# CROP SUPPLY RESPONSES UNDER UNCERTAINTY IN TWO SENEGALESE REGIONS: A COMPARATIVE STUDY

By

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## ABSTRACT

## CROP SUPPLY RESPONSES UNDER UNCERTAINTY IN TWO SENEGALESE REGIONS: A COMPARATIVE STUDY

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Farm resource allocation decision, particularly in developing countries, is generally a risky process. The uncertainty related to yields and farm product prices suggests that farmers behave in risk-averse ways.

This research uses linear programming models under a risk framework to investigate about cropping patterns and technologies most profitable to farmers in two senegalese zones: the Center of the Peanut Basin and the Upper Casamance.

Normative supply responses are derived for the two agricultural zones investigated under a food security perspective by making assumptions about farm price levels. In the Central Peanut Basin, acreage under cultivation does not respond to price increases; supply responses have constant slopes. In the Upper Casamance zone, interesting aspects of land competition between crops is found. Among all crops, maize showed higher acreage responses to price increase.

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# CHAPTER I

# INTRODUCTION

## 1.1 Background

The extent to which farmers in less developed countries (LDCs) respond to price changes in agricultural products has been extensively debated in recent years. Attempts to estimate crop supply responses to price change have reached divergent conclusions. For example, Hopper (1965), in a study carried out in India, provide empirical evidence to support the theory that farmers in LDCs are remarkably efficient in allocating the resources at their disposal. This theory, referred to as the "poor but efficient " hypothesis, assumes that farmers in LDCs are profit maximizers. And Yotopoulos and Nugent (1976), following the same framework, concluded more specifically that Indian farmers seem to be remarkably price efficient.

Although those two studies lend support to the "poor but efficient" hypothesis, risk aversion attitudes typical to farmers in subsistence agriculture are not included in their framework. Subrata and Ken (1984) argue that peasant farmers operate in an environment where considerable uncertainties exist and where institutional and cultural constraints are important.

Hence, risk and uncertainty should be taken into account in any attempt to analyze farmers' resource allocation process. Gotsch and Falcon (1975), in a study initiated in the Punjab region of India, emphasized the fact that farmers are more responsive to a farm-level net revenue change than to a relative price change. The uncertainty related to meeting subsistence requirements can offset any price incentive.

This research takes risk aversion into account to model farmers' behavior in two Senegalese regions with regard to farm resource allocation plans. In the Senegalese farming system context, risks confronting farmers are related to yield for crops produced for home consumption and income for crops produced for sale.

## 1.2 Justification

Traditionally, Senegalese agricultural policies have promoted food self-sufficiency by focusing on issues such as the expansion of rural credit, rural cooperatives, and the efficiency of development agencies. This supply side orientation was largely based on the country's comparative advantage in producing cash-crops (groundnut, cotton) for export, and on the import of cereals (rice, wheat) to support urban consumption. Locally produced cereals were used to secure the food needs of rural zones.

Recently, new preoccupations have emerged. The New Agricultural Policy (NAP) emphasizes the limitation of state intervention in the rural economy, the promotion of cereal production to achieve higher food self-sufficiency rates and the expansion of the peanut processing industry to increase exports of peanut products. In sum, the NAP is the Senegalese Government's attempt to add a food security perspective to previously more narrow food self-sufficiency objectives. Indeed, the alteration of existing cropping patterns seems necessary to reconcile both food self-sufficiency goals and food security concerns. But the NAP remains silent on a crucial point: better price policies are a prerequisite to the achievement of a better crop mix.

This research is an attempt to measure the impact of government price policy on farmers' resource allocation. It is part of a larger agricultural sector simulation model developed at Michigan State University (MSU) by Martin and Crawford (Martin, 1986a; Martin and Crawford, 1987).

## 1.3 Objectives

This work is based on a set of regional models of the Senegalese agricultural sector. It focuses on the Central Peanut Basin and the Upper Casamance zones. The objectives pursued are to:

1) derive normative supply curves for several crops in each of the agricultural zone considered above, given a crop price vector.

2) determine the impact on farm resource allocation plans of requiring increased cereal food self-sufficiency rates during bad rainfall years.

3) measure the effects of population growth on prevailing cropping patterns.

4) investigate the change in cropping patterns when marginal lands are cultivated.

5) study the relationship between the starting capital owned by farmers and their use of input intensive technologies.

6) develop a simple expert system to facilitate interpretation of optimal farm plans derived from the linear programming models.

### 1.4 Anticipated uses

The results derived from this study are primarily intended to be used as a diagnostic tool to aid the regional planning of agriculture in Senegal. Several policy alternatives can be tested for their short-term effects at the regional level. Knowledge obtained from producer behavior in response to farm price increases may help identify where regional comparative advantage lies. The identification of binding constraints creating bottlenecks for regional development may clarify where efforts should be put in the future. It should however be pointed out that model results are not a perfect representation of reality.

### 1.5 Methodology

The basic assumption underlying this work is that Senegalese farmers, as in most less developped countries (LDCs) try to maximize expected net revenue subject to ensuring that their subsistence needs are met under the most adverse state of nature. This decision rule is stated by Low (1974) as the minimum cost of security criterion.

A typical farm is modeled in each of the two regions by using a linear programming approach. Production activities are broken down into food crops produced for household consumption and food and cash crops produced for sale. Fifteen states of nature are identified based on two criteria: the total annual quantity of rain and its distribution within the year. Uncertainty is included in the model by using the minimization of total absolute deviations (MOTAD) procedure as suggested by Hazell and Norton (1986). For the home consumed crops, deviations from the average yield expressed in terms of calories are calculated under each state of nature. The same procedure is used for deviations from mean income for production activities used for sale. The states of nature showing the highest deviations from average yields (in calorie) for the home consumed crops and average income for crops produced for sale are included in the constraint rows of the LP tableau. Purchases of farm inputs are addressed by input procurement activities (transfer activities). The capital constraint is divided in two rows: one where borrowing is allowed and the second where borrowing is not allowed. The model also takes into account food habits prevailing in each zone studied.

Supply responses are derived by making various assumptions about price levels for the different crop producing activities. Six price levels are assumed for each cereal produced for sale and for home consumption, starting from their weighted mean prices over the fifteen states of nature incremented by 20% up to 100%. The model is run with each price vector and supply responses are derived with regard to land allocation under alternative technologies.

The impact of increasing food self-sufficiency rates during bad rainfall years is determined by increasing the initial rate(30%) through increments of 10% up to a point of infeasible solution. The process requires the calculation of a new technical coefficient at each step, reflecting the desire of meeting 80% of total needs in good rainfall years in association with the worst years' rates mentioned above. This coefficient is calculated by taking the ratio bad rainfall and good rainfall food self-sufficiency rates. It is entered into the model in the food self-sufficiency constraint under an activity expressing the risk of not meeting food needs.

A farm population increase affects both consumption and production sides of the farm model. From the consumption side, an increase in household size increases total food needs expressed in terms of calories and increases the household food requirements to be satisfied by home consumed crops. From the production side, the amount of family labor available for field work augments. For example, a child is considered an active agricultural worker when he enters the age group starting from eight years of age. The model is run with these knew parameters.

Introducing marginal lands to expand the capacity of the farm to produce more food when producer prices increase involves broadening the model to include new cereal producing activities for sale. The LP is run with these modifications and with a new land constraint.

The impact of the starting capital is studied by running the model with a knew starting capital level. The results given by the base run solution are used as guides to formulate assumptions concerning realistic starting capital levels.

The knowledge base of the expert system is developed in terms of relations (predicates) and rules. The relations represent the factual information given by the LP optimal solution. The rules are based on the interpretation of the optimal plan parameters. The fifth generation programming language Prolog is used to implement the system. Due to time constraints, the application is carried out only for the Central Peanut Basin.

The microcomputer package LP88 is used to solve all the LP problems. The crop budgets set up by Martin (1987a) are the main source of information for the technical coefficients used in the LP tableau.

# CHAPTER II

# THE AGRICULTURAL SYSTEM IN SENEGAL

This chapter contains a description of the Senegalese agricultural system. Special features of the farming system are presented followed by a description of cropping patterns at the national level. The rationale behind the choice of the two regions used in this study is discussed.

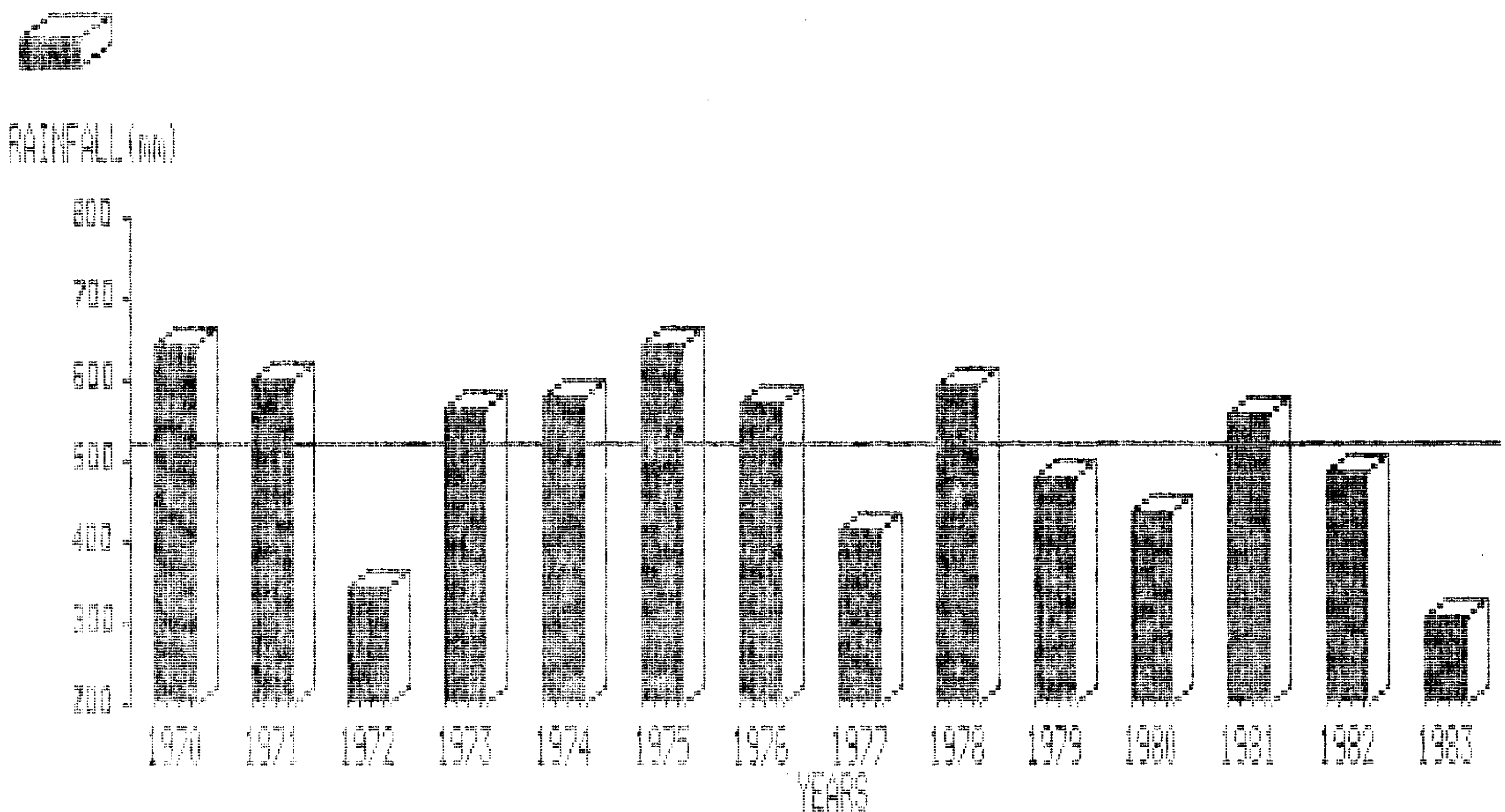
## 2.1 Farming system description

The purpose of this section is to highlight special features of the Senegalese farming system. The prevailing cropping patterns are analyzed from a historical point of view. The data set used covers the years 1970 to 1983.

### 2.1.1 Special features

The Senegalese concept of the farm is based upon the farm-household unit. According to Cattin and Faye (see Cattin and Faye, 1982), the farm-household generally follows two levels of organization. First, at the "concession" level (compound), the farm unit is composed of several households which are under

GRAPH 2.1.1 : AVERAGE RAINFALL IN SENEGAL FROM 1970 to 1983




Source : Direction Generale de la Production Agricole, MPA, annexes p 6-18, 1984

# TABLE 2.1.1 : CULTIVATED AREA BY MAJOR CROP
( 000 Ha)

| CROPS | Millet Sorghum | | Maize | | Rice Paddy | | Cowpeas | | Ground nuts | | Cotton | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % | |
| 1970 | 967 | 43.2 | 51 | 2.3 | 94 | 4.2 | 63 | 2.8 | 1049 | 46.8 | 14 | 0.6 | 2237 |
| 1971 | 973 | 43.1 | 49 | 2.2 | 85 | 3.8 | 71 | 3.1 | 1060 | 46.9 | 18 | 0.8 | 2257 |
| 1972 | 936 | 42.5 | 32 | 1.5 | 54 | 2.5 | 86 | 3.9 | 1071 | 48.6 | 20 | 0.9 | 2200 |
| 1973 | 1103 | 47.8 | 35 | 1.5 | 65 | 2.8 | 53 | 2.3 | 1025 | 44.3 | 28 | 1.2 | 2309 |
| 1974 | 1145 | 47.1 | 49 | 2.0 | 85 | 3.5 | 59 | 2.4 | 1052 | 43.3 | 38 | 1.6 | 2428 |
| 1975 | 965 | 38.3 | 50 | 2.0 | 94 | 3.7 | 62 | 2.4 | 1312 | 52.0 | 39 | 1.6 | 2521 |
| 1976 | 949 | 38.1 | 49 | 2.0 | 89 | 3.6 | 63 | 2.5 | 1295 | 52.0 | 44 | 1.8 | 2489 |
| 1977 | 943 | 40.5 | 54 | 2.3 | 63 | 2.7 | 57 | 2.5 | 1161 | 49.9 | 47 | 2.0 | 2325 |
| 1978 | 1055 | 42.7 | 56 | 2.3 | 91 | 3.7 | 62 | 2.5 | 1154 | 46.7 | 48 | 2.0 | 2468 |
| 1979 | 968 | 43.0 | 68 | 3.0 | 79 | 3.5 | 55 | 2.5 | 1048 | 46.6 | 31 | 1.4 | 2248 |
| 1980 | 1117 | 46.3 | 78 | 3.2 | 67 | 2.8 | 54 | 2.2 | 1066 | 44.1 | 30 | 1.2 | 2412 |
| 1981 | 1184 | 48.4 | 78 | 3.2 | 76 | 3.1 | 68 | 2.8 | 1010 | 41.2 | 32 | 1.3 | 2449 |
| 1982 | 991 | 41.6 | 86 | 3.6 | 68 | 2.9 | 48 | 2.0 | 1149 | 48.1 | 42 | 1.8 | 2384 |
| 1983 | 828 | 38.9 | 71 | 3.3 | 52 | 2.4 | 62 | 2.9 | 1081 | 50.8 | 33 | 1.6 | 2126 |
| MEAN | 1009 | 43.0 | 58 | 2.5 | 76 | 3.2 | 62 | 2.6 | 1110 | 47.3 | 33 | 1.4 | 2347 |
| SD | 94 | 3.3 | 16 | 0.7 | 14 | 0.5 | 9 | 0.5 | 91 | 3.1 | 10 | 0.4 | 116 |
| MIN | 828 | 38.1 | 32 | 1.5 | 52 | 2.4 | 48 | 2.0 | 1010 | 41.3 | 14 | 0.6 | 2126 |
| MAX | 1184 | 48.4 | 86 | 3.6 | 94 | 4.2 | 86 | 3.9 | 1312 | 52.0 | 48 | 2.0 | 2521 |

Source : Nouvelle Politique Agricole, Direction Generale de la Production Agricole, annexes p 6-18, 1984.
Statistics calculated by the author

the direction of the "chéf de concession" (head of compound). The latter, often the oldest family member, is responsible forproduction and consumption decision making processes. Second, the "farm-concession" may contain more than one "ménage" (household sharing the same meals). Decision making processes regarding production and consumption are held by the "chef de ménage", hence, the "ménage" represents the basic production and consumption unit, although it may depends on the "chéf de concession" for access to animal traction equipment.

The association between climate and the farming system is especially important in Senegal and should be discussed here. The marked difference in rainfall between Northern and Southern Senegal is a critical factor in explaining differences in crop calendars between regions. For example, in Northern Senegal, annual rainfall is 300 mm, and in Southern Senegal, it is an average of 1400 mm (Abt Associates, Inc, p. 26, 1985). Also, from 1970 to 1983, the country experienced periods of heavy drought particularly during the years 1972, 1977 and 1983. Graph 2.1.1 shows the average rainfall levels for the years mentioned above.

### 2.1.2 Cropping patterns

Table 2.1.1 shows the area cultivated in the major crops in Senegal. Several points of interest are worth mentioning. Groundnut and millet/sorghum have the largest shares of total cultivated land, 47.3 and 43 % respectively, during the 1970-83 period. Although groundnut has a larger share than millet on the average, the calculated percentages of table 2.1.1 do show a greater share of land in millet during the two years following a period of drought.

TABLE 2.1.2 : LAND SHARE OF MAJOR CROPS IN SENEGAL
Average from 1970 to 1983

| Millet | Maize | Rice paddy | Cowpeas | Ground nuts | Cotton | Total |
|---|---|---|---|---|---|---|
| 43.0 | 2.5 | 3.2 | 2.6 | 47.3 | 1.4 | 100.0 |

Source : Data taken from "Nouvelle Politique Agricole", Direction Generale de la Production Agricole, annexes p. 6-18, 1984.

TABLE 2.1.3 : LAND SHARE OF FOOD-CROPS AND CASH-CROPS IN SENEGAL
Average from 1970 to 1983

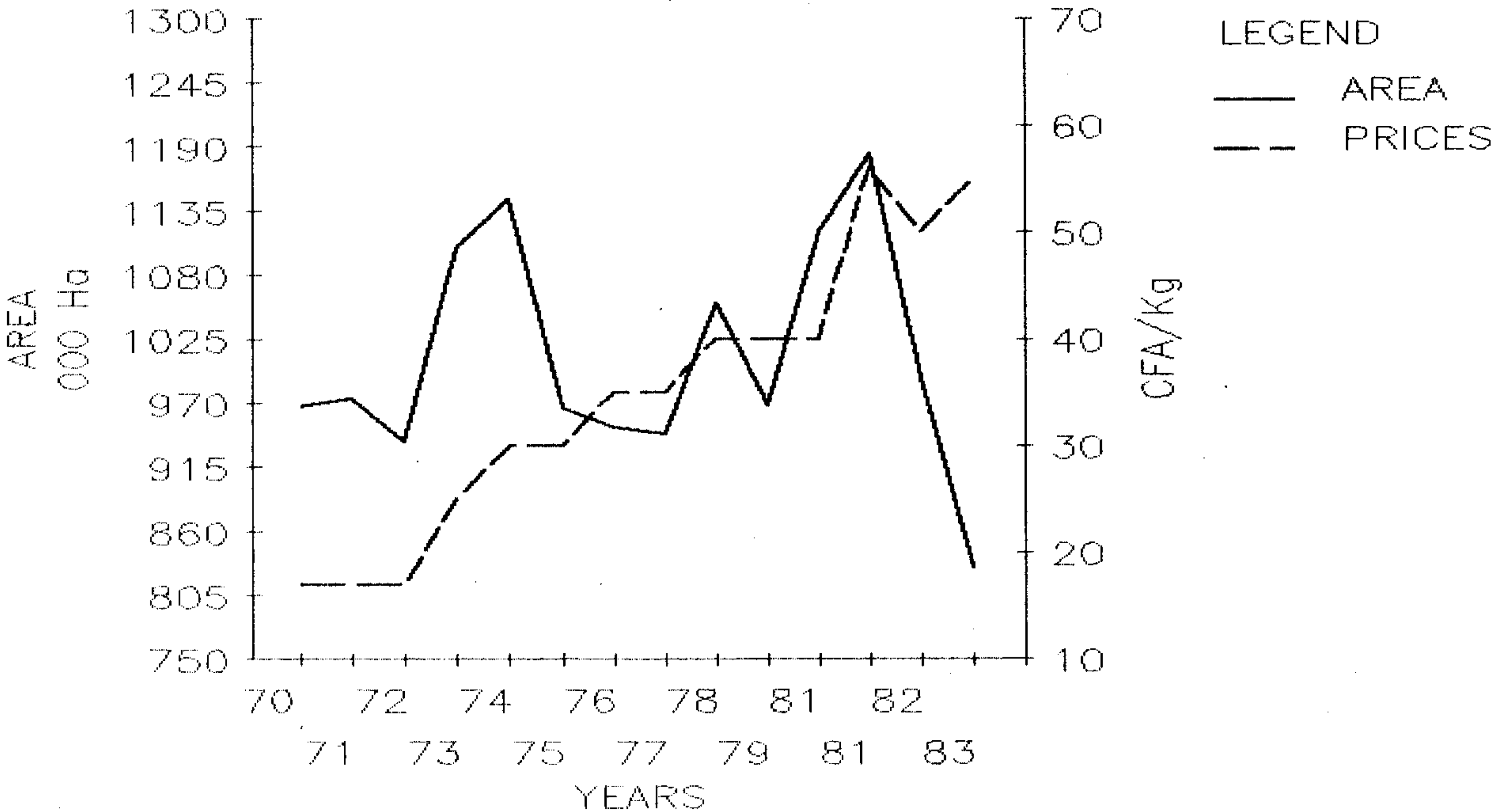
| | Food-crops | Cash-crops | Total |
|---|---|---|---|
| Shares | 51.3 | 48.7 | 100.0 |

Source : Data taken from "Nouvelle Politique Agricole", Direction Generale de la Production Agricole, annexes p. 6-18, 1984.

It seems that in years of good rainfall, groundnuts are grown predominantly for income purposes. In years following poor rainfall, millet is grown as an assurance that home consumption needs are met, first. Rice occupies about 3 % of cultivated lands; however, the calculated percentages show a decreasing trend ranging from 4.2% in 1970 to 2.4% during 1983. Maize exhibits a positive trend; its average acreage is 3% during the last five years as opposed to about 2% during 1970 to 1976. Cotton and cowpeas show fairly constant trends averaging about 1.4 and 2.6 % of cultivated land. An illustration of the respective shares of these different crops is given in table 2.1.2. Table 2.1.3 illustrates the different shares of land of the food-crops as opposed to the cash-crops.

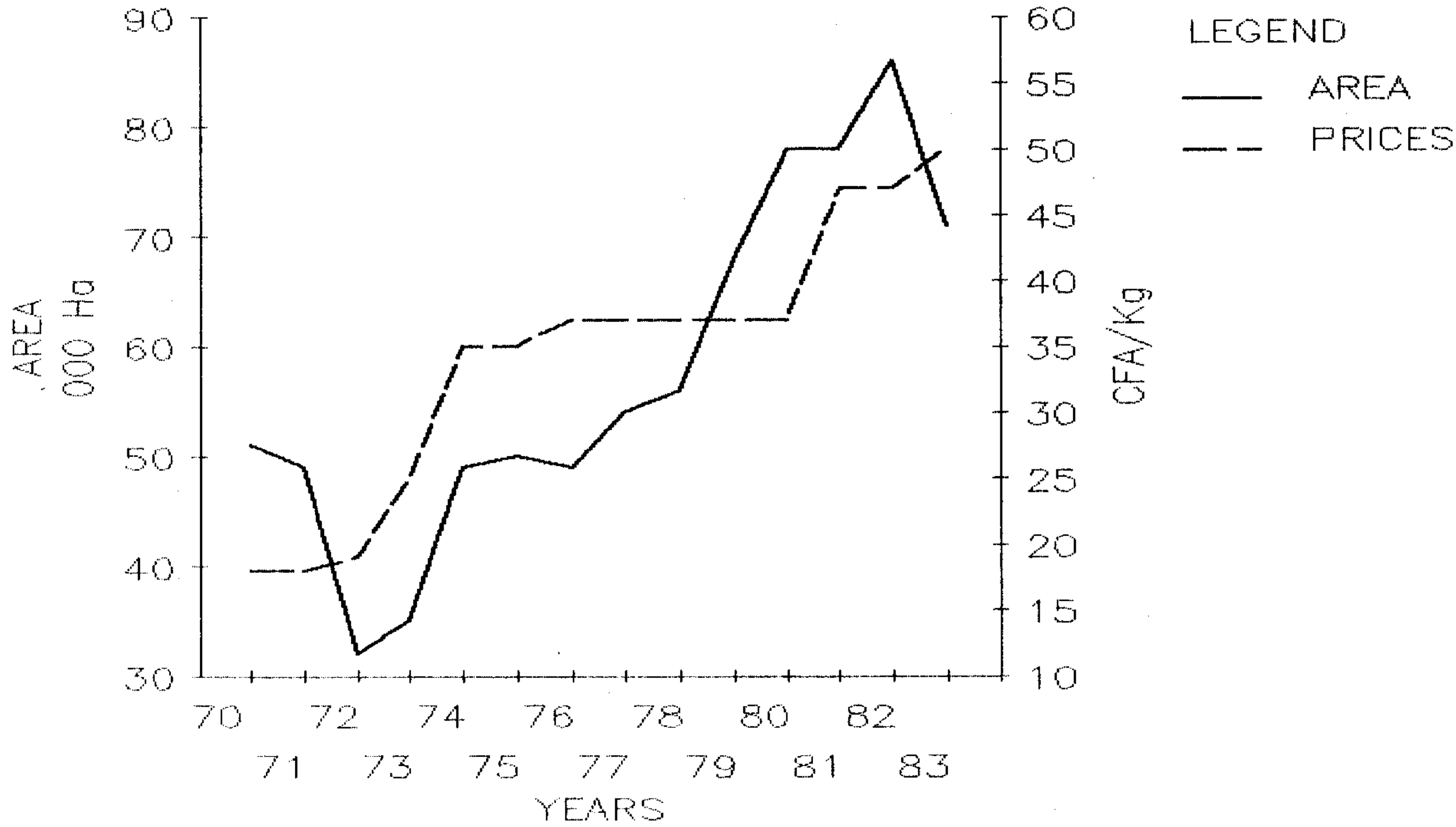
Several factors are usually associated with the within-year variations of land allocated to various crops. Among other factors, producer prices contribute in a significant way to explain those variations. Amadou Niane (MSU, 1980) used an econometric model to show that the supply of millet/sorghum in Senegal is responsive to the previous year's official producer price. Although there is evidence that only a small part of the millet/sorghum produced is marketed officially (4 to 5%) (see Ndoye, 1984), official millet prices may influence farmers' land allocation decisions for millet thereby effecting millet supply. For example, in the case of groundnuts, the impact of government groundnut pricing policies on land allocation was noticeable during the years 1967 to 1974 (Abt Associates, 1985). Graphs 2.1.2 to 2.1.4 depict the relationships between land allocated to millet, maize and groundnut with respect to their official prices from 1970 to 1983. Graph 2.1.2 shows that an increase in millet price

# GRAPH 2.1.2 CULTIVATED AREA AND OFFICIAL PRICES OF MILLET 1970 – 1983



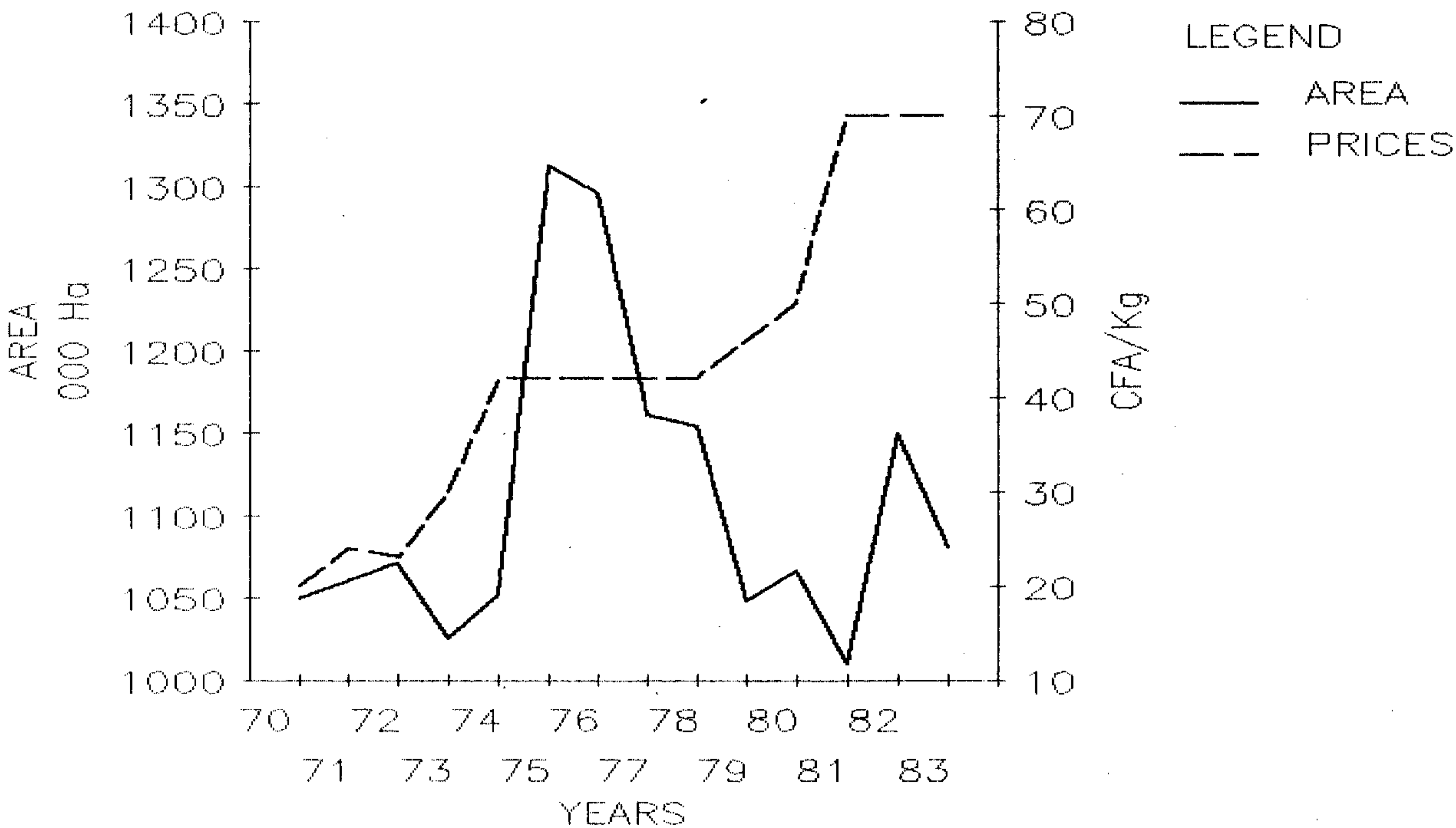

US $ = 238 CFA

## GRAPH 2.1.3 CULTIVATED AREA AND OFFICIAL PRICES OF MAIZE 1970 – 1983




US $ = 238 CFA

## GRAPH 2.1.4 CULTIVATED AREA AND OFFICIAL PRICES OF GROUNDNUT 1970 – 1983




US $ = 238 CFA

is followed by an upward shift in millet acreage. This is particularly visible during years 1973, 1974 and 1981. Maize acreages respond to a larger extent to price increases than millet; this fact is particularly noticeable in graph 2.1.3. Groundnut acreages were responsive to price increases up to 1976. The high prices observed after 1980 are not followed by acreage increases.

Farmer responsiveness to official price changes appears to be effective during the observed years. However, that effect does differ depending on the type of crop. While land allocated to maize shows a positive trend during the observed years, groundnuts seem to be losing popularity among farmers.

## 2.2 Zone overview

This section provides a description of the relative importance of the two regions involved in this work: the Peanut Basin and Casamance. Comparisons are made between those regions and the rest of the country in terms of population structure, land utilization and production patterns. The rationale behind the choice of an agricultural zone within each region is then discussed.

### 2.2.1 Description of the regions

Table 2.2.1 summmarizes the population structure in each region and the rest of the country. About 46% of the Senegalese population and 54% of its rural population live in the Peanut Basin. Casamance shelters 14% of the total population and accounts for 16% of the rural population.

TABLE 2.2.1 : POPULATION STRUCTURE
(000 individuals)

| Regions | Total % | Urban % | Rural % |
|---|---|---|---|
| Peanut Basin | 2912 (46) | 521 (28) | 2391 (54) |
| Casamance | 860 (14) | 150 (8) | 710 (16) |
| Senegal | 6300 (100) | 1890 (100) | 4410 (100) |

Sources : RAPID II population projection for 1987
Percentages are calculated by the author.

TABLE 2.2.2 : LAND UTILIZATION
Units = 000 Ha

| Regions | Total land % | Arable land % | Crop land % | Land use rate |
|---|---|---|---|---|
| Peanut Basin | 4442 (21) | 2169 (59) | 1749 (79) | 81 |
| Casamance | 2835 (14) | 750 (20) | 297 (13) | 40 |
| Senegal | 20000 (100) | 3700 (100) | 2220 (100) | 60 |

Sources : Data taken from "Nouvelle Politique Agricole", Direction Generale de la Production Agricole, annexes p. 6-18, 1984.
Percentages are calculated by the author. Land use rate is calculated by dividing arable land into crop land and multiplying the quotient by 100.

The land distribution prevailing in 1984 is shown in table 2.2.2. It is interesting to note that in the Peanut Basin, 81% of the arable land is in use; that figure is far above the 40% land use rate calculated for Casamance.

The cropping patterns existing in each region are given in Table 2.2.3. Both groundnut and millet/sorghum are particularly popular in the Peanut Basin; each of them uses about 80% of cultivated land. Rice and cotton are mainly cultivated in Casamance; their shares in total cropland used are respectively of 75 and 45%. Maize is a more important crop in Casamance than in the Peanut Basin (35% of the total area cultivated to maize in Senegal is in the Casamance versus 17% in the Peanut Basin). 43% of the land allocated to cowpeas is in the Peanut Basin.

### 2.2.2 Zone identification

The tables listed above illustrate the importance of the Peanut Basin. The reasons for its selection as an area of focus for this study may be summarized as follows:

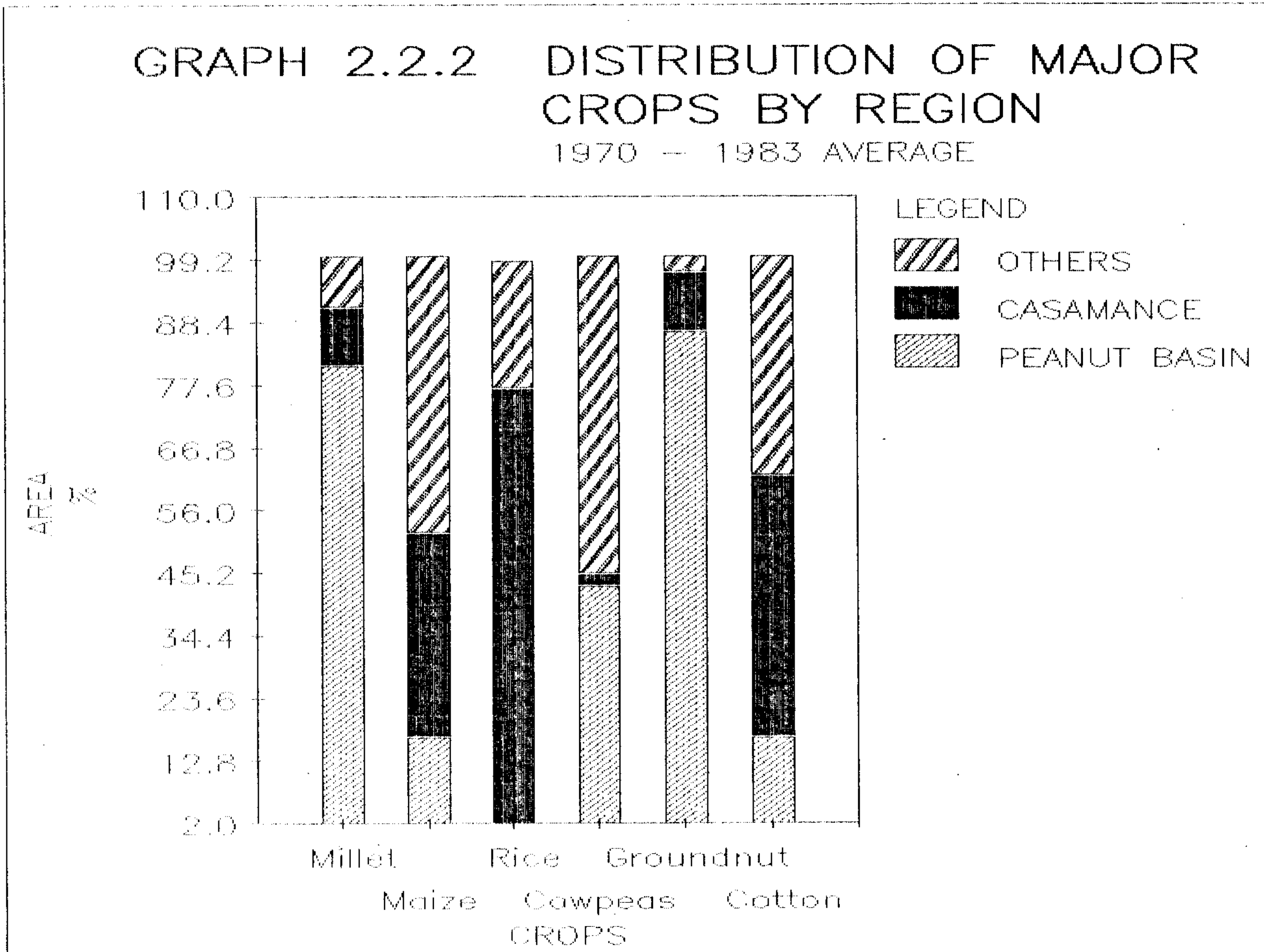
- More than 50% of the Senegalese rural population and 28% of its urban population live there.
- More than 80% of the total area cultivated to both groundnuts and millet in Senegal is in the Peanut Basin.

It should, however, be pointed out that the Peanut Basin shows a great heterogeneity in terms of rainfall, soil types and ethnic groups. Based on those criteria, four agricultural zones are identified in this region (Martin, 1987a). This study will focus on the Center of the Peanut Basin (CPB) which, in terms of area, covers

TABLE 2.2.3 : PERCENTAGE AREA CULTIVATED FOR MAJOR CROPS

| Regions | Millet | Maize | Rice paddy | Cowpeas | Ground nuts | Cotton |
|---|---|---|---|---|---|---|
| Peanut Basin | 81.4 | 17.1 | 2.5 | 43.0 | 86.9 | 16.8 |
| Casamance | 9.6 | 35.4 | 75.5 | 2.0 | 9.9 | 45.0 |
| Others | 9.0 | 47.5 | 22.0 | 55.0 | 3.2 | 38.2 |
| | 100 | 100 | 100 | 100 | 100 | 100 |

Source : Data taken from "Nouvelle Politique Agricole", Direction Generale de la Production Agricole, annexes p. 6-18, 1984.


GRAPH 2.2.2 DISTRIBUTION OF MAJOR CROPS BY REGION
1970 – 1983 AVERAGE
110.0
99.2
88.4
77.6
66.8
56.0
45.2
34.4
23.6
12.8
2.0
AREA %
LEGEND
OTHERS
CASAMANCE
PEANUT BASIN
Millet
Maize
Rice
Cowpeas
Groundnut
Cotton
CROPS

30% of the region's total land. 40% of the millet and 80% of the cowpeas produced in the region are grown in that zone (SONED, 1981).

On the other hand, the Casamance region is chosen as a second region of study for these reasons:

- Its average annual rainfall of 1500 mm (above the West African Semiarid Tropics (WASAT) norms) and its land use rate of 40% reveal important unused agricultural potential in that region.
- Rice and cotton, two important cash crops in Senegal are primarily grown in that region.

Similarly to the Peanut Basin, this region is divided into three agricultural zones on the basis of climate, rainfall and ethnic group. The Upper Casamance (UPC), considered as a high potential zone for growing millet maize and cotton, is selected as the second agricultural zone in this study.

# CHAPTER III

# LINEAR PROGRAMMING MODEL

This chapter sets out the framework of the LP model used in this study. It includes a description of a typical farm structure, crop production activities, objective function and main constraints existing in the studied zones.

## 3.1 Typical farm structure

This section describes a typical farm in each of the two zones considered in this work. Comparisons are made between those two zones in terms of land size and family composition. The technical packages and the field work periods prevailing in each zone are then discussed.

### 3.1.1 Land and population size

Table 3.1.1 summarizes the land size and the demographic composition of a typical farm household in both zones. Compared to the Upper Casamance, farms are typically larger in the Center of the Peanut Basin in terms of area (6.5 versus 4.5 Ha) but smaller in terms of family size (9.5 versus 16 individuals). In terms of family composition, both zones have identical percentages of adult males and females. It should be noted that the population categories in

Table 3.1.1 reflect the norms being used at the Senegalese Institute of Agricultural Research (ISRA). Children younger than seven years of age are not considered active agricultural workers.

3.1.2 Cropping pattern

Three major rainfed crops are taken into account in the Center of the Peanut Basin: millet/sorghum, cowpeas and groundnut. Table 3.1.2 shows the on-station expected yields of these crops under three rainfall conditions.

Six major crops are retained in the Upper Casamance: millet/sorghum, maize, groundnuts, cotton, rainfed rice and lowland rice. Table 3.1.3 gives the expected yields of these crops.

A between-zone comparison shows that for millet, the Upper Casamance has a much better potential to achieve high yields than the Center of the Peanut Basin. This can be partially explained by the more adequate distribution and average levels of rainfall observed in the Upper Casamance. The same kind of observation can be made for groundnut yields between the two zones.

3.1.3 Technical packages

The expression "technical packages" refers to a set of technologies available to farmers in a given region for a particular crop. Overall, five different technologies (modules) each representing a combination of inputs and outputs are used in this study.

Module one corresponds to highly intensive technologies based on formal research recommendations. It makes extensive use of chemical

**TABLE 3.1.1 : FARM SIZE AND POPULATION COMPOSITION**

| | | AGE CATEGORIES | | | | |
|---|---|---|---|---|---|---|
| Regions | (Ha) Land size | Child -8 | Young 8 - 14 | Men 15 - 59 | Women 15 - 59 | Old 60+ |
| Peanut Basin | 6.5 | 2.3 | 1.1 | 2.5 | 2.5 | 1.1 |
| Casamance | 4.5 | 3.5 | 2.4 | 4.2 | 4.2 | 1.7 |

Source : Martin and Sidibé (Martin 1986b; Martin and Sidibé 1987).

**TABLE 3.1.2 : EXPECTED YIELDS IN THE CENTRAL PEANUT BASIN**
(units = Kg/Ha)

| Rainfall | Millet | Cowpeas | Groundnuts |
|---|---|---|---|
| Bad year | 250 | 200 | 450 |
| Average year | 700 | 700 | 950 |
| Good year | 900 | 1000 | 1200 |

Source: Martin (1986b)

**TABLE 3.1.3 : EXPECTED YIELDS IN THE UPPER CASAMANCE ZONE**
**(units = Kg/Ha)**

| Rainfall | Millet | Maize | Rainfed Rice | Lowland Rice | Ground nuts | Cotton |
|---|---|---|---|---|---|---|
| Bad | 700 | 500 | 0 | 500 | 650 | 1100 |
| Average | 1200 | 1500 | 1500 | 2000 | 1200 | 1500 |
| Good | 1500 | 3000 | 2000 | 3000 | 1800 | 1800 |

Source: Martin and Sidibe (1987)

inputs. Good soil types and careful crop management practices are required to achieve expected yields.

Modules two and three are also based on research recommendations. However, they require respectively less intensification than module one and module three is less intensive than module two. Those technologies are more compatible with farmers' actual conditions.

Module four represents crops grown on "house fields", i.e., land next to the house which is put into cultivation before the first useful rain. Millet, maize or vegetables are usually grown in those fields. They do not require chemical inputs.

Module five corresponds to crops that were planted late as a result of labor constraints or seed problems during the normal work schedule. Yields are lower than expected in this package as a result of insufficient rainfall or incomplete maturing cycle.

#### 3.1.4 Cropping calendars

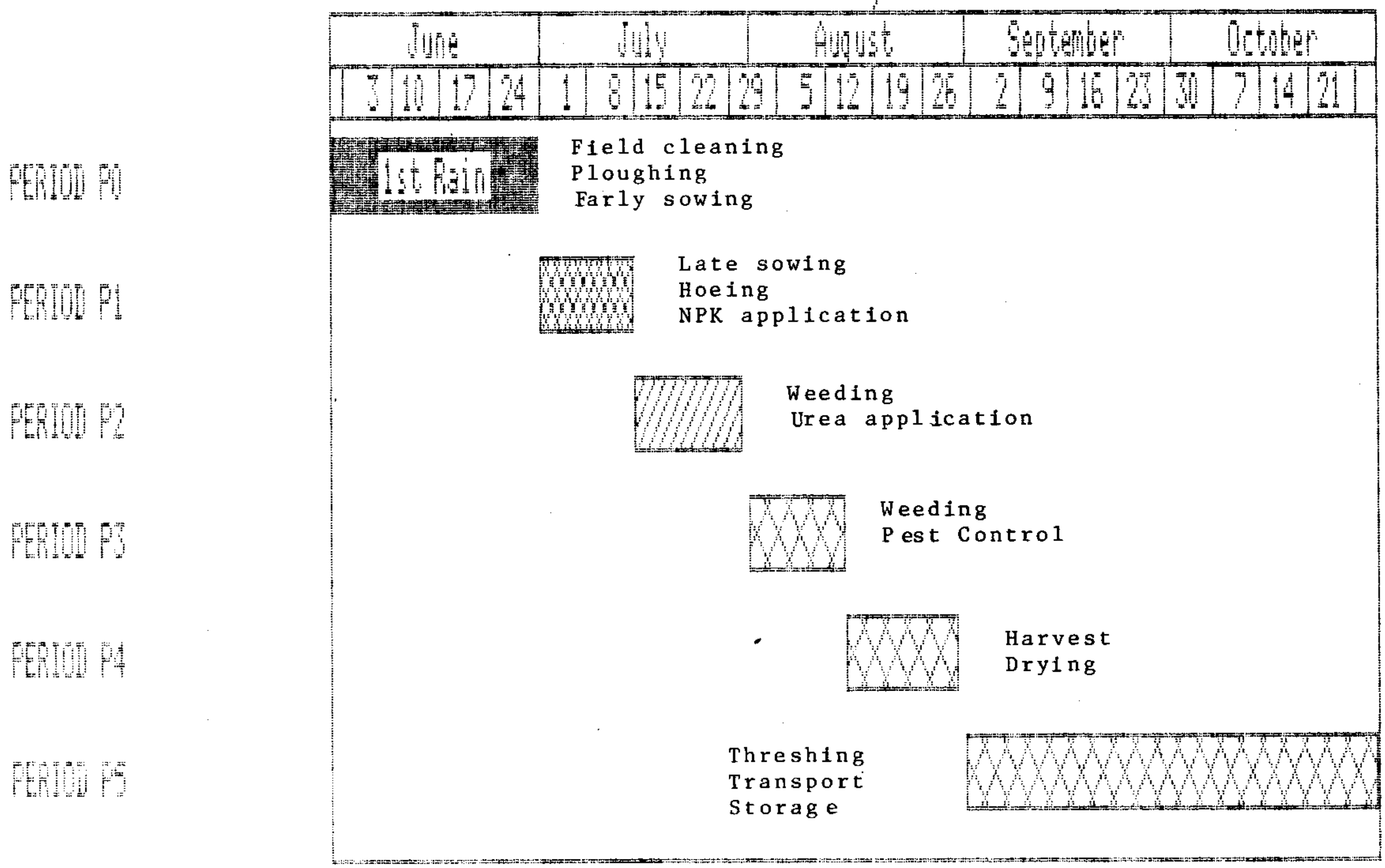
The cropping calendars prevailing in each zone are largely determined by the length of the rainy season. Prior to the first useful rain, a succession of land preparation operations must be carried out by farmers to secure themselves against sharp yield losses. Graphs 3.1.1 and 3.1.2 show the different growing periods used in this study for the Center of the Peanut Basin and the Upper Casamance respectively. The Center of the Peanut Basin has more labor periods (6 versus 4) than the Upper Casamance.

### 3.2 Theoretical considerations

The purpose of this section is to clarify some key concepts underlying this research. First, the possible states of nature used to

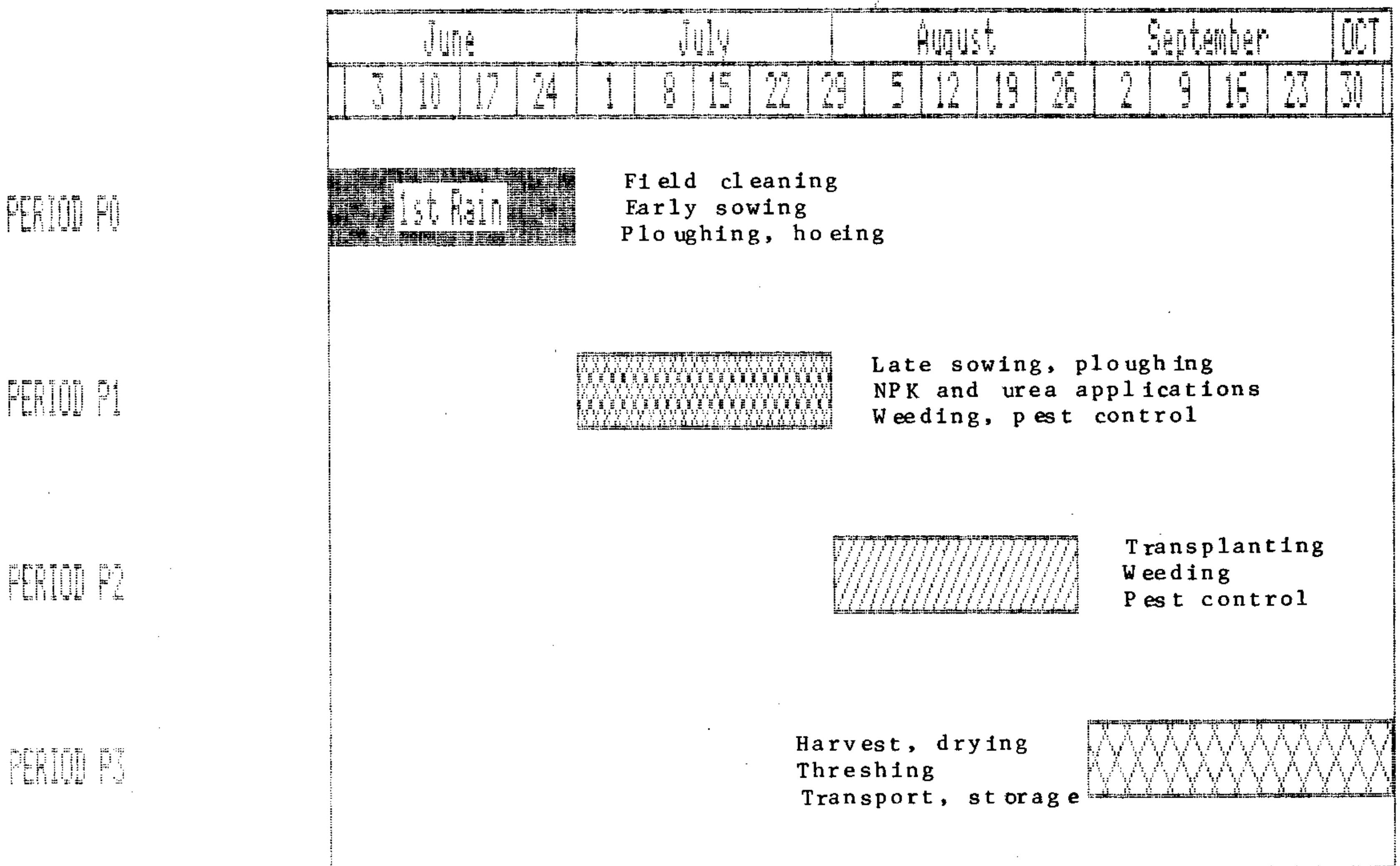
GRAPH 3.1.1 CROP CALENDAR IN CENTRAL PEANUT BASIN

(Periods in days)



GRAPH 3.1.2 CROP CALENDAR IN THE UPPER CASAMANCE

(Periods in days)



model risk are discussed. Second, the theoretical model representing a typical farm decision context is specified.

3.2.1 States of nature

It is assumed in this model that farmers maximize expected net income subject to meeting their subsistence needs under the most adverse situations. This objective reflects the fact that Senegalese farmers are not considered exclusively as profit maximizers. They have other objectives expressed in terms of food security and social obligations which are treated as constraints in this model. Income and food derived from rainfed crops are strongly dependent on yields and therefore on rainfall. The latter affects the uncertain variable "yields" in two ways: by the volume of rain observed in a given year, and its distribution across the rainy season. Based on historical data on rainfall, the amount of rain is categorized in five groups (see table 3.2.1) and the distribution of rainfall in three classes (see table 3.2.2). A crosstabulation of these two "categorical variables" produces fifteen different combinations of rainfall or possible states of nature affecting crop yields. Table 3.2.3 illustrates the method used to calculate expected yields over the fifteen states of nature for different crops.

3.2.2 Mathematical model

The typical farm is represented in terms of the following linear programming model:

Maximize :

$$R = \Sigma_i \; -C_i \; X_i$$

(i = 1, ... k activities)

Subject to :

TABLE 3.2.1 DEFINITION OF RAINFALL AMOUNT CATEGORIES

| Categories | Ranges |
|---|---|
| 1) Very low | q < .7 * Q |
| 2) Low | .7 * Q <= q < .9 * Q |
| 3) Average | .9 * Q <= q < 1.1 * Q |
| 4) High | 1.1 * Q <= q < 1.3 * Q |
| 5) Very high | q >= 1.3 * Q |

Source : Martin (1987a)
q = Amount of rain during a given year
Q = average rainfall between 1970-80

TABLE 3.2.2 DEFINITION OF RAINFALL DISTRIBUTION CATEGORIES

| Categories | Ranges |
|---|---|
| 1) Bad | e >= E * 1.25 |
| 2) Average | E * 1.25 > e >= E * .75 |
| 3) Good | E * .75 > e |

Source : Martin (1987a)
e = Sum of deviations of rainfall across month from average rainfall of that particular month across years of observation.
E = ( Σ e ) / n : n = number of observed years.

$$\Sigma_{i,j}\ a_{ij}\ X_i \qquad <= b_j$$

$$(j = 1, \ldots \text{ constraints})$$

$$\vdots$$

$$[DA]\ X_m \qquad >= 0$$

$$AU\ X_m \qquad >= b_j$$

$$[DI]\ X_n \qquad >= 0$$

$$IN\ X_n \qquad >= b_j$$

$$\vdots$$

$$MIN_1 \qquad >= MI_1$$

$$MAX_1 \qquad <= MA_1$$

Where :

R = Net revenue

C = Net total cost

X(i) = Activity i

X(m) = Activities for crops produced for home consumption

X(n) = Activities for crops produced for sale

b(j) = Resources available or needs of farm unit

DA = Vector of worst deviations from average yield for crops produced for home consumption(calories).

AU = Minimum level of cereal self-sufficiency

DI = Vector of worst deviations from average income for crops produced for sale.

IN = Minimum level of income

MIN = Minimum needs for cereal 1 due to food habits

MAX = Maximum needs for cereal 1 due to food habits

TABLE 3.2.3 : EXPECTED YIELDS AND STATES OF NATURE

| Distribution of rainfall | Volume of rain: Very low | Low | average | High | Very high |
|---|---|---|---|---|---|
| | | | Millet/Sorghum | | |
| Bad | B * .9 | (B+A)/2 | A | A | B |
| Average | (B+A)/2 | A | G | G | A |
| Good | A | G | G * 1.2 | G * 1.2 | G |
| | | | Groundnut, Cotton, Cowpeas | | |
| Bad | B * .9 | (B+A)/2 | A | (B+A)/2 | B |
| Average | (B+A)/2 | (A+G)/2 | G | (A+G)/2 | A |
| Good | A | G | G * 1.2 | G | (A+G)/2 |
| | | | Maize | | |
| Bad | B * .7 | B | A | B | B * .7 |
| Average | B * .9 | A | G | A | B |
| Good | (B+A)/2 | (A+G)/2 | G * 1.2 | G | A |
| | | | Rice | | |
| Bad | B * .6 | B * .8 | B | A | G |
| Average | B * .8 | B | A | G | G * 1.1 |
| Good | B | A | G | G * 1.1 | G * 1.2 |

Source : Martin (1987a)
B = average yield in bad rainfall years
A = average yield in average rainfall years
G = average yield in good rainfall years

### 3.3 Model activities

This section describes the activities carried out in each of the agricultural zones involved in this study. For the Central Peanut Basin, forty-four activities are retained while the Upper Casamance accounts for seventy-two activities. The following section discusses the different types of activities in these two zones by type of crops.

3.3.1 Crop producing activities

Millet/sorghum is grown for home consumption and for sale. Home consumed millet is cultivated under the five technical packages defined in Chapter Two. Millet is grown for sale using four technologies. Both regions contain nine combinations of millet-producing activities.

Maize is cultivated only in the Upper Casamance (UPC) under five different technologies, three for home consumption and two for sale.

Cowpeas is produced in the Central Peanut Basin (CPB) for home consumption only. Technologies one and two are used for this crop.

Two types of rice are produced in the Upper Casamance: rainfed and lowland rice. Rainfed rice accounts for six activities: four modules for home consumption and two modules for sale. Lowland rice acounts for ten activities: five modules for home consumption and five for sale.

Groundnut is cultivated in both regions for sale under four different technologies.

Cotton is produced in the Upper Casamance under four different technical packages. This crop is used only for sale.

Tables 3.3.1 and 3.3.2 summarize the different types of activities carried out in both zones.

3.3.2 Input procurement activities

The tables mentioned in the preceding section show the seven different types of input procurement activities in the two models. The following discussion highlights special features inherent to each zone.

Seed buying activities are included in both models for groundnut and cowpeas in the CPB, groundnut and cotton in the UPC. Six fertilizer buying activities are used in the Upper Casamance model while the Central Peanut Basin uses only three of these activities. Insecticide, herbicide and fungicide buying activities are used in both models at varying levels depending on the type of crop grown. The number of labor hiring activities in the two zones is different. Five growing periods were identified in the CPB yielding five labor hiring activities while the UPC model includes four hiring activities.

3.3.3 Output selling activities

In the Central Peanut Basin model, three crop selling activities are included: millet/sorghum, cowpeas and groundnut. However, groundnut and cowpea hay selling activities are added to the model, which yields five different activities.

The Upper Casamance model accounts for seven output selling activities reflecting the six crops grown in that zone and an additional groundnut hay selling activity.

3.3.4 Cereal buying activities

Four different cereals buying activities are taken into account by the model in both zones. Millet/sorghum, maize, rice and wheat (in form of bread) may be purchased. For millet/sorghum and maize, the mean weighted price over the fifteen states of nature is used as the

TABLE 3.3.1 : MODEL ACTIVITIES IN THE CENTRAL PEANUT BASIN

| Activity number | Activity description | Activity name |
|---|---|---|
| | Production | |
| A1 - A5 | Millet/sorghum for home consumption | PMIC1 to PMIC5 |
| A6 - A9 | Millet/sorghum for sale (no module 4) | PMIV1 to PMIV5 |
| A10 - A11 | Cowpeas | PNIE1 to PNIE2 |
| A12 - A15 | Groundnut (no module 4) | PARA1 to PARA5 |
| | Input procurement | |
| A16 | Buy groundnut seed | ASEAR |
| A17 | Buy NPK (14-7-7) for millet/sorghum | ANPK1 |
| A18 | Buy NPK (6-20-10) for groundnut and cowpeas | ANPK2 |
| A19 | Buy urea | AUREE |
| A20 | Buy insecticide 1 for cowpeas | ANIN1 |
| A21 | Buy insecticide 2 for cowpeas | ANIN2 |
| A22 | Buy fungicide for groundnut | ARAFO |
| A23 | Hire labor in period P1 | AMO1 |
| A24 | Hire labor in period P2 | AMO2 |
| A25 | Hire labor in period P3 | AMO3 |
| A26 | Hire labor in period P4 | AMO4 |
| A27 | Hire labor in period P5 | AMO5 |
| A28 | Borrow capital to buy groundnut seed or food | ACAP |
| | Risk transfer rows | |
| A29 | Risk transfer column for food self-sufficiency | RISKA |
| A30 | Risk transfer column for minimum income | RISKR |

| Activity number | Activity description | Activity name |
|---|---|---|
| | <u>Capital transfer columns</u> | |
| A31 | Capital group 1 transfer column (borrowing possible) | CAPT1 |
| A32 | Capital group 2 transfer column (borrowing not possible) | CAPT2 |
| | <u>Cereal buying activities</u> | |
| A33 | Buy millet/sorghum | AMIL |
| A34 | Buy maize | AMAIS |
| A35 | Buy rice | ARIZ |
| A36 | Buy wheat | ABLE |
| | <u>Output selling activities</u> | |
| A37 | Sell millet for sale | VMIL |
| A38 | Sell maize | VMAIS |
| A39 | Sell groundnut shells | VARAG |
| A40 | Sell groundnut hay | VARAF |
| A41 | Sell cotton | VCOT |
| | <u>Dummy activities</u> (provisory) | |
| A42 | Self-sufficiency constraint | DUMA |
| A43 | Income constraint | DUMR |

Source : Martin (1986b)

TABLE 3.3.2 : MODEL ACTIVITIES IN THE UPPER CASAMANCE

| Activity number | Activity description | Activity name |
|---|---|---|
| | **Production** | |
| A1 to A5 | Millet/sorghum for home consumption | PMIC1 to PMIC5 |
| A6 to A9 | Millet/sorghum for sale (no module 4) | PMIV1 to PMIV5 |
| A10 to A12 | Maize for home consumption (no module 3) | PMAC1 to PMAC4 |
| A13 to A14 | Maize for sale | PMAV1 to PMAV2 |
| A15 to A17 | Rainfed rice for home consumption | PRRC1 to PRRC4 |
| A18 to A19 | Rainfed rice for sale | PRRV1 to PRRV2 |
| A20 to A24 | Lowland rice for home consumption | PLRC1 to PLRC5 |
| A25 to A29 | Lowland rice for sale | PLRV1 to PLRV5 |
| A30 to A33 | Groundnuts (no module 4) | PARA1 to PARA5 |
| A34 to A37 | Cotton (no module 4) | PCOT1 to PCOT5 |
| | **Input procurement** | |
| A38 | Buy groundnut seed | ASEAR |
| A39 | Buy cotton seed | ASECO |
| A40 | Buy NPK (14-7-7) for millet/sorghum | ANPK1 |
| A41 | Buy NPK (8-18-27) for maize | ANPK2 |
| A42 | Buy NPK (18-46-0) for rice | ANPK3 |
| A43 | Buy NPK (6-20-10) for groundnut | ANPK4 |
| A44 | Buy NPK (6-14-35) for cotton | ANPK5 |
| A45 | Buy urea | AUREE |
| A46 | Buy herbicide for millet/sorghum and maize | AHEMM |
| A47 | Buy herbicide for rice | AHERI |
| A48 | Buy fungicide for groundnut | AFOAR |
| A49 | Buy herbicide # 1 for cotton | AHEC1 |
| A50 | Buy herbicide # 2 for cotton | AHEC2 |
| A51 | Buy insecticide for cotton | AINC |
| A52 | Hire labor in period P1 | AMO1 |
| A53 | Hire labor in period P2 | AMO2 |
| A54 | Hire labor in period R1 | AMOR1 |
| A55 | Hire labor in period R2 | AMOR2 |

| Activity number | Activity description | Activity name |
|---|---|---|
| A56 | Borrow capital to buy groundnut seed or food | ACAP |
| | <u>Risk transfer rows</u> | |
| A57 | Risk transfer column for food self-sufficiency | RISKA |
| A58 | Risk transfer column for minimum income | RISKR |
| | <u>Capital transfer columns</u> | |
| A59 | Capital group 1 transfer column (borrowing possible) | CAPT1 |
| A60 | Capital group 2 transfer column (borrowing not possible) | CAPT2 |
| | <u>Cereal buying activities</u> | |
| A61 | Buy millet/sorghum | AMIL |
| A62 | Buy maize | AMAIS |
| A63 | Buy rice | ARIZ |
| A64 | Buy wheat | ABLE |
| | <u>Output selling activities</u> | |
| A65 | Sell millet | VMIL |
| A66 | Sell maize | VMAIS |
| A67 | Sell rice (rainfed and lowland) | VRIZ |
| A68 | Sell groundnut shells | VARAG |
| A69 | Sell groundnut hay | VARAF |
| A70 | Sell cotton | VCOT |
| | <u>Dummy activities</u> (provisory) | |
| A71 | Self-sufficiency constraint | DUMA |
| A72 | Income constraint | DUMR |

Source : Martin and Sidibe (1987)

market price. The prices used for the other cereals reflect those prevailing in Dakar plus the transportation cost from Dakar to the corresponding regions.

3.3.5 Capital transfer activities

Two capital transfer activities are used in each model to handle situations where borrowing is allowed or not allowed. Repayment of borrowed capital is handled by a third activity.

3.3.6 Risk transfer activities

Two activities are used to handle risk situations faced by farmers relative to income and subsistence requirements. In the case of income requirements, the level of the risk transfer activity indicates the amount by which crops produced for sale must increase to satisfy the income constraint. For the subsistence requirements, the level of the risk transfer activity indicates the amount by which crops produced for home consumption must increase to meet the minimum food needs.

3.3.7 Dummy activities

Two dummy activities are used in each model as check activities. Their presence in the optimal solution is an indication of inconsistencies in the income or food self sufficiency deviations constraints.

### 3.4 Objective function values

In this model, the objective is to minimize costs. For computational convenience, the objective function coefficients have been multiplied by -1 to convert the problem to one of maximization. The purpose in this section is to clarify the derivations of the coefficients used in the objective function.

3.4.1 Production coefficients

For the crop producing activities, the coefficients used in this model represent the per hectare cost of inputs used and not specified in the input procurement activities. This will include the variable cost of using agricultural equipment and some amount of depreciation on this equipment.

3.4.2 Input procurement coefficients

The objective function coefficients for the input procurement activities are their respective prices to the producers (1986 figures), excluding any special short-term subsidy. A monthly interest rate of seven percent is estimated for repayment of borrowed capital to buy inputs.

3.4.3 Cereal buying and output selling coefficients

The mean weighted prices over the fifteen states of nature are used for objective function values of the cereal buying and selling activities. For rice and wheat, the prices prevailing in Dakar plus an inter-region transportation cost represent their coefficients.

3.4.4 Other coefficients

The objective function values of the risk and capital transfer activities are equal to zero.

**3.5 Model constraints**

This section describes the different types of constraints which the two regional models include, with a special emphasis on the food-security constraints. The Central Peanut Basin zone has forty-three constraints while the Upper Casamance model accounts for forty-seven constraints.

TABLE 3.5.1 : MODEL CONSTRAINTS IN THE CENTRAL PEANUT BASIN ZONE

| Constraint | Description | Units | Sign | RHS |
|---|---|---|---|---|
| | Resource Use | | | |
| C1 | Land | Ha | <= | 6.5 |
| C2 | Groundnut seeds | Kg | <= | 0.0 |
| C3 | Cowpeas seeds | Kg | <= | 0.0 |
| C4 - C7 | Labor in period 1 to 4 | Man/day | <= | 41.2 |
| C8 | Labor in period 5 | Man/day | <= | 137.0 |
| C9 -C12 | Animal traction 1 to 4 | Ani./day | <= | 10.0 |
| C13 | Animal traction 5 | Ani./day | <= | 64.0 |
| | Chemical input | | | |
| C14 | NPK for millet | Kg | <= | 0.0 |
| C15 | NPK for Cowpeas | Kg | <= | 0.0 |
| C16 | Urea for millet | Kg | <= | 0.0 |
| C17 | Insecticide 1 cowpeas | Treatment | <= | 0.0 |
| C18 | Insecticide 2 cowpeas | Treatment | <= | 0.0 |
| C19 | Fungicide groundnut | Treatment | <= | 0.0 |
| | Food security | | | |
| C20 | Risk rows for FSS | Calories | >= | 0.0 |
| C21 | Minimum level of FSS | Calories | >= | 4270.0 |
| C22 | Risk rows for income | CFA | >= | 0.0 |
| C23 | Minimum income | CFA | >= | 100000 |
| | Others | | | |
| C24 | Starting capital | CFA | <= | 20000 |
| C25 | Capital group 1 | CFA | <= | 0 |
| C26 | Capital group 2 | CFA | <= | 0 |
| C27 | Repayment of capital | CFA | <= | 0 |
| C28 | Millet sold | Kg | <= | 0 |
| C29, C30 | Cowpea grain, hay sold | Kg | <= | 0 |
| C31 | Groundnut unshelled | Kg | <= | 0 |
| C32 | Groundnut hay | Kg | <= | 0 |
| C33 | Nutrition needs | Calories | >= | 5103 |
| C34 | Minimum acreage M4 | Ha | >= | .05 |
| C35 | Maximum acreage M4 | Ha | <= | 1.0 |
| C36 | Min consumption millet | Kg/Ha | >= | 1026.0 |
| C37 | Max consumption millet | Kg/Ha | <= | 1710.0 |
| C38 | Min consumption maize | Kg/Ha | >= | 0.0 |
| C39 | Max consumption maize | Kg/Ha | <= | 95.0 |
| C40 | Min consumption rice | Kg/Ha | >= | 314.0 |
| C41 | Max consumption rice | Kg/Ha | <= | 523.0 |
| C42 | Min consumption wheat | Kg/Ha | >= | 19.0 |
| C43 | Max consumption wheat | Kg/Ha | <= | 114.0 |

Source : Martin, 1986b
FSS is defined as food self-sufficiency.

## TABLE 3.5.2 : MODEL CONSTRAINTS IN THE UPPER CASAMANCE ZONE

| Constraint | Description | Units | Sign | RHS |
|---|---|---|---|---|
| | <u>Resource use</u> | | | |
| C1 | Land 1 | Ha | <= | 3.9 |
| C2 | Land 2 | Ha | <= | 0.6 |
| C3, C4 | Groundnut and cotton seed | Kg | <= | 0.0 |
| C5 | Labor in period 1 | Man/day | <= | 104.0 |
| C6,C7 | Labor in periods 2 and 4 | Man/day | <= | 98.0 |
| C8 | Labor in period 3 | Man/day | <= | 126.6 |
| C9 | Animal traction 1 | Ani./day | <= | 20.0 |
| | <u>Chemical input</u> | | | |
| C10, 11 | NPK for millet and maize | Kg | <= | 0.0 |
| C12 | NPK for rice | Kg | <= | 0.0 |
| C13 | NPK for groundnut | Kg | <= | 0.0 |
| C14 | NPK for cotton | Kg | <= | 0.0 |
| C15 | Urea for millet and maize | Kg | <= | 0.0 |
| C16 | Herbicide for millet | Treatment | <= | 0.0 |
| C17 | Herbicide for rice | Treatment | <= | 0.0 |
| C18, 19 | Herbicide 1, 2 for cotton | Treatment | <= | 0.0 |
| C20 | Insecticide for cotton | Treatment | <= | 0.0 |
| C21 | Fungicide groundnut | Treatment | <= | 0.0 |
| | <u>Food security</u> | | | |
| C22 | Risk rows for FSS | Calories | >= | 0.0 |
| C23 | Minimum level of FSS | Calories | >= | 5165.0 |
| C24 | Risk rows for income | CFA | >= | 0.0 |
| C25 | Minimum income | CFA | >= | 85000 |
| | <u>Others</u> | | | |
| C26 | Starting capital | CFA | <= | 25000 |
| C27, 28 | Capital groups 1 and 2 | CFA | <= | 0 |
| C29 | Repayment of capital | CFA | <= | 0 |
| C30, 31 | Millet and maize sold | Kg | <= | 0 |
| C32, 33 | Rainfed lowland rice sold | Kg | <= | 0 |
| C34 | Groundnut unshelled sold | Kg | <= | 0 |
| C35 | Groundnut hay sold | Kg | <= | 0 |
| C36 | Cotton sold | Kg | <= | 0 |
| C37 | Nutrition needs | Calories | >= | 6489 |
| C38 | Minimum acreage module 4 | Ha | >= | .05 |
| C39 | Maximum acreage Module 4 | Ha | <= | 1.0 |
| C40 | Min consumption millet | Kg/Ha | >= | 1026.0 |
| C41 | Max consumption millet | Kg/Ha | <= | 1710.0 |
| C42 | Min consumption maize | Kg/Ha | >= | 0.0 |
| C43 | Max consumption maize | Kg/Ha | <= | 95.0 |
| C44 | Min consumption rice | Kg/Ha | >= | 314.0 |
| C45 | Max consumption rice | Kg/Ha | <= | 523.0 |
| C46 | Min consumption wheat | Kg/Ha | >= | 19.0 |
| C47 | Max consumption wheat | Kg/Ha | <= | 114.0 |

Source : Martin and Sidibe (1987)
FSS is defined as food self-sufficiency.

3.5.1 Resource use constraints

These constraints deal with land, labor, crop seeds and animal traction resource restrictions and availability. Tables 3.5.1 and 3.5.2 lay out these constraints for both zones. The major differences between the two models are discussed below. The Upper Casamance (UPC) model has two types of land, one for rainfed crops and the other for lowland rice, yielding two land constraints. The Central Peanut Basin (CPB) model has only one type of land and therefore one land constraint. Because of its shorter rainy season, the CPB model requires more labor and animal traction constraints than its counterpart.

3.5.2 Chemical input constraints

These constraints represent the resource restrictions put on fertilizer, herbicide, insecticide and fungicide used by crops under different technologies. Tables 3.5.1 and 3.5.2 show the types of chemical inputs used in both zones.

3.5.3 Food-security constraints

Food security constraints are divided into Food Self- Sufficiency (FSS) constraints applying to food crops, and into Income constraints applying to cash crops. Table 3.5.3 illustrates the structure of the FSS constraints for a hypothetical zone. Millet is used as an example of a food crop.

The millet activity is broken down into millet produced for home consumption and millet produced for sale. There are 5 levels of technology for millet production. Level of technology 4 is missing in the millet for sale category because it represents "kitchen garden" technology which is used only for home consumption.

In the case of millet produced for home consumption, there are two sets of constraints. The first set is represented by the most unfavorable states of nature across levels of technology measured by the most negative deviations of mean yields from mean weighted yields. The second set is represented by the mean weighted yields across levels of technology. The Right-Hand Side (RHS) of this second set of constraints is represented by the family food needs in calories which must be satisfied by cereals (65% of total needs).

In the case of millet produced for sale, there is only one set of constraints represented by the weighted yields of the most unfavorable states of nature identified in the case of millet produced for home consumption.

All deviations, weighted yields and mean weighted yields are expressed in calories. The FSS constraints operate as follows: if farmers want to secure their FSS need during the most unfavorable states of nature, the negative deviations for a given technology is compensated by transfering millet produced for sale to millet produced for home consumption. If the millet produced for sale transfered to home consumption is not sufficient to cover the "downside deviations", the "risk penalty" of not satifying the food need arises. The LP algorithm will attempt to transfer the "risk penalty" through a FSS coefficient (see Table 3.5.3 (1)) to increase the level of millet produced for home consumption. The "downside deviation" may not be compensated if a farm is incapable of achieving FSS objectives. In this case, an infeasible solution is obtained.

The income constraints applying to cash crops follow basically the same structure and mechanism. However, only the crop for sale category

TABLE 3.5.3 : STRUCTURE OF THE FOOD SELF-SUFFICIENCY CONSTRAINTS FOR A HYPOTHETICAL ZONE

| PRODUCTION ACTIVITIES | MILLET FOR HOME CONSUMPTION | | | | | MILLET FOR SALE | | | | RISK TRANSFER COLUMN | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TECHNOLOGIES | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 5 | | |
| DEVIATIONS OF MEAN YIELDS FROM MEAN WEIGHTED YIELDS (calories) | | | | | | | | | | | |
| state 1 | d11 | d12 | d13 | d14 | d15 | y11 | y12 | y13 | y15 | 1 | >=0 |
| state 2 | d21 | d22 | d23 | d24 | d25 | y21 | y22 | y23 | y25 | 1 | >=0 |
| . | . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . | . |
| state n | dn1 | dn2 | dn3 | dn4 | dn5 | yn1 | yn2 | yn3 | yn5 | 1 | >=0 |
| MINIMUM LEVEL OF CEREAL FOOD SELF-SUFFICIENCY (calories) | | | | | | | | | | | |
| FSS | wy1 | wy2 | wy3 | wy4 | wy5 | | | | | (1) -.375 | Family >=food needs |

dij represents most negative deviations from mean weighted yields for state of nature i and technology j expressed in terms of calories.

yij represents millet weighted yields for state of nature i and technology j expressed in terms of calories.

wyj represents mean weighted yields over the fifteen states of nature for technology j expressed in terms of calories.

(1) The coefficient -.375 on the FSS row and the Risk column expresses the objective of achieving 80% of FSS on average during good rainfall years and at least 30% of FSS during bad rainfall years. Is is obtained by taking the ratio 30 over 80. The minus sign means an increase in crops produced for home consumption.

is represented. Deviations are of mean income from mean weighted income (instead of yields). Mean weighted income appears in the minimum income constraint (the counterpart of the FSS constraint) across levels of technology. The RHS for the minimum income constraint is represented by an estimated minimum desired income.

3.5.4 Other constraints

Several other constraints are present in both models. Food habits constraints are built into the models to keep household consumption of different cereals within realistic bounds. Accounting identities are used to ensure that quantities sold for any crops are no more than quantities produced. They also provide a means of separating the capital constraint into two rows: one where borrowing is possible and the other where borrowing is not allowed. A minimum acreage constraint is set up for technical package four to reflect the importance of the "kitchen garden" in farmers' food security.

Appendices Tables 1 and 2 show the initial LP tableau of the two zones involved in this study.

# CHAPTER IV

# PROBLEM SOLUTION AND SENSITIVITY ANALYSIS

This chapter focuses on the analysis of the optimal solutions of the two models discussed in the previous chapters. The first section addresses the optimal enterprise mix prevailing in the two zones studied. It is followed by a comparison of cropping intensities derived in the two models with primary data. A post-optimality analysis is then performed on the optimal plans observed in the two zones with emphasis on resource and objective function ranges. The last section is devoted to the development of a knowledge base, supporting the expert system that this study seeks to implement.

## 4.1 Base run

Two assumptions form the basis of the results derived from the base run of the LP models. First, it is assumed that farmers want to achieve 80% food self-sufficiency (FSS) in average years and at least 30% FSS during bad years. Second, minimum income estimates (see Chapter 3) in the Central Peanut Basin (CPB) and Upper Casamance (UPC) zones are used as farmers' objectives with regard to desired income.

**TABLE 4.1.1 : OPTIMAL PLAN AND CROPPING INTENSITY IN THE CENTRAL PEANUT BASIN (Return = 171 656 CFA)**

| Crops | TECHNICAL PACKAGES 1 | 2 | 3 | 4 | 5 | TOTAL Ha | % |
|---|---|---|---|---|---|---|---|
| Area Planted (Ha) | | | | | | | |
| Millet for home consumption | 1.48 | | 1.42 | 1.00 | | 3.9 | 60 |
| Groundnut | | | 2.60 | | | 2.6 | 40 |

Source: LP88 printout.
Technical packages 1 to 5 refered to crop technologies defined in chapter 3.

**TABLE 4.1.2 : OPTIMAL REAL ACTIVITIES IN THE CENTRAL PEANUT BASIN ZONE**

| Activity | Level | Unit | Net return |
|---|---|---|---|
| Buy NPK millet | 147.7 | Kg | -81.5 |
| Buy urea | 73.9 | Kg | -72.5 |
| Fungicide groundnut | 2.6 | Treatment | -1000.0 |
| Buy capital | 55148.3 | CFA | -0.28 |
| FSS risk | 3763.4 | Calorie | 0.0 |
| Income risk | 148399.5 | CFA | 0.0 |
| Buy rice | 95.0 | Kg | -163.0 |
| Buy wheat | 19.0 | Kg | -278.0 |
| Unshelled groundnuts | 1896.2 | Kg | 90.0 |
| Groundnut hay | 2290.1 | Kg | 40.0 |

Source : LP88 printout.
FSS is defined as food self-sufficiency.

### 4.1.1 Cropping intensity

Table 4.1.1 illustrates the optimal plan and cropping intensity for the CPB zone. Millet/sorghum for home consumption is retained by the model under technologies one, three and four with a share of 60% of land use. Intensive technologies are the most economically attractive packages for this crop. Groundnut under package three, the least intensive module recommended by research, has a land share of 40% of total land use. Cowpeas have not been found to be an economically interesting crop in this zone. The net return associated with the optimal plan is 171656 CFA. Other activities in the optimal solution are also shown in Table 4.1.2. Labor hiring activities are not in this plan, denoting an unused labor capacity in all periods. This plan requires borrowing of capital to buy food or cash-crop inputs to support it. Model results show that both the minimum food self-sufficiency (FSS) and the minimum income risks are in the solution. A food deficit of 3763 units of calories in association with an imcome loss of 148400 CFA francs would have been incurred to farmers if risk has not been taken into account. The cereal buying activities show that farmers in this zone are better off by not selling millet and by buying rice and wheat for consumption. Inputs must be purchased for both millet and groundnut crops.

For the UPC model, a combination of six crops under different technologies is included in the optimal enterprise mix of that zone. An illustration of this plan is given in Table 4.1.3. Millet/sorghum for home consumption is produced in packages one, three and four;it has a land share of 38%. Maize is cultivated in package two with

**TABLE 4.1.3 : OPTIMAL PLAN AND CROPPING INTENSITY IN THE UPPER CASAMANCE ZONE (Return = 85035 CFA)**

| | TECHNICAL PACKAGES | | | | | TOTAL | |
|---|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | 5 | Ha | % Upland |
| Millet cons. | 0.16 | | 1.58 | 0.74 | | 1.48 | 38 |
| Maize cons. | | 0.74 | | | | 0.74 | 20 |
| Rainfed rice | | 0.03 | | | | 0.03 | 0.8 |
| Lowland rice | | | 0.58 | | 0.02 | 0.60 | * |
| Groundnut | | | 1.30 | | | 1.30 | 33 |
| Cotton | 0.36 | | | | | 0.36 | 9.2 |

Source: LP88 printout.
(*) Lowland rice is cultivated on different land therefore, it does not appear in the percentage calculation.

**TABLE 4.1.4 : OPTIMAL REAL ACTIVITIES IN THE UPPER CASAMANCE ZONE**

| Activity | Level | Unit | Net return |
|---|---|---|---|
| Buy groundnut seeds | 153.6 | Kg | -110.0 |
| Buy cotton seeds | 17.0 | Kg | -110.0 |
| Buy NPK millet | 15.5 | Kg | -90.9 |
| Buy NPK Rainfed rice | 73.4 | Kg | -93.9 |
| Buy NPK lowland rice | 1.7 | Kg | -115.9 |
| Buy NPK groundnut | 153.7 | Kg | -88.9 |
| Buy NPK cotton | 54.0 | Kg | -90.9 |
| Buy urea | 101.3 | Kg | -81.9 |
| Buy herbicide millet | 0.2 | Treatment | -9750.0 |
| Buy herbicide cotton 1 | 0.4 | Treatment | -8750.0 |
| Buy herbicide cotton 2 | 0.4 | Treatment | -10000.0 |
| Buy insecticide cotton | 1.8 | Treatment | -7350.0 |
| Fungicide groundnut | 2.6 | Treatment | -1000.0 |
| Buy capital | 63555.8 | CFA | -0.28 |
| FSS risk | 4718.7 | Calorie | 0.0 |
| Buy millet | 182.3 | Kg | -63.0 |
| Sell cotton | 613.4 | Kg | 95.0 |
| Sell ground. shell | 1810.6 | Kg | 90.0 |
| Sell ground. hay | 2947.7 | Kg | 13.0 |

Source : LP88 printout.
FSS is defined as food self-sufficiency.

20% share of rainfed land. Rainfed rice in package one, groundnut in package 3 and cotton in package 1 have respective rainfed land shares of 0.8, 33 and 9% of total land use. The optimal objective function value (net revenue) is 85035 CFA francs. The remaining optimal activities are given in Table 4.1.4. The borrowing of capital to buy food or cash-crop inputs at a 28% interest rate is necessary to carry out this plan. The FSS risk activity indicates that 4719 units of calories are transfered from crops produced for sale to crops produced for home consumption.

4.1.2 Scarcity values of binding constraints

The implicit resource values given by the solution to the dual LP problem are referred to as the shadow prices of those resources. This section discusses the scarcity values of the binding constraints existing in the two zones included in this study.

For the CPB model, Table 4.1.5 illustrates the shadow prices of the binding constraints prevailing in that zone, and highlights some interesting aspects of model results. Land shows the very high opportunity cost of 84686 CFA francs, attesting that an additional unit of land would greatly improve the net revenue of a typical farm. Millet fertilizer is a key input to this plan: its implicit price shows that farmers should be willing to support more than a 300% price increase and still remain efficient. The same observation can also be made for urea fertilizer. The starting capital constraint is strongly binding to this optimal solution; each additional unit of it would triple its contribution to the net return. The capital type two constraint, closely related to the starting capital, follows the same behavior. The capital type one constraint does show that borrowing is still profitable even at a doubled interest rate.

Table 4.1.6 illustrates the shadow prices prevailing in the UPC model. Both land types are binding constraints to this plan. The implicit price of the lowland rice land is 50% higher than its counterpart. A between-zone comparison shows land is more valuable in the CPB than in the UPC zone. All fertilizers and crop protection products are scarce resources in this model. Labor in period one was found to be a binding constraint. However, its contribution to net income is only slightly above its actual value of 500 CFA. All capital constraints are binding for this enterprise mix. Their scarcity values are lower in this zone than they were for the CPB.

4.1.3 Model validation

Tables 4.1.7 and 4.1.8 show the shares of the different crops in total land cultivated for the model results compared to observed data in the two agricultural zones. The following observations are worth mentioning for both zones.

In the CPB, millet land share was 12% higher in the model results than in the observed data, groundnut area was 10% smaller in the model and cowpeas are not in the optimal enterprise mix. These variations can be explained in part by the following facts. When agricultural inputs are available as assumed in this study, there are alterations in the actual cropping patterns. There is a shift away from groundnut and cowpeas towards millet/sorghum, yielding a transfer of land traditionally devoted to the former in favor of millet. Cowpeas, which seems to be an important crop at the present time, become economically unattractive.

The UPC zone shows also some interesting results. Millet produced in the model increases by 1% from observed data. Maize increases by 5% and rice by 2% indicating that rice and maize could potentially be

TABLE 4.1.5 : SCARCITY VALUES OF BINDING CONSTRAINTS IN THE CENTRAL PEANUT BASIN ZONE

| Constraints | Shadow price | Unit | RHS Value |
|---|---|---|---|
| Land | 84686.0 | CFA/Ha | 6.5 |
| Groundnut seeds | 140.8 | CFA/Kg | 0.0 |
| Fertilizer millet | 356.2 | CFA/Kg | 0.0 |
| Fertilizer ground. | 196.8 | CFA/Kg | 0.0 |
| Urea | 316.8 | CFA/Kg | 0.0 |
| Insecticide cotton 1 | 8640.0 | CFA/Treat. | 0.0 |
| Insecticide cotton 2 | 6528.0 | CFA/Treat. | 0.0 |
| Fungicide groundnut | 4370.0 | CFA/Treat. | 0.0 |
| Starting capital | 3.4 | CFA | 20000.0 |
| Capital 1 | .28 | CFA | 0.0 |
| Capital 2 | 3.4 | CFA | 0.0 |
| Food self-sufficiency | 110.4 | CFA | 4270.0 |

Source: LP88 printout.

TABLE 4.1.6 : SCARCITY VALUES OF BINDING CONSTRAINTS IN THE UPPER CASAMANCE ZONE

| Constraints | Shadow price | Unit | RHS Value |
|---|---|---|---|
| Rainfed land | 75223.0 | CFA/Ha | 3.9 |
| Lowland land | 116183.0 | CFA/Ha | 0.6 |
| Groundnut seeds | 140.8 | CFA/Kg | 0.0 |
| Cotton seeds | 140.8 | CFA/Kg | 0.0 |
| Fertilizer millet | 321.4 | CFA/Kg | 0.0 |
| Fertilizer rice 1 | 332.0 | CFA/Kg | 0.0 |
| Fertilizer rice 2 | 409.8 | CFA/Kg | 0.0 |
| Fertilizer groundnut | 314.3 | CFA/Kg | 0.0 |
| Fertilizer cotton | 116.4 | CFA/Kg | 0.0 |
| Urea | 104.8 | CFA/Kg | 0.0 |
| Herbicide millet | 34471.6 | CFA/Treat. | 0.0 |
| Herbicide rice | 44365.5 | CFA/Treat. | 0.0 |
| Herbicide cotton 1 | 11200.0 | CFA/Treat. | 0.0 |
| Herbicide cotton 2 | 12800.0 | CFA/Treat. | 0.0 |
| Fungicide groundnut | 3535.0 | CFA/Treat. | 0.0 |
| Labor period 1 | 513.9 | CFA/Day | 104.0 |
| Starting capital | 2.5 | CFA | 25000.0 |
| Capital 1 | .28 | CFA | 0.0 |
| Capital 2 | 2.5 | CFA | 0.0 |
| Food self-sufficiency | 37.7 | CFA | 4270.0 |

Source : LP88 printout.

leading crops in the UPC zone. Groundnuts lose some of its popularity(4%) and cotton land share remains constant between model results and observed data.

**4.2 Sensitivity analysis**

This section focuses on the analysis of changes in the optimal solutions of the LP problems given changes in various coefficients associated with the problems. The discussions are centered around the resource range variations of the binding constraints and the objective function values of the optimal activities.

4.2.1 Resource range variations

Table 4.2.1 illustrates the results derived for the CPB model. Farm land size can vary from 6.0 to 9.0 Ha without affecting the actual enterprise mix. This shows that model results can tolerate 35% variation in land size without any effect on this optimal plan. The millet fertilizer resource range shows that this plan will be maintained whether farmers purchase at least 205 kgs. of NPK millet or hold carry-over stock of up to 136 kgs. An amount of 313 kgs. of urea for millet must also be available to carry out this plan. The starting capital is allowed to vary within the range 3269 to 31071 CFA francs without any effects on the actual resource allocation. The repayment of the borrowed capital is not a binding constraint to this plan; this point supports the fact that borrowing at 28% interest rate is still worthwhile to farmers.

Model results are sensitive to the minimum food self-sufficiency constraint. An 11% increase in the actual level of calorie needs would bring about another enterprise mix.

TABLE 4.1.7 : OBSERVED AND CALCULATED LAND SHARES IN THE CENTRAL PEANUT BASIN ZONE

| Crops | Observed | Model | Differences |
|---|---|---|---|
| Millet | 48 | 60 | -12 |
| Groundnut | 50 | 40 | +10 |
| Cowpeas | 2 | 0 | +2 |

Source : observed data from SODEVA, 1982-84

TABLE 4.1.8 : OBSERVED AND CALCULATED LAND SHARES IN THE UPPER CASAMANCE ZONE

| Crops | Observed | Model | Differences |
|---|---|---|---|
| Millet | 32 | 33 | -1 |
| Maize | 11 | 16 | -5 |
| Rice | 12 | 14 | -2 |
| Groundnut | 33 | 29 | +4 |
| Cotton | 8 | 8 | 0 |

Source : observed data from SODEVA, 1982-84

Table 4.2.2 shows the resource range variations derived from the UPC model. More than a 13% increase in rainfed land and a 7% increase in lowland land would affect model results. The rainfed land in this zone shows a greater sensitivity to land size than was the case in the CPB. This plan is sensitive to all herbicide constraints and to labor in period one. An additional work-hour in that period can affect the optimal solution. The food self-sufficiency constraints allow only a 10% increase in calorie needs before a change in this optimal plan occurs.

4.2.2 Objective function coefficients

The post-optimality analysis, for objective function coefficients, deals with the determination of the range of variations of those coefficients, within which the actual enterprise mix remains unchanged.

Table 4.2.3 illustrates the range of optimality of the objective function for the CPB optimal solution. Home-consumed millet produced under technology one, will remain in this optimal plan even if its net total cost increased by 100%. However, the millet selling activities will never be part of any optimal solution.

That same information is shown in Table 4.2.4 for the UPC optimal solution. Home consumed millet, under technology one, will remain in the optimal plan even if its net total cost is doubled. Millet produced for sale under all technologies is unlikely to be in any optimal plan. Home consumed maize produced in packages one and four show the same behavior. Rainfed rice produced for home consumption is only attractive under technology two.

TABLE 4.2.1 : RESOURCE RANGE VARIATION IN THE CENTRAL PEANUT BASIN

| Constraints | RHS | Unit | Minimum | Maximum |
|---|---|---|---|---|
| Land | 6.5 | Hectare | 6 | 9 |
| Groundnut seeds | 0.0 | Kg | -2137 | 313 |
| Fertilizer millet | 0.0 | Kg | -205 | 136 |
| Fertilizer groundnut | 0.0 | Kg | 0 | 313 |
| Urea | 0.0 | Kg | -230 | 105 |
| Insecticide cotton 1 | 0.0 | Treatment | -34 | 0 |
| Insecticide cotton 2 | 0.0 | Treatment | -46 | 0 |
| Fungicide groundnut | 0.0 | Treatment | -17 | 3 |
| Starting capital | 20000.0 | CFA | 3269 | 31071 |
| Capital group 1 | 0.0 | CFA | -235113 | 55148 |
| Capital group 2 | 0.0 | CFA | -16731 | 11071 |
| Food self-sufficiency | 4270.0 | Calorie | 4224 | 4743 |

Source: LP88 printout

TABLE 4.2.2 : RESOURCE RANGE VARIATIONS IN THE UPPER CASAMANCE ZONE

| Constraints | RHS | Unit | Minimum | Maximum |
|---|---|---|---|---|
| Rainfed land | 3.9 | Hectares | 3.7 | 4.3 |
| Lowland land | 0.6 | Hectares | 0.5 | 0.6 |
| Groundnut seeds | 0.0 | Kg | -1631 | 154 |
| Cotton seeds | 0.0 | Kg | -1630 | 18 |
| Fertilizer millet | 0.0 | Kg | -53 | 22 |
| Fertilizer rice 1 | 0.0 | Kg | -51 | 74 |
| Fertilizer rice 2 | 0.0 | Kg | -41 | 2 |
| Fertilizer groundnut | 0.0 | Kg | -53 | 99 |
| Fertilizer cotton | 0.0 | Kg | -1972 | 54 |
| Urea | 0.0 | Kg | -2190 | 101 |
| Herbicide millet | 0.0 | Treatment | -.5 | .2 |
| Herbicide rice | 0.0 | Treatment | 0 | 0 |
| Herbicide cotton 1 | 0.0 | Treatment | -20 | .4 |
| Herbicide cotton 2 | 0.0 | Treatment | -17 | .4 |
| Labor in period 1 | 104.0 | Man/Day | 79 | 104 |
| Starting capital | 25000.0 | CFA | 20217 | 33820 |
| Capital group 1 | 0.0 | CFA | -195997 | 63555 |
| Capital group 2 | 0.0 | CFA | -4783 | 8820 |
| Food self-sufficiency | 5165.0 | Calorie | 4621 | 5704 |

Source : LP88 printout.

### 4.3 Knowledge representation

This section introduces the concept of expert system (ES) in the context of this study. In that respect, the various components of an ES are first discussed and the remainder of this section is devoted to the design of a knowledge base (KB) from the LP optimal tableau. As specified in Chapter One, only the CPB results are taken into account for this purpose.

#### 4.3.1 Components of an expert system

Loosely defined, an ES is a set of computer programs capable of exhibiting a certain degree of intelligence in a given field, which simulates to some extent a human expert in that field. An ES has three major components illustrated in Figure 4.3.1.

The knowledge base (KB) is an essential part of an ES; it stores all the knowledge necessary for it to apply its expertise. The KB includes factual information on the relations between entities and on the rules describing those relations.

The inference engine (IE) is the driving force of an expert system. It contains operating rules and principles designed to use the KB efficiently in order to match consistent conclusions. The user interface (UI) constitutes the link between the end user and the inference engine. Its purpose is to carry out the user's queries and return the inferred knowledge back to him.

The last two components, known as an expert system shell, interact with the user and the KB to get the system to perform its task.

#### 4.3.2 Knowledge base

The Turbo Prolog expert system shell (Borland, 1986) is used to integrate the LP optimal solution into a workable KB. This fifth

TABLE 4.2.3 : OBJECTIVE FUNCTION RANGES IN THE CENTRAL PEANUT BASIN

| Activity | Net return | Unit | Minimum | Maximum |
|---|---|---|---|---|
| Millet consumed 1 | -3600.0 | CFA/Ha | -11896 | 159634 |
| Millet consumed 3 | -3600.0 | CFA/Ha | -26252 | 11192 |
| Millet consumed 4 | -3298.0 | CFA/Ha | -55057 | 99999(*) |
| Groundnut 3 | -5488.0 | CFA/Ha | -8794 | 18126 |
| Groundnut seeds | -110.0 | CFA/Ha | -225 | 30 |
| Buy NPK millet | -81.5 | CFA/Kg | -315 | 100 |
| Buy urea | -72.5 | CFA/Kg | -238 | 375 |
| Fungicide groundnut | -1000.0 | Treatment | -14863 | 3586 |
| Buy capital | -0.28 | CFA | -1 | 0 |
| Capital group 2 | 0.0 | CFA | -3 | 99999(*) |
| Risk FSS | 0.0 | Calorie | -101 | 31 |
| Risk income | 0.0 | CFA | -.4 | 0 |
| Buy rice | -95.0 | CFA/Kg | -99999(*) | 46 |
| Buy wheat | -278.0 | CFA/Kg | -99999(*) | 77 |
| Sell groundnut unshelled | 90.0 | CFA/Kg | 35 | 11490 |
| Sell groundnut hay | 40.0 | CFA/Kg | 5 | 7270 |

Source : LP88 printout.
(*) 99999 or -99999 means no upper or lower bound respectively.
FSS is defined as food self-sufficiency.

**TABLE 4.2.4 : OBJECTIVE FUNCTION RANGES IN THE UPPER CASAMANCE ZONE**

| Activity | Net return | Unit | Minimum | Maximum |
|---|---|---|---|---|
| Millet consumed 1 | -20687.0 | CFA/Ha | -42645 | -11580 |
| Millet consumed 3 | -7149.0 | CFA/Ha | -11694 | 2770 |
| Millet consumed 4 | -2837.0 | CFA/Ha | -6930 | 99999(*) |
| Maize consumed 2 | -15249.0 | | -19917 | 99999(*) |
| Rainfed rice 2 | -30590.0 | | -41999 | 13580 |
| Lowland rice 3 | -14827.0 | | -25028 | -11929 |
| Lowland rice 5 | -13542.0 | | -16440 | -3340 |
| Cotton 1 | -37746.0 | | -39178 | 26707 |
| Groundnut 3 | -18676.0 | CFA/Ha | -23624 | 2122 |
| Groundnut seeds | -110.0 | CFA/Ha | -384 | -71 |
| Cotton seeds | -110.0 | CFA/Ha | -99999(*) | 30 |
| Buy NPK millet | -90.9 | CFA/Kg | -310 | .2 |
| Buy NPK maize | -94.0 | | -140 | 178 |
| Buy NPK rice | -115.0 | | -344 | 206 |
| Buy NPK groundnut | -89.0 | | -130 | 84 |
| Buy NPK cotton | -91.0 | | -100 | 25 |
| Buy urea | -82.0 | CFA/Kg | -107 | 23 |
| Buy herbicide millet | -9750.0 | | -31709 | -644 |
| Buy berbicide cotton 1 | -8750.0 | | -10182 | 2450 |
| Buy herbicide cotton 2 | -10000 | | -11432 | 2800 |
| Buy insecticide cotton | -7350.0 | | -7827 | 2058 |
| Fungicide groundnut | -1000.0 | Treatment | -33911 | 2656 |
| Buy capital | -0.28 | CFA | -.3 | -.1 |
| Capital 2 | 0.0 | CFA | -2 | 99999(*) |
| Risk FSS | 0.0 | Calorie | -14 | 11 |
| Risk income | 0.0 | CFA | -.1 | 0 |
| Buy millet | 63.0 | CFA/Kg | 0 | 117 |
| Sell groundnut unshelled | 90.0 | CFA/Kg | 67 | 104 |
| Sell groundnut hay | 13.0 | CFA/Kg | 0 | 22 |
| Sell cotton | 95.0 | Cfa/Kg | 94 | 132 |

Source : LP88 printout.
(*) 99999 or -99999 means no upper or lower bound respectively.
FSS is defined as food self-sufficiency.

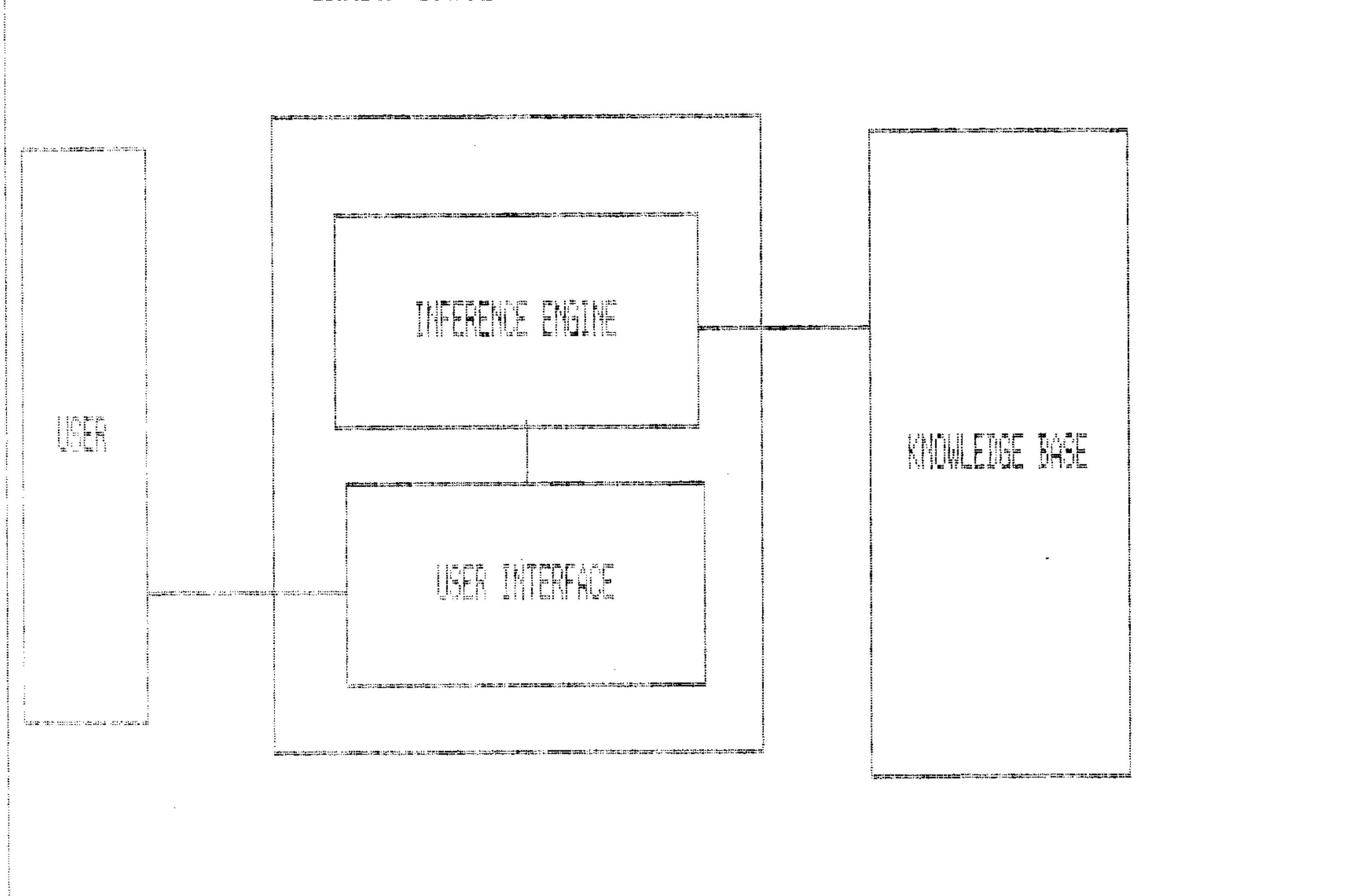
generation computer language allows knowledge to be represented in two different forms. First, knowledge can be expressed with factual relationships between entities taking an If ...Else type of structure. This representation leads to the rule based expert system. Second, knowledge can take the form of causal relations between facts (Predicates), yielding the so- called logic based expert system. This study makes use of both types of knowledge representation.

Table 4.3.1 (read across columns) shows the status of different variables in an LP optimal tableau and the different characteristics that those variables can have. A "yes" in any cell means that a given variable has the attribute of that characteristic. The set of "yes" attributes of a given variable forms the body of the rule that must be satisfied to get a successful matching. For example, a real activity is in the optimal solution if: (1) it is a decision variable, (2) has a level greater than zero and (3) does not have a shadow price (shadow price equals to zero). A slack is in the optimal (not binding) if: (1) it is a resource, (2) has a level equal to zero and (3) has a shadow price greater than zero.

**TABLE 4.3.1 : VARIABLE ATTRIBUTES AND OPTIMAL LP TABLEAU**

| | VARIABLE STATUS | | | |
|---|---|---|---|---|
| Characteristics | Real activity in | Real Activity out | Slack in | Slack out |
| Decision variable | yes | yes | no | no |
| Resource | no | no | yes | yes |
| Level = 0 | no | yes | no | yes |
| Level > 0 | yes | no | yes | no |
| Shadow price = 0 | yes | no | yes | no |
| Shadow price >= 0 | no | yes | no | yes |

GRAPH 4.3.1 : COMPONENTS OF AN EXPERT SYSTEM



Several other attributes should be included in the list of characteristics to allow the expert system (ES) to carry out sensitivity analyses on objective function coefficients and resource ranges of optimality. These attributes are described in the following list:

(1) The return per unit for the real activities.

(2) The right-hand-side (RHS) for resources.

(3) The minimum range of optimality for real activities and resources.

(4) The maximum range of optimality for real activities and resources.

It may also be convenient, in the future, to include labels for activities and resources in this representation to make the computer displays more readable to users.

The expanded list of characteristics (see above and Table 4.3.1) are the cardinality (number of elements) of the relation used to store the LP optimal solution in a knowledge base. For representational convenience, the following modifications are brought into the data structure defined above:

(1) The characteristics "Decision variable" and "Resource" are collapsed into a single variable. This variable takes the value "A" for the former and the value "C" for the latter.

(2) The characteristics "Level = 0" and "Level > 0" are represented by an integer variable, the same precedure is applied to "Shadow price = 0" and "shadow price > 0".

A illustration of the knowledge base data definition used in this study is shown in Table 4.3.2.

**TABLE 4.3.2 : KNOWLEDGE BASE DATA DEFINITION**

| Variable names | Designation | Type |
|---|---|---|
| Var | Activity or Constraint name | Symbol |
| Type | "A" for activities | Character |
| | "C" for constraints | Character |
| Value | Activity level or Shadow price | Real |
| Coeff | Return per unit or RHS | Real |
| Sprice | Shadow price | Real |
| Unit | Activity or resource unit | Symbol |
| Min | Min range of optimality | Real |
| Max | Max range of optimality | Real |

# CHAPTER V

# DISCUSSION OF OBJECTIVES AND SUPPLY RESPONSES

The purpose in this chapter is threefold: (1) to discuss the objectives formulated in Chapter 1; (2) to discuss the derivation of crop supply responses; and (3) to describe the different functions available through the expert system.

## 5.1 Discussion of objectives

### 5.1.1 Starting capital

This section deals with the impact of varying the starting capital level on optimal resource allocation plans. It was hypothesized that higher starting capital levels would shift the optimal cropping patterns towards more input intensive crops. This process is evaluated by setting the starting capital level at values above the optimality range of this resource, as determined in the sensitivity analysis. For the purposes of this exercise, it is assumed that the starting capital is doubled in both zones from its initial levels.

Table 5.1.1 shows the new cropping patterns observed for the CPB zone when the starting capital is set at the level of 40000 CFA francs.

TABLE 5.1.1 : CROPPING PATTERN WHEN STARTING CAPITAL = 40000 CFA FRANCS IN CENTRAL PEANUT BASIN (Return = 222838 CFA)

| | TECHNOLOGIES | | | TOTAL | |
|---|---|---|---|---|---|
| Crops | 1 | 3 | 4 | Ha | % |
| Area planted (Ha) | | | | | |
| Millet for consumption | 2.37 | 0.0 | 1 | 3.37 | 52 |
| | (1.48) | (1.42) | (1) | (3.90) | (60) |
| Groundnut | .94 | 2.19 | | 3.13 | 48 |
| | (0) | (2.60) | | (2.60) | (40) |

Source : LP88 printout.
Figures in parenthesis are areas from the base run model
Technologies 1 to 4 refer to technical packages (chapter 3)

The net return increases by 30% and the new cropping patterns call for the following observations. Area under millet decreases by 8% in favor of groundnut. Within the millet crop, technology one becomes more attractive to farmers while technology three disappears from the farm plan. The additional land transferred to groundnut is used entirely in technology one. These facts lend support to the hypothesis formulated before namely, increasing the starting capital level in the CPB yields a move towards more input intensive modules.

Table 5.1.2 illustrates the new cropping patterns observed in the UPC zone with a starting capital level of 50000 CFA francs.

Net return improves by 48% and the new cropping patterns show the following features. Millet land share decreases by 14%, groundnut share increases by 13% and maize share increases by 1%. Obviously, there is transfer of land from millet in favor of groundnut and maize.

**TABLE 5.1.2 : CROPPING PATTERN WHEN STARTING CAPITAL = 50000 CFA FRANCS IN THE UPPER CASAMANCE ZONE (Return = 125836 CFA)**

| | TECHNOLOGIES | | | | | TOTAL | |
|---|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | 5 | Ha | % Upland |
| Millet for consumption | .93 | | 0.0 | 0.0 | | .93 | 24 |
| | (.16) | | (1.58) | (.74) | | (2.74) | (38) |
| Maize consumed | | .08 | | .75 | | .83 | 21 |
| | | (.74) | | (0.0) | | (.74) | (20) |
| Lowland rice | .09 | | .22 | | .29 | .60 | * |
| | (0.0) | | (.58) | | (.02) | (.60) | * |
| Groundnut | 1.78 | | | | | 1.78 | 46 |
| | (0.0) | | (1.30) | | | (1.30) | (33) |
| Cotton | .36 | | | | | .36 | 9 |
| | (.36) | | | | | (.36) | (9) |

Source : LP88 printout.
Figures in parenthesis are areas from the base run model
Technologies 1 to 5 refer to technical packages (chapter 3)
* Percentages are calculated only for upland crops.

While millet and groundnut are grown in the most intensive technology, maize and lowland rice show a preference for the less intensive modules.

5.1.2 <u>Marginal land</u>

The impact of cultivating marginal lands on the optimal enterprise mix prevailing in the zones involved was also investigated. The amount of marginal land available was set at 0.3Ha and 1.6Ha in the CPB and UPC zones, respectively.

This investigation is performed by introducing new crop producing activities for sale (which use marginal land) in the initial LP tableau. This type of land is more labor intensive than normal land, modelled by doubling the labor input-output coefficients. As pointed out in Chapter One, marginal land is only used for the production of millet or maize in this model.

Table 5.1.3 shows the new cropping patterns observed for the CPB zone.

**TABLE 5.1.3 : CROPPING PATTERNS WHEN MARGINAL LAND IS CULTIVATED IN CENTRAL PEANUT BASIN (Return = 176653 CFA)**

| | TECHNOLOGIES | | | TOTAL | |
|---|---|---|---|---|---|
| Crops | 1 | 3 | 4 | Ha | % |
| <u>Area planted</u> (Ha) | | | | | |
| Millet consumed | 1.47<br>(1.48) | 1.40<br>(1.42) | 1<br>(1) | 3.87<br>(3.90) | 59<br>(60) |
| Groundnut | | 2.63<br>(2.60) | | 2.63<br>(2.60) | 41<br>(40) |
| Millet for sale (marginal land) | | 0.30 | | 0.30 | |

Source : LP88 printout.
Figures in parenthesis are areas from the base run model
Technologies 1 to 4 refer to technical packages (chapter 3)

Model results show that cultivating marginal land in the CPB has reduced the normal land share used by millet by 1% in favor of groundnut. A new millet-producing activity enters the optimal solution under technology three and net return improves by 3%.

Table 5.1.4 show the corresponding results for the UPC zone.

From the model results, it is also observed that in this zone, cultivating marginal land has reduced millet (for home consumption) normal land share by 4% in favor of groundnut (1%) and rainfed rice (3%). All marginal land available is used to grow millet for sale under technology three. In comparison with the base run solution, net farm return has improved by 24%.

TABLE 5.1.4 : CROPPING PATTERNS WHEN MARGINAL LAND IS CULTIVATED IN UPPER CASAMANCE (Return = 105210 CFA)

| | TECHNOLOGIES | | | | TOTAL | |
|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | Ha | % |
| Area planted (Ha) | | | | | | |
| Millet consumed | 0.27<br>(0.16) | | 0.67<br>(0.58) | 0.38<br>(0.74) | 1.32<br>(1.48) | 34<br>(38) |
| Maize consumed | | 0.41<br>(0.74) | | 0.37<br>(0.00) | 0.78<br>(0.74) | 20<br>(20) |
| Rainfed rice | | 0.12<br>(0.03) | | | 0.12<br>(0.03) | 3<br>(.8) |
| Groundnut | 1.32<br>(0.00) | | (1.30) | | 1.32<br>(1.30) | 34<br>(33) |
| Cotton | 0.36<br>(0.36) | | | | 0.36<br>(0.36) | 9<br>(9) |
| Millet for sale (marginal land) | | | 1.60 | | 1.60 | |

Source : LP88 printout.
Figures in parenthesis are areas from the base run model
Technologies 1 to 4 refer to technical packages (chapter 3)

5.1.3 Impact of population growth

This section seeks to evaluate the effect of population growth on farm resource allocation plans. An increase in farm population size affects the consumption side of a typical farm by raising the family calorie requirement to be met by cereals.It also affects the production side of a typical farm by increasing the total family labor force available for field work.

The process is carried out by making predictions on farm population levels. For the purpose of this exercise, a 5% increase in farm population size is assumed in this section. The next step involves the recalculation of new parameters for model coefficients. These coefficients concern the minimum food self-sufficiency needs, the farm labor force available in all periods and the nutritional needs of the farm unit to be met by cereals. The following describes the results obtained in both zones.

For the CPB, Table 5.1.5 shows model results with a 5% growth rate in the population size. Compared to the base run solution, land share for millet produced for home consumption increases by 3% while groundnut land share decreases by the same amount. A sustained growth in farm population size alters prevailing cropping patterns. More food crop (millet) is grown to support a higher demand for food.

For the UPC zone, Table 5.1.5 illustrates model results with a 5% growth rate in farm population size in comparison with the base run solution. Here again, millet for home consumption land share increases by 3% while groundnut land share drops by 3% and the other crops' land share remain constant. The excess demand for food is satisfied by growing more millet (for home consumption) rather than groundnut (for income).

5.1.4 Food self-sufficiency (FSS) rates

This exercise seeks to determine the impact of varying the FSS rates during bad rainfall years on farm resource allocation plans, assuming that on average, 80% of FSS is desired on good rainfall years.

The process is carried out through series of model simulations by calculating, at each step, a new FSS risk coefficient (see table 3.5.3). The farm net return is taken as a performance measure of system behavior in response to different FSS rates. As pointed out earlier, the base run LP problems assumed that 30% FSS rate was desired during bad rainfall years (worst states of nature). Therefore,

**TABLE 5.1.5 CROPPING PATTERNS WHEN POPULATION GROWTH RATE = 5% IN CENTRAL PEANUT BASIN**

| | TECHNOLOGIES | | | TOTAL | |
|---|---|---|---|---|---|
| Crops | 1 | 3 | 4 | Ha | % |
| <u>Area planted</u> (Ha) | | | | | |
| Millet consumed | 1.50 | 1.60 | 1 | 4.10 | 63 |
| | (1.48) | (1.42) | (1) | (3.90) | (60) |
| Groundnut | | 2.40 | | 2.40 | 37 |
| | | (2.60) | | (2.60) | (40) |

**TABLE 5.1.6 CROPPING PATTERNS WHEN POPULATION GROWTH RATE = 5% IN UPPER CASAMANCE**

| | TECHNOLOGIES | | | | TOTAL | |
|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | Ha | % |
| <u>Area planted</u> (Ha) | | | | | | |
| Millet consumed | 0.23 | | 0.63 | 0.75 | 1.61 | 41 |
| | (0.16) | | (0.58) | (0.74) | (1.48) | (38) |
| Maize consumed | | 0.74 | | | 0.74 | 20 |
| | | (0.74) | | | (0.74) | (20) |
| Rainfed rice | | 0.03 | | | 0.03 | .8 |
| | | (0.03) | | | (0.03) | (.8) |
| Groundnut | 1.16 | | | | 1.16 | 30 |
| | (0.00) | | (1.30) | | (1.30) | (33) |
| Cotton | 0.36 | | | | 0.36 | 9 |
| | (0.36) | | | | (0.36) | (9) |

Source : LP88 printout.
Figures in parenthesis are areas from the base run model
Technologies 1 to 4 refer to technical packages (chapter 3)

model simulation will start from that rate and progress by increments of 10% until an infeasible solution is reached. The rest of this section discusses the model results in both zones.

Table 5.1.7 summarizes the results obtained through several simulation cycles; the following comments are made for both zones. Increasing the rate of cereal FSS during bad rainfall years leads, in both zones, to a deterioration of net farm return. The desire to achieve 70% of FSS during worst years is not an attainable objective in either zone (infeasible solution). The UPC zone has a better potential to protect itself against food deficit than the CPB zone. In practical terms, a typical farm in the CPB can only achieve a maximum of 40% of FSS during bad rainfall years while its counterpart in the UPC can sustain 50% of FSS during bad rainfall years.

## 5.2 Supply responses

In underdeveloped agriculture, supply responses are assumed to be equivalent to response of acreage under cultivation to changes in economic and non-economic factors( Subrata and Ken, 1984).

In this section, price assumptions about farm products are discussed first, followed by the derivation of normative supply curves under alternative technologies.

### 5.2.1 Price assumptions

Based on assumptions about the relationship between price and quantity supplied in the regional market, a set of prices for millet, maize and rice is determined. Producer prices of groundnut, and cotton, and the rice consumer price are based on government price setting policies. Six price levels are assumed in this study, starting from the actual

TABLE 5.1.7 NET FARM RETURN AT DIFFERENT REQUIRED FOOD SELF-SUFFICIENCY LEVELS (Unit = CFA)

| | WORST YEAR FSS RATES | | | | |
|---|---|---|---|---|---|
| Zones | 30 | 40 | 50 | 60 | 70 |
| Central Peanut Basin | 171656 | 163194 | -370000 | -11856557 | infeasible |
| Upper Casamance | 85035 | 60346 | 23388 | -120247 | infeasible |

prices used in the base run solutions, progressing by increments of 20% up to the level where all prices are doubled. Prices are all expressed in financial terms. Tables 5.2.1 and 5.2.2 show the price levels used for the CPB and UPC zones. Only two crops are considered in the CPB because rice is not produced in that zone and the consumer price of rice is under goverment control.

5.2.2 Normative supply curves

The mechanism used to derive the crop supply responses under alternative technologies is explained at this point. Cropping patterns, for price vector one (base price) are already obtained from the base run solution. The next step consists of introducing price vector two in the LP tableau for the cereal buying and selling activities whose prices are determined in the regional market. The procedure used for that is described below:

(1) The new prices are introduced as coefficients of the objective function for the cereal buying activities (minus sign) and the cereal selling activities (positive sign).

(2) Those same prices are also used as coefficients of the capital one constraint (borrowed capital) under the cereal buying activities with positive signs.

(3) Price vector two is also entered as coeeficients of the repayment of the borrowed capital constraint under the cereal selling activities with negative signs.

The model is run with those modifications and the optimal cropping patterns are derived from model results. This process is repeated for price vectors three to six.

Tables 5.2.3 and 5.2.4 show the results obtained. The following are the most important points to note for the two zones investigated.

For the CPB, results show that no land competition exists between crops through the different price levels assumed. Land share between millet and groundnut remains constant all along. This rigid situationis partly due to the fact that millet is the most profitable food crop grown in that zone, and groundnut is the only cash crop. Any trade-off between them can only occur at high millet price (150% increase) as revealed by the sensitivity analysis. (A cowpea production activity is included in the model, but it does not enter the optimal solution. The analysis of the crop gross margins (Martin, 1987) reveals that, although cowpeas have great potential in terms of gross return, it is the most labor intensive crop in CPB. This fact

TABLE 5.2.1 CROP PRICE VECTOR IN THE CENTRAL PEANUT BASIN

(Unit = CFA/Kg)

| Labels | % increase | Millet | Maize |
|---|---|---|---|
| PF1 | base | 62.0 | 79.0 |
| PF2 | 20 | 74.4 | 94.8 |
| PF3 | 40 | 86.8 | 110.6 |
| PF4 | 60 | 99.2 | 124.4 |
| PF5 | 80 | 116.6 | 142.2 |
| PF6 | 100 | 124.0 | 158.0 |

TABLE 5.2.2 CROP PRICE VECTOR IN THE UPPER CASAMANCE

(Unit = CFA/Kg)

| Labels | % increase | Millet | Maize | Rice paddy |
|---|---|---|---|---|
| PF1 | base | 63.0 | 68.0 | 85.0 |
| PF2 | 20 | 75.6 | 81.6 | 102.0 |
| PF3 | 40 | 88.2 | 95.2 | 119.0 |
| PF4 | 60 | 100.8 | 108.8 | 136.0 |
| PF5 | 80 | 113.4 | 122.4 | 153.0 |
| PF6 | 100 | 126.0 | 136.0 | 170.0 |

makes it too unattractive to be included in the optimal enterprise mix.

Table 5.2.4 shows for the UPC interesting aspects of land competition between crops. After price vector two, groundnut disappears from the enterprise mix and maize jumps from 19% of land share to 60%. This result mainly from the 40% drop in groundnut land share, lends support to the hypothesis that maize can potentially be a leading crop in the UPC, as groundnut did in the CPB, given enough price incentive. Rainfed rice also, after price vector two, leaves the optimal plan. Within the lowland rice, land is transferred from technology two to five. A tentative explanation of this would be that inputs, currently used for rainfed crop, should have been transferred to lowland rice, making it worthwhile to grow more rice for consumption under technology five. Millet land share decreases by 7% and then remains constant at 30% share in the last two price levels.

For pricing policy purposes, table 5.2.5 shows the acreage responses derived above, translated in terms of quantities produced for different crops in the UPC zone. Those quantities are calculated by multiplying the respective crop acreages by their corresponding yields and finally by the number of producers in that zone.

## 5.3 Expert system functions

This section highlights the main features involved in the implementation of the LP expert system (ES) developed in this study for the interpretation of a LP optimal solution.

### 5.3.1 Design considerations

As defined in chapter four, an ES shell has two major components: a user interface (UI) and an inference engine (IE). The following

TABLE 5.2.3 PRICE LEVELS AND CROPPING PATTERNS

IN CENTRAL PEANUT BASIN

(Units = Ha)

| | TECHNICAL PACKAGES | | | | | TOTAL | |
|---|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | 5 | Ha | % |
| | | | PF1 | | | | |
| Millet | 1.48 | | 1.42 | 1.0 | | 3.90 | 60 |
| Groundnut | | | 2.60 | | | 2.60 | 40 |
| | | | PF2 | | | | |
| Millet | 1.48 | | 1.41 | 1.0 | | 3.89 | 59 |
| Groundnut | | | 2.61 | | | 2.61 | 41 |
| | | | PF3 | | | | |
| Millet | 1.48 | | 1.41 | 1.0 | | 3.89 | 59 |
| Groundnut | | | 2.61 | | | 2.61 | 41 |
| | | | PF4 | | | | |
| Millet | 1.48 | | 1.41 | 1.0 | | 3.89 | 59 |
| Groundnut | | | 2.61 | | | 2.61 | 41 |
| | | | PF5 | | | | |
| Millet | 1.48 | | 1.41 | 1.0 | | 3.89 | 59 |
| Groundnut | | | 2.61 | | | 2.61 | 41 |
| | | | PF6 | | | | |
| Millet | 1.48 | | 1.41 | 1.0 | | 3.89 | 59 |
| Groundnut | | | 2.61 | | | 2.61 | 41 |

Source : LP88 printout.

**TABLE 5.2.4 PRICE LEVELS AND CROPPING PATTERNS IN UPPER CASAMANCE (Units = Ha)**

| | TECHNICAL PACKAGES | | | | | TOTAL | |
|---|---|---|---|---|---|---|---|
| Crops | 1 | 2 | 3 | 4 | 5 | Ha | % of upland |
| | | | PF1 | | | | |
| Millet | 0.16 | | 0.58 | 0.75 | | 1.49 | 38.0 |
| Maize | | 0.74 | | | | 0.74 | 19.0 |
| Rainfed rice | | 0.03 | | | | 0.03 | 0.8 |
| Lowland rice | | | 0.58 | | 0.20 | 0.60 | * |
| Groundnut | 1.30 | | | | | 1.30 | 33.0 |
| Cotton | 0.36 | | | | | 0.36 | 9.2 |
| | | | PF2 | | | | |
| Millet | 0.16 | | 0.58 | 0.75 | | 1.49 | 38.0 |
| Maize | | 0.74 | | | | 0.74 | 19.0 |
| Rainfed rice | | 0.03 | | | | 0.03 | 0.8 |
| Lowland rice | | | 0.58 | | 0.20 | 0.60 | * |
| Groundnut | 1.28 | | | | | 1.30 | 33.0 |
| Cotton | 0.36 | | | | | | 9.2 |
| | | | PF3 | | | | |
| Millet | 0.16 | | 0.29 | 0.75 | | 1.20 | 31.0 |
| Maize | | 2.34 | | | | 2.34 | 60.0 |
| Lowland rice | | | 0.09 | | 0.51 | 0.60 | * |
| Cotton | 0.36 | | | | | 0.36 | 9.0 |
| | | | PF4 | | | | |
| Millet | 0.16 | | 0.29 | 0.75 | | 1.20 | 31.0 |
| Maize | | 2.34 | | | | 2.34 | 60.0 |
| Lowland rice | | | 0.09 | | 0.51 | 0.60 | * |
| Cotton | 0.36 | | | | | | 9.2 |
| | | | PF5 | | | | |
| Millet | 0.15 | | 0.28 | 0.75 | | 1.18 | 30.3 |
| Maize | | 2.35 | | | | 2.35 | 60.3 |
| Lowland rice | | | 0.26 | | 0.34 | 0.60 | * |
| Cotton | | | | | 0.36 | 0.36 | 9.4 |
| | | | PF6 | | | | |
| Millet | 0.15 | | 0.28 | 0.75 | | 1.18 | 30.0 |
| Maize | | 2.36 | | | | 2.36 | 61.0 |
| Lowland rice | | | 0.26 | | 0.34 | 0.60 | |
| Cotton | | | | | 0.36 | 0.36 | 9.0 |

Source : LP88 printout.
(*) Percentage area are calculated only for crops cultivated in rainfed upland.

discussion describes some special features inherent to the design of the ES shell developed in this study.

The knowledge derived from the LP solution is represented under the form of statements of facts between different LP variables (predicates). This type of representation is more adaptable to the nature of a LP optimal tableau. The information is stored in a computer disk file as a permanent storage device under the form of a database. At the beginning of every consultation, the database is read into computer RAM (Random Access Memory) for better performance (speed). This data management technique is known as a dynamic database (Borland, 1986). The UI developed here handles the management of the database through a user oriented menu. Operations performed are currently limited to the tasks of adding, listing and deleting data from the knowledge base. The program listing of the UI is shown in Appendix Table 3.

The inference engine designed for this ES is shown in Appendix Table 4. Its implementation is based on rules applying to the interpretation of a LP optimal tableau. Rules are executed by using a "backward chaining" structure, meaning that Prolog' s strategy is to find a goal by proving that all sub-goals in the body of a rule are satisfied.

5.3.2 Expert system functions

The expert system designed in this study is "menu driven"; it performs four basic functions described as follow:

Option one is devoted to the analysis of the LP primal solution. The ES will display the optimal and nonoptimal real activities with

TABLE 5.2.5 SUPPLY RESPONSES AND PRICE EFFECTS
IN UPPER CASAMANCE
(Quantities = 000 Kg)
(Price = CFA/Kg)

| Millet | | Maize | | Rice | | |
|---|---|---|---|---|---|---|
| | | | | | Rainfed | Lowland |
| Price | quantity | price | quantity | price | quantity | quantity |
| 63.0 | 12570 | 68.0 | 11641 | 85.0 | 289 | 9470 |
| 75.6 | 12570 | 81.6 | 11641 | 102.0 | 289 | 9470 |
| 88.2 | 10662 | 95.2 | 36810 | 119.0 | 0 | 5492 |
| 100.8 | 10662 | 108.8 | 36810 | 136.0 | 0 | 5492 |
| 113.4 | 10468 | 122.4 | 36968 | 153.0 | 0 | 6348 |
| 126.0 | 10468 | 136.0 | 37125 | 170.0 | 0 | 6348 |

Source : LP88 printout.

the pertinent information related to them. A short interpretation of the listed information is also provided.

Option two performs the analysis of the dual solution of the optimal LP tableau. Information related to the shadow prices of the binding constraints and to the slack resources are displayed in this option. A brief interpretation of results is also given.

Options three and four perform sensitivity analyses on resource and objective function ranges of optimality. In each case, pertinent information is displayed along with a short interpretation of listed information.

Table 5.3.1 shows a sample printout produced during a consultation. A listing of the complete computer program written in Turbo Prolog is given in Appendix Table 4.

**TABLE 5.3.1 EXPERT SYSTEM SAMPLE PRINTOUT**

```
  *******************************
   1.  PRIMAL SOLUTION ANALYSIS
   2.  DUAL VALUES ANALYSIS
   3.  RESOURCE RANGE ANALYSIS
   4.  OBJECTIVE VALUES ANALYSIS
   5.  EXIT TO PROLOG SYSTEM
  *******************************
ENTER YOUR CHOICE   3


Constraint Name  :       TERRE
Its shadow price is  :  84686    CFA
Range of optimality :   5.6      8.8(Ha)
57%  variation in  TERRE  is acceptable
Press space bar ... when done


Constraint Name  :       SEMARA
Its shadow price is  :  140.8    CFA
Range of optimality :   -2137    313(Kg/ha)
115%  variation in  SEMARA  is acceptable
Press space bar ... when done


Constraint Name  :       NPK1
Its shadow price is  :  356      CFA
Range of optimality :   -205     136(Kg/ha)
166%  variation in  NPK1  is acceptable
Press space bar ... when done
```

# CHAPTER VI

## CONCLUSION AND RECOMMENDATIONS

This study has used a linear programming approach, taking into account the risk under which Senegalese farmers operate, to investigate cropping patterns and technologies most profitable in two agricultural zones. This chapter summarizes the major findings of this study, and highlights some policy recommendations related to those findings. The last section suggests some areas for further research to improve model performance.

### 6.1 Summary of findings

Several hypotheses have been tested throughout this study. Model results support the following points:

(1) Increasing the starting capital level in the two models has two major effects. First, there are alterations in acreage grown, and intensive technologies become more interesting economically for millet and groundnut. Second, land is transferred from millet to groundnut in the CPB and from millet to groundnut and maize in the UPC.

(2) The introduction of marginal lands into the two models leads to a reallocation of land between crops. In the CPB, millet grown on non-marginal land is reduced in favor of groundnut. This decrease in

millet share is compensated by the millet produced in marginal lands. The same effect is observed in the UPC: millet grown on non-marginal land decreases to the profit of groundnut and rainfed rice in particular.

(3) The study of the impact of farm population growth on farm resource allocation decisions reveals that a 5% increase in farm population will change cropping patterns. More food-crops are grown to support the higher demand for food while areas used for cash-crops decrease. Model results, in both zones, lend support to this point.

(4) Varying the worst years food self-sufficiency (FSS) rates reveals that a desire to secure 70% of food needs during bad rainfall years is not an attainable goal in either zone. However, the UPC zone can achieve a maximum of 50% of FSS during bad rainfall years while the CPB secures a maximum of 40% of FSS rate during bad rainfall years.

(5) Supply responses are derived under six price assumptions concerning cereals when cash-crop prices are kept constant. In the CPB no land competition between millet and groundnut was observed through the price ranges. This fact leads to the conclusion that doubling prices does not affect cropping patterns. Results from the UPC model show that maize area increases substantially given a 40% price increase. This finding lends acceptance to the idea that maize can be a leading crop in the UPC zone.

### 6.2 Recommendations

This section suggests some major issues decision makers should consider in their interventions in the agricultural sector. These are based on model results through the different simulation exercises.

Policies aiming to increase the starting capital available to farmers will favor a shift towards intensive technologies. Planners should take this fact into account and make agricultural inputs available to farmers at the right time.

Extensive development policies bringing marginal lands into cultivation could reduce millet produced in normal land and expand rainfed rice and groundnut production, in those regions similar to the UPC. The magnitude of this reduction will however, depend on the amount of millet produced on marginal land. This situation can deteriorate the rural terms of trade through higher millet price in the long run.

Any pricing policy should be introduced with care in those regions with cropping patterns similar to the UPC. High producer price will sharply increase maize produced and decrease groundnut production. If marketing alternatives are not anticipated, the long run price of maize will suffer.

A high annual increase in the rural population (5% used) will lead to a higher population pressure on the available land. This situation would change farmer strategies with regard to resource allocation. Subsistence requirements will dominate the minimum income need and cropping patterns will move towards more food than cash crops.

Pursuing higher rates of national food self-sufficiency without taking into account regional potentials and disparities can bring about many side effects. As seen in this study, farmers want to achieve certain FSS goals even in the worst years. The objective to secure 70% of FSS during bad rainfall years is not sustainable in the two zones studied. A national goal to cover 80% of food needs may conflict with regional potentials.

Farmers' desire to have a minimum income is another point that decision makers must keep in mind in national agricultural planning efforts. Food self-sufficiency at any cost may not be a desirable social objective. A food security perspective, linking both food self-sufficiency goals and income needs, may lead to a more optimal resource allocation. Model results show that net returns are higher at lower FSS levels and that an optimal mix between food-crops and cash-crop can better maximize farmers' objectives.

### 6.3 Areas for further research

This section focuses on possible improvements of this model. The discussion includes concerns related to model management, model structure and inclusion of other sectors in model activities.

It is known at the present time that agricultural inputs are not used in Senegal as suggested by agronomic research while model results are based on the assumption that inputs are available. In order to accommodate a particular situation and use the model as a diagnostic tool, more investigations should be made about actual technologies used by farmers.

Under present conditions, cotton is expected to be a very promising crop in the UPC, yet model results do not reflect that fact. The cotton crop budget should be reviewed by agronomists and other knowledgeable people in order to improve model coefficients.

The livestock subsector is not represented directly in the model although the crop selling activities take into account a possible integration between agricultural and animal feeding. This fact is reflected in the groundnut and cotton selling activities. It would be more appropriate, in the future, to investigate the possibility of including that subsector in the model activities.

The fishery subsector also is not taken into account by the model. This is not a limiting factor under present conditions since it is assumed that 65% of calorie needs are satisfied by cereals. However, model performance could gain credibility by including activities and constraints related to this subsector in the model structure. This could be done through fish purchasing activities to complement food needs associated with food habits constraints prevailing within regions.

A representative farm concept is used to model farmer behavior in a given zone. This type of representation does however introduce aggregation biases into model results in an upward direction. It would have been more realistic to model at least three categories of farms in each zone, ranging from large to small farms. This consideration will involve investigating further farm structures prevailing in the different regions used in the model in order to reduce the magnitude of those biases.

Yield estimates for rainfed crops are based on the amount of rain observed through a period of twelve years and on rainfall distribution across the rainy season for each year. More formal methods of estimating yields are available through the Comprehensive Resource Inventory and Evaluation System (CRIES) project which is currently underway in the Department of Natural Resources at Michigan State University (see Schultink, 1987). The yield model of the CRIES project is a microcomputer based simulation model capable of predicting yields for a large number of food and export crops based on agro-ecological zones. The yield model and the other modules available in the CRIES project are widely being used world-wide, in more than twenty nations.

APPENDIX TABLE 1 : CENTRAL PEANUT BASIN
INITAIL TABLEAU

| | SIGN | RHS | | SIGN | RHS | PMIC1 | PMIC2 | PMIC3 | PMIC4 | PMIC5 | PMIV1 | PMIV2 | PMIV3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | RETURN | | 0 | -3600 | -3600 | -3298 | -3004 | -3600 | -3600 | -3600 | -3600 |
| TERRE1 | <= | 6.5 | TERRE1 | <= | 6.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SEMARA | <= | 0 | SEMARA | <= | 0 | | | | | | | | |
| SEMNIE | <= | 0 | SEMNIE | <= | 0 | | | | | | | | |
| NPK1 | <= | 0 | NPK1 | <= | 0 | 100 | 100 | | | | 100 | 100 | |
| NPK4 | <= | 0 | NPK4 | <= | 0 | | | | | | | | |
| UREE | <= | 0 | UREE | <= | 0 | 50 | | | | | 50 | | |
| NIINS1 | <= | 0 | NIINS1 | <= | 0 | | | | | | 1 | | |
| NIINS2 | <= | 0 | NIINS2 | <= | 0 | | | | | | | | |
| FONARA | <= | 0 | FONARA | <= | 0 | | | | | | | | |
| MO1 | <= | 41.2 | MO1 | <= | 41.2 | 5.5 | | | 8 | 2 | 5.5 | | |
| MO2 | <= | 41.2 | MO2 | <= | 41.2 | 7.5 | 13 | 7 | 10 | 1 | 7.5 | 13 | 7 |
| MO3 | <= | 41.2 | MO3 | <= | 41.2 | 3 | 2 | 2 | 2 | 5 | 3 | 2 | 2 |
| MO4 | <= | 41.2 | MO4 | <= | 41.2 | | | | | 2 | | | |
| MOR1 | <= | 137 | MOR1 | <= | 137 | 3 | 3 | 2 | | 2 | 3 | 3 | 3 |
| TA1 | <= | 10 | TA1 | <= | 10 | | | | 0.5 | | | | |
| TA2 | <= | 10 | TA2 | <= | 10 | 1 | 1 | 1 | 1.5 | 0.5 | 1 | 1 | 1 |
| TA3 | <= | 10 | TA3 | <= | 10 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 |
| TA4 | <= | 10 | TA4 | <= | 10 | | | | | 1 | | | |
| SCAP | <= | 20000 | SCAP | <= | 20000 | | | | | | | | |
| CAP1 | <= | 0 | CAP1 | <= | 0 | | | | | | | | |
| CAP2 | <= | 0 | CAP2 | <= | 0 | | | | | | | | |
| RCAP | <= | 0 | RCAP | <= | 0 | | | | | | | | |
| QVMIL | <= | 0 | QVMIL | <= | 0 | | | | | | -652 | -558 | -417 |
| QVNIEP | <= | 0 | QVNIEP | <= | 0 | | | | | | | | |
| QVNIEF | <= | 0 | QVNIEF | <= | 0 | | | | | | | | |
| QVARAG | <= | 0 | QVARAG | <= | 0 | | | | | | | | |
| QVARAF | <= | 0 | QVARAF | <= | 0 | | | | | | | | |
| DEVA1 | >= | 0 | DEVA1 | >= | 0 | -1103 | -977 | -727 | -1103 | -656 | 581 | 465 | 349 |
| AUTO | >= | 4270 | AUTO | >= | 4270 | 1685 | 1442 | 1076 | 1685 | 656 | | | |
| DEVR1 | >= | 0 | DEVR1 | >= | 0 | | | | | | -18300 | -16652 | -12342 |
| DEVR2 | >= | 0 | DEVR2 | >= | 0 | | | | | | -18800 | -17052 | -12642 |
| REVENU | >= | 100000 | REVENU | >= | 100000 | | | | | | 40800 | 34652 | 25842 |
| NUTRI | >= | 5103 | NUTRI | >= | 5103 | 1432 | 1226 | 915 | 1432 | 558 | | | |
| MIN4 | >= | 0.05 | MIN4 | >= | 0.05 | | | | 1 | | | | |
| MAX4 | <= | 1 | MAX4 | <= | 1 | | | | 1 | | | | |
| MINMIL | >= | 1026 | MINMIL | >= | 1026 | 455 | 389 | 290 | 455 | 177 | | | |
| MAXMIL | <= | 1710 | MAXMIL | <= | 1710 | 455 | 389 | 290 | 455 | 177 | | | |
| MINMAI | >= | 0 | MINMAI | >= | 0 | | | | | | | | |

APPENDIX TABLE 1 - Continued

| | SIGN | RHS | PMIV5 | PNIE1 | PNIE2 | PARA1 | PARA2 | PARA3 | PARA5 | ASEAR | ASENIE | ANPK1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -3004 | -9617 | -7148 | -6084 | -6084 | -5488 | -4927 | -110 | -110 | -81.5 |
| TERRE1 | <= | 6.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| SEMARA | <= | 0 | | | | 120 | 120 | 120 | 120 | -1 | | |
| SEMNIE | <= | 0 | | 20 | 20 | | | | | | -1 | |
| NPK1 | <= | 0 | | | | | | | | | | -1 |
| NPK4 | <= | 0 | | 150 | | | | | | | | |
| UREE | <= | 0 | | | | | | | | | | |
| NIINS1 | <= | 0 | | 1 | 1 | | | | | | | |
| NIINS2 | <= | 0 | | 2 | 1 | | | | | | | |
| FONARA | <= | 0 | | | | 1 | 1 | 1 | 1 | | | |
| MO1 | <= | 41.2 | 2 | 1 | 1 | 4 | 4 | 1 | 2 | | | |
| MO2 | <= | 41.2 | 1 | 3 | 2 | 2 | 2 | 2 | 1 | | | |
| MO3 | <= | 41.2 | 5 | 11.5 | 7.5 | 11 | 7 | 3 | 2 | | | |
| MO4 | <= | 41.2 | 2 | 3 | 2 | 2 | 2 | 2 | | | | |
| MOR1 | <= | 137 | 2 | 91 | 72 | | 11 | 10 | 8 | | | |
| TA1 | <= | 10 | | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | | | | |
| TA2 | <= | 10 | 0.5 | 1 | 1 | 1 | 1 | 1 | 0.5 | | | |
| TA3 | <= | 10 | | | | | | | 1 | | | |
| TA4 | <= | 10 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| SCAP | <= | 20000 | | | | | | | | | | |
| CAP1 | <= | 0 | | | | | | | | 110 | 110 | |
| CAP2 | <= | 0 | | | | | | | | | | 81.5 |
| RCAP | <= | 0 | | | | | | | | | | |
| QVMIL | <= | 0 | -254 | | | | | | | | | |
| QVNIEP | <= | 0 | | -697 | -494 | | | | | | | |
| QVNIEF | <= | 0 | | -1393 | -988 | | | | | | | |
| QVARAG | <= | 0 | | | | -885 | -802 | -728 | -562 | | | |
| QVARAF | <= | 0 | | | | -1400 | -1267 | -1148 | -876 | | | |
| DEVA1 | >= | 0 | | | | | | | | | | |
| AUTO | >= | 4270 | | | | | | | | | | |
| DEVR1 | >= | 0 | -15254 | -52884 | -35987 | -65887 | -60480 | -56975 | -46790 | | | |
| DEVR2 | >= | 0 | -9254 | -9584 | -5937 | -54751 | -50552 | -48299 | -40618 | | | |
| REVENU | >= | 100000 | 15254 | 96884 | 68987 | 136492 | 123570 | 112055 | 85850 | | | |
| NUTRI | >= | 5103 | | | | | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | |
| MAX4 | <= | 1 | | | | | | | | | | |
| MINMIL | >= | 1026 | | | | | | | | | | |
| MAXMIL | <= | 1710 | | | | | | | | | | |
| MINMAI | >= | 0 | | | | | | | | | | |

APPENDIX TABLE 1 - Continued

| | SIGN | RHS | ANPK4 | AUREE | ANIN1 | ANIN2 | ARAFO | AMO1 | AMO2 | AMO3 | AMO4 | AMOR1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -79.5 | -72.5 | -6750 | -5100 | -1000 | -500 | -500 | -500 | -500 | -500 |
| TERRE1 | <= | 6.5 | | | | | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | |
| SEMNIE | <= | 0 | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | | | | | |
| NPK4 | <= | 0 | -1 | | | | | | | | | |
| UREE | <= | 0 | | -1 | | | | | | | | |
| NIINS1 | <= | 0 | | | -1 | | | | | | | |
| NIINS2 | <= | 0 | | | | -1 | | | | | | |
| FONARA | <= | 0 | | | | | -1 | | | | | |
| MO1 | <= | 41.2 | | | | | | -1 | | | | |
| MO2 | <= | 41.2 | | | | | | | -1 | | | |
| MO3 | <= | 41.2 | | | | | | | | -1 | | |
| MO4 | <= | 41.2 | | | | | | | | | -1 | |
| MOR1 | <= | 137 | | | | | | | | | | -1 |
| TA1 | <= | 10 | | | | | | | | | | |
| TA2 | <= | 10 | | | | | | | | | | |
| TA3 | <= | 10 | | | | | | | | | | |
| TA4 | <= | 10 | | | | | | | | | | |
| SCAP | <= | 20000 | | | | | | | | | | |
| CAP1 | <= | 0 | | | 6750 | 5100 | | | | | | |
| CAP2 | <= | 0 | 79.5 | 72.5 | | | 1000 | 500 | 500 | 500 | 500 | 500 |
| RCAP | <= | 0 | | | | | | | | | | |
| QVMIL | <= | 0 | | | | | | | | | | |
| QVNIEP | <= | 0 | | | | | | | | | | |
| QVNIEF | <= | 0 | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | |
| DEVA1 | >= | 0 | | | | | | | | | | |
| AUTO | >= | 4270 | | | | | | | | | | |
| DEVR1 | >= | 0 | | | | | | | | | | |
| DEVR2 | >= | 0 | | | | | | | | | | |
| REVENU | >= | 100000 | | | | | | | | | | |
| NUTRI | >= | 5103 | | | | | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | |
| MAX4 | <= | 1 | | | | | | | | | | |
| MINMIL | >= | 1026 | | | | | | | | | | |
| MAXMIL | <= | 1710 | | | | | | | | | | |
| MINMAI | >= | 0 | | | | | | | | | | |

APPENDIX TABLE 1 - Continued

| | SIGN | RHS | ACAP | RISKA | RISKR | CAPT1 | CAPT2 | AMIL | AMAIS | ARIZ | ABLE | VMIL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -0.28 | | | | | -62 | -79 | -163 | -278 | 62 |
| TERRE1 | <= | 6.5 | | | | | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | |
| SEMNIE | <= | 0 | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | | | | | |
| NPK4 | <= | 0 | | | | | | | | | | |
| UREE | <= | 0 | | | | | | | | | | |
| NIINS1 | <= | 0 | | | | | | | | | | |
| NIINS2 | <= | 0 | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | | | |
| MO1 | <= | 41.2 | | | | | | | | | | |
| MO2 | <= | 41.2 | | | | | | | | | | |
| MO3 | <= | 41.2 | | | | | | | | | | |
| MO4 | <= | 41.2 | | | | | | | | | | |
| MOR1 | <= | 137 | | | | | | | | | | |
| TA1 | <= | 10 | | | | | | | | | | |
| TA2 | <= | 10 | | | | | | | | | | |
| TA3 | <= | 10 | | | | | | | | | | |
| TA4 | <= | 10 | | | | | | | | | | |
| SCAP | <= | 20000 | | | | 1 | 1 | | | | | |
| CAP1 | <= | 0 | -1 | | | -1 | | 62 | 79 | 163 | 278 | |
| CAP2 | <= | 0 | | | | | -1 | | | | | |
| RCAP | <= | 0 | 1 | | | | | | | | | -62 |
| QVMIL | <= | 0 | | | | | | | | | | 1 |
| QVNIEP | <= | 0 | | | | | | | | | | |
| QVNIEF | <= | 0 | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | |
| DEVA1 | >= | 0 | | 1 | | | | | | | | |
| AUTO | >= | 4270 | | -0.63 | | | | | | | | |
| DEVR1 | >= | 0 | | | 1 | | | | | | | |
| DEVR2 | >= | 0 | | | 1 | | | | | | | |
| REVENU | >= | 100000 | | | -1 | | | | | | | |
| NUTRI | >= | 5103 | | | | | | 3.15 | 3.17 | 2.42 | 3 | |
| MIN4 | >= | 0.05 | | | | | | | | | | |
| MAX4 | <= | 1 | | | | | | | | | | |
| MINMIL | >= | 1026 | | | | | | 1 | | | | |
| MAXMIL | <= | 1710 | | | | | | 1 | | | | |
| MINMAI | >= | 0 | | | | | | | 1 | | | |

APPENDIX TABLE 1 - Continued

| | SIGN | RHS | VNIEP | VNIEF | VARAG | VARAF | DUMA | DUMR |
|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | 79 | 30 | 90 | 40 | -9999 | -9999 |
| TERRE1 | <= | 6.5 | | | | | | |
| SEMARA | <= | 0 | | | | | | |
| SEMNIE | <= | 0 | | | | | | |
| NPK1 | <= | 0 | | | | | | |
| NPK4 | <= | 0 | | | | | | |
| UREE | <= | 0 | | | | | | |
| NIINS1 | <= | 0 | | | | | | |
| NIINS2 | <= | 0 | | | | | | |
| FONARA | <= | 0 | | | | | | |
| MO1 | <= | 41.2 | | | | | | |
| MO2 | <= | 41.2 | | | | | | |
| MO3 | <= | 41.2 | | | | | | |
| MO4 | <= | 41.2 | | | | | | |
| MOR1 | <= | 137 | | | | | | |
| TA1 | <= | 10 | | | | | | |
| TA2 | <= | 10 | | | | | | |
| TA3 | <= | 10 | | | | | | |
| TA4 | <= | 10 | | | | | | |
| SCAP | <= | 20000 | | | | | | |
| CAP1 | <= | 0 | | | | | | |
| CAP2 | <= | 0 | | | | | | |
| RCAP | <= | 0 | -79 | -30 | -90 | -40 | | |
| QVMIL | <= | 0 | | | | | | |
| QVNIEP | <= | 0 | 1 | | | | | |
| QVNIEF | <= | 0 | | 1 | | | | |
| QVARAG | <= | 0 | | | 1 | | | |
| QVARAF | <= | 0 | | | | 1 | | |
| DEVA1 | >= | 0 | | | | | | |
| AUTO | >= | 4270 | | | | | 1 | |
| DEVR1 | >= | 0 | | | | | | |
| DEVR2 | >= | 0 | | | | | | |
| REVENU | >= | 100000 | | | | | | 1 |
| NUTRI | >= | 5103 | | | | | | |
| MIN4 | >= | 0.05 | | | | | | |
| MAX4 | <= | 1 | | | | | | |
| MINMIL | >= | 1026 | | | | | | |
| MAXMIL | <= | 1710 | | | | | | |
| MINMAI | >= | 0 | | | | | | |

APPENDIX TABLE 2

UPPER CASAMANCE ·

INITAIL TABLEAU

| | | RHS | PMIC1 | PMIC2 | PMIC3 | PMIC4 | PMIC5 | PMAC1 | PMAC2 | PMAC14 | PRPC1 | PRPC2 | PRPC4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -20687 | -18600 | -7149 | -2837 | -4122 | -26022 | -15249 | -3797 | -35703 | -30590 | -14827 |
| TERRE1 | <= | 3.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| TERRE2 | <= | 0.6 | | | | | | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | | |
| SEMCOT | <= | 0 | | | | | | | | | | | |
| NPK1 | <= | 0 | 100 | 100 | | | | | | | | | |
| NPK2 | <= | 0 | | | | | | 200 | 100 | | | | |
| NPK3 | <= | 0 | | | | | | | | | 100 | 50 | |
| NPK4 | <= | 0 | | | | | | | | | | | |
| NPK5 | <= | 0 | | | | | | | | | | | |
| UREE | <= | 0 | 50 | | | | | 200 | 100 | | 100 | 50 | |
| MIHERB | <= | 0 | 1 | | | | | 1 | | | | | |
| RIHERB | <= | 0 | | | | | | | | | 1 | | |
| HEC1 | <= | 0 | | | | | | | | | | | |
| HEC2 | <= | 0 | | | | | | | | | | | |
| INC | <= | 0 | | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | | | | |
| MO1 | <= | 104 | 11.5 | 15 | 9 | 42 | 3 | 20 | 23.5 | 71 | 12.5 | 18 | 46 |
| MO2 | <= | 98 | 14 | 17 | 9 | 25 | 28 | 9.5 | 14.5 | 15 | 18 | 17 | 40 |
| MOR1 | <= | 122.6 | 8 | 6 | 5 | 6 | 4 | | | | 34 | 28 | 18 |
| MOR2 | <= | 98 | | | | | | | | | | | |
| TA1 | <= | 20 | 5 | 4 | 1.5 | 1 | | 6.5 | 5.5 | 1 | 4 | 4 | |
| SCAP | <= | 25000 | | | | | | | | | | | |
| CAP1 | <= | 0 | | | | | | | | | 1 | 1 | |
| CAP2 | <= | 0 | | | | | | | | | 2 | 2 | |
| RCAP | <= | 0 | | | | | | | | | | | |
| QVMIL | <= | 0 | | | | | | | | | | | |
| QVMAIS | <= | 0 | | | | | | | | | | | |
| QVRPLU | <= | 0 | | | | | | | | | | | |
| QVRNAP | <= | 0 | | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | | |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | -1706 | -1389 | -1010 | -1389 | -758 | -3581 | -2830 | -2384 | -1872 | -1559 | -1180 |
| AUTO | >= | 5165 | 3333 | 2319 | 1707 | 2319 | 1223 | 4385 | 3634 | 3188 | 1872 | 1559 | 1180 |
| DEVR1 | >= | 0 | | | | | | | | | | | |
| DEVR6 | >= | 0 | | | | | | | | | | | |
| REVENU | >= | 85000 | | | | | | | | | | | |
| NUTRI | >= | 6489 | 2833 | 1971 | 1451 | 1971 | 1040 | 3727 | 3089 | 2710 | 1591 | 1325 | 1003 |
| MIN4 | >= | 0.05 | | | | 1 | | | | 1 | | | |
| MAX4 | <= | 0.75 | | | | 1 | | | | 1 | | | |
| MINMIL | >= | 720 | 899 | 626 | 461 | 626 | 330 | | | | | | |
| MAXMIL | <= | 1440 | 899 | 626 | 461 | 626 | 330 | | | | | | |
| MINMAI | >= | 480 | | | | | | 1176 | 975 | 855 | | | |
| MAXMAI | <= | 720 | | | | | | 1176 | 975 | 855 | | | |
| MINRIZ | >= | 360 | | | | | | | | | 658 | 548 | 414 |
| MAXRIZ | <= | 840 | | | | | | | | | 658 | 548 | 414 |
| MINBLE | >= | 0 | | | | | | | | | | | |
| MAXBLE | <= | 120 | | | | | | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | PRC1 | PRC2A | PRC2B | PRC3 | PRC5 | PMIV1 | PMIV2 | PMIV3 | PMIV5 | PMAV1 | PMAV2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -33505 | -32220 | -15660 | -14827 | -13542 | -20687 | -18600 | -7149 | -4122 | -26022 | -15249 |
| TERRE1 | <= | 3.9 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 |
| TERRE2 | <= | 0.6 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | | |
| SEMCOT | <= | 0 | | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | 100 | 100 | | | | |
| NPK2 | <= | 0 | | | | | | | | | | 200 | 100 |
| NPK3 | <= | 0 | 150 | 75 | 75 | | | | | | | | |
| NPK4 | <= | 0 | | | | | | | | | | | |
| NPK5 | <= | 0 | | | | | | | | | | | |
| UREE | <= | 0 | 100 | 50 | 50 | | | 50 | | | | 200 | 100 |
| MIHERB | <= | 0 | | | | | | 1 | | | | 1 | |
| RIHERB | <= | 0 | 1 | 1 | 1 | | | | | | | | |
| HEC1 | <= | 0 | | | | | | | | | | | |
| HEC2 | <= | 0 | | | | | | | | | | | |
| INC | <= | 0 | | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | | | | |
| MO1 | <= | 104 | 19.5 | 19 | 49 | 45 | | 11.5 | 15 | 9 | 3 | 20 | 23.5 |
| MO2 | <= | 98 | 11.5 | 50.5 | 50.5 | 49 | 45 | 14 | 17 | 9 | 28 | 9.5 | 14.5 |
| MOR1 | <= | 122.6 | 61 | 48 | 48 | 35 | 30 | | | | | | |
| MOR2 | <= | 98 | | | | | | | | | | | |
| TA1 | <= | 20 | 9 | 9 | | | | 5 | 4 | 1.5 | | 6.5 | 5.5 |
| SCAP | <= | 25000 | | | | | | | | | | | |
| CAP1 | <= | 0 | | | | | | | | | | | |
| CAP2 | <= | 0 | | | | | | | | | | | |
| RCAP | <= | 0 | | | | | | | | | | | |
| QVMIL | <= | 0 | | | | | | -1290 | -898 | -661 | -474 | | |
| QVMAIS | <= | 0 | | | | | | | | | | -1908 | -1581 |
| QVRPLU | <= | 0 | | | | | | | | | | | |
| QVRNAP | <= | 0 | | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | | |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | -2498 | -1668 | -1668 | -1147 | -877 | 1627 | 930 | 697 | 465 | 804 | 804 |
| AUTO | >= | 5165 | 2981 | 2152 | 2152 | 1630 | 1360 | | | | | | |
| DEVR1 | >= | 0 | | | | | | -19027 | -20388 | -14602 | -11572 | -76163 | -54847 |
| DEVR6 | >= | 0 | | | | | | -20427 | -21188 | -15202 | -11972 | -70163 | -48847 |
| REVENU | >= | 85000 | | | | | | 82027 | 56388 | 41602 | 29572 | 128663 | 107347 |
| NUTRI | >= | 6489 | 2534 | 1829 | 1829 | 1386 | 1156 | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | | |
| MAX4 | <= | 0.75 | | | | | | | | | | | |
| MINMIL | >= | 720 | | | | | | | | | | | |
| MAXMIL | <= | 1440 | | | | | | | | | | | |
| MINMAI | >= | 480 | | | | | | | | | | | |
| MAXMAI | <= | 720 | | | | | | | | | | | |
| MINRIZ | >= | 360 | 1047 | 756 | 756 | 573 | 478 | | | | | | |
| MAXRIZ | <= | 840 | 1047 | 756 | 756 | 573 | 478 | | | | | | |
| MINBLE | >= | 0 | | | | | | | | | | | |
| MAXBLE | <= | 120 | | | | | | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | PRPV1 | PRPV2 | PRV1 | PRV2A | PRV2B | PRV3 | PRV5 | PARA1 | PARA2 | PARA3 | PARA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -35703 | -30590 | -33505 | -32220 | -15660 | -14827 | -13542 | -18676 | -8026 | -7125 | -4927 |
| TERRE1 | <= | 3.9 | 1 | 1 | | | | | | 1 | 1 | 1 | 1 |
| TERRE2 | <= | 0.6 | | | 1 | 1 | 1 | 1 | 1 | | | | |
| SEMARA | <= | 0 | | | | | | | | 120 | 160 | 160 | 160 |
| SEMCOT | <= | 0 | | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | | | | | | |
| NPK2 | <= | 0 | | | | | | | | | | | |
| NPK3 | <= | 0 | 100 | 50 | 150 | 75 | 75 | | | | | | |
| NPK4 | <= | 0 | | | | | | | | 120 | 80 | | |
| NPK5 | <= | 0 | | | | | | | | | | | |
| UREE | <= | 0 | 100 | 50 | 100 | 50 | 50 | | | | | | |
| MIHERB | <= | 0 | | | | | | | | | | | |
| RIHERB | <= | 0 | 1 | | 1 | 1 | 1 | | | | | | |
| HEC1 | <= | 0 | | | | | | | | | | | |
| HEC2 | <= | 0 | | | | | | | | | | | |
| INC | <= | 0 | | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | 1 | 1 | 1 | 1 |
| MO1 | <= | 104 | 12.5 | 18 | 19.5 | 19 | 49 | 45 | | 10 | 14 | 9 | 3 |
| MO2 | <= | 98 | 18 | 17 | 11.5 | 50.5 | 50.5 | 49 | 45 | 15 | 11 | 6 | 6 |
| MOR1 | <= | 122.6 | 34 | 28 | 61 | 48 | 48 | 35 | 30 | 15 | 21 | 20 | 16 |
| MOR2 | <= | 98 | | | | | | | | | | | |
| TA1 | <= | 20 | 4 | 4 | 9 | 9 | | | | 5 | 4 | 1.5 | |
| SCAP | <= | 25000 | | | | | | | | | | | |
| CAP1 | <= | 0 | | | | | | | | | | | |
| CAP2 | <= | 0 | | | | | | | | | | | |
| RCAP | <= | 0 | | | | | | | | | | | |
| QVMIL | <= | 0 | | | | | | | | | | | |
| QVMAIS | <= | 0 | | | | | | | | | | | |
| QVRPLU | <= | 0 | -1162 | -967 | | | | | | | | | |
| QVRNAP | <= | 0 | | | -1850 | -1335 | -1335 | -1012 | -844 | | | | |
| QVARAG | <= | 0 | | | | | | | | -1414 | -1097 | -993 | -782 |
| QVARAF | <= | 0 | | | | | | | | -2302 | -1750 | -1575 | -1227 |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | | | 484 | 484 | 484 | 484 | 484 | | | | |
| AUTO | >= | 5165 | | | | | | | | | | | |
| DEVR1 | >= | 0 | -98728 | -82229 | -131716 | -87984 | -87984 | -60486 | -46240 | -83288 | -53948 | -53511 | -41249 |
| DEVR6 | >= | 0 | -98728 | -82229 | -123216 | -79484 | -79484 | -51986 | -37740 | -72346 | -43846 | -45089 | -34514 |
| REVENU | >= | 85000 | 98728 | 82229 | 157216 | 113484 | 113484 | 85986 | 71740 | 156138 | 121148 | 109411 | 86049 |
| NUTRI | >= | 6489 | | | | | | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | | |
| MAX4 | <= | 0.75 | | | | | | | | | | | |
| MINMIL | >= | 720 | | | | | | | | | | | |
| MAXMIL | <= | 1440 | | | | | | | | | | | |
| MINMAI | >= | 480 | | | | | | | | | | | |
| MAXMAI | <= | 720 | | | | | | | | | | | |
| MINRIZ | >= | 360 | | | | | | | | | | | |
| MAXRIZ | <= | 840 | | | | | | | | | | | |
| MINBLE | >= | 0 | | | | | | | | | | | |
| MAXBLE | <= | 120 | | | | | | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | PCOT1 | PCOT2 | PCOT3 | PCOT5 |
|---|---|---|---|---|---|---|
| RETURN | | 0 | -37746 | -32181 | -12662 | -11905 |
| TERRE1 | <= | 3.9 | 1 | 1 | 1 | 1 |
| TERRE2 | <= | 0.6 | | | | |
| SEMARA | <= | 0 | | | | |
| SEMCOT | <= | 0 | 50 | 50 | 50 | 50 |
| NPK1 | <= | 0 | | | | |
| NPK2 | <= | 0 | | | | |
| NPK3 | <= | 0 | | | | |
| NPK4 | <= | 0 | | | | |
| NPK5 | <= | 0 | 150 | 100 | 100 | |
| UREE | <= | 0 | 50 | 50 | | |
| MIHERB | <= | 0 | | | | |
| RIHERB | <= | 0 | | | | |
| HEC1 | <= | 0 | 1 | 1 | | |
| HEC2 | <= | 0 | 1 | 1 | | |
| INC | <= | 0 | 5 | 5 | 5 | 2 |
| FONARA | <= | 0 | | | | |
| MO1 | <= | 104 | 24.5 | 23.5 | 46 | 3 |
| MO2 | <= | 98 | 6 | 6 | 9 | 34 |
| MOR1 | <= | 122.6 | 2.5 | 2.5 | 2.5 | 12 |
| MOR2 | <= | 98 | 50 | 43 | 23 | 13 |
| TA1 | <= | 20 | 6.5 | 5.5 | 2 | |
| SCAP | <= | 25000 | | | | |
| CAP1 | <= | 0 | | | | |
| CAP2 | <= | 0 | | | | |
| RCAP | <= | 0 | | | | |
| QVMIL | <= | 0 | | | | |
| QVMAIS | <= | 0 | | | | |
| QVRPLU | <= | 0 | | | | |
| QVRNAP | <= | 0 | | | | |
| QVARAG | <= | 0 | | | | |
| QVARAF | <= | 0 | | | | |
| QVCOT | <= | 0 | -1704 | -1430 | -861 | -512 |
| DEVA1 | >= | 0 | | | | |
| AUTO | >= | 5165 | | | | |
| DEVR1 | >= | 0 | -46932 | -41815 | -29561 | -27786 |
| DEVR6 | >= | 0 | -33632 | -24715 | -21961 | -14486 |
| REVENU | >= | 85000 | 161882 | 135865 | 81811 | 48686 |
| NUTRI | >= | 6489 | | | | |
| MIN4 | >= | 0.05 | | | | |
| MAX4 | <= | 0.75 | | | | |
| MINMIL | >= | 720 | | | | |
| MAXMIL | <= | 1440 | | | | |
| MINMAI | >= | 480 | | | | |
| MAXMAI | <= | 720 | | | | |
| MINRIZ | >= | 360 | | | | |
| MAXRIZ | <= | 840 | | | | |
| MINBLE | >= | 0 | | | | |
| MAXBLE | <= | 120 | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | ASEAR | ASECOT | ANPK1 | ANPK2 | ANPK3 | ANPK4 | ANPK5 | AUREE | AHMM | AHERIZ | AHEC1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -110 | -110 | -90.9 | -93.9 | -115.9 | -88.9 | -90.9 | -81.9 | -9750 | -21600 | -8750 |
| TERRE1 | <= | 3.9 | | | | | | | | | | | |
| TERRE2 | <= | 0.6 | | | | | | | | | | | |
| SENARA | <= | 0 | -1 | | | | | | | | | | |
| SENCOT | <= | 0 | | -1 | | | | | | | | | |
| NPK1 | <= | 0 | | | -1 | | | | | | | | |
| NPK2 | <= | 0 | | | | -1 | | | | | | | |
| NPK3 | <= | 0 | | | | | -1 | | | | | | |
| NPK4 | <= | 0 | | | | | | -1 | | | | | |
| NPK5 | <= | 0 | | | | | | | -1 | | | | |
| UREE | <= | 0 | | | | | | | | -1 | | | |
| MIHERB | <= | 0 | | | | | | | | | -1 | | |
| RIHERB | <= | 0 | | | | | | | | | | -1 | |
| HEC1 | <= | 0 | | | | | | | | | | | -1 |
| HEC2 | <= | 0 | | | | | | | | | | | |
| INC | <= | 0 | | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | | | | |
| MO1 | <= | 104 | | | | | | | | | | | |
| MO2 | <= | 98 | | | | | | | | | | | |
| MOR1 | <= | 122.6 | | | | | | | | | | | |
| MOR2 | <= | 98 | | | | | | | | | | | |
| TA1 | <= | 20 | | | | | | | | | | | |
| SCAP | <= | 25000 | | | | | | | | | | | |
| CAP1 | <= | 0 | 110 | 110 | | | | | 90.9 | 81.9 | | | 8750 |
| CAP2 | <= | 0 | | | 90.9 | 93.9 | 115.9 | 88.9 | | | 9750 | 21600 | |
| RCAP | <= | 0 | | | | | | | | | | | |
| QVMIL | <= | 0 | | | | | | | | | | | |
| QVMAIS | <= | 0 | | | | | | | | | | | |
| QVRPLU | <= | 0 | | | | | | | | | | | |
| QVRNAP | <= | 0 | | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | | |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | | | | | | | | | | | |
| AUTO | >= | 5165 | | | | | | | | | | | |
| DEVR1 | >= | 0 | | | | | | | | | | | |
| DEVR6 | >= | 0 | | | | | | | | | | | |
| REVENU | >= | 85000 | | | | | | | | | | | |
| NUTRI | >= | 6489 | | | | | | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | | |
| MAX4 | <= | 0.75 | | | | | | | | | | | |
| MINMIL | >= | 720 | | | | | | | | | | | |
| MAXMIL | <= | 1440 | | | | | | | | | | | |
| MINMAI | >= | 480 | | | | | | | | | | | |
| MAXMAI | <= | 720 | | | | | | | | | | | |
| MINRIZ | >= | 360 | | | | | | | | | | | |
| MAXRIZ | <= | 840 | | | | | | | | | | | |
| MINBLE | >= | 0 | | | | | | | | | | | |
| MAXBLE | <= | 120 | | | | | | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | AHEC2 | AINC | ARAFO | AMO1 | AMO2 | AMOR1 | AMOR2 | ACAP | RISKA | RISKR | CAPT1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | -10000 | -7350 | -1000 | -500 | -500 | -500 | -500 | -0.28 | | | |
| TERRE1 | <= | 3.9 | | | | | | | | | | | |
| TERRE2 | <= | 0.6 | | | | | | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | | |
| SEMCOT | <= | 0 | | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | | | | | | |
| NPK2 | <= | 0 | | | | | | | | | | | |
| NPK3 | <= | 0 | | | | | | | | | | | |
| NPK4 | <= | 0 | | | | | | | | | | | |
| NPK5 | <= | 0 | | | | | | | | | | | |
| UREE | <= | 0 | | | | | | | | | | | |
| MIHERB | <= | 0 | | | | | | | | | | | |
| RIHERB | <= | 0 | | | | | | | | | | | |
| HEC1 | <= | 0 | | | | | | | | | | | |
| HEC2 | <= | 0 | -1 | | | | | | | | | | |
| INC | <= | 0 | | -1 | | | | | | | | | |
| FONARA | <= | 0 | | | -1 | | | | | | | | |
| MO1 | <= | 104 | | | | -1 | | | | | | | |
| MO2 | <= | 98 | | | | | -1 | | | | | | |
| MOR1 | <= | 122.6 | | | | | | -1 | | | | | |
| MOR2 | <= | 98 | | | | | | | -1 | | | | |
| TA1 | <= | 20 | | | | | | | | | | | |
| SCAP | <= | 25000 | | | | | | | | | | | 1 |
| CAP1 | <= | 0 | 10000 | 7350 | | | | | | -1 | | | -1 |
| CAP2 | <= | 0 | | | 1000 | 500 | 500 | 500 | 500 | | | | |
| RCAP | <= | 0 | | | | | | | | 1 | | | |
| QVMIL | <= | 0 | | | | | | | | | | | |
| QVMAIS | <= | 0 | | | | | | | | | | | |
| QVRPLU | <= | 0 | | | | | | | | | | | |
| QVRNAP | <= | 0 | | | | | | | | | | | |
| QVARAG | <= | 0 | | | | | | | | | | | |
| QVARAF | <= | 0 | | | | | | | | | | | |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | | | | | | | | | 1 | | |
| AUTO | >= | 5165 | | | | | | | | | -0.38 | | |
| DEVR1 | >= | 0 | | | | | | | | | | 1 | |
| DEVR6 | >= | 0 | | | | | | | | | | 1 | |
| REVENU | >= | 85000 | | | | | | | | | | -1 | |
| NUTRI | >= | 6489 | | | | | | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | | |
| MAX4 | <= | 0.75 | | | | | | | | | | | |
| MINMIL | >= | 720 | | | | | | | | | | | |
| MAXMIL | <= | 1440 | | | | | | | | | | | |
| MINMAI | >= | 480 | | | | | | | | | | | |
| MAXMAI | <= | 720 | | | | | | | | | | | |
| MINRIZ | >= | 360 | | | | | | | | | | | |
| MAXRIZ | <= | 840 | | | | | | | | | | | |
| MINBLE | >= | 0 | | | | | | | | | | | |
| MAXBLE | <= | 120 | | | | | | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | CAPT2 | AMIL | AMAIS | ARIZ | ABLE | VMIL | VMAIS | RPLU | VRNAP | VARAG | VARAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RETURN | | 0 | | -63 | -68 | -169 | -284 | 63 | 68 | 85 | 85 | 90 | 13 |
| TERRE1 | <= | 3.9 | | | | | | | | | | | |
| TERRE2 | <= | 0.6 | | | | | | | | | | | |
| SEMARA | <= | 0 | | | | | | | | | | | |
| SEMCOT | <= | 0 | | | | | | | | | | | |
| NPK1 | <= | 0 | | | | | | | | | | | |
| NPK2 | <= | 0 | | | | | | | | | | | |
| NPK3 | <= | 0 | | | | | | | | | | | |
| NPK4 | <= | 0 | | | | | | | | | | | |
| NPK5 | <= | 0 | | | | | | | | | | | |
| UREE | <= | 0 | | | | | | | | | | | |
| MIHERB | <= | 0 | | | | | | | | | | | |
| RIHERB | <= | 0 | | | | | | | | | | | |
| HEC1 | <= | 0 | | | | | | | | | | | |
| HEC2 | <= | 0 | | | | | | | | | | | |
| INC | <= | 0 | | | | | | | | | | | |
| FONARA | <= | 0 | | | | | | | | | | | |
| MO1 | <= | 104 | | | | | | | | | | | |
| MO2 | <= | 98 | | | | | | | | | | | |
| MOR1 | <= | 122.6 | | | | | | | | | | | |
| MOR2 | <= | 98 | | | | | | | | | | | |
| TA1 | <= | 20 | | | | | | | | | | | |
| SCAP | <= | 25000 | 1 | | | | | | | | | | |
| CAP1 | <= | 0 | | 63 | 68 | 169 | 284 | | | | | | |
| CAP2 | <= | 0 | -1 | | | | | | | | | | |
| RCAP | <= | 0 | | | | | | -63 | -68 | -85 | -85 | -90 | -13 |
| QVMIL | <= | 0 | | | | | | 1 | | | | | |
| QVMAIS | <= | 0 | | | | | | | 1 | | | | |
| QVRPLU | <= | 0 | | | | | | | | 1 | | | |
| QVRNAP | <= | 0 | | | | | | | | | 1 | | |
| QVARAG | <= | 0 | | | | | | | | | | 1 | |
| QVARAF | <= | 0 | | | | | | | | | | | 1 |
| QVCOT | <= | 0 | | | | | | | | | | | |
| DEVA1 | >= | 0 | | | | | | | | | | | |
| AUTO | >= | 5165 | | | | | | | | | | | |
| DEVR1 | >= | 0 | | | | | | | | | | | |
| DEVR6 | >= | 0 | | | | | | | | | | | |
| REVENU | >= | 85000 | | | | | | | | | | | |
| NUTRI | >= | 6489 | | 3.15 | 3.17 | 2.42 | 3 | | | | | | |
| MIN4 | >= | 0.05 | | | | | | | | | | | |
| MAX4 | <= | 0.75 | | | | | | | | | | | |
| MINMIL | >= | 720 | | 1 | | | | | | | | | |
| MAXMIL | <= | 1440 | | 1 | | | | | | | | | |
| MINMAI | >= | 480 | | | 1 | | | | | | | | |
| MAXMAI | <= | 720 | | | 1 | | | | | | | | |
| MINRIZ | >= | 360 | | | | 1 | | | | | | | |
| MAXRIZ | <= | 840 | | | | 1 | | | | | | | |
| MINBLE | >= | 0 | | | | | 1 | | | | | | |
| MAXBLE | <= | 120 | | | | | 1 | | | | | | |

APPENDIX TABLE 2 - Continued

| | | RHS | VCOT |
|---|---|---|---|
| RETURN | | 0 | 95 |
| TERRE1 | <= | 3.9 | |
| TERRE2 | <= | 0.6 | |
| SEMARA | <= | 0 | |
| SEMCOT | <= | 0 | |
| NPK1 | <= | 0 | |
| NPK2 | <= | 0 | |
| NPK3 | <= | 0 | |
| NPK4 | <= | 0 | |
| NPK5 | <= | 0 | |
| UREE | <= | 0 | |
| MIHERB | <= | 0 | |
| RIHERB | <= | 0 | |
| HEC1 | <= | 0 | |
| HEC2 | <= | 0 | |
| INC | <= | 0 | |
| FONARA | <= | 0 | |
| MO1 | <= | 104 | |
| MO2 | <= | 98 | |
| MOR1 | <= | 122.6 | |
| MOR2 | <= | 98 | |
| TA1 | <= | 20 | |
| SCAP | <= | 25000 | |
| CAP1 | <= | 0 | |
| CAP2 | <= | 0 | |
| RCAP | <= | 0 | -95 |
| QVMIL | <= | 0 | |
| QVMAIS | <= | 0 | |
| QVRPLU | <= | 0 | |
| QVRNAP | <= | 0 | |
| QVARAG | <= | 0 | |
| QVARAF | <= | 0 | |
| QVCOT | <= | 0 | 1 |
| DEVA1 | >= | 0 | |
| AUTO | >= | 5165 | |
| DEVR1 | >= | 0 | |
| DEVR6 | >= | 0 | |
| REVENU | >= | 85000 | |
| NUTRI | >= | 6489 | |
| MIN4 | >= | 0.05 | |
| MAX4 | <= | 0.75 | |
| MINMIL | >= | 720 | |
| MAXMIL | <= | 1440 | |
| MINMAI | >= | 480 | |
| MAXMAI | <= | 720 | |
| MINRIZ | >= | 360 | |
| MAXRIZ | <= | 840 | |
| MINBLE | >= | 0 | |
| MAXBLE | <= | 120 | |

APPENDIX TABLE 3

```
/* --------------- USER INTERFACE PROGRAM ----------          */
/*        KNOWLEDGE BASE CONSTRUCTION FOR DAT PREDECATE        */
/*                     ------------------                      */


domains
    var, class, unit   =  symbol   /*var = name activity(constraint)    */
    type               =  symbol   /*type = A for real activities       */
    val, coeff, nret   =  real     /*       C for constraints           */
    min, max           =  real     /* coeff = Obj. coefficients or RHS */
    choice             =  integer
    file = datafile
    fname = symbol
database
    ddat(var,type,val,coeff,nret,unit,min,max)

predicates
    dat(var,type,val,coeff,nret,unit,min,max)
    process(integer)
    mybase
    menu
    saveit(fname)
    repeat
    clear_ram
    do_file(fname)

goal
    mybase.

clauses

    repeat .
    repeat :- repeat.
    dat("PMIC1","A",1.48,-3600,0,"Ha",-11884,159642).


/*    Module to clear the ram          */

      clear_ram  :-
      retract(ddat(_,_,_,_,_,_,_,_)),
      fail.
      clear_ram :- !.
```

APPENDIX TABLE 3 - Continued

```
/*   this is the main module   */

    mybase  :-
    makewindow(1,7,7,"CENTRAL PEANUT BASIN ",0,0,25,80),
    write(" enter file name ")    ,
    readln(Fname)    ,
    do_file(Fname),      /* check if file exists, else create it */
    clear_ram,
    consult(Fname),
    menu    ,
    saveit(Fname).  /*  write to file*/

/*  end of main module          */


/*    Check  file               */

    do_file(Fname)  :-
    existfile(Fname), !.

    do_file(Fname):-
    openwrite(datafile,Fname),
    dat(Var,Type,Val,Coeff,Nret,Unit,Min,Max)    ,
    assertz(ddat(Var,Type,Val,Coeff,Nret,Unit,Min,Max)),
    saveit(Fname),
     !.

    menu   :-
    repeat,
    clearwindow ,
    write("  *******************************"),nl,
    write("   1.  CREATE/EDIT KNOWLEDGE BASE"),nl,
    write("   2.  LIST   ALL   DATABASE     "),nl,
    write("   3.  QUIT   THE   SYSTEM       "),nl,
    write("   ******************************"),nl,
    write("ENTER YOUR CHOICE   "),
    readint(Choice),  nl,
    process(Choice),
    Choice  = 3,
    !.
```

APPENDIX TABLE 3 - Continued

```
/*   module 1 : EDIT                 */

     process(1)  :-
     makewindow(2,7,7,"CREATE EDIT MODULE",2,20,18,58),
     shiftwindow(2),
     write("Enter variable name:   "),
     readln(Var),
     write("Enter type          :   "),
     readln(Type),
     write("Enter activity level:  "),
     readreal(Val),
     write("Enter coefficient   :  "),
     readreal(Coeff),
     write("Enter   net return  :  "),
     readreal(Nret),
     write("Enter     unit      :  "),
     readln(Unit),
     write("Enter   minimum     :  "),
     readreal(Min),
     write("Enter   maximum     :  "),
     readreal(Max),nl,
     assertz(ddat(Var,Type,Val,Coeff,Nret,Unit,Min,Max)),
     write(Var,"has been added to the data base"),
     !,
     removewindow.

/*   list all predicates module    */

    process(2)    if
    makewindow(4,7,7," LIST MODULE",7,20,8,50),
    shiftwindow(4),
    ddat(Var,Type,Val,Coeff,Nret,Unit,Min,Max),
    write(Var," ",Type," ",Val," ",Coeff,"  ",Nret," ",Unit," ",Min," ",Max),nl
    write("press space bar to continue  "),nl,
    readchar(_),
    fail.
    process(2) if removewindow.


    /*   quit menu                  */

    process(3)    :-
    write(" DO YOU WANT TO QUIT ?  "),
    readln(Answer),
    frontchar(Answer,'Y',_), !.

    saveit(Fname)     :-
    save(Fname),
    !.
```

APPENDIX TABLE 4

```
/* --------------- LINEAR PROGRAMING INTERPRETER  -------  */
/*                  ------------------                      */

domains
    var, unit, type  =  symbol   /*var = name activity(constraint)   */
    val, coeff, nret    =  real     /*       C for constraints          */
    min, max            =  real
    stat                =  integer
    choice              =  integer
    pcent              = real

database
    ddat(var,type,val,coeff,nret,unit,min,max)

predicates
    main
    level1
    level2
    shadow1
    shadow2
    process(integer)
    menu
    repeat
    clear_ram
    resource

goal
    main.

clauses

    repeat .
    repeat :- repeat.


      /*    Module to clear the ram            */
       clear_ram  :-
       retract(ddat(_,_,_,_,_,_,_,_)),
       fail.
       clear_ram :- !.


/*   this is the main module   */

    main  :-
    makewindow(1,7,7,"LINEAR PROGRAMMING  ES",0,0,25,80),
    consult("pbasin.dbf"),
    menu   ,
    clear_ram .

/*  end of main module        */
```

APPENDIX TABLE 4 - Continued

```
    menu    :-
    repeat,
    clearwindow ,
    write("   ******************************"),nl,
    write("    1.   PRIMAL SOLUTION ANALYSIS  "),nl,
    write("    2.   DUAL VALUES ANALYSIS      "),nl,
    write("    3.   RESOURCE RANGE ANALYSIS   "),nl,
    write("    4.   OBJECTIVE VALUES ANALYSIS "),nl,
    write("    5.   EXIT TO PROLOG SYSTEM     "),nl,
    write("    *****************************"),nl,
    write("ENTER YOUR CHOICE    "),
    readint(Choice),  nl,
    process(Choice),
    Choice  = 5,
    !.
   /* ##########    I N F E R E N C E   E N G I N E  ############   */

/* ------ Primal solution module ------   */

    process(1)    :-
    makewindow(2,7,7,"PRIMAL SOLUTION  ",2,10,20,60),
    shiftwindow(2) ,
    level1 ,    /*  check for optimal real activities      */
    level2 ,    /*  check for non optimal real activities */
    removewindow ,
    shiftwindow(1),
    !.

/*  -------- Dual solution module ---------- */

    process(2)  :-
    makewindow(3,7,7,"DUAL  SOLUTION  ",2,10,20,60),
    shiftwindow(3) ,
    shadow1 ,   /*  check for binding contraints           */
    shadow2 ,   /*  check for non binding constraints      */
    removewindow ,
    shiftwindow(1),
    fail.

/*  -------- Resource range module ---------- */

    process(3)  :-
    makewindow(4,7,7,"RESOURCE RANGES",2,10,20,60),
    shiftwindow(4) ,

    resource   ,
    readchar(_),
    removewindow,
    !.
```

APPENDIX TABLE 4 - Continued

```
/*  -------- Objective function module ---------- */

     process(4)  :-
     makewindow(5,7,7,"OBJECTIVE VALUES",2,10,20,60),
     shiftwindow(5) ,
/* TO BE IMPLEMENTED LATTER  */
    write("COMMING UP ..."),
    readchar(_),
    removewindow,
    !.

    process(5)     :-
    write(" DO YOU WANT TO QUIT ?  "),
    readln(Answer),
    frontchar(Answer,'y',_), !.


        /*  ##########  P R O D U C T I O N   R U L E S  ########## */

/*  ------ Check for optimal real activity -------*/
    level1  :-
      makewindow(21,7,7,"OPTIMAL REAL ACTIVITIES",4,0,18,80),
      shiftwindow(21)  ,
      write(" NAME",'\9',"LEVEL",'\9',"RETURN",'\9',"UNIT"), nl,
      write(" --------------------------------  "),nl,
      fail .

    level1  :-
      ddat(Var,Type,Val,Coeff,_,Unit,_,_),
      Val > 0      ,
      Type= "A"   ,
      write(Var,'\9', Val,'\9',Coeff,'\9', Unit),nl,
      fail.
      level1 :-
      cursor(10,0) ,
      write("These are the real activities in the enterprise mix."),nl,
      cursor(11,0),
      write("Levels indicate how many units of each activity "),nl,
      cursor(12,0),
      write("are carried out in this plan."),nl,
      write("press space bar ..."),
      readchar(_),
      !.
```

APPENDIX TABLE 4 - Continued

```
/*  ------ Check for cost of non optimal real activities -------*/
   level2  :-
     makewindow(22,7,7,"NON OPTIMAL REAL ACTIVITIES",6,0,16,80),
     shiftwindow(22)  ,
     write(" NAME",'\9',"RETURN",'\9',"COST",'\9',"UNIT"), nl,
     write("---------------------------------  "),nl,
     fail .

   level2  :-
     ddat(Var,Type,Val,Coeff,Nret,Unit,_,_),
     Val = 0      ,
     Type= "A"  ,
     write(Var,'\9',Coeff,'\9',Nret,'\9', Unit),nl,
     fail.

     level2 :-
     cursor(10,0) ,
     write("These activities are not in the enterprise mix."),nl,
     cursor(11,0),
     write("Costs represent  the cost of forcing one unit of activity "),nl,
     cursor(12,0),
     write("in the optimal plan."),nl,
     write("press space bar ..."),
     readchar(_),
     removewindow, !.

/*  ------ Check for binding constraints  -------*/
   shadow1 :-
     makewindow(31,7,7,"SCARCITY   VALUES ",4,0,16,80),
     shiftwindow(31)  ,
     write("NAME",'\9',"RHS",'\9',"SHADOW P.",'\9',"UNIT"), nl,
     write("---------------------------------  "),nl,
     fail .

   shadow1  :-
     ddat(Var,Type,Val,Coeff,Nret,Unit,_,_),
     Val = 0      ,
     Type= "C"  ,
     write(Var,'\9',Coeff,'\9',Nret,"\9\9", Unit),nl,
     fail.

     shadow1 :-
     cursor(10,0) ,
     write("These represent the constraints binding to this enterprise "),nl,
     cursor(11,0),
     write("mix. Shadow prices measure the contribution of an additional"),nl,
     cursor(12,0),
     write("unit of resource to net farm return."),nl,
     write("press space bar ...when done"),
     readchar(_),
     !.
```

APPENDIX TABLE 4 - Continued

```
  /* ------ Check for slack resources    -------*/
shadow2 :-
  makewindow(32,7,7,"SLACK  RESOURCES",6,0,16,80),
  shiftwindow(32)  ,
  write("NAME",'\9',"RHS",'\9',"SLACK ",'\9',"UNIT"), nl,
  write("--------------------------------  "),nl,
  fail .

shadow2  :-
  ddat(Var,Type,Val,Coeff,_,Unit,_,_),
  Val > 0       ,
  Type= "C"   ,
  write(Var,'\9',Coeff,'\9',Val,'\9', Unit),nl,
  fail.

  shadow2 :-
  cursor(10,0) ,
  write("These constraints are in the optimal enterprise mix."),nl,
  cursor(11,0),
  write("Their levels represent unused capacity or idle farm"),nl,
  cursor(12,0),
  write("resources."),nl,
  write("press space bar ...when done"),
  readchar(_),
  removewindow, !.

/* Resource range analyses  */
  resource     :-
  ddat(Var,Type,Val,_,Nret,Unit,Min,Max) ,
  Type = "C"   ,
  Val  =  0    ,
  Pcent =( Max - Min)/ Min * 100  ,
  write("Constraint Name  :",'\9',Var)    ,nl,
  write("Its implicit price is  :",'\9',Nret,'\9',"CFA")   ,nl,
  write("Range of optimality :   ",'\9',Min,'\9',Max,"(",Unit,")"),nl,
  write(Pcent,"%","  variation in  ",Var,"  available" ),nl,
  write("Press space bar ... when done"),
  readchar(_),nl,nl,
  fail.
  resource :-
  !.
```

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