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A Bio-economic Model of Small-ruminant Production in the Semi-arid Tropics of the Northeast Region of Brazil: Part 2—Linear Programming Applications and Results

Nestor Gutierrez-Aleman

Winrock International/EMBRAPA-Centro Nacional de Pesquisa de Caprinos, 62.110 Sobral, Ceara, Brazil

A. J. De Boer

Winrock International, Morrilton, Arkansas 72110, USA

&

E. W. Kehrberg

Department of Agricultural Economics, Purdue University, West Lafayette, Indiana 47907, USA

SUMMARY

Survey data covering production systems for mixed farms in the Northeast region of Brazil has been synthesized within a linear programming (LP) framework. The resulting model contains activities covering the production of cattle, sheep and goats, and a vector of alternative cropping activities. Farm resources include two categories of grazing land, planted forages, family labour, two categories of hired labour, and working capital. The major livestock activities represented in the region were included as production options.

Initial results did not discriminate between categories of available grazing resources. Therefore, cattle, by virtue of their higher dressing percentages and higher price per kilogram, were the optimal livestock species. A series of adjustments was then carried out to reflect types of feed resources and patterns of animal species selectivity. Optimal farm

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solutions for a representative traditional-production unit found objective function levels close to those found by farm surveys, but discrepancies between model results and the actual farm situations for sheep and goat activities. Model results excluded small-ruminant breeding activities because of the low net offtake at weaning levels assumed in the model. Data that became available after these initial model runs showed a higher net offtake level, and these revised coefficients resulted in optimal LP results very close to those actually found on farms.

The model was then used to simulate the response of activities and farm economic performance to 'good' and 'bad' years defined by ± half standard deviation from mean annual levels of precipitation. Model results indicated much higher variability of farm income in response to weather than that found with changes in levels of technical efficiency of sheep and goat production.

INTRODUCTION

Part 1 of this paper describes the conceptualization of the hierarchies of systems present in mixed farms in the semi-arid tropics of the Northeast region of Brazil (Gutierrez-Aleman *et al.*, 1985). A major objective of this research was to develop quantitative models based upon these system relationships that would allow researchers of the Brazilian National Goat Research Center to carry out ex-ante evaluations of proposed interventions for traditional farm systems. Realistic evaluations had to consider most, if not all, of the relationships and interactions specified in Part 1 of this series. Another objective was to identify current gaps in knowledge about these systems and to provide a convenient framework through which current research results could be quickly integrated into the model to improve its realism and predictive ability. Finally, the analytical model needed to account for different states of nature, particularly the highly variable rainfall patterns characteristic of this region.

This paper develops a linear programming formulation that has the features descibed above. First, the farm resources, subsystems, inputs and outputs, interactions, and household needs described in Part 1 are defined according to the structure of a linear programming matrix. Second, the farm objectives, constraints, and formal model structure are specified. Third, the results are presented for the 'average farm' described in Part 1 and some procedures used in validating these results are described.

Fourth, the model is used to illustrate the potential impact of a specific technology. Finally, the model is used to simulate three states of nature represented by three levels of rainfall. The concluding discussion centres upon some recent results and their incorporation into the base matrix.

A variety of analytical tools is available for analysis of whole-farm systems. In this study, the model needed to focus on the livestock component and particularly interactions between cattle, sheep and goats as they compete for a limited supply of feed, land, capital and labour. To realistically capture this situation, the model had to include categories of animals; management systems; crop–livestock interactions; decision rules regarding sales, purchases, home consumption, allocation of labour and capital; and multiple time periods. Ghodake & Hardaker (1981) reviewed the various techniques available to analyse whole-farm situations. To satisfy the above requirements, they limited these techniques to linear programming (LP), multiperiod linear programming, discrete stochastic programming, and systems simulation. A careful review of these techniques indicated that virtually every requirement could be handled by the LP technique. The model structure is less complex and requires much less computer memory than the multiperiod programming and discrete stochastic programming techniques. Systems simulation was not used because some of the biological relationships on the farms did not allow for specification of verifiable system functions, and also because a major objective was to develop a model that could be easily understood and modified by collaborating EMBRAPA scientists. We judged that an LP model would be more suitable than a system simulation model for this purpose.

CONSTRUCTION OF A LINEAR PROGRAMMING MODEL FOR A TRADITIONAL MIXED-FARMING SYSTEM

Model objectives and assumptions

The model assumes that the following questions are of major concern to sheep and goat producers in this environment:

1. How large an inventory of cattle, sheep and goats it is desirable to have at the beginning of the wet season.
2. How many hectares to plant in crops.
3. How much supplemental feed to purchase.

4. How many animals to sell at the end of the season.
5. How much food (corn, beans) to produce on the farm for sale and how much to keep for home consumption.
6. How many animals to purchase at the beginning of the dry season.
7. How many animals to use for home consumption.
8. How many hectares of *caatinga* to clear for next year.

The basic constraints involved are:

1. Maximum land available for crops.
2. Maximum family labour available.
3. Maximum hired labour available.
4. Minimum subsistence consumption needs.
5. Maximum capital available to buy animals.
6. Land available for *caatinga* and number of hectares of *caatinga* cleared.

The basic time unit starts at the beginning of the wet season and finishes at the end of the dry season (an entire calendar year). To increase the realism of the feed-supply component, it is necessary to break the year into four periods in which the nutrient quantity/quality varies by period. The animal component works on a quarterly basis by generating the demand for feed to determine the stocking rate.

The unit of analysis is a farm operating under the assumptions of perfect competition, which implies that sheep and goat producers are price takers in the input and output markets.

The following overview of the model components has four parts: activities, rows, objective function and coefficients, as shown in Fig. 1.

In Fig. 1 the signs (+, −) are those associated with the model's objective function and activity coefficients. A positive coefficient represents activity demand for a resource while a negative coefficient represents activity supply of a resource. Positive signs on the right-hand side of the constraints represent a positive endowment of the resource, the exception being the home-consumption requirements where signs are switched because the inequality is reversed.

Description of activities

1. Producing crops and grazing land—describes land-use categories including land for crops, *caatinga*, cleared *caatinga*, and planted

pastures. These production activities require other inputs and supply dry-matter production in the respective quarters.

2. Clearing *caatinga*—transforms native *caatinga* into cleared *caatinga*. It does not have an impact on production for the current period because it is executed during the first or second half of the dry season. This activity alters constraint values for future periods. The major input used by this activity is labour.
3. Purchasing and selling grain—allows additional grain purchased to be used at home or fed to animals. Grain is produced during the third quarter and can be sold during the same or next period.
4. Supplementing animal feed—allows purchases in any quarter at a fixed price. It is an important component of the feed supply, given the seasonal production of feed, and is critical during the dry season, especially for cattle.
5. Supplying feed—allocates quantities of dry matter supplied by either purchases or farm production in each quarter. The same activity converts dry matter into protein and digestible organic matter.
6. Transferring and producing livestock—transfers animals in each category within species from quarter to quarter. Livestock production activates the nutrient requirements per head each quarter, as well as the other inputs. In the case of breeding animals, it supplies calves, lambs, or kids. This category reports the number of head per quarter after purchases and sales.
7. Purchasing livestock—reports the number of livestock purchased by category within each species.
8. Selling livestock—can be activated by any livestock category in any quarter.
9. Producing horses and mules—maintains these species for the provision of draft power, not as a direct source of income.
10. Supplying family and hired labour—allocates labour available from the family and the amount of man-equivalent days of hired labour used per quarter.
11. Providing for home consumption—allows consumption of farm produced crops and livestock by the family to fulfil certain fixed protein and caloric requirements. In the case of crops, there is a maximum amount per product that could be consumed.
12. Purchasing inputs—allows purchase of inputs used by crops and livestock (fertilizer, salt, medicines, etc).

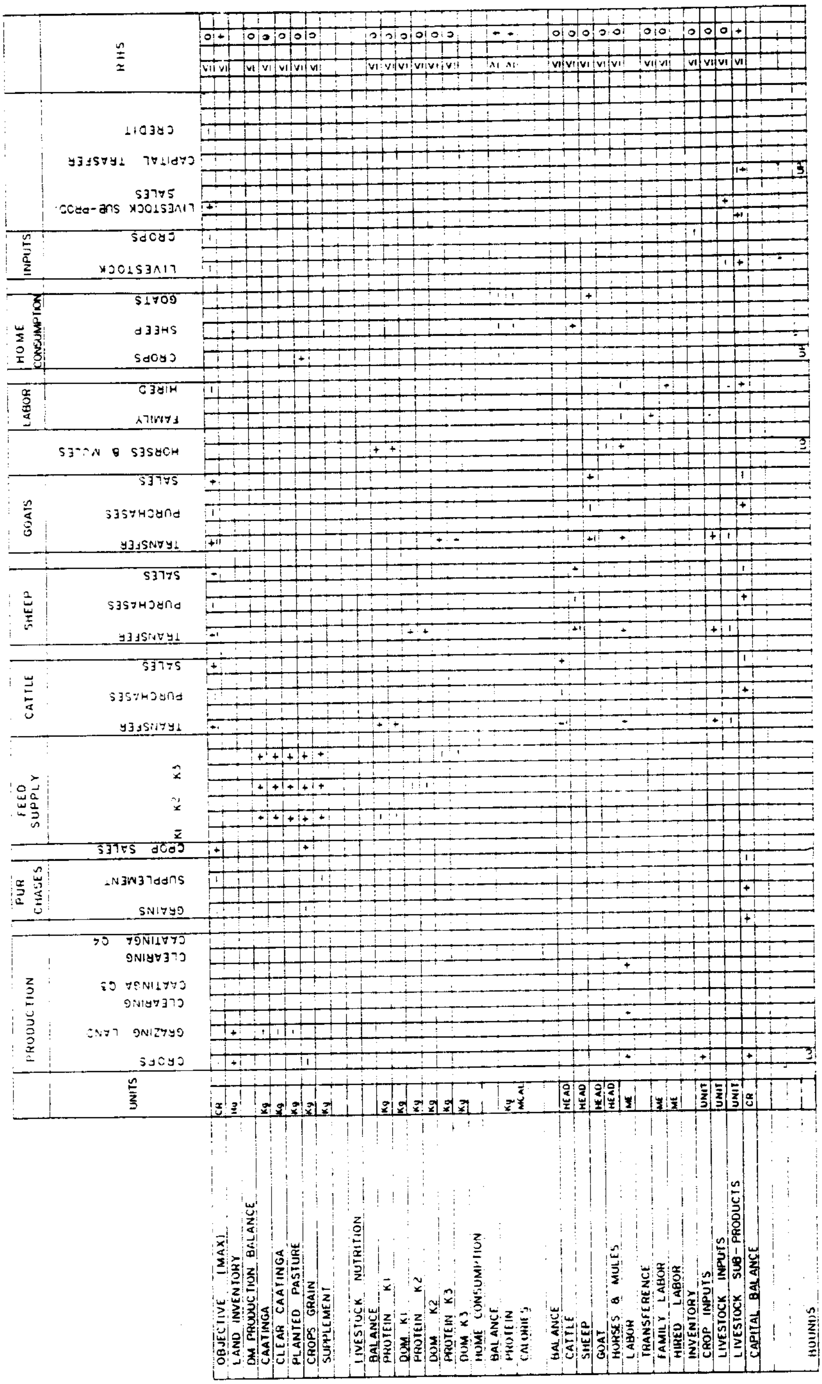

Fig. 1. Linear programming matrix.

13. Selling livestock by-products—determines the on-farm-produced units sold under the livestock by-product category, including sheep and goat skins produced from home slaughter, or cheese, which is the most common way of marketing milk in the region.
14. Allocating credit—determines the amount of credit required for the purchase of supplement feeds, livestock, and food.

Description of rows

1. Inventory of land by use of category—the land endowment by land-use category.
2. Dry-matter balance—the output per quarter from crops and grazing land are balanced with their use by the family, livestock, or sales activities.
3. Livestock nutritional requirements balance—the nutrients supplied by the different sources are balanced with the demand for livestock feeding. It is specified by quarter.
4. Minimum protein and calories for home consumption—a minimum consumption level of protein and calories is specified for the family.
5. Livestock balance—livestock production and purchases are balanced with sales and transfer activities by quarter.
6. Labour balance—requires that labour used in crops and livestock is less than or equal to the labour provided by the family plus the hired labour. It is specified for five different periods.
7. Family labour transfer—transfers labour from the family endowment to the 'labour balance' row.
8. Hired labour transfer—transfers labour from hired labour endowment to the 'labour balance' row.
9. Crops and livestock input balance—balances the input demand (use in crops and livestock) with the input supply (purchases).
10. Capital balance—requires that capital used to purchase livestock and supplement be less than or equal to the amount of credit available.

The objective is the maximization of farm gross margin (total revenue less variable costs). The income reported by the optimal solution excludes the value of family consumption from farm-produced crops and livestock activities.

The basic data required for this formulation involve crops and grazing-land yields and inputs, nutrient content of feed, nutrient requirements of animals, livestock weight gain, production and input use, resource availabilities, consumption requirements, and prices. Most of the values for the 1995 coefficients used in the model were obtained from the baseline survey (Gutierrez-Aleman *et al.*, 1981) and periodic surveys (Gutierrez-Aleman, 1983), but many of the biological parameters were derived from several sources of experimental data.

The model determines the inventories of cattle, sheep and(or) goats by quarter. The model also determines the optimal livestock activities (breeding, growing or fattening) and derives the optimal age for sale and purchase. For crops, it determines area planted as well as the production systems (monoculture or mixed cropping).

Description of the traditional farm and derivation of model coefficients

The traditional farm is defined using the average results of the baseline and periodic surveys. It has 600 ha of grazing land distributed as 40 % cleared *caatinga* and 60 % native *caatinga*. Additional land is reserved for crops (20 ha) and planted pasture (5 ha). Farmers grow mostly corn, beans and cotton with different crop-production alternatives, represented in the model by activity vectors. The most common cropping system in the sertao is mixed cropping with low yields relative to the average yields for the state of Ceara. The main reasons for low agricultural productivity cited by Albuquerque & Sanders (1975) are the scarce use of commercial inputs other than seeds purchased or retained from previous years and the irregular distribution of rainfall. The crop-production coefficients used in the model (Table 1) came from data generated at Caninde (central sertao

TABLE 1
Crop Yields (kg/*ha*)

Crop	*Single crop*	*Mixed cropping*[a]
Cotton	109	40
Beans	149	70
Corn	235	90

Source: Albuquerque & Sanders (1975).
[a] Estimated.

of Ceara) in a survey made by EMBRAPA during October and November 1973, an average year with more than 800 mm of rainfall.

Grazing-land production is a very important component within the whole-farm production system because it determines the livestock performance as well as the mix of animal species. Grazing-land productivity is dependent upon weather, vegetation type and grazing management. Climatic factors were introduced with the rainfall variable where good historical data are available for the region. Monthly average rainfall for 36 meteorological stations is distributed among the nine counties surveyed in the sertao zone. Average rainfall for the surveyed region is 762 mm.

Next, a simple relationship between rainfall and grazing-land productivity was established, based on the work of Le Houerou & Hoste (1977). The only grazing-land productivity information comes from Utah State/EMBRAPA-CNPC (1982) research during 1980–82, which indicates dry-matter (DM) yields for grasses and forbs in *caatinga* and cleared *caatinga* to be 356 kg and 707 kg, respectively, during the mid-growing season (leaf foliage from woody species is not included). It is assumed that this amount corresponds to the actual grasses and forbs consumed by livestock; in the study by Le Houerou & Hoste (1977), 70 % of the above-ground biomass was considered consumable during the wet season and only 30 % during the dry season.

The seasonal distribution of grazing-land production each season was divided into four quarters (Q1, . ., Q4) based on unpublished information provided by Pfister (1983) and Mesquita (personal communication). The estimated distribution of consumable forage (proportion of total) was Q1 = 0·22, Q2 = 0·41, Q3 = 0·22 and Q4 = 0·15.

Information is also needed on feed quality, especially on the changes in DM quality that occur in both cleared and native *caatinga* during the year. Relatively little is known about the nutritional value of dry matter (DM) produced in the sertao. However, preliminary results by Pfister (1983) and Kirmse *et al.* (1984) provide data on seasonal botanical composition, chemical content, and digestibility of diets selected by small ruminants in native *caatinga*. These results were used to determine the total protein (TP) and digestible organic matter (DOM) values. Table 2 shows the values assigned in the model by grazing-land category and other feed résources available in the area. These latter feedstuffs allow the option of supplementation during the dry season. Cottonseed meal is the most common feedstuff used.

TABLE 2
Composition of Feed Sources by Quarter

Source	*Total protein (%)*				*DOM (%)*			
	Q1	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*
Caatinga[a]	0·06	0·07	0·05	0·04	0·65	0·65	0·50	0·40
Cleared *caatinga*[b]	0·07	0·08	0·06	0·05	0·70	0·75	0·60	0·50
Pasture[b]	0·08	0·09	0·07	0·06	0·75	0·75	0·65	0·60
Corn[c]	0·09	0·09	0·09	0·09	0·78	0·78	0·78	0·78
Stover[c]			0·07				0·78	
Beans[c]	0·22	0·22	0·22	0·22	0·80	0·80	0·80	0·80
Bean residues			0·03				0·80	
Cotton residues[c]				0·03				0·81
Cottonseed supplement[c]	0·41	0·41	0·41	0·41	0·81	0·81	0·81	0·81

[a] Utah State/EMBRAPA-CNPC (1982).
[b] Estimated.
[c] National Academy of Sciences (1981).

In the initial stages of the model, a single feed-nutrient pool was used to allocate feed resources among the livestock species. This resulted in cattle activities being selected exclusively because of higher dressing percentages and higher prices relative to small ruminants. This was in sharp contrast with baseline survey results showing a high proportion of mixed-species grazing with cattle, sheep and goats. We realize that large differences in animal selectivity for the DM produced could occur within each grazing-land category, especially when woody plants are present. Complementarity in grazing-land use is possible depending on management.

Therefore, the model was modified to allow for differences in potential use by species of DM produced in each grazing-land category. This was done by creating three different feed pools, taking into account the three livestock species available on the farm. Each pool represented feed quality, botanical composition (grass, browse, forbs), and feed quantity available for each animal species. Competition within the same feed pool by two or more livestock species is still open.

Experimental results were not available to allow an accurate allocation of DM production by the main types of plants to each feed pool. An arbitrary allocation was made for the purpose of the representative traditional farm model. The DM proportion in each pool was calculated based on the distribution of animal units found in the baseline survey

(Table 3). An equal nutritional value for each pool was assumed based on figures in Table 2.

Livestock production is the second major component of the model and includes activities representing cattle, sheep and goats produced for meat. Each species is subdivided by sex and age categories. For small ruminants, two different lambing (kidding) seasons were considered to give the model the opportunity to differentiate between animals born during the wet or dry season. This meant a duplication of activities by age and sex within each species so that every group of animal from weaning up to sale age could be traced.

TABLE 3
Feed Share Per Pool

Source	*Pool 1 (cattle)* (%)				*Pool 2 (sheep)* (%)				*Pool 3 (goats)* (%)			
	Q1	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*
Caatinga	0·50	0·50	0·50	0·50	0·25	0·25	0·25	0·25	0·25	0·25	0·25	0·25
Cleared *caatinga*	0·60	0·60	0·60	0·70	0·20	0·30	0·20	0·15	0·20	0·10	0·20	0·15
Pasture	1·0	1·0	1·0	1·0								
Corn	0·50	0·50	0·50	0·70	0·25	0·25	0·25	0·20	0·25	0·25	0·25	0·10
Stover			0·60				0·20				0·20	
Beans	0·50	0·50	0·50	0·70	0·25	0·25	0·25	0·20	0·25	0·25	0·25	0·10
Bean residues			0·60				0·20				0·20	
Cotton residues				0·50				0·25				0·25
Cottonseed supplement	0·70	0·70	0·70	0·70	0·25	0·25	0·20	0·25	0·05	0·05	0·10	0·05

Source: Estimated.

The model basically adjusts the most profitable stocking rate to the feed supply and selects the most profitable combination of species every quarter. The stocking-rate-adjustment process works via purchases and sales.

The approach used in the model is dynamic within the four quarters in which the production time unit (year) is subdivided. The objective function is maximized on an annual basis. Although strictly speaking the model cannot be classified as dynamic programming according to Bellman's principles of optimality (Kennedy, 1981), dynamism is shown in the way each category handles production, purchases, sales and deaths every quarter. That is, the results per activity each quarter are transferred to the next activity as initial inventory, and reported by quarter as production, sales and purchase activities.

Since the three ruminant species considered in the model have different nutrient requirements and different output prices, the model treats them as separate 'activities'. Also, each livestock species has different requirements for energy and protein depending on category, which is determined by sex, age, growth stage, pregnancy and lactation. Final livestock inventories are reported by quarter and consist of transfers from the last category plus purchases, minus sales and deaths. Another factor considered is the type of grazing system in the region. Nutrient requirements vary depending upon whether the production system is intensive or extensive. Protein and digestible-organic-matter requirements by species, sex and age are based on the National Academy of Sciences (1975, 1976, 1981) recommendations.

Weight changes enter the model by quarter and are estimated using unpublished results from a farm-recording scheme covering 4000 animals on 32 farms during 1980–82. Data recorded on animal weights show high variability within categories both within and among farms, significant differences between mean weights for sheep and goats in the same age categories, and significant differences in performance of animals born during the wet versus the dry season. The values used in the representative traditional farm correspond to average values by species, category and season of birth.

The additional production characteristics used to complete the livestock component are given in Table 4. Net yields at weaning per breeding female maintained are defined as the net fertility after adjusting for mortality of mature breeding females (older than 3·5 years in cows and 18 months for ewes and does). The male–female ratio at birth is used to differentiate by sex the animals born during the wet and dry seasons. Weaning age determines for the model the age at which the nutrient requirements start for each animal born on the farm. Culling rates are used to activate animal-replacement activities. Mortality is a factor considered in the model by animal category and quarter. Carcass yields per category are used when the prices considered are per kilogram of bone-in meat produced per head.

Purchases and sales represent two types of activities that allow for adjustment between livestock population and feed supply. Other factors affect the purchase-and-sale decision in the model, for example, price

TABLE 4
Livestock Technical Coefficients

	Cattle	*Sheep*	*Goats*
Net yields per breeding female maintained/year, %	0·55[a]	0·70[c]	0·70[c]
Male–female ratio at birth, %	0·50[a]	0·50[a]	0·50[a]
Proportion of births per season: wet, %	0·20[a]	0·20[b]	0·20[b]
dry, %	0·80[a]	0·80[b]	0·80[b]
Weaning age, month	6[a]	3–6[a]	3–6[f]
Culling rate/breeding females, %	0·10[a]	0·20[c]	0·20[c]
male, %	0·20[a]	0·50[c]	0·50[c]
Adult mortality rate/quarter, % 1	0·01[a,e]	0·02[f,e]	0·03[f,e]
2	0·01[a,e]	0·02[f,e]	0·03[f,e]
3	0·01[a,e]	0·02[f,e]	0·05[f,e]
4	0·01[a,e]	0·02[f,e]	0·06[f,e]
Carcass yields, %	0·50[a]	0·41[d]	0·41[c]

[a] J. A. Araujo-Filho, personal communication, 1983.
[b] Periodic survey 1981 only.
[c] Estimated from baseline survey (Gutierrez-Aleman *et al.*, 1981).
[d] Fitzhugh & Bradford (1983).
[e] Different coefficient by sex and category.
[f] Estimated.

ratios between seasons. Another factor considered is the price of grains and supplements that can be purchased. The model allows optional purchases and sales at any quarter in any of the marketable categories in order to maximize the objective function.

Home consumption is the third major component of the model. Despite the fact that sheep and goat producers in the sertao are market-oriented, a substantial proportion of their production is consumed at home. In the baseline survey it was established that the basic part of the farmers' diets comes from corn, beans, sheep and goats. There were other products such as beef that could be produced on the farm but in general were purchased. It is assumed that the farm must provide at least half of the nutritional needs of the family. For the traditional farm considered here, a family of five adults is used as the base for the human protein and caloric nutrient requirements as recommended by Ward & Tavares (1975) in their study in Caninde, Ceara. The model reduces sheep and goat meat and grain into protein and calorie units, using the coefficients presented by Gutierrez-Aleman (1983). The model determines the most efficient way to meet these minimal nutritional requirements.

Use of inputs

Each resource and activity included in the model has an objective function value represented by a gross margin (activity) or marginal cost per unit (resource). Labour is the exception (see below). The average quantities of purchased inputs used per activity were recorded during the baseline and periodic surveys. The input–output coefficients used for crop and livestock activities in the traditional farm model were reported by Gutierrez-Aleman (1983). The model uses the input cost figures per year in the case of crops and per quarter for livestock.

Labour

The average labour force on surveyed sheep- and goat-producing units comprises 3·9 persons over 15 years and 3·4 persons below 15 years, respectively. Hired labour consisting of sharecroppers and employees plays an important role in the production system. There is seasonality in the use of labour, especially that used for cropping. In the model, labour does not have the quarterly pattern used for the rest of the activities. A distribution of five periods of crop activities (planting, post-planting, harvest 1, harvest 2 and land preparation) is specified. Hired and family labour restrictions and coefficients are expressed in man-equivalent days (MED) where an adult male equals one unit, an adult female equals 0·7 units, and children under 15 or adults over 65 provide 0·5 units. A calendar month is assumed to contain an average of 22 working days. The LP matrix is structured to allocate labour among the crop and livestock activities. The on-the-farm cost of hired labour or sharecropper labour corresponds to the average monetary salary paid on farms surveyed in the region (Table 5).

Crop and livestock subproduct sales

In the baseline survey it was established that most of the sheep and goat producers sell some crop products after meeting home consumption needs.

Some farmers also sell livestock products. An average production of 600 litres/year represented the average quantity of cow milk going into cheese production (J. A. Araujo-Filho, personal communication). It was assumed that 50% of the cows were in lactation and that the conversion

TABLE 5
Use of Labour in Major Activities by Periods

Activities	*Periods*				
	1	*2*	*3*	*4*	*5*
Crops (ME/hA)					
Corn	4	36	5	—	46
Beans	4	13	13	—	36
Cotton	5	49	—	11	37
Cotton/bean/cotton intercrop	4	43	10	7	40
Livestock (ME/head)					
Cattle	0·94	0·94	0·94	0·94	0·94
Sheep	0·44	0·44	0·44	0·44	0·44
Goats	0·44	0·44	0·44	0·44	0·44

Source: Baseline and periodic surveys.

rate of milk to cheese was 10:1 (Kosikowski, 1977). Manure production was estimated based on the time the animals spent in the corral. Half of the total production per animal reported by Utah State/EMBRAPA-CNPC (1982) was considered. Sometimes manure is sold for construction purposes. A very low price was assigned to reflect the limited market. Almost all producers sell the skins of the animals consumed at home. Skin prices differ by species depending upon the region. Prices of Cr$100 (Cr$64 – 1US$ in December 1980) and Cr$120 were used for sheep and goat skins, respectively. The minimum animal size to produce an acceptable skin for market is considered to be 20 kg to 22 kg.

Prices

Within each animal category, selling and buying prices are specified by quarter. There were no long-term price series available, so information from the periodic-survey data collected during 1980 and 1981 was used. Price ratios were: cattle meat to sheep and goat meat at 130:100, sheep to goat meat 100:100, and dry to wet season 120:100 for all animals. No difference between goat and sheep meat prices at the market level was noticed. No price differentials in the price per kilogram of livestock were found for animals sold for slaughter.

Capital constraints

The capital constraints under which the farms operate reflect allocative decisions between activities and between quarters. In the annual income-maximization process, the model farm is allowed to transfer capital from one activity to another and to allocate capital within and between quarters. These decisions are based on annual maximization of gross margins.

In the model each activity appears with a separate coefficient in the capital row by quarter. Constraints on capital availability reflect funds generated within the farm during the year and the availability of credit.

Credit

Cost of credit is represented by the quarterly interest rate. Constraints are specified by quarter. The credit variable can be used as a policy tool to analyse subsidized credit and credit needs for farm expansion over time.

The next section summarizes initial results of the model of the representative traditional-farm, model validation, and some demonstration of adjustment in the technical parameters to evaluate the impact of technology on the optimal farm plan.

REPRESENTATIVE TRADITIONAL-FARM RESULTS

The solution that maximizes the representative traditional-farm gross margins is summarized in Tables 6 through 9 in the 'T' columns. Four activities are included in the optimal solution: crops, cattle, sheep and goats with a net cash income of Cr$325 038 (about US$5078).

Feed resources utilized in the optimal solution included the quantities of native *caatinga*, cleared *caatinga*, planted pasture and purchased supplements shown in Table 6. Feed use varied by season. The second quarter registered the lowest use of cleared *caatinga* and no grazing of native *caatinga*. During the second quarter, the quality and quantity of the rangeland production was at a maximum, while in quarter four all the available land was used for grazing because of the low feed availability during the dry season. Supplementation was used at the beginning of the year when the native grazing lands were starting to recuperate and the farmers were restocking their herds. Heavy use of supplements was also present in the fourth quarter. The bottom section of Table 6 summarizes crop production and use. Part of the grain produced was consumed on the farm and the balance was sold.

Cattle production was the most important activity. Average herd size

TABLE 6

Optimal Levels of Land Use, Crop Production and Crop Utilization for Traditional (T) and Improved (I) Farms

Activity	*Unit*	*Constraint level*	*Activity level by quarter*								*Input cost Cr$*
			Q1		*Q2*		*Q3*		*Q4*		
			T	*I*	*T*	*I*	*T*	*I*	*T*	*I*	
Caatinga	ha	353	326	196	—	267	265	247	353	353	
Cleared *caatinga*	ha	248	247	247	208	181	243	245	248	248	
Planted pasture	ha	5	5	5	5	5	5	5	5	5	[a]
Mixed crops	ha	20	10	10	10	10	10	10	10	10	−2 200
Purchased supplement feeds	kg		700	2 051					1 701	1 898	−13; −14
Corn produced	kg						900	900			[b]
sold	kg						400	400			11
consumed	kg						500	500			
Beans produced	kg						700	700			[b]
sold	kg						500	500			50
consumed	kg						200	200			
Cotton produced	kg								400	400	[b]
sold	kg								400	400	25

[a] The input costs for planted pasture are family labour and hired labour. The hired-labour costs are included under hired-labour activity costs.

[b] Production costs are included under mixed-crops costs (−2 200).

TABLE 7
Traditional and Improved Farm Cattle Production and Use

Activity	*Activity level by quarter (head)*								*Input cost Cr$*
	Q1		*Q2*		*Q3*		*Q4*		
	T[a]	*I*[b]	*T*	*I*	*T*	*I*	*T*	*I*	
Breeding									1 204
Cows	30	24	30	24	30	24	30	24	
Replacement 1–2 year	4	3	4	3	4	3	4	3	
Replacement 2–3 year	3	2	3	2	3	2	3	2	
Replacement 3–4 year	3	2	3	2					
Bulls	1	1	1	1	1	1	1	1	
Calves	4	3			13	10			
Purchases									
Heifers 24 month					7	20			−14 303
Heifers 30 month	13	12							−13 177
Sales									
Wet season (females 11–12 month)	2[c]	2[c]							10 400
Calves (males 11–12 month)	2[c]	1[c]							11 200
Dry season (females 11–12 month)					3[c,d]	2[c,d]			9 100
Calves (males 11–12 month)					6[c]	5[c]			9 750
Purchased heifers 36 month					19	31			20 002
Culled cows					3	2			[e]

[a] Traditional.
[b] Improved.
[c] No mortality counted in calves because the unit used is net yield at weaning.
[d] A proportion goes to the replacement pool.
[e] Value included in the breeding-activity cost.

TABLE 8
Traditional and Improved Farm Sheep Production and Use

Activity	*Activity level by quarter (head)*								*Input cost Cr$*
	Q1		*Q2*		*Q3*		*Q4*		
	T	*I*	*T*	*I*	*T*	*I*	*T*	*I*	
Breeding									268
Ewes	—	25	—	25	—	25	—	25	
Replacement 6-18 month	—	6	—	6	—	6	—	6	
Replacement 18-24 month	—	5	—	5	—	—	—	—	
Rams	—	1	—	1	—	1	—	1	
Lambs	—	6	—	—	—	20	—	—	
Purchases									
Females 6 month					20				−706
Males 6 month					20	20			−706
Males 12 month	20	20							−875
Males 6 month	5								−689
Males 12 month					20				−981
Sales									
Wet season (females 11-12 month)						2			1 248
Lambing (males 11-12 month)						2			1 330
Dry season (females 11-12 month)		4[a]							640
Lambing (males 11-12 month)						9			931
Females 18 month					17				1 248
Males 18 month					38	25			1 330
Males 24 month					10				1 605
Culled ewes						5			[b]
Consumption									
Males 18 month						14			[c]
Males 24 month					12				[c]

[a] Part goes to replacement.
[b] Value included in the breeding-activity cost.
[c] Not counted as net cash income. Satisfied part of home-food-consumption constraint.

TABLE 9
Traditional and Improved Goat Production and Use

Activity	*Activity level by quarter (head)*								*Input cost Cr$*
	Q1		*Q2*		*Q3*		*Q4*		
	T	*I*	*T*	*I*	*T*	*I*	*T*	*I*	
Breeding									
Does	—	31	—	31	—	31	—	31	215
Replacement 6–18 month	—	9	—	9	—	9	—	9	
Replacement 18–24 month	—	8	—	8	—		—		
Bucks	—	1	—	1	—	1	—	1	
Kids	—	6	—		—	25	—		
Purchases									
Males 6 months					20	20			−665
Males 18 month					20				−1 257
Males 12 month					17				−858
Males 18 month	20	20							−962
Sales									
Wet season (females 6 month)						3[a]			574
Kidding (males 6 month)						3[a]			615
Dry season (females 6 month)		4[a,b]							639
Kidding (males 6 month)		12[a]							639
Purchased (males 24 month)	37					19			1 207
(males 24 month)					34	19			1 295
Culled does						8			[c]

[a] No mortality is counted in kids because the unit used is net yield at weaning.
[b] A proportion goes to the replacement pool.
[c] Value included in the breeding-activity cost.

was 75 head: 30 cows, 17 calves and the balance composed of replacement and growing animals (Table 7). Calving occurred twice per year—at the beginning of the wet and dry seasons. The model showed cattle sales of 11- to 12-month-old animals during both periods. Fattening heifers (animals purchased at 24 months to 30 months of age) was chosen as a secondary activity. They were sold when 36 months old at the end of the wet season for Cr$20 002 (US$313) per head. Supplementation was used during the critical periods of feed shortages.

The sheep activity consisted of purchasing 6-month-old lambs and selling them at 18 months or 24 months (Table 8). Most of the purchases occurred at the beginning of the dry season. This implied that feed production was adequate for this type of activity, at least for maintaining lamb condition during the dry season. Selling time for all categories was the end of the wet season or the beginning of the dry season. Some of the males maintained up to 24 months were consumed at home and the rest were sold.

It is important to observe that the breeding activity was not included in the optimal solution. Reasons include the low net offtake at weaning age per female maintained in the herd (70%), which made the breeding activity less competitive compared with the growing-out phase. In a subsequent section, this aspect is studied in detail.

Table 9 summarizes goat-production activities that occur under the same basic management environment as sheep production. Again, no breeding activity was included in the optimal solution and growing out purchased males was the main activity. Home consumption of goats was not included in the optimal solution.

Labour requirements in the representative traditional-farm exceeded the family labour supply during the second and fifth periods. Hiring 272 man-equivalent-days (MED) and 229 MED, respectively, was necessary in these two periods.

Demand for capital was greater during the first two quarters because of the expenditures for purchased animals. Borrowing was concentrated at the beginning of the wet season. Credit was used at the maximum levels during quarters one and two.

MODEL VALIDATION AND EXPERIMENTATION

The ideal validation procedure for the model would compare optimal model solutions for a given intervention with the results obtained from an on-farm trial using the same intervention. In the absence of such results, the validation procedure used here is limited to comparing the most important model results with actual farm characteristics to determine how well the model structure and underlying assumptions approximate actual production conditions and producer management strategies.

A basic feature of the model is its ability to adjust the stocking rate based on nutrients (protein and DOM) available from all possible sources of farm-produced feed and purchased supplement at any time during the year. Livestock numbers are adjusted through the purchase-and-sale mechanism. The validation consists of comparing the stocking rates generated by the model with stocking rates found in an experiment carried out during 1979–80 at the EMBRAPA National Goat Research Center in Sobral. These latter results showed 1 ha of native *caatinga* and 1/2 ha of cleared *caatinga* per adult goat as the optimal rate (Mesquita-M. *et al.*, no date, Table 1). Conversion of these experimental results to a common stocking rate (hectares per animal unit carried by available feed resources—or ha/AU) gives an average stocking rate of 6·9 ha/AU while the optimal model solution resulted in an annual average stocking rate of 7·4 ha/AU.

Another important aspect is the animal species composition on the farm. In the baseline survey, the proportion of small ruminants to cattle was 1·7:1 while the optimal solution was 2:1. This is due to the arbitrary allocation of available feed pools per species used in the revised model.

A result from the traditional-farm model that warranted further attention was that the breeding activity for small ruminants was not included in the optimal solution. A sensitivity analysis was performed to determine the annual net yields per breeding female maintained in the herd in order to estimate the level of reproductive efficiency required for the sheep- and goat-breeding activities to be included in the optimal solution.

The results from the sensitivity analysis showed that to include the breeding activity for sheep and goats in the optimal solution, it was necessary to increase the net offtake of lambs/kids at weaning to 100%. This implies an increase of 42% in net weaning yields over the initial assumption of 70% (Tables 8 and 9).

The periodic survey of animal performance monitoring later found average net yields at weaning of 110% in sheep and 102% in goats (Gutierrez-Aleman & Ponce de Leon-B, 1984). The above results combine to provide a predictive power of the model.

Using these revised coefficients (100 % net yields at weaning), 'improved (I)' results are presented in Tables 6 to 9. In Table 6, land use had a significant shift from cleared *caatinga* to native *caatinga*, especially during the second quarter. The crops and supplement feeding component did not change appreciably from the base solution.

The main change in the cattle activity (Table 7) was the reduction of the breeding activity and a small increase in the growing-out activity of this enterprise. This resulted from substitution effects between small ruminants and cattle due to the increased level of productivity assumed for sheep- and goat-breeding activities.

The mix of sheep-producing activities showed significant changes. The breeding activity entered at a level of 25 ewes with 20 % of the lambing occurring at the beginning of the wet season and 80 % at the end-of-wet-season/beginning-of-dry-season period (Table 8). One important difference in management compared to the baseline traditional-farm result is that lambs born in the wet season were kept up to 18 months of age (in the baseline results, all lambs were sold at weaning). There was still a growing-out activity, with sales occurring primarily at the beginning of the dry season. Average herd size was 67 head. These results were close to those reported in a baseline survey in the region by Gutierrez *et al.* (1981).

Another attempt to validate the model was made through varying annual precipitation levels in the model. Initially, the productivity levels assumed for cleared *caatinga* and native *caatinga* corresponded to the 1981–82 period. They were based upon average rainfall for the central sertao of Ceara using 28 years (1950–78) of rainfall data from 36 meteorological stations located in the survey area. The criteria to define an average year according to the rainfall was the average (762 mm) in the area, plus or minus half of the standard deviation ($\pm$ 197 mm). Rainfall below and above this level classified the year as 'poor' or 'good'.

The rangeland dry-matter-production figures used in the representative traditional-farm correspond to 707 kg/ha for cleared *caatinga* and 356 kg/ha for native *caatinga* measured at the midpoint of the growing season in 1982 when rainfall was 781 mm, as reported by Utah State/EMBRAPA-CNPC (1982). The next step in the modeling of the three weather situations (good, average, poor) was to relate rainfall and dry-matter production. Le Houerou & Hoste (1977) found a correspondence of 1 mm of rainfall to 1 kg of consumable dry matter in the rangeland of the semi-arid Sahelian and Sudanian zones of Africa. In the sertao zone, the results from Utah State/EMBRAPA-CNPC found basically the same relationship for cleared *caatinga*. The representative traditional-farm model results reported above are based upon the 'average year' rangeland-productivity coefficients. For the below- and above-average years, the following procedure was followed. First the precipitation level for each situation was calculated and DM production was adjusted accordingly, using the average situation as 100% (Table 10). It was assumed that distribution of rangeland by class, by quarter, and by feed quality does not change from those used for the representative traditional-farm.

TABLE 10
Dry Matter Production by Weather Situation

Weather situation	*Average rainfall*[a]		*Consumable DM (kg/ha)*[b]		
	mm	%	Caatinga	*Cleared* caatinga	*Planted pasture*
Good	1 153	156	555	1 081	2 205
Average	739	100	356[c]	707[c]	1 414
Poor	460	62	220	438	876

[a] FUNCEME (1983).
[b] Estimated.
[c] Utah State/EMBRAPA-CNPC (1982) Table 1.

For crops, the procedure used to classify production into 'good, average and poor' years was different. Crop productivity levels were adjusted based upon Dillon & Mesquita's study (1976), where they related crop-production risk to weather. The information provided was collected at Caninde (1972–73) and is restricted to beans. Extrapolations to other crops were made based on this relationship (Table 11). Crop and livestock prices were assumed to be the same for the three situations.

In the remaining analysis, the improved farm used in the last section will correspond to the average situation, rather than the representative traditional farm, because it includes the breeding activity for small ruminants. This provides an opportunity for studying the response of productivity improvements to different weather situations.

The optimal farm results for the three weather situations showed major differences. These are reflected in the net-cash-income results shown in

TABLE 11
Crop Yields by Weather Situation (kg/ha)

Weather situation	*Beans*[a]	*Corn*[b]	*Cotton*[b]	*Mixed crop*[b]		
				Corn	*Beans*	*Cotton*
Good	317 (213)[c]	500	232	191	149	86
Average	149 (100)[c]	235[d]	109[d]	90	70	40
Poor	30 (20)[c]	47	22	18	14	8

[a] Dillon & Mesquita (1976) p. 11.
[b] Estimated.
[c] Percentage variation from the average level is in parentheses.
[d] Albuquerque & Sanders (1975) p. 18.

Table 12. Under good weather conditions, income increased by 185% over the average situation. For the poor weather situation, income decreased to 53% below the average level. Compared with the initial change in DM production (Table 10, column 2), the changes in income are greater than the proportional change in DM production for both good and poor conditions. However, this result shows the tremendous influence of weather on feed production and farm income when compared with an improvement of small-ruminant-herd/flock productivity. Only a 3% increase in net cash income is obtained from a 42% increase in small-ruminant productivity.

TABLE 12
Net Cash Income by Weather Situation

Weather situation	*Model results*	
	Net cash income (Cr$)	*Percentages*
Good	621 210	185
Average	335 204	100
Poor	177 577	53

Source: Gutierrez-Aleman (1983).

Net cash income estimated from the optimal farm plan for the poor-weather year provided another opportunity for model validation. Model results for the poor weather situation were Cr$177 577 while average net farm margins estimated from the periodic-survey farms were Cr$133 572 during 1980–81, considered as a poor year with 549·4 mm of rainfall. However, the farm recording carried out during the periodic survey did not include milk and cheese production.

Optimal land use varied depending upon the weather. Land used for crops showed basically the same patterns for the poor and average cases, but for the good situation 6·5 ha more were incorporated for bean production. The use of grains (purchase and sale) varied according to the yields established in Table 11. It should be noted that during the poor year, the grain-purchase activity was activated to cover the deficit for home consumption, and 320 kg of corn and 60 kg of beans were purchased.

Purchased supplemental feed showed some changes between good and poor weather situations. In the good year, when cattle were proportionally more important, more supplement feed was purchased during the dry season (2903 kg). This amount decreased to 176 kg in the poor weather situation when the proportion of animal units held as goats increased.

Optimal livestock activities provided further insights into model validation and livestock-management strategies. An example is the relative proportion of each species held for breeding in each weather situation (Table 13). In poor weather emphasis shifted from cattle to goats. The relative number of small ruminants increased in poor years. These last results are consistent with observed producer behaviour in the

TABLE 13
Livestock Population by Weather Situation

Weather situation	*Model results by species (average numbers per quarter)*		
	Cattle	*Sheep*	*Goats*
Good	117	161	126
Average	74	67	120
Poor	49	65	89

Source: Gutierrez-Aleman (1983).

region during the last 4 years (1980–83) of drought. Queiroz *et al.* (1984) reported that for the farms included in the periodic survey, a decrease of about 33 % for cattle and 18 % for sheep occurred, while there was a net increase in the goat population of about 17 %.

CONCLUSIONS

The linear programming approach to modeling whole-farm performance is potentially very useful as a device for ex-ante or preliminary evaluation of technologies (Knipscheer *et al.*, 1983). However, the assumptions, structure, and data upon which the model is based must approximate reality to the extent that results bear a close resemblance to the actual farm conditions represented by the model. The LP model of representative traditional farms was judged to be a valid representation of the complex mixed-farming systems found in the Northeast of Brazil. Further validations conducted using updated information on animal performance and variable climatic states lent further credibility to the underlying model. The next step will be the routine use of the model for screening technologies being developed at the National Goat Research Center.

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REFERENCES

Albuquerque, L. & Sanders, J. M. (1975). *Selecting and evaluating new technology for small farmers in the central sertao of Ceara.* Working paper, Department of Agricultural Economics, Federal University of Ceara, Fortaleza, Brazil.

Dillon, J. L. & Mesquita, T. C. (1976). *Atitudes dos pequenos agricultores do* *sertao do Ceara diante do risco*. Department of Agricultural Economics Research Paper Series No. 12, Federal University of Ceara, Fortaleza, Brazil.

Fitzhugh, H. A. & Bradford, G. E. (Eds.) (1983). *Hair sheep of Western Africa and the Americas*. Boulder, CO, Westview Press.

Fundacao Cearence de Meteorologia e Chuvas Artificiais (FUNCEME). (1983). *Dados pluviometricos*. Fortaleza. Mimeographed.

Ghodake, R. D. & Hardaker, J. B. (1981). *Whole-farm modeling for assessment of dryland technology*. Economics Program Progress Report 29. Hyderabad, India, International Crops Research Institute for the Semi-arid Tropics.

Gutierrez-Aleman, N. (1983). *Sheep and goat production systems in the sertao region of northeast Brazil: A characterization and linear programming analysis*. Unpublished PhD Thesis, Purdue University.

Gutierrez-Aleman, N. & Ponce de Leon, F. A. (1984). Traditional farming systems in the sertao of Ceara, northeast Brazil: I. description of small-ruminant management. Sobral, Brazil. National Goat Research Center. Unpublished manuscript.

Gutierrez-Aleman, N., De Boer, A. J. & Alves, J. U. (1981). Interacoes de recursos e caracteristicas economicas dos criadores de ovinos e caprinos no sertao de Ceara, Nordeste do Brasil. EMBRAPA-CNPC Research Bulletin No. 3, Sobral, Brazil.

Gutierrez-Aleman, N., De Boer, A. J. & Hart, R. D. (1985). A bioeconomic model of small-ruminant production in the semi-arid tropics of northeast Brazil: Part 1—Model description and components. *Agricultural Systems* (in press).

Kennedy, J. O. (1981). Agricultural applications of dynamic programing: Review and prognosis. Presented to the *Australian Agricultural Economics Society 25th Annual Conference, Christchurch, New Zealand.*

Kirmse, R. D., Provenza, F. D. & Malechek, J. C. (1984). Clearcutting effects on dry season forage reserves in Brazil's semi-arid northeast. *Proceedings of Second International Rangeland Congress, Adelaide, Australia.*

Kosikowski, F. V. (1977). *Cheese and fermented milk food*, 2nd edn. Edwards Brothers, Inc., Ann Arbor, MI.

Knipscheer, H. C., Menz, K. M. & Verinumbe, I. (1983). The evaluation of preliminary farming systems technologies: Zero-tillage systems in West Africa. *Agricultural Systems*, **11**, 95–104.

Le Houerou, H. N. & Hoste, C. H. (1977). Rangeland production and annual rainfall relations in the Mediterranean Basin and in the African Sahelo-Sudanian zone. *Journal of Range Management*, **30**, 181–9.

Mesquita-M., R. C., Lopez-A., E., De Oliveira-B., J. G., Vale-V., L., Ramos-D., A. & Vasconcelos-M., H. (no date). *Efeito do pastejo na caatinga natural e modificada sob diferentes taxas de lotacao com caprinos*. EMBRAPA-CNPC, Sobral, Ceara. Mimeographed.

National Academy of Sciences (1981). *Nutrient requirements of goats*. National Academy Press, Washington, DC.

National Academy of Sciences (1975). *Nutrient requirements of sheep*. National Academy Press, Washington, DC.
National Academy of Sciences. (1976). *Nutrient requirements of beef cattle*. National Academy Press, Washington DC.
Pfister J. A. (1983). *Nutritional and feeding behavior of goat and sheep grazing deciduous shrub-woodland in northeastern Brazil*. Unpublished PhD. Thesis, Utah State University.
Queiroz, J., Gutierrez-Aleman, N. & Ponce de Leon, F. A. (1984). Ecology and management of small-ruminant-production systems in the sertao of Ceara State, northeast Brazil. Unpublished.
Utah State/EMBRAPA-CNPC (1982). *Annual report of range management research*. Sobral, Brazil, National Goat Research Center.
Ward, J. D. & Tavares de A, A. (1975). *Nutricao, renda e tamanho da familia: um exame da situacao nutricional em Caninde, Ceara*. Associacao Nacional de Centros de Pos-Graduacao em Economia, III Encontro Anual, Garanhus, Fortaleza, Brazil.