (Appendix Figure 24). This contradicts the general theory that higher temperatures cause increases in lignification (Van Soest 1982). Few generalizations can be made from the literature, however, concerning the effect of temperature on forbs. Perhaps these data for forbs are more in line with Wilson and Minson's (1980) findings for herbaceous legumes; that their digestibility is less affected by temperature than that of grasses. Differences in reaction to heat by forbs and grasses may be explained by their differences in anatomy. Grass leaves are supported erect by the structural function of the cell wall and the leaves of forbs are held erect by turgidity. The differences may reflect, therefore, a different lignin-cell wall association. More tightly controlled studies are required, however, before making conclusive statements on the relative importance of temperature and solar radiation on the substrate quality of the foliage of forbs growing in the caatinga.

Microbial activity and decomposition tend to be inversely related to cell wall content and lignification (Witkamp and Van Der Drift 1961, Fogel and Cromack 1977, Meentemeyer 1978). Lignin probably retards microbial decomposition by physical interference with cellulase and may have an antibacterial function (Fogel and Cromack 1977, Van Soest 1982). Fogel and Cromack (1977) also found that lignin content is more important than is the C:N ratio in depressing decomposition.

Cutin is a water insoluble compound that may also affect decomposition by its resistance to the invasion of pathogens (Swift et al. 1979). Cutin is a component of crude lignin (Van Soest 1982) but is rarely examined in decomposition studies. The potential importance of cutin in depressing decomposition is illustrated in the chemical analysis of the tree foliage. For example, the lignin content of Auxemma oncocalyx was higher than for Mimosa caesalpiniaefolia and Caesalpinia pyramidalis (22 percent versus 9 and 10 percent, respectively), but its cutin level was lower (0.7 percent versus 2.6 and 3.0 percent). The lower decomposition rates of Mimosa caesalpiniaefolia and Caesalpinia pyramidalis relative to Auxemma oncocalx (26.0 and 21.0 percent versus 33.6 percent, respectively, by the December collection period) correspond better to the higher cutin levels of the former two species than to the higher lignin contents of Auxemma oncocalyx.

Source of foliage. The rates of weight loss for two forbs, (Wissadula spp. and Blainvillea rhombordea) and two trees (Auxemma oncocalyx and Caesalpinia pyramidalis) are pooled and presented along with the grass (Brachiaria mollis) in Figure 22. By the end of the dry season in December the forb litter had lost 46 percent of its original mass, the grass 58 percent, and the tree litter 27 percent. Due to their different phenologies, the timing for placement of the grass,

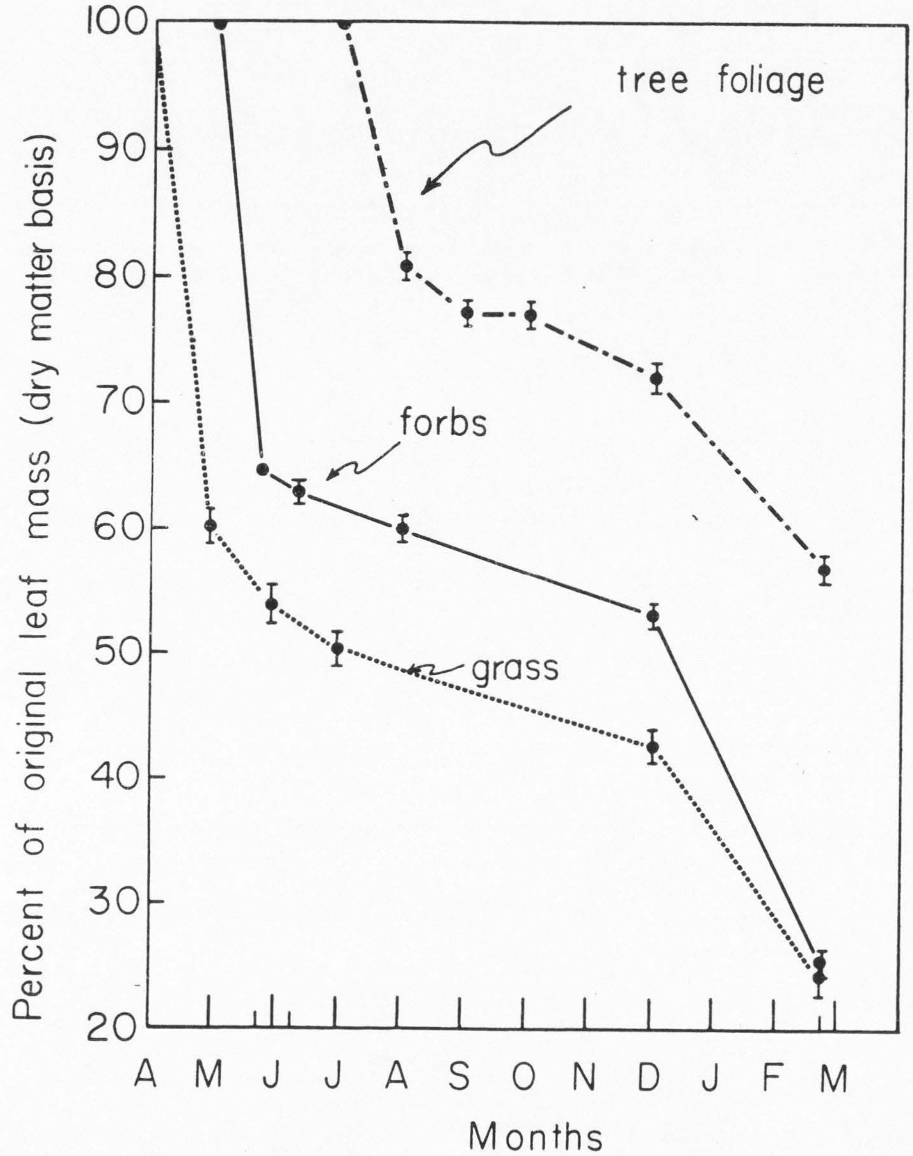

Figure 22. Decomposition rates of tree (Auxemma oncocalyx, and Caesalpiniae pyramidalis) litter, forb (Wissadula spp. and Blainvillea rhombordea) litter, and grass (Brachiaria mollis) litter, 1982-1983.

forbs and tree leaf litter in the field differed (grass one month prior to the forbs, and forbs two months prior to the tree litter). As a result, the grass litter bags received 176 mm of rainfall while the forbs received only 11 mm and the tree leaf litter received none.

As noted earlier, moisture is an important factor affecting litter decomposition rates and therefore a comparison of the rates of decline of tree, forb and grass leaf litter is confounded by this precipitation. These are the design restrictions inherent in following the natural phenology of the plant community. As a result, I am unable to establish whether the cause for more rapid decline of the herbaceous material was substrate quality or moisture level. Under natural conditions, however, plant materials falling to the ground in May or June stand a much greater chance of receiving rainfall than those falling later in the season.

Because Brachiaria mollis matured earlier than the forbs, it was possible to place a second set of litter bags containing this grass at the same time as the forbs for an unconfounded comparison of decomposition rates. The grass lost weight less rapidly than the forbs ($P < 0.05$) when comparisons were made over the same time period (Fig. 23). The difference in rates may be accounted for by the higher fiber contents (NDF) or the lower crude protein, or both, of the grass compared with the forbs (Appendix Table 19).

Arthropod activity. Arthropods were active during the early stages of this study. Some of the litter bags containing herbaceous species that were placed in the field at the end of the rainy season (April and May) were partially eaten, and remains of grasshoppers were

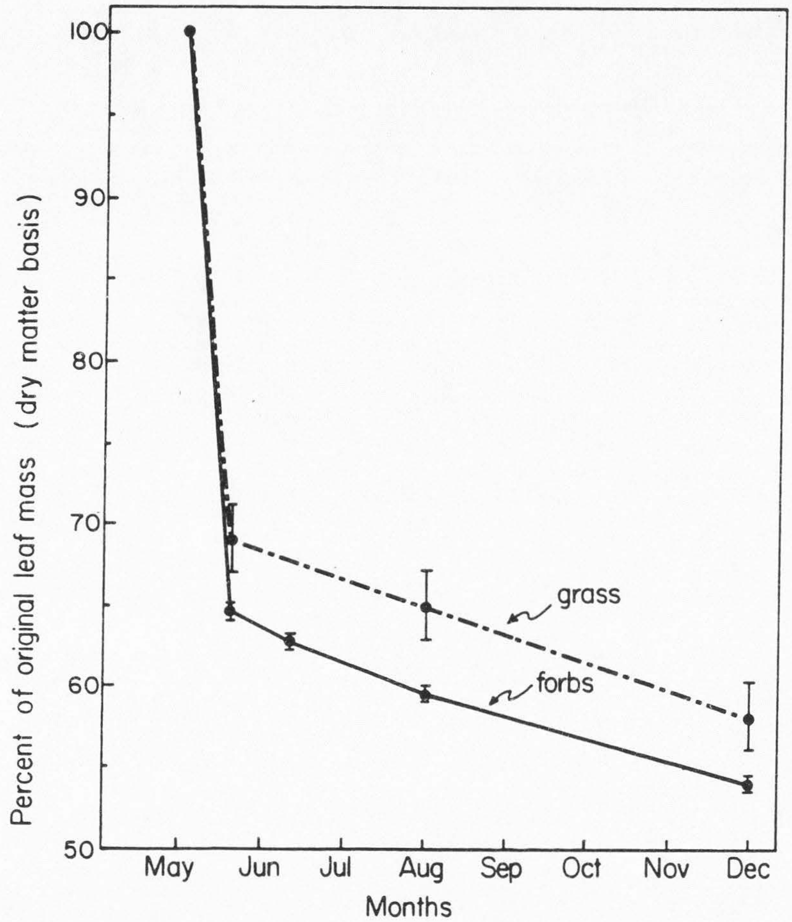

Figure 23. Decomposition rates of grass (Brachiaria mollis) litter and forb (Wissadula spp. and Blainvillea rhombordea) litter that was placed in the field at the same time.

found in several of these bags. No indication of such activity was apparent on the bags containing tree litter that had been placed in the field after all rains had ceased in June and July. Comparison of the disappearance rates for leaf litter in the 15 mm insect bags and the 1 mm herbaceous litter bags at 91 days indicated that the arthropods did not contribute significantly ($P > 0.05$) to herbaceous litter decomposition (Appendix Table 20).

Arthropods are apparently most active during the rainy season and during that period they prefer the ready supply of green foliage over the decaying leaf litter. Insect activity decreased rapidly at the onset of the dry season (June), and no activity was observed at the height of the dry season (August-December). A similar decline in arthropod activity was observed in a seasonal rainfall forest and savanna in Nigeria (Madge 1969).

Conclusion

This study provides evidence that clearcutting a semi-arid woodland will accelerate the rates of leaf litter decomposition. Changes in the microclimate, however, played only a minor role in this difference. This is probably because the caatinga woodland is leafless during the dry season. Modifications of the chemical composition of the plant material due to removal of shade during development also was of minor importance to changes in decomposition rates.

The reduction in the amount of tree leaf litter relative to the herbaceous litter had the greatest effect on decomposition rates. This was simply because tree leaf litter decomposed less than herbaceous leaf litter by the late dry season. Whether this lower absolute amount of decomposition was due to the delayed leaf fall of tree litter relative to herbaceous litter or to differences in chemical composition is of little importance. The fact is that there were 2758 kg $\cdot$ ha^{-1} of forage on the uncleared caatinga at the end of the dry season, and tree litter represented 98 percent of this total. This compared with 1316 kg $\cdot$ ha^{-1} per ha for the cleared areas, of which 85 percent was tree leaf litter.

Tree leaf litter on uncleared caatinga is probably the most underrated dry season forage reserve in the Northeast. Results from this study (Chapter V) as well as Pfister's (1983) indicate that leaf litter from woody plants is the principal fodder resource available to and consumed by sheep and goats during the dry season. Although tree and shrub foliage is generally believed to be of poor nutritional quality (Wilson 1969) it could assume a major role in livestock survival in areas such as the caatinga where it may be the only available forage source during the critical dry season.

This study suggests that there is no critical time during the dry season when grazing the forage is recommended to avoid excessive loss to decomposer organisms. This is because, after the initial rapid decomposition during the first 20-30 days after litter fall, there was minimal but consistent weight loss throughout the remainder of the dry season.

Mid-dry season rains have been reported for the Northeast and farmers fear the rains will cause prematurely decomposition of forage. There was no such event during the course of this study; however, the increased decomposition rates at the beginning of the 1983 rainy season indicate that this could be true and if so would have an important negative impact on the amount of forage reserve. Fifty-three years of rainfall data show that there is less than a 10 percent probability of rainfall greater than 9 mm occurring during the months of August, September or October (Hargreaves 1973).

CHAPTER VII

SUMMARY, CONCLUSIONS, AND MANAGEMENT IMPLICATIONS

This study demonstrated that the removal of the trees increased herbaceous plant yields (sixfold) during the first year post-treatment. Detailed vegetation and diet sampling, however, disclosed that the uncleared areas may produce as much usable forage in the form of leaf litter from the intact woody perennials and palatable herbaceous stem that can be grazed during the dry season. The total herbage yield (tree leaf litter + herbaceous standing crop) was 3,923 kg$\cdot$ ha^{-1} on uncleared paddocks and 4,677 kg$\cdot$ ha^{-1} on cleared areas (Chapter IV). The grazing study reported in Chapter V revealed that on the cleared paddocks only 28 percent of the standing herbaceous stem was consumed, while the tree leaf litter was eaten throughout the trial. If the 72 percent of the stem that remained on the cleared areas was unpalatable (Chapter V), only 3,627 kg$\cdot$ ha^{-1} of the herbage produced on the cleared areas could be considered potential forage. Accounting for the amount of forage remaining at any time during the dry season would also involve a larger decomposition factor on the cleared areas because of the greater ratio of herbaceous foliage to tree foliage on cleared areas.

The relatively low decomposition rates of leaf litter during the dry season suggest that deferment of the range forage for use in the latter part of the dry season is feasible. Large losses to decomposer organisms would not be expected unless highly improbable (less than 10 % probability) mid-season rains occur (Hargreaves 1973).

Clearing did not influence the level of nutrition that goats and sheep obtained from deferred forage during the first two weeks of a 6-week grazing trial. Herbage intake and diet digestibility dropped more rapidly on the uncleared than cleared paddocks, however, with increasing grazing pressure. Although the quality of the available forage was lower on the uncleared areas under intensive use, the quantity of forage remained higher than on the cleared areas.

The generally improved plane of nutrition of animals on the cleared areas may be attributed to an increase in the absolute quantities of the preferred herbaceous forage components (i.e., low fiber herbaceous leaf litter, fruits, and flowers). It may also be due to the persistent green foliage on the coppicing woody plants. When present, such green leaves may provide sufficient nitrogen to render the microbial digestion of the other low-quality roughages in the diet more efficient at this time of year. The nutritional value and accessibility of browse from juvenile shoots of mechanically-treated trees and shrubs have been recognized in other parts of the world (Reynolds and Sampson 1943, Powell and Box 1979, Lawton 1980), but have not been studied for the caatinga.

The potential nutritional benefits from coppicing caatinga trees, however, may only be a short-lived phenomenon. Non-systematic observations on an area cleared two years earlier than my study area indicated that trees begin to revert to the normal deciduous pattern typical of mature trees during the second year after cutting. Investigations into successional patterns of cleared caatinga will probably suggest that a rapid redomination by the woody canopy occurs. These trends have been confirmed by studies in other woodlands of the world (eg. Beale 1973, Pressland 1976, Blair and Brunett 1976), but have not been quantitatively documented for the caatinga.

My data suggest that low levels of crude protein may limit intake, and clearing did not significantly improve the levels of crude protein in the diets of goats and sheep. Research is needed to determine the proper timing, types, and amounts of supplemental feeding required for obtaining maximum economic benefit of dry season forage reserves in the caatinga.

The success of a brush or tree management project should be judged not only by its immediate potential benefits for livestock production, but also on long-term ecosystem stability and productivity. This study highlights the potential importance of the tree leaf litter as a perennial fodder reserve. The woody species of the caatinga are also capable of producing new leaves after minimal precipitation. By contrast the growth of annual herbs varies more with yearly rainfall. By favoring annual species, the long-term predictibility of the dry season forage crop may be compromised.

As Kelly (1977) pointed out for South African woodlands, there is evidence that indescriminant clearing of the caatinga may lead to environmental degradation. Areas of northeastern Brazil with intact caatinga vegetation lose less top soil than do cleared areas (Ramos and Marinho 1980). This can largely be attributed to the protective cover of the leaf litter which moderates the effects of the intense seasonal rains characteristic of the Northeast. Trees and shrubs are also instrumental in maintaining soil nutrient status. Woody perennials extract nutrients from deep layers of the soil profile and deposit them on the surface in the form of leaf litter (Fireman and Haywood 1952, Richard 1965, Charley 1972, Kirmse and Norton 1984).

Walker et al. (1972) suggested for an Australian woodland that a certain amount of the woody vegetation is desirable because it assures a stable plant-soil-animal system. Others have also suggested maintaining a balance of tree density and herbaceous production to provide forage during drought in other semi-arid woodlands (Dawson et al. 1975, Pressland 1976).

Similar recommendations are in order for the caatinga. Although additional years of research are required, with the present understanding of vegetation dynamics I can offer tentative management recommendations for improving livestock production. I propose a rotational clearing scheme that would involve cutting successive strips each year. For example, a ten-year cycle may be incorporated whereby a strip cleared in year one would again be cleared in year eleven. The duration of the cycle would depend on the productivity of the site. Personal observation has indicated that a 10 year cycle would be appropriate on highly productive sites because trees would grow to a mature size suitable for firewood harvesting by that time. This scheme provides multiple advantages for livestock production and ecosystem stability. Yearly clearing would contribute to better animal nutrition during the dry season because of green leaves on the coppiced tree species. Production of herbaceous plant material on the edges of the clearing would also be increased, while the remaining woody vegetation would provide protection from erosion and a safeguard against drought in the form of tree leaf litter.

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APPENDIX

Table 5: Major tree species and their densities on the research area near Sobral, Ceara, Northeast Brazil.

common name	scientific name	no. per hectare
Pau branco	Auxemma oncocalyx	1094
Sabia	Mimosa caesalpiniaefolia	375
Catingueira	Caesalpiniae pyramidalis	406
Mofumbo	Combretum leprosum	281
Marmeleiro	Croton hemiargyreus	177
Mororo	Bauhinia forficata	156

Table 6. Major herbaceous species and their frequencies on the cleared and uncleared research paddocks near Sobral, Ceara, Northeast Brazil, in May of 1982.

Common name	Genus	Family	Frequency %[1] Uncleared	Cleared
Paco paco	Wissadula sp.	Malcaceae	63	69
Bamburral branco	Blainvillea rhomboindea	Compositae	83	20
Jitirana [2]	Ipomoea spp.	Convolvulaceae	30	34
Grass [3]		Poaceae	53	77
Bamburral verdadeiro	Hyptis suaveolens	Labiatae	0	6
Quebra panela	Alternanthera	Amaranthaceae	33	43
Feijao de rola	Phaseolus latyroides	Leguminosae	17	23
Melosa	Ruellia	Acanthaceae	4	9
Carrapicho de agulha	Bidens	Compositae	3	6
Milho de cobra	Dracontium asperum	Araceae	13	11
Cabeca branca	Barreria	Rubiaceae	1	6
Mariana	Commelina	Comelinaceae	23	34
Maracuja rasteiro	Passiflora serrata	Passifloraceae	23	52
Fedegoso	Heliotropium indicum	Borraginaceae	17	6

[1] Thirty sample plots per treatment (10 per block).
[2] Jitirana vines consisted of 5 unknown species of the genus Ipomae that were recorded as a group.
[3] Grasses were recorded as a group. Important genera included Panicum, Paspalum, Setaria, Brachiaria, and Dactyloetemium.

Table 7: Herbaceous leaf and stem standing crop (ka · ha^{-1}) and leaf/stem rations (L/S) through the season (1982) on the cleared and uncleared research blocks (A, B and C).

Months/ Blocks	Uncleared			Cleared		
	Leaf	Stem	L/S	Leaf	Stem	L/S
March						
A	243	149	1.7	253	81	2.82
B	66	56	1.16	659	253	2.54
C	207	95	2	432	173	2.1
April						
A	352	346	1.18	1100	1597	0.91
B	128	147	1.13	710	592	1.32
C	195	105	1.68	750	664	1.1
May						
A	385	567	0.82	1417	3500	0.47
B	144	166	1.35	897	1400	0.71
C	182	248	0.77	1160	1862	0.71
June						
A	349	669	0.52	1023	2849	0.36
B	83	93	0.89	921	2298	0.40
C	192	305	0.63	570	1023	0.56
July						
A	60	572	0.1	489	3167	0.15
B	28	116	0.24	561	2110	0.265
C	50	280	0.18	409	1292	0.32
August						
A	99	608	0.16	498	3115	0.16
B	4	166	0.02	375	1478	0.255
C	48.7	174	0.26	228	1435	0.16
September						
A	15.7	449	0.03	216	2190	0.10
B	5.4	108	0.05	116	1333	0.09
C	18	156	0.11	413	1277	0.03
October						
A	7.4	238	0.03	197	2020.6	0.10
B	7	103.7	0.07	272	1336	0.20
C	23.9	189	0.13	63	1044	0.06
December						
A	0	302.6	0	82.8	1943.2	0.04
B	0	56.4	0	68.4	1253	0.05
C	0	188	0	7.3	1011.7	0.01

Table 8. Basal stem diameter (cm) of two prevalent forbs on the three blocks (ABC) of the cleared and uncleared research pastures in June, 1982.

	Uncleared			Cleared		
	A	B	C	A	B	C
Paco paco (*Wissadula* spp.)	2.6 ± 1.2[1]	2.1 ± 0.7	2.3 ± 0.3	9.2 ± 3.1	12.2 ± 3.0	7.8 ± 2.2
bamburral branco (*Blainvillea rhombordea*)	2.7 ± 1.1	2.2 ± 0.8	3.2 ± 1.4	11.3 ± 4.3	13.3 ± 4.4	10.2 ± 6.1

[1]Mean ± std. dev.

Table 9. Percent composition by weight (oven dry basis) of grass and forbs on cleared and uncleared caatinga, June 1982.

	Uncleared		Cleared	
Blocks	forbs	grass	forbs	grass
A	99	1	74	26
B	100	t	54	46
C	97	3	90	10

[t]Trace amounts.

Table 10: Seasonal crude protein contents (%) in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

Months	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
March	15.9[1]	14.1	15.6	16.1
April	15.1	14.3	16.4	15.1
May	15.7	14.5	15.8	13.7
June	15.7	14.5	13.4	12.8
July	12.3	10.1	11.7	12.1
August	11.2	9.7	10.4	10.5
September	10.3	8.6	9.7	9.7
October	8.3	7.9	8.4	9.3
December	7.3	7.4	9.1	9.0

[1]Mean ± 0.56 (std. error), n = 3.

Table 11. Major components of the peak tree leaf litter on the cleared (Dec.) and uncleared (Sept.) research paddocks near Sobral, Ceara, Northeast Brazil.

	UNCLEARED	%	CLEARED	%
	($Kg \cdot ha^{-1} \pm$ 90% CI)			
Sabia (*Mimosa caesalpiniaefolia*)	224 (63)	7.7	242 (82)	22
Pau branco (*Auxemma oncocalyx*)	1619 (294)	56	482 (169)	44.5
Catingueira (*Caesalpinia pyramidalis*)	477 (141)	16	102 (33)	9.4
Others[1]	592 (195)	20	265 (159)	24.5
	Σ = 2912		Σ = 1082	

[1] Other woody species were grouped into one category as they each represented relatively minor components. The species included:

common names	scientific names
Angico	*Anadenanthera macrocarpa*
Aroeira	*Astronium urundeuva*
Juazeiro	*Zizyphus joazeiro*
Jucazeiro	*Caesalpinia ferrea*
Jurema branca	*Pithecolobium dumosum*
Marmeleiro	*Croton hemiargyreus*
Mofumbo	*Combretum leprosum*
Mororo	*Bauhinia forficata*

Table 12: Seasonal botanical composition of the diets (percent of diet) of goats grazing on cleared and uncleared caatinga, 1982.

	Cleared			Uncleared		
Common Name	May	Oct.	Dec.	May	Oct.	Dec.
Woody Plants	22	45	48	26	33	30
Sabia	3	-	3	3	3	2
Catingueira	3	17	3	6	17	7
Mororo	6	25	9	10	9	11
Pau branco	0	1	4	2	5	-
Mofumbo	-	-	3	-	-	-
Juazeiro	-	2	4	-	-	-
Jurema branca	7	5	21	-	-	-
Marmeleiro	-			-		-
Feijao bravo	-	1		-	-	-
Aroeira	-	-		4	T	5
Manicoba	-	-		1	-	4
Capauba	2			1		1
Herbaceous plants	77	50	53	71	65	63
banburral branco	10	5	4	12	16	5
jitirana peludo	15	13	7	11	2	3
Ervanco	5	-	8	4	6	5
Melosa	14	1	2	12	13	11
Malva paco paco	-	12	9	-	12	14
Paco paco	3	-		3	6	
Cabeca branca	5	-	3	4	-	4
Quebra panela	-	1	T	2	2	3
Melosa brava	-	1	T	-	3	4
Maracuja estalo	-	6			-	T
Feijao de rola	-	1			-	
Fava de boi	-	5	8	1	5	1
Grass (capim)	11	-	9	9	-	13
Jitirona lisa	-	-			-	T
Mariona	-	-	2		-	
Fedigoso	2			1		
Canifistula bravo	5			2		
Frei george	1			3		
Bamburral verdadeiro	-			1		
Bamburral rusarente	1			2		
Pescoso ganso	-			1		
Carrapicho de agula	7			4		
Canifistula lajoa	1			-		

Table 13: Seasonal botanical composition of the diets (percent of diet) of sheep grazing on cleared and uncleared caatinga, 1982.

	Cleared			Uncleared		
Common Name	May	Oct.	Dec.	May	Oct.	Dec.
Woody plants	25	28	40.6	31	14	11.8
Sabia	4	4	9.9	11	2	29
Catingueira	1	11	1.1	2	7	3.2
Mororo	4	9	3.5	1	2	1.4
Paubranco	1	T	T	5	3	-
Mofumbo	-	4	-	-	-	-
Jucazeiro	-	-	10.9		T	-
Aroeira	-	-	7	3	1	1.8
Jurema branco	15	1	-	1	-	-
Marmeleiro	-	-	-		-	-
Feijao bravo	-	1	T		-	
Manicoba	-	-	-	1		1.4
Cipouba	-	-	-	T		1.1
Herbaceous plants	75	71	59.4	67	84	86.4
bamburral branco	8	15	12.3	10	19	20.7
Jitirana peludo	19	10	8.8	4	-	T
Ervanco	2	10	5.7	2	17	19.3
Melosa	3	3	2.5	11	11	3.9
Malva paco paco	-	1	-	-	12	5
Baco paco	1	5	-	3	7	5.7
Cabeca branca	T	4	2.8	4	-	6
Quebra panela	2	3	5.2	-	7	6.4
Melosa brava	3	6	2.5	3	9	6.4
Maracuja estalo		7	7.4	-	-	-
Feijao de rola	3	1	-	2	-	-
Jitirana lisa	-	T	-	T	-	T
Canifistula de lagoa	-	2	-	4	-	-
Mirasol	-	T	-	-	1	-
Maracuja rasteiro	1	1	-	T	-	-
Banburral verdadeiro	T	-	-	-	T	-
Fava de boi	8	-	3.5	8	-	3.2
Grass (capim)	-	-	3.1	2	-	8.2
Mariana	-	-	2.1	-	-	T
Fedigosa	4	-	2.5	5	-	T
Canipistula bravo	15	-	-			
Bamburral rusarente	2	-	-	3		
Carripicho de agulha	4	-	-	4		

Table 14: Dry matter intake ($g \cdot d^{-1}$) of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats[2]	Sheep	Goats	Sheep
0	727 ± 161[1]	1062 ± 203	823 ± 110	1164 ± 204
2	614 ± 103	693 ± 168	668 ± 112	1058 ± 115
4	404 ± 122	621 ± 144	588 ± 120	944 ± 118
6	356 ± 98	535 ± 103	598 ± 116	703 ± 63

[1]Mean ± std. dev., n = 6.
[2]Animal weights are in table 3.

Table 15: Standing crop and leaf litter (ka · ha^{-1}) remaining on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

	Uncleared				Cleared			
Weeks of Grazing	Standing Herbaceous Foliage	Standing Herbaceous Stem	Herbaceous Leaf Litter	Tree Leaf Litter	Standing Herbaceous Foliage	Standing Herbaceous Stem	Herbaceous Leaf Litter	Tree Leaf Litter
0	13[1]	171[2]	49[3]	2970[4]	178[1]	1467[2]	230[3]	890[4]
2	0	13	18	2547	19	1051	120	580
4	0	0	4	2017	0	1127	120	1183
6	0	0	3	1900	0	1039	37	677

[1]Mean ± 13 (std. error), n = 30, for each period.
[2]Mean ± 167 (std. error), n = 30, for each period.
[3]Mean ± 21 (std. error), n = 30, for each period.
[4]Mean ± 134 (std. error), n = 30, for each period.

Table 16. Botanical composition of the diets (%) of goats under grazing pressure gradients[1] on deferred cleared and uncleared caatinga range.

	Cleared				Uncleared			
Common name	0	2	4	6	0	2	4	6
Woody plants	28	24	35	56	14	43	57	56
Sabia	4	10	14	18	2	15	19	19
Catingueira	11	6	10	5	7	5	13	14
Mororo	9	6	10	15	2	19	14	12
Pau branco	T	10	2	3	3	4	5	7
Mofumbo	4	-	2	8	-	-	-	-
Jucazeiro	-	1	-	-	T	-	-	-
Aroeira	-	-	T	-	1	-	-	-
Jurema branca	1	-	-	-	-	-	-	-
Marmeleiro	-	-	-	6	-	-	-	-
Cipauba	-	-	-	-	-	-	-	3
Feijao bravo	1	-	-	-	-	-	-	-
Herbaceous plants	71	76	65	44	84	50	38	35
Bamburral branco	15	11	11	5	19	14	10	3
Jitirana peludo	10	8	8	1	-	-	-	-
Ervanco	10	8	5	-	17	8	4	1
Melosa	3	9	10	6	11	7	5	7
Malva paco paco	1	9	7	5	12	4	2	1
Paco paco	5	5	7	5	7	2	1	-
Cabeca branca	4	5	1	1	-	6	-	2
Quebra panela	3	2	T	1	7	-	1	1
Melosa brava	6	3	1	1	9	4	-	-
Maracuja estalo	7	4	2	-	-	-	-	-
Feijao de rola	1	T	-	-	-	-	-	-
Jitirana lisa	T	-	-	-	-	-	-	-
Canafistula de lagoa	2	-	-	-	-	-	-	-
Mirasol	T	-	-	-	1	-	-	-
Maracuja rasteiro	1	-	-	-	-	-	-	-
Bamburral verdadeiro	-	-	-	-	T	-	-	-
Fava de boi	-	T	-	-	-	-	-	-
Capim	-	7	13	17	-	5	16	18

[1]Grazing prcssure gradients: 0-6 weeks of continous grazing with 2 goats and 2 sheep on each .32 ha paddock.

T indicates less than .5%.

Table 17. Botanical composition of the diets (%) of sheep under grazing pressure gradients[1] on deferred cleared and uncleared caatinga range.

	Cleared				Uncleared			
Common name	0	2	4	6	0	2	4	6
Woody plants	45	20	24	45	33	40	45	55
Sabia	-	2	6	13	3	-	9	8
Catingueira	17	7	5	9	17	12	9	15
Mororo	25	8	7	15	9	17	11	14
Pau branco	1	3	6	3	5	9	9	10
Mofumbo	-	-	1	1	-	-	3	5
Jucazeiro	2	-	-	-	-	-	-	-
Aroeira	-	-	-	-	T	2	5	1
Jurema branca	5	-	-	-	-	-	-	-
Jurema preta	-	-	-	-	1	-	-	-
Manicoba	-	-	-	4	-	-	-	2
Feijao bravo	1	-	-	-	-	-	-	-
Herbaceous plants	50	80	76	55	65	60	55	45
Bamburral branco	5	3	5	1	16	3	3	6
Jitirana peludo	13	-	8	-	2	9	7	-
Ervanco	-	10	9	10	6	12	9	2
Melosa	1	10	13	14	13	6	4	9
Malva paco paco	12	27	17	16	12	11	17	15
Paco paco	-	-	-	-	6	-	-	2
Cabeca branca	-	-	7	3	-	3	1	-
Quebra cabeca	1	-	2	-	2	-	-	3
Melosa brava	1	8	2	-	3	3	1	-
Maracuja estalo	6	-	-	-	-	-	-	-
Feijao de rola	1	-	-	-	-	-	-	-
Fava de boi	5	-	-		5	-	-	
Capim	-	8	13	10	-	9	12	8

[1] Grazing pressure gradients: 0 - 6 weeks of continuous grazing by 2 sheep and 2 goats on each .32 ha paddock.

T indicates less than 0.5%.

Table 18: Percent neutral detergent fiber of goat and sheep diets grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
0	46[1]	43	49	43
2	55	52	55	45
4	58	49	54	46
6	53	51	52	48

[1] Sample number is 3 and std. error is 1.74 for each mean.

Table 19. Chemical composition of herbaceous foliage grown under shade and full sunlight in a caatinga woodland of Northeast Brazil, 1982.

	PERCENT			
	NDF[1]	LIGNIN	CUTIN	CRUDE PROTEIN
HERBACEOUS				
Brachiaria mollis				
shade[2]	72	10	1.07	6.4
sun	77	10	0.50	7.2
Wissadula spp.				
shade	47	13	0.86	17.0
sun	40	9	0.30	13.4
Blainvillea rhombordea				
shade	43	10	12.20[3]	12.1
sun	41	8	11.70	7.7

1 NDF=Neutral detergent fiber.

2 Shade and sun refers to plant material that developed under the shade of the uncleared caatinga and that grown in full sunlight on the cleared areas, respectively.

3 These unusually high levels of cutin could be laboratory errors.

Table 20: Weight loss (percent of original weight) of Brachiaria mollis, Wissadula spp. and Blainvillea rhombordea foliage that was collected at senescence and contained in 1 mm and 15 mm mesh litterbags[1] on the cleared and uncleared research paddocks for a period of 90 days.

	Uncleared		Cleared	
	1 mm mesh	15 mm mesh	1 mm mesh	15 mm mesh
Brachiaria mollis	28 ± 9.7[3]	35 ± 13.1	38 ± 4.1	33 ± 2.4
Wissadula spp.	27 ± 4.6	29 ± 6.4	33 ± 13.1	34 ± 2.5
Blainvillea rhombordea	30 ± 7.0	32 ± 6.7	24 ± 2.6	30 ± 5.0

[1]The 1 mm mesh is assumed to block the entrance of litter eating arthropods while the 15 mm mesh is assumed to allow access to the contained litter by these insects.

[2]Brachiaria mollis was placed in the field on April 19, 1982, and collected on July 19; the two forbs Wissadula spp. and Blainvillea rhombordea were placed on May 19, 1982, and collected on August 19.

[3]Mean ± std. dev., n = 3.

Table 21: Seasonal *in vitro* organic matter digestibilities (%) in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

Month	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
April	64.7[1]	65.3	68.3	68.3
June	55.0	53.7	64.0	62.3
August	49.7	51.7	50.0	52.0
October	55.3	56.3	53.3	53.3

[1]Mean ± 2.4 (std. error), n = 3.

Table 22: Seasonal neutral detergent fiber (%) in diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

	Uncleared		Cleared	
Month	Goats	Sheep	Goats	Sheep
April	42.3[1]	43.9	43.1	45.2
June	42.2	43.5	45.8	41.5
August	52.6	51.8	46.7	50.2
October	55.8	53.4	49.3	49.6

[1]Mean $\pm$ (std. error), n = 3.

Table 23: Seasonal lignin contents (%) in the diets of goats and sheep grazing on cleared and uncleared caatinga, 1982.

	Uncleared		Cleared	
Month	Goats	Sheep	Goats	Sheep
April	11.0[1]	11.7	11.9	10.1
June	15.8	18.4	12.4	13.3
August	19.1	14.8	14.9	16.7
October	17.8	16.6	14.8	13.3

[1]Mean ± 0.997 (std. error), n = 3.

Table 24: Percent *in vitro* dry matter digestibilities of the diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
0	62.0[1]	59.4	59.1	59.2
2	49.0	44.7	51.5	54.9
4	39.1	42.1	43.1	53.0
6	40.1	42.9	43.1	48.1

[1]Mean ± 1.0 (std. error), n = 3.

Table 25: Percent lignin in diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
0	13.2[1]	12.2	15.7	14.4
2	17.2	16.0	11.7	9.1
4	14.5	16.9	12.6	14.2
6	19.7	17.4	17.2	16.7

[1] Mean ± 1.3 (std. error), n = 3.

Table 26: Percent crude protein in the diets of goats and sheep grazing on cleared and uncleared caatinga under increasing levels of grazing pressure during the dry season, 1982.

Weeks of Grazing	Uncleared		Cleared	
	Goats	Sheep	Goats	Sheep
0	8.3[1]	7.9	8.4	9.4
2	6.9	7.4	7.2	7.7
4	5.9	6.9	6.2	6.3
6	6.7	6.5	5.8	5.7

[1] Mean ± .4 (std. error), n = 3.

Table 27: Seasonal weight loss (percent of original weight) of Mimosa caesalpiniaefolia leaf litter that was contained in litterbags and placed on the cleared and uncleared paddocks on June 19, 1982.

Period	Uncleared	Cleared
July 20	13.6[1]	14.2
August 19	16.5	18.3
September 19	22.3	21.4
December 17	22.9	29.5
March 11	34.6	47.6

[1]Mean ± 1.2 (std error) n=3, for all periods except March 11 on the uncleared where only two samples were available and the std. error was 1.5.

Table 28 Seasonal weight loss (percent of original weight) of pau branco (Auxemma oncocalyx) and catinguera (Caesalpinia pyramidalis) leaf litter that was contained in litter bags and placed on the cleared and uncleared paddocks on July 20, 1982.

	Uncleared		Cleared	
Period	Pau branco	Catinguera	Pau branco	Catinguera
August 19	25.8[1]	12.1[2]	26.8	11.8
September 19	28.6	14.9	28.1	17.4
October 19	29.2	14.0	30.5	16.2
December 17	29.4	15.2	37.8	26.9
March 11	38.6	39.9	50.7	43.9

[1]Mean $\pm$ 1.2 (std. error), n = 3.

[2]Mean $\pm$ 1.4 (std. error), n = 3.

Table 29: Seasonal weight loss (percent of original) of shade-grown and full sunlight-grown _Brachiaria mollis_ foliage that was placed in litterbags on the cleared and uncleared paddocks on April 19, 1982.

	Uncleared		Cleared	
Periods	Shade-Grown	Sun-Grown	Shade-Grown	Sun-Grown
1982				
May 19	37[1]	50	31	43
June 19	44	54	39	51
July 19	43	55	44	55
Dec. 19	52	65	50	66
1983				
March 11	61	74	74	91
April 10	75	72	83	83

[1]Mean ± 2.2 (std. error), n = 3.

Table 30: Seasonal weight loss (percent of original weight) of *Brachiaria mollis* foliage that was contained in litterbags and placed on the cleared and uncleared research paddocks on May 19 1982.

Period	Uncleared	Cleared
June 10	31.5[1]	30.2
June 29	27.5	29.4
August 19	30.6	38.7
December 17	37.1	45.5

[1]Mean ± 2.08 (std. error) for each period except December 17 on the uncleared paddocks where the standard error was 2.28 (one missing subsample); n = 3.

Table 31: Seasonal weight loss (percent of original weight) of shade-grown and full-sunlight-grown Wissadula spp. foliage that was contained in litterbags and placed on the cleared and uncleared research paddocks on May 19, 1982.

	Uncleared		Cleared	
Period	Shade-Grown	Sun-Grown	Shade-Grown	Sun-Grown
June 10	35[1]	39	30	35
June 29	34	42	34	37
August 19	39	40	37	43
December 17	43	44	48	50
March 11	70	75	80	76

[1] Mean $\pm$ 2.06 (std. error), n = 3.

Table 32: Seasonal weight loss (percent of original weight) of shade-grown and full-sunlight-grown Blainvillea rhombordea foliage that was contained in litterbags and placed on the cleared and uncleared research paddocks on May 19, 1982.

	Uncleared		Cleared	
Perio	Shade-Grown	Sun-Grown	Shade-Grown	Sun-Grown
June 10	35.1[1]	39.1	34.4	35.3
June 29	42.6	39.4	33.0	35.0
August 19	41.9	40.8	38.2	40.9
December 17	43.8	43.9	45.5	47.3
March 11	70.6	71.1	77.2	75.3

[1]Mean ± 1.6 (std. error), n = 3.

Table 33: Crude protein content of leaf and stem components of the herbaceous vegetation growing on cleared and uncleared caatinga from early growing stage to senescence, 1982.

	Uncleared		Cleared	
Months	Stem	Leaf	Stem	Leaf
March	4.3[1]	13.6	6.5	11.7
May	3.3	14.6	2.4	11.6
July	2.9	9.3	2.4	5.3

[1]Mean $\pm$ .74 std. error and n = 3 for all periods except the stem component in March on the uncleared areas where n was only one and the std. error was 4.3.

Table 34: Neutral detergent fiber of leaf and stem components of the herbaceous vegetation growing on cleared and uncleared caatinga from early growth to senescence, 1982.

	Uncleared		Cleared	
Months	Stem	Leaf	Stem	Leaf
March	58.6[1]	37.3	58.9	43.5
May	67.4	42.3	73.4	43.8
July	77.2	47.2	75.8	54.9

[1]Mean ± 2.32 std. error, n = 3

Table 35: *In vitro* dry matter digestibility of leaf and stem components of the herbaceous vegetation growing on cleared and uncleared caatinga from early growing stage to senescence 1982.

	Uncleared		Cleared	
Month	Stem	Leaf	Stem	Leaf
March	33.9[1]	38.0[2]	43.9[1]	57.3[2]
May	31.4[1]	47.8[2]	31.7[2]	50.5[2]
July	10.0[2]	28.7[2]	11.6[2]	19.6[2]

[1]Mean $\pm$ 5.51 $\pm$ std. error, n = 2.
[2]Mean $\pm$ 4.11 $\pm$ std. error, n = 3.

Table 36: Edge effect. Herbaceous vegetation production ($g \cdot plot^{-1}$) along a 14 m transect into the uncleared research blocks[1] (A, B, and C) in May 1982.

Meters from Line of Clearing	Blocks		
	A	B	C
2	47 ± 16[2]	134 ± 55	57 ± 19
4	44 ± 10	96 ± 31	56 ± 36
6	30 ± 22	51 ± 36	41 ± 27
8	19 ± 16	28 ± 28	34 ± 25
10	17 ± 10	22 ± 18	17 ± 6
14	20 ± 13	9 ± 4	18 ± 8

[1]Plot size is 3000 cm^2.

[2]Mean ± std. dev., n = 5.

Table 37. Common and scientific names of the plants found in the analysis of botanical composition of goat and sheep diets in the caatinga, 1982.

common name	scientific name[1]
TREES	
Pau branco	Auxemma oncocalyx
Sabia	Mimosa caesalpiniaefolia
Catingueira	Caesalpiniae pyramidalis
Mofumbo	Combretum leprosum
Marmeleiro	Croton hemiargyreus
Mororo	Bauhinia forficata
Angico	Anadenanthera macrocarpa
Aroeira	Astronium urundeuva
Juazeiro	Zizyphus joazeiro
Jucazeiro	Caesalpinia ferrea
Jurema branca	Pithecolobium dumosum
Feijao bravo	Capparia flexuosa
HERBS	
Paco paco	Wissadula sp.
Malva paco paco	Wissadula periplocifolia
Bamburral branco	Blainvillea rhomboindea
Jitirana [2]	Ipomoea spp.
Grass[3]	
Bamburral verdadeiro	Hyptis suaveolens
Quebra panela	Alternanthera sp.
Feijao de rola	Phaseolus latyroides
Melosa	Ruellia sp.
Carrapicho de agulha	Bidens sp.
Milho de cobra	Dracontium asperum
Cabeca branca	Barreria sp.
Mariana	Commelina sp.
Maracuja	Passiflora serrata
Fedegoso	Heliotropium indicum
Malva	Sida sp.
Ervanco or cabeca branca	Borreria sp.
Mirasol	Melanthera
Canifistuala de lagoa	Cassia sp.
Pescoco de ganso	Stachytorpheta sp.
Fava de boi	Canavalia brasiliensi

[1] Many of the species have not been identified.

[2] Jitirana vines consisted of 5 unknown species of the genus Ipomae that were recorded as a group.

[3] Grasses were recorded as a group. Important genera included Panicum, Paspalum, Setaria, Brachiaria, and Dactyloetemium.

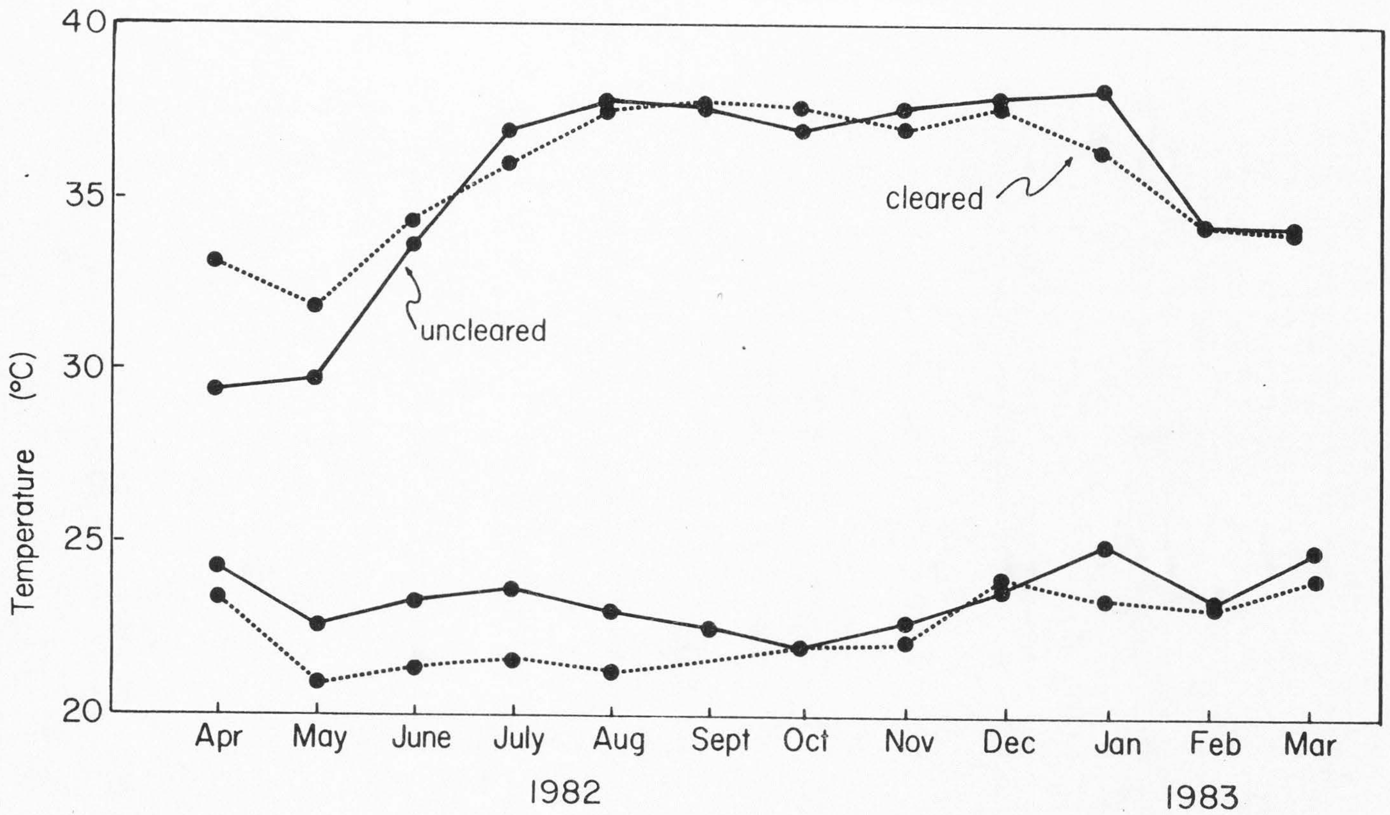

Figure 24. High and low temperatures on cleared and uncleared caatinga woodland near Sobral, Ceara, Northeast Brazil

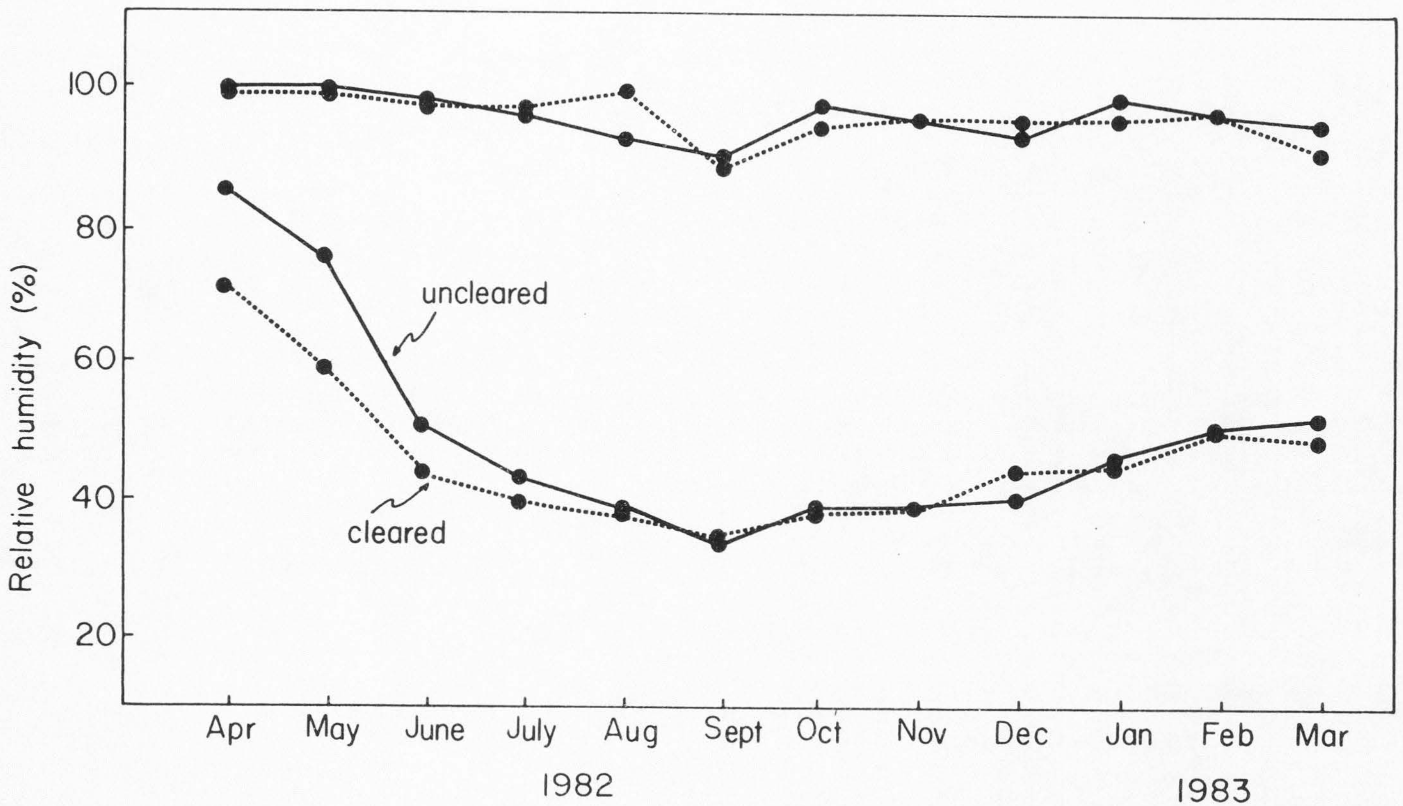

Figure 25. High and low relative humidities on cleared and uncleared caatinga woodland near Sobral, Ceara, Northeast Brazil.

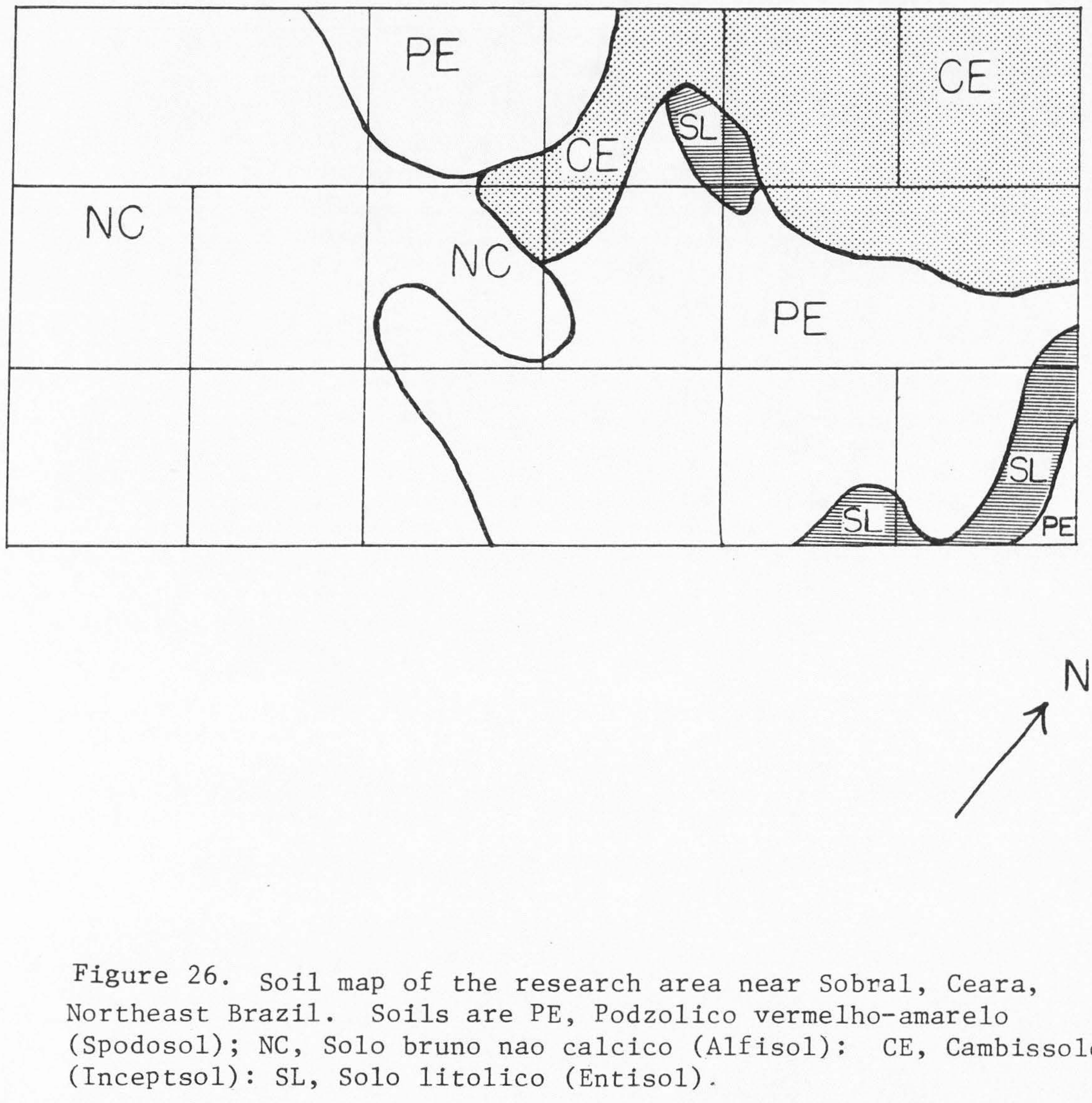

Figure 26. Soil map of the research area near Sobral, Ceara, Northeast Brazil. Soils are PE, Podzolico vermelho-amarelo (Spodosol); NC, Solo bruno nao calcico (Alfisol): CE, Cambissolo (Inceptsol): SL, Solo litolico (Entisol).

VITA

Robert D. Kirmse

Candidate for the Degree of

Doctor of Philosophy

Dissertation: Effects of Clearcutting on Forage Production, Quality and Decomposition in the Caatinga Woodland of Northeast Brazil: Implications to Goat and Sheep Nutrition.

Major Field: Range Science

Biographical Information:

Personal Data: Born at Janesville, Wisconsin, October 27, 1946, Son of Robert D. and Marjorie Kirmse; married Mireille Delay April 13, 1979; Child--Robert Justin .

Education: Graduated from W. B. Ray High School, Corpus Christi, Texas in 1965; received the Bachelor of Arts degree from the University of Texas, Austin, with a major in Botany in 1969; Completed the requirements for the degree of Masters of Science in Range Science at Utah State University, Logan, in 1980; will complete the requirements for the Doctor of Philosophy degree at Utah State University, with a major in Range Science, in 1984.

Professional Experience: 1970-1972, Peace Corps Volunteer in Costa Rica and Nicaragua working on reforestation project; 1973-1978, Agroforester with CARE in Liberia and Chad; 1980-1983, Research Associate and Project Administrator with Utah State University Small Ruminant-CRSP in Brazil.