Synopsis of a linear programming study of farmers' strategies on the Central Plateau in Burkina Faso

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Summary

The contents of this paper is based on an extensive linear programming study of farmers' strategies on the Central Plateau in Burkina Faso. Use was made of a large number of secondary sources, in particular all village level studies previously effected in Burkina Faso. Linear programming models were set up to describe at household level farmers' strategies of production, selling and purchasing, and consumption. A hypothetical household was considered, which is representative for a large group of Mossi households on the Central Plateau. It corresponds to a production system without any "modern" inputs, e.g. animal traction is not used and chemical fertilizers are not applied either. The results of the study have been reported in various reports and publications.

In this paper a concise survey is given of the main elements of the study with an emphasis on the process of developing the models. A systems approach is applied to structure the analysis of farmers' strategies. This also serves as the basis for the formulation of the linear programming models. Particular attention is given to the stepwise process of interpretation of results, comparison with actual farming practices and improvement of the model. A thorough justification is given of the structure of the model, the handling of various factors influencing farmers' strategies, and of the choice of the values of all parameters. Special issues in this paper are the handling of sometimes conflicting objectives and some risk factors. The paper ends with a discussion of final results and an exploration of possibilities of improving households' food security.

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Preface

The present study has its roots in the CEDRES/AGRISK research project on risk in food supply on the Central Plateau in Burkina Faso. In this project researchers from the Centre of Economic and Social Studies, Documentation and Research (CEDRES) of the University of Ouagadougou, Burkina Faso collaborated with researchers from the University of Groningen, the Netherlands. Meanwhile, the institutional framework of the research collaboration has been changed. To a large extent it has been integrated into a large-scale research programme, called SADAOC[1], on sustainable food security in West Africa. This programme is carried out by researchers from several Universities and Research Institutes in Burkina Faso, Ghana and the Netherlands, in close collaboration with policy-makers of various governmental departments.

It is impossible to mention all who, knowingly and unknowingly, contributed to the production of this paper. However, we would like to express our gratitude to former colleagues of the CEDRES/AGRISK project: T. Thiombiano, G. Konaté, E. Yonli and A. Djiguemdé, J. van Andel, T.A.B. Snijders, E.A. Baerends, G. Bakker, M. van Noordwijk, J. van der Heide, M.C. Gardeur, E.A.R. Mellaart and A. Stanneveld. Since June 1992 we have worked closely together with researchers of the Farming Systems Research Programme (INERA/RSP) of the National Institute of Agricultural Studies and Research (INERA), and in particular with the INERA/RSP team of the north-western zone, based in Tougan: M. Nignan (coordinator), A.A. Ouedraogo, J. Gué, H. Sawadogo (researchers), A. Sienou and M. Ouadraogo (supervisors), H. Guel, I. Tassembedo, I. Beli, M. Combéré, A. Sourwema and M. Ouedraogo (enumerators). The discussions on farmers' problems and strategies have been a great inspiration. We have appreciated very much the comments on a draft of the present report by D. Cappitt, Roehampton Institute, London.

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[1]. Sécurité Alimentaire Durable en Afrique de l'Ouest Centrale.

1. Introduction

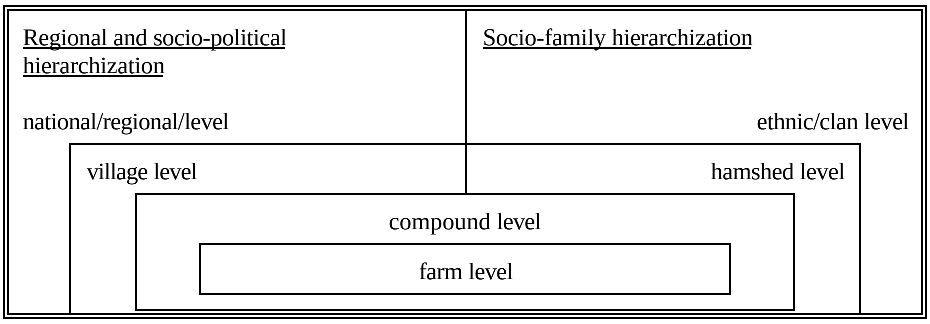
The population of the Central Plateau in Burkina Faso faces a gloomy prospect. In fact, the situation is critical: the prevailing systems of production and distribution do not prevent serious food shortages for the majority of people, and, through force of circumstance, natural resources are overexploited in the extreme.

Despite, or rather owing to this critical situation, farmers have taken important initiatives. At farm and village level, they have progressively adapted their strategies to the new conditions. With regard to agricultural methods, we can mention for instance, the use of anti-erosion measures, the intensification of water and soil conservation methods, the reinforcement of the link between cattle keeping and cultivation and the intensification of tree and shrub planting in the fields. Moreover, through reforms in their organization, by co-operation and in particular, by creating cooperatives, the people endeavour to implement new forms of social life that will allow them to work out new strategies by using the scarce available resources. More and more supported by the Government, credit banks, Non-Governmental Organisations, etc., those initiatives of the people also deserve to be supported by scientific research.

The objective of this study is to understand better the determinants on which farmers' strategies are based, and to identify the most influential factors. To what extent do these strategies help to increase food security, both in the short and long term? In the end, attainment of this objective should lead to the working out of recommendations for decision makers at several levels (farmers, farmers associations, agricultural information services, credit banks, Non-Governmental Organisations, Ministry of Agriculture and Animal Resources, etc.): strategies which could be adopted in order to achieve, in the short and long term, increased food security; and the role which Government and Non-Governmental Organisations should play in this process.

The farmers' strategies and the way they act are greatly influenced by external factors at various levels: the national or international level (e.g. prices on the world market, monetary policy of the Government, national policy on prices, tax system, etc.), the regional or provincial level (e.g. environmental conditions, role of merchants, presence of credit banks, etc.), and the level of the village (e.g. access to local markets, presence of village associations, etc.). Other hierarchical levels, related for instance to ethnic and clan systems, interfere with the regional and socio-political hierarchical systems, see figure 1.1 where different hierarchical levels are illustrated. The kinship system plays an important role, since farmers' strategies are considerably influenced by factors deriving from this system (e.g. the right of land use, traditional processes of decision making etc.). It should be noted that a farm may comprise several socio-economic units - and several decision-makers - each with their own responsibilities, objectives and activities.

Figure 1.1 Different hierarchical levels



Basing our argument on secondary data from various sources, we shall develop linear programming models for an "average" farm. This is a hypothetical farm type representative of a large group of Mossi households on the Central Plateau. In this farm no modern inputs are used, such as tractors, animal traction or chemical fertilizers. This representative farm will be called "Exploitation Centrale". Linear programming models will be developed step by step. The present paper contains a short survey of the main elements of the development of the model. A more detailed report on backgrounds, farming conditions in Burkina Faso and results of various village level studies carried out in the past can be found in Maatman and Schweigman, 1995, 1996.

Content of the study

Chapter 2 will introduce the situation on the Central Plateau, in particular some determining factors of agricultural conditions there. In chapter 3 on methodology a systems approach will be applied. It allows us to disentangle the most important factors which influence farmers' decisions and strategies and their coherence. Moreover, it provides a reference framework for the linear programming models to be developed. Chapter 4 discusses the village studies executed on the Central Plateau, on which the estimations used in the linear programming models constructed in chapters 5 and 6 are based. In chapter 5 a first model to describe the farmers' strategies of food production and trade in food crops of the "Exploitation Centrale" is discussed. This model is very much centred on the production factors "land" and "labour". It is postulated that a certain percentage of desired cereal production is indeed produced. Results are discussed in detail and it is shown why this model is not yet satisfactory. In chapter 6 a new model is worked out where, as a result of the stepwise process of constructing the model and interpreting the results, various new elements are included which are crucial to a realistic description of the farmers' strategies. The most important modificiations are the expression of food requirements in terms of energy and protein requirements, the inclusion of financial balances along with a more detailed analysis of consumption, storage and marketing strategies, the introduction of different periods of sowing, the distinction between intensive and extensive (light) weeding, the distinction between common and individual fields and the handling of various objectives. A thorough discussion of this multi-objective model is presented, including possibilities of improving food security. Finally, in chapter 7 some general conclusions are drawn about the situation of the households in the Central Plateau and about the methods of analysis used in this report.

2. Central Plateau: some observations

2.1 Food production

The Central Plateau is a vast extent of land (about 70,668 km^2, occupying 1/4 of the Burkinabe territory) located on a plateau in the central part of Burkina Faso. This is where we find Ouagadougou the capital city of the country, and other important cities such as Koudougou, Ouahigouya and Kaya. The population of the Plateau, which amounts to about 3,800,000 inhabitants, represents 48% of the total population, according to the figures of the last census, effected in 1985 (Konaté, 1988). The Central Plateau consists of the major part of five regions: the Centre, Centre-South, Centre-East, Centre-North and Yatenga (also called North), see figure 2.1. The rural population of the Central Plateau mainly consists of (semi) nomads and farmers practising rainfed farming[1], the latter group constituting the majority of the population.

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The Mossi people form the largest ethnic group on the Central Plateau (also called the Mossi Plateau). The farmers of the Central Plateau mainly cultivate millet and sorghum. Nearly 92% of the total cultivated area of the Central Plateau is used for the cultivation of cereals (sorghum, millet, maize and rice), with the following proportions: 87.5% for millet and sorghum, and only 3.5% for maize (Djiguemdé 1988, referring to CILSS-OCDE-Club of the Sahel, 1982). The greater part of the produce is for consumption by the family. White sorghum and millet are food crops and are sold only when necessary. The need to sell may occur shortly after harvesting, when for example, farmers must pay back debts contracted at the beginning of the (rainy) season (Yonli, 1988). Later on, when crop stocks run low, those farmers often find themselves having to buy cereals again, but at much higher prices. Red sorghum is not so much used for food, because of its taste. It is basically used for the brewing of local beer (*dolo*). Maize is mostly grown in fields in the immediate vicinity of houses. Though its total yield is rather low, it is still of great importance to farmers. As a matter of fact, maize can be harvested a few weeks before sorghum and millet, and since cereal stocks are very low or even depleted at that time of year, i.e. towards September, the new harvest of maize is very welcome. Rice, which in terms of quantity is the least important of cereals cultivated on the Central Plateau, is mostly grown in fields situated in swamps, where there is plenty of water. The rice produced is usually sold. Groundnuts are more important for farmers of the Central Plateau: almost every farm includes small fields of groundnuts, and the harvested produce is mostly sold. Cotton is disappearing: formerly much cultivated in the Central Plateau it is now found only in more southern regions of the Plateau. Besides those main crops, many others are cultivated, often intercropped (mixed cropping). Mixed cropping of cereals with cowpeas is very frequent on the Central Plateau.

By making use of population census data and agricultural statistics for the period 1975-1985, Snijders et al., (1988) have compared, for several regions of the Central Plateau, the actual cereal production with the desired cereal consumption. Their statistical analysis showed that in all regions of the Central Plateau the probability of cereal shortage was close to 1; for regions of the Centre, Centre-North and Yatenga the expected deficit amounted to 40% of the cereal demand, and "only" to 17% for the Centre-East. These results confirm that the population is barely self-sufficient in cereal production.

2.2 Demographic situation and rural density

Compared with the situation of the whole country, the Central Plateau very densely populated. The density varies according to region: it is much higher in the Centre region than in Centre-North and Centre-West region (see table 2.1 showing the demographic composition). In spite of the high population density, the Central Plateau faces a shortage of manpower, especially during the peak periods of sowing and weeding (see e.g. Kohler, 1971; McIntire, 1981; FSU/SAFGRAD, 1983; Imbs, 1987). This aspect will be thoroughly examined in chapter 4.

The population is young. The rate of dependence, that is, the ration of the total population to the working population (from 15 to 65 years old) is 2.18 (Konaté, 1988): each person active in agricultural production thus has to support 2 people.

The regional rate of dependence for the Central Plateau is greater than the national rate of Burkina Faso, which is 2.07 (see Konaté, 1988), because a great number of people in their most active years have left. The availability of manpower varies with the influence of *migration*. This is an important phenomenon on the Central Plateau: the census of 1985 shows that about 493,000 inhabitants of the Central Plateau went abroad in that year (especially to Ivory Coast, sometimes to Mali), the total of Burkinabè emigrants amounting to 741,000. Besides emigration, there is also migration within the country: long-lasting migration to the city or to less populated areas (the "new lands" in the south of the country) and temporary migration in the dry season for instance, when there is not much work in the countryside.

Most migrants are men from 20 to 29 years old (Konaté, 1988). The high rate of dependence and the various forms of migration have serious consequences for labour distribution. As a result of the migration of so many men, women are left with more and more work to do (Konaté, 1988). But migration does not only have an important

Table 2.1 Age structure, density and growth of population in five regions of in 1985[1]

	Centre	Centre-East	Centre-North	Centre-West	Yatenga	Total
Population (x 1000)	1,525	567	799	1,015	537	4,443
Age -14	47%	48%	49%	50%	50%	49%
-15 - 49	42%	40%	39%	37%	35%	39%
-50 et +	11%	12%	12%	12%	14%	12%
Population (inhab./km2)	68[3]	55	39	40	44	49
Growth rates between 1975-1985	4.1%	2.5%	1.5%	0.3%	-0.7%	1.96%[2]

Notes:
1. The figures are from the general censuses effected in 1975 and 1985 by INSD (National Institute emography). Since INSD admits that for the 1975 census, the resident population in 1975 has been a proportion of 8%, the figures given in this table represent the corrected form of the results.
2. Because of the low growth rate of the population in the region Centre-West, the total growth rate regions together is lower than the growth rate calculated for the 4 regions (without region Centre-

3. If we exclude the area surrounding Ouagadougou (Kadiogo province), the density for the inhabitants/km^2 (figure taken from Konaté, 1988: p.41).

Source: Konaté (1988).

effect on the availability of manpower on the Central Plateau, since it often occurs that (e)migrants send money to their families. Migrations, especially those of short duration, are part of the survival strategies of several farms on the Central Plateau (see e.g. Billaz, 1980; Benoit, 1982; P. Dugué, 1989; Reardon et al., 1992). Due to the importance of migration the annual rate of population growth in the Central Plateau (1.96%) is lower than the national rate (2.64%). The Yatenga region even faces a decrease of population (see table 2.1). The high rate of migration in the Yatenga region is due to the fact that population pressure on the available arable land is high (see table 2.2)

Table 2.2 Resident population, potentially available areas in the five regions eau

	Centre	Centre-East	Centre-North	Centre-West	Yatenga	Total
Total area (km^2)	21,952	11,166	21,578	26,992	12,293	95,991
SAU[1] (km^2)	7,400	3,250	6,150	8,050	3,500	28,350
Pasture (km^2)	14,450	5,100	13,950	15,750	8,000	57,250
Cultivated (km^2)	3,750	1,650	2,420	3,050	2,450	13,320
Rural population (x 1000 inhab)	762	402	626	740	493	3,023
SAU[1] per inhab (ha/hbt)	0.97	0.81	0.98	1.09	0.71	0.94
Cultivated by each inhabitant (ha/inhab)	0.49	0.41	0.39	0.41	0.49	0.44

Notes:
1. SAU: Superficie Agricole Utile (Area Arable Land)

Source: Taken from CILSS-OCDE-Club of the Sahel (1980) and adapted uemdé (Djiguemdé, 1988:67).

Table 2.2 provides an estimate of the area of land suitable for cultivation on the Central Plateau. From this, it can be inferred that in 1988 an average of about 50% of the area intended for farming was already used (this even amounts to 70% in the Yatenga region). Owing to the increase of population pressure, farmers were forced to modify their rather extensive farming system of natural regeneration and preservation of original vegetation (shifting cultivation). This is how the present farming system arose, consisting of a (semi-) permanent cultivation incorporating relatively short fallow periods (Marchal, 1983; Prudencio, 1987; Broekhuyse, 1988).

Most analyses of farming systems on the Plateau Central reveal that, in many cases, environmental limits are reached, and even exceeded (e.g. Kessler, Ohler, 1983). As a result of the present over-exploitation of soils, there is a serious loss of soil fertility. Likewise, the physical properties of soils being affected, arable lands become more and more vulnerable: they lose their vegetation and are more exposed to erosion and less capable of preserving rain water. As a result, agriculture has become vulnerable to rainfall. There seems to be a vicious circle: the decline of soil productivity requires a constant enlargement of the cultivated area which, in its turn, loses its fertility (therefore its productivity) due to deficient fertilization and insufficient duration of fallow periods.

2.3 Climatic conditions

The semi-arid[2] Central Plateau, spreads over two pluviometrical zones[3]:

- in the North, the transitional area between Sahelian and Sudanian zones, characterized by rainfall ranging between 600 and 800 mm a year and where water shortage is frequent.
- the rest of the Central Plateau, South of the zone mentioned above is part of the North-Sudanian zone where rainfall varies from 800 mm in the North, to 1000 mm in the South.

There is a dry season and a rainy season. The climatic zone determines the length of the rainy season which, in its turn, is a determining factor for the types of crops that can be grown. When the rainy season is of a short duration (from 60 to 90 days), it is only possible to grow crops and varieties with a relatively short crop

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2. Troll (1966) defines the semi arid tropical zones as areas where the rate of precipitations is higher than the potential evapotranspiration for 2 to 7 months of the year.

3. For climatic and pedological conditions, we have taken information from publications of the CEDRES/AGRISK project: Mellaart (1987); (1988); Djiguemdé, Mellaart and Lougué (1987); Djiguemdé (1988).

cycle and, as a result, with limited yield. When the same season is long (120 days), it is not only possible to till the soil at the beginning of the season, but also to grow crops and varieties of longer growth cycles and with higher yield. Figure 2.2 shows the isohyets and annual rainfall of Burkina Faso.

To understand farmers' strategies, it is also important to understand how farmers' face the uncertainty caused by variations in rainfall. Rainfall varies from one year to another, and from one area to another. The annual variations are usually considerable. But even in the same year, there can be tremendous variations within a relatively small area: so, within an area consisting of only one or two villages, we can find fields where the rainfall was relatively good, and others where it was rather bad. A diversification of crops and varieties, and sequential processes of decision making constitute important elements in farmers' strategies aiming to control, even to reduce as much as possible the risks related to agricultural production and deriving from variations in rainfall. In various chapters of the study of Maatman and Schweigman (1995, 1996) the influence of rainfall is discussed.

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2.4 Socio-economic organization of the Mossi people on the Central Plateau

The social organization of the Mossi people is to a large extent based on patrilineal descent (*clan*). Members of the same *clan* are generally dispersed over several villages. The local segment of a *clan* within a village is called *hamshed*. The *hamshed* is therefore a social group formed according to territorial factors (co-residence) as well as genealogical factors (patrilineal descent). Wives in a given *hamshed* all come from another *hamshed* which is part of another *clan*. So, individuals from different *clans* are related to one another through alliance, forming networks of extreme importance for co-operation and mutual assistance.

The *hamshed* is usually subdivided into smaller social residential units (*compounds*). Each compound contains families of three to five generations. Girls stop being part of a *compound* when they get married and move to their husband's compound. As for the wife coming from another *hamshed*, she belongs to her husbands' *compound*, although she will remain part of her father's *clan*. The *compounds*, which are easy to distinguish in the field, since they are separated from each other by walls and fields, have since the colonial period been considered as an official unit for census and tax collecting.

Called *zaka*, the smallest units within the *compound* are formed of families going back to a maximum of 2 or 3 generations. The *zaka* generally consists of a man (the *zaksoba*), his wives and his unmarried children, sometimes with one or more married sons, with their wives and children. Figure 2.3 illustrates a typical *compound*.

The socio-economic organization of the Mossi, being founded on the kinship relationships described above, comprises several levels. Each level has an important role in the social and economic life of the Mossi. Obviously, this has implications for the research on farmers' strategies. Ancey (1976) distinguishes the following levels:

1. The individual level, with a distinction between elder men, young men, and women;
2. The level of the "restricted" production unit;
3. The level of the "consumption group";
4. The level of the "farming group";
5. The level of the compound (the "residential unit");
6. The level of the family extended to the *clan* or *hamshed*;
7. The village level;
8. The supra-village level.

In this study, the farm (level 4) forms the basic unit. The *Mossi farm* can be defined as: "the human community putting together its efforts on one or several (large) common fields whose harvest serves the collective consumption of the members participating in the work and their inactive dependents" (adapted from

Ancey, 1975)[4]. The Mossi call these large fields *pukasinga*. The Mossi people do not use the term farm, but rather speak of "common granary". It is the head of the farm who organizes the work on the common fields, who decides which fields are to be cultivated, which crops will be grown and what methods will be used. He manages the harvested crops of the common fields, and decides for instance on the allocation of cereals stored in the common granaries for the preparation of meals. He also manages the livestock of the farm, and organizes the work concerning feeding and watering the cattle; he decides about financial transactions and is responsible for social exchanges between the different farms. He is the principal decision maker within the farm. It is noted that in this study the terms *farm* and *household* are interchangeable, i.e. they refer to the same socio-economic unit.

The *zaka* is increasingly becoming the fundamental unit in the socio-eco-nomic organization of the Mossi. However, the role of higher-level units as the *compound*, *hamshed* and *clan* still remain important. Decisions about investments, marriage and migration are often discussed at these levels; also land-laws - accessibility, control of land - are principally governed at these levels. In daily life the *compound* remains a fundamental economic unit. Often all *zaksoba* and sons and brothers eat their meals together, they help each other with the work on the fields, with the management of the livestock, and with a lot of other things.

Considering the distribution of responsibilities within the farm we should also recognize the role of the "restricted" production units (level 2). A "restricted" production unit is formed by a person (or group of persons) within the farm who cultivate one or more "individual" fields. In particular, the wives of the farm head are cultivating individual fields; sometimes their elder sons also have individual fields. The products of these fields are managed by the cultivators themselves. The Mossi farm is therefore not a unit where all revenues are put together to satisfy the needs of all its members. It also includes "restricted" production units, constituting budgetary units as well.

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[4]. The definition given by Ancey (1975) was more general in order to cover several ethnic groups in West Africa (Lobi, Mossi, Senoufo, Haussa, Wolof etc.). See also Tallet (1985) for a comprehensive discussion on the concept of a farm in the rural areas of West Africa (based on field studies in Burkina Faso).

The farm not only comprises several production units, but may also comprise several consumption units (level 3). This depends on the source of the cereals consumed (communal granary, individual granary). The sociologist Gué gives the following example: "During the year, food intakes of the *zaka* are taken from the communal granary, women, by turns, take care of the preparation of meals and their distribution to all the members of the *zaka*; in this case the consumption unit corresponds more or less to the farm. However, when the food is taken from the individual granaries, the distribution of the meals takes place at the level of more restricted production units: the *dogo* (house) or a group of houses (*dodo*). At the moment, the number of "plates" to the *zaksoba* often corresponds to the number of his wives. Actually, each wife who has cooked, brings one plate to him" (INERA/RSP Nord-Ouest, 1993).

Summarizing, the Mossi farm is a unit where a large part of the principal decisions - but not all - are taken. It is not a homogeneous unit, as it comprises several sub-units with their own means, objectives and responsibilities. An adequate analysis of farmers' strategies has to take into consideration the influence of decisions taken at other levels, supra- and sub-farm, of the socio-economic organization of the Mossi.

2.5 Access to agricultural land for the Mossi farmers

The earth guardian

Within a region the rights to land are held by maximal patrilineages (*clan*) and within each patrilineage land is allocated to its segments (*hamshed*) and on the next level to the farms (*compounds*) within each segment. This distribution of land among social groups of different levels is inherent to the locally prevailing 'traditional' system of land law. Within this system land belongs to the patrilineage of the 'original' inhabitants of the area who were the first to clear the bush and cultivate the land. The Earth Guardian (*tengsoba*), that is the head of the autochthonous patrilineage descending from the first occupants of the land, is responsible for the entire territory belonging to his patrilineage. It is his duty to see to it that the land is allocated and exploited in a "right" way. Usually over the years other people, from outside the earth guardian's own patrilineage, have come to live beside members of his own patrilineage in his area. According to the customary law of the Mossi every newcomer, whether he belongs to the own patrilineage or not, is allocated a piece of land. In first instance he receives temporary users' rights; in principle the earth guardian may revoke or reallocate such rights every year. But if members of another patrilineage have tilled the same land for a long time (i.e. several generations), their users' rights will become more secure. They will, however, remain under the control of the earth guardian, the representative of the initial lineage.

The lineage right of disposal

Basic control over land resides with the patrilineage (*clan*). Actual management and control takes place at the level of the local lineage-segment (*hamshed*). The property rights of the lineage with respect to its territory can best be described by the notion of "right of disposal" (Van Vollenhoven, 1909). Van Vollenhoven defines the right of disposal as the basic right of a jural community to dispose of the uncultivated land, water and other resources within its territory and exercise residual control over the cultivated land in use by members of the community or, incidentally, by co-resident strangers. Land for cultivation is allocated by the community to individual members of the community, usually male farm heads, who control the land received on behalf of their production unit.

The individual rights of the farms

The various farms ("exploitations") within the *hamshed* can obtain '*individual users' rights*' on part of the area of the *hamshed*. Such "individual users" rights are allotted to the heads of the farm. The farm land that has been acquired in such a manner, will in practice not easily be redistributed. Only, if the head of the farm lets part of his land lie fallow for a longer period, he runs the risk that these fields are allocated to other farmers, for instance to newcomers, to a farm that has just turned independent, or to a farm where more labour has become available because the children are old enough to help till the land.

The largest and best part of the land allotted to a farm ("exploitation") will be cultivated by all members of the farm under the management of the head of the farm; these are the *common fields* (*pukasinga*, see section 2.4). All members of the farm will work together on these collective fields as soon as and as long as they are able to do so. In addition, the head of the farm will allot part of the land to his wife/wives for private use. The users' rights of wives to these *individual fields* (*beogo*) allotted to them are very insecure. They may have different fields allotted to them every year. Moreover they are often allotted fields that are less fertile or farther away.

2.6 Composition of Mossi farms

The definitions of the farm found in the different village studies carried out on the Central Plateau are far from being in complete accord. Consequently, it is often difficult to compare data from different village studies on the composition of farms. Sometimes the definitions are rather vague, and in that case it is up to the enumerator concerned to determine which socio-economic units will be regarded as a farm and which people will be considered as members of the farm. Besides, a clear-cut delimitation between farms is not always possible, due to the close links existing between the *zaksé* of the same *compound*, especially between those of the father (head of *compound*) and his sons. Even with the description just given, the enumerator does not yet have the criteria to determine easily which people are part of the farm and which are not: e.g. whether temporary workers are part of the farm; what to do about guests?

In general, the data collected on the composition of the farms concern the number of members and/or inhabitants, of men and women, of *actives* and composition according to age. The notion of *actives* (those who considerably contribute to farm labour) is not always easy to define, for neither the intensity nor the length of labour time are the same for all. Indeed, whereas the older people sometimes only take care of their individual fields, children, for their part, work on the communal fields from the age of about ten years old where they chase the birds away, keep the cattle away from crops, carry the harvest back home and help during seed sowing. One method of defining the numbers of *actives* is based on the distribution of tasks according to age. The labour force is taken to consist of people aged from 10 to 15 up to 65, who are assumed to bring a considerable contribution to farm labour.

Data concerning the composition of the Mossi farms have been gathered among others by the Burkinabe authorities through two censuses and several surveys. In 1986, during a thorough survey carried out in the Centre-North region on the Central Plateau, a distinction was made between the compound and the household; the latter being defined more or less analogously to our definition of the farm. Table 2.3 includes some results of this survey. The same kind of data have been gathered in village level studies, see table 2.4. In spite of the great number of village studies, the dynamics of the socio-economic organisation of the Mossi people has hardly been studied.

We will now discuss the composition of the representative "Exploitation Centrale", which was introduced in chapter 1.

The composition of "Exploitation Centrale"

The estimation of the number of persons belonging to the "Exploitation Centrale" is based on the data of the studies mentioned in table 2.3 and 2.4. The average number of persons per farm in the extensive village survey of the Ministry of Agriculture and Animal Resources in the region Centre-North was about 8. The average number of persons per farm in the various village studies varied from 7 to a little bit more than 12. In most village studies the number was larger than the figure 8 found by the Ministry of Agriculture and Animal Resources. This might be due to differences in definition of farm (see the discussion in section 2.4). The number of persons belonging to the "Exploitation Centrale" will be equal to the average number, 10, of persons per farm found in the village studies on the Central Plateau.

The ratio of the number of persons in the "Exploitation Centrale" under 15 and above 15 years corresponds to the age structure on the Central Plateau. The population census in 1985 shows that about 49% of the population of the Central Plateau is younger than 15 years. The village studies show similar results: the total number of members of the farms and the number of "actives" (i.e. persons older than 15 years) varies from 1.6 to 2.2.

Summarizing we assume that the "Exploitation Centrale" consists of ten persons, of whom 5 are older than 15. These five, including the head of the farm (*zaksoba*), are supposed to make a major contribution to the work on the "common fields" of the farm; they are the so-called "active" members. Of these active members, 3 are women, 2 are men. Members under the age of 15 may assist in smaller tasks, for instance chasing away birds or keeping small cattle at a distance etc, but they are not "active members".

Table 2.3 Results of the population census of may 1986 in the districts of the region Centre-North

districts and sub-districts	Population of 1985	Number of compounds	Number of households	Population of 1986	Number of actives	Mean number of persons per compound	Mean number of actives per compound	Mean Number of persons per household	Mean number of actives per household	Mean number of households per compound	Number of actives per person
District Kaya-Ouest											
Kaya	65634	5720	8228	64874	31128	11.3	5.4	7.9	3.8	1.4	0.48
Boussouma	57806	3991	5894	47015	23875	11.8	6.0	8.0	4.1	1.5	0.51
Korsimoro	65721	4448	9268	59212	30152	13.3	6.8	6.4	3.3	2.1	0.52
Mane	31074	2019	3493	28030	13538	13.9	6.7	8.0	3.9	1.7	0.49
Tema	36660	2176	3625	32241	14818	14.8	6.8	8.9	4.1	1.7	0.46
Total district	256895	18354	30508	231372	113511	12.6	6.2	7.6	3.7	1.7	0.49
District Kaya-Est											
Barsalogho	81704	4871	8177	72353	35765	14.9	7.3	8.8	4.4	1.7	0.50
Pissila	66818	4831	8070	60806	30991	12.6	6.4	7.5	3.8	1.7	0.51
Tougouri	100633	7064	10963	89238	38331	12.6	5.4	8.1	3.5	1.6	0.43
Total district	249155	16766	27210	222397	105087	13.3	6.3	8.2	3.9	1.6	0.48
District Boulsa											
Boulsa	102119	7481	12066	98556	48628	13.2	6.5	8.2	4.0	1.6	0.49
Andemtenga	47051	4238	5128	41398	21483	9.8	5.1	8.1	4.2	1.2	0.52
Total district	149170	11719	17194	139954	70111	11.9	6.0	8.1	4.1	1.5	0.51
District Kongoussi											
Kongoussi	54516	3076	6185	52247	25273	17.0	8.2	8.4	4.1	2.0	0.49
Sabce	21039	1154	2042	18277	8967	15.8	7.8	9.0	4.4	1.8	0.49
Tikare	41902	1895	3937	38185	18212	20.2	9.6	9.7	4.6	2.1	0.47
Bourzanga	48537	2386	4459	43308	19944	18.2	8.4	9.7	4.5	1.9	0.46
Total district	165994	8511	16623	152017	72396	17.9	8.5	9.1	4.4	2.0	0.48
Total	821214	55350	91535	745740	361105	13.5	6.5	8.1	3.9	1.7	

Note:
- The population of 1985 is from the general population census of december 1985 - (source INSD).

Source: Ministère de l'Agriculture et de l'Elévage, 1988.

Table 2.4 Data on the composition of farms, gathered in several village studies on the Central Plateau.

Village studies[1]	Number of farms[2]	Persons per farm	Actives per farm	Rate of dependence[3]	Other data
Broekhuyse, 1983					Women Men
Village studies, 1980 et 1981					(in %)
- Tanpooré	8	8.5	3.8	2.24	56% 44%
- Basperiké	8	11	5.9	1.86	59% 41%
- Koalma	7	8.4	3.8	2.21	54% 46%
ICRISAT (McIntire, 1981)					
Village studies, 1980					
- Nakamtenga	24 (67% AT)	9.7			
- Nabitenga	20 (55% AT)	10.9			
ICRISAT					
(Matlon and Fafchamps,					
1988)					% Extended Families[4]
Village studies, 1981-1985	21	14.1			43%
- Kolbila	13	7.1			17%
- Ouonon					
SAFGRAD/FSU (Lang et al.,					Actives
1984)					Fem. Mas. Child
Village studies, 1981-1986	30 (4 AT)	9.1 (3.8)[5]	5.8 (2.6)[5]	1.57	2.2 2.1 1.4
- Bangassé	30 (17 AT)	10.7 (4.4)[5]	5.4 (2.1)[5]	1.99	2.8 2.0 0.5
- Nedogo					
Dugué, M.J., 1987					
Village studies, 1982-1985					Migrants per active
- Sabouna	129	10.7	5.9	1.8	0.32
- Kerga	52	12.5	5.9	2.1	0.3

Notes:
1) Appendix 1 of Maatman and Schweigman (1995) includes a short explanation of those village studies as well as maps showing the villages
2) Unless otherwise stated, these are only the sample results of farms without animal traction. For mixed samples, which take into account farms with (AT) and without animal traction, each time the proportion between both types of households is given.
3) Rate of dependence = number of persons depending on an active per farm.
4) Percentage of large families where many married couples with children live and work.
5) Standard deviation in brackets.

2.7 Observations on the objectives of decision making

This section is centred on the collective objectives of the farm and the individual objectives of the members of the farm. It is through those objectives, combined with agro-ecological, economic and social conditions, that the farming strategies of the farm are determined. In most studies, researchers restrict themselves to a superficial examination of the objectives - assumed to be more or less collective - of the farm. Ancey (1976) is the only one who has studied the objectives as they exist at the different levels of the organization. Prudencio (1983) provides a classification of objectives, worked out on the basis of interviews with the heads of the different farms, which is as follows:

1) self-sufficiency, as regards foodcrops;
2) production of a surplus for sale;
3) preservation of the minimal security stock of foodcrops in barns;
4) realization of savings permitting increase of livestock, obtaining capital for dry season activities etc.
5) maintenance or improvement of access to land for the household;
6) minimization of risk.

The importance of the objectives 1), 2), 3) and 6) is mentioned in almost all village studies. Objective 4), which is not necessarily related to agricultural crop production, is not explicitly taken into consideration in this report, nor is objective 5); the complex system of land use rights has been discussed in the previous section.

Objective 2) is related to obtaining *financial income*. It turns out to be more and more important for farmers of the Central Plateau to have this at their disposal, not only to pay for agricultural production for which they often run into debt at the beginning of the season, but also and above all, to buy food when stocks begin to run low (see e.g. Broekhuyse, 1983, Yonli, 1988).

The objective of *reserve stocks* is in fact included in that of self-sufficiency: a stock of cereals destined - in principal - neither for consumption in the current year, nor for sale or other requirements, but supposed to be kept until after the next farming season. It can be used if the next harvest fails to produce enough food for the farm.

Risk has an important role in the obtaining of income (from farming and other activities) as well as in agricultural production itself. The fact of having an aversion for risk could influence farmers in their choice of crops and combinations of crops (diversification of crops and varieties, mixed crops), see for example Norman, 1974.

Kristjanson (1987) points out that most (risk) studies are based on the principle that decisions are all made at the same moment, for example just before sowing the first field. Yet, farmers make their decisions at different moments of the cropping season, while taking into consideration the information obtained in the meantime (rainfall, vegetable growth, presence of diseases, etc.). Kristjanson concludes that the production systems of farmers should be characterized by optimal flexibility. The flexibility could be increased if there were more possibilities to adapt agricultural methods in the course of the season to the specific conditions of that moment.

In this report the minimisation of risk is not considered as an isolated objective. All the above-mentioned objectives include risks. The extent to which a given objective is realized depends on the results of a great number of different activities which are often all uncertain, and it is up to farmers to adapt their strategies through a diversification of activities (dispersion of risks) and through the aforementioned processes of sequential decision making (risk control).

Broekhuyse (1988) pictures the development of the farms on the Central Plateau going from

- a surplus economy through
- a subsistence economy, to
- a survival economy.

According to him most farms on the Central Plateau are in the last phase: *the survival economy*, a phase where long term investments in the farm are no longer feasible. Consequently, farmers' strategies are determined by short term considerations. The only objective is to get a maximal harvest which permits survival for as many months as possible. All means are used to achieve this objective, even if the long term consequences are disastrous.

3. Some methodological observations on the analysis of farmers' strategies: Systems Approach and Linear Programming

3.1 Systems Approach

In the analysis below use will be made of a *systems approach*. Many types of systems approach exist. Our choice will be dictated by the following objectives:

- to disentangle all factors which influence the farmers' decisions and to clarify their interrelationships.
- to establish a reference framework as basis of linear programming models to be developed to analyse farming systems in quantitative terms.

The systems approach will be centred on a single farm on the Central Plateau in Burkina Faso. A systems approach requires an accurate description of important concepts. A distinction will be made between a descriptive analysis and a normative analysis of farmers' strategies.

A *descriptive analysis* supplies a description of strategies and of factors influencing them. Questions to be studied in such an analysis, are called *empirical questions*. They refer to actual situations in the present and past; examples are: what is the social organisation, what was the reason of migration, what is the method of storage, what were the deficits etc. Most field studies focus on empirical questions.

A *normative analysis* addresses the question of which strategies do well under various conditions and how strategies can be improved. It refers to required changes and to measures to effect these changes. In a normative analysis, *normative questions* or *decision questions* play an important role. Examples of decision questions are: should a member of the family emigrate; should loans be taken up, if yes, how big; when should the farmers sow; which methods of cultivation should be applied etc. A descriptive analysis focuses particularly on present and past, normative analysis on present and future. Results of descriptive analyses are important inputs of normative analysis. Normative analysis can be an important tool for drawing conclusions from descriptive analyses. In this chapter, we will restrict ourselves to normative analysis of farmers' strategies.

A distinction will be made between a *decision* and a *decision (normative) question*. A decision is an answer to a decision question. We will structure the normative analysis by discussing the following items:

- Which decision questions should be addressed? Who takes the decisions?
- Which factors influence the decisions, and which of these factors are explicitly taken into consideration?
- How do the factors influence the decisions?
- On the basis of which criteria are the decisions taken?

We will discuss these questions one by one.

Which decision questions should be addressed?

The decisions taken at the farm level are of a remarkably diverse nature and refer to various domains. In this report we will concentrate on decisions about crop production, consumption, storage and trade of produce.

Crop production decisions are those which have a *direct* influence on the quantity of harvest produce, for instance, decisions on the areas of land to be sown. However, a decision to send some members of the family abroad to earn some money is not considered to be a production decision, although it can have a considerable influence on the production capacity of the family. In this case the influence is *indirect*, via the availability of labour, areas which can be cultivated and other production decisions. Crop production decisions refer to:

- crops to be cultivated and choice of varieties;
- fields to be cultivated (e.g. area to be cultivated); fields to lie fallow;
- timing of sowing and other activities (e.g. weeding);
- agricultural methods to be applied;
- distribution of tasks;
- most appropriate investments; expenditures on tools, mechanical equipment, inputs and other investments in cultivation methods and water management.

Consumption decisions are, for instance:

- the part of the harvest to be kept for consumption;
- the amount of food (cereals) to be taken each time from the granaries for the preparation of meals; the order in which the cereals are to be taken from the granaries;
- the daily consumption pattern (cereals, vegetables);
- what can be done if people face deficits;
- how much sorghum is to be used for the preparation of beer.

Storage decisions may refer to:

- how to store the different cereals (threshed or in the ear) and other crops to reduce storage losses;
- the part of the harvest to be stored as seed for the next season;
- part reserved as safety stock for the next year.

Trade decisions:

- the part of the harvested produce to be sold; where and when?
- how many vegetables are to be purchased? where and at what moment? what are the expenses?
- how can the buying of vegetables be financed? to what extent can income from livestock and other activities of the farm-household members be used? are there transfers from emigrants available? if credits can be obtained, how much should be borrowed?
- what expenses have to be made to transport agricultural produce to and from the markets? what are the most appropriate means of transport (e.g. bicycle, cart)?

It is noted that this list of questions is not exhaustive. Which decision questions should be included in the normative analysis depends primarily on the purpose of the analysis. If the purpose is to explore farmers' strategies on the acquisition and the allocation of credits, it does not make much sense to take into account detailed questions on, for instance, which local varieties of sorghum and millet should be cultivated. Whether a decision question will be included in the analysis also depends on whether enough information is or can be made available to answer it. One must also avoid including too many decision questions in the analysis, so that the analysis cannot be handled properly.

In this report, it will be explored what the determinants of farmers' strategies are. It will in particular be discussed how strategies can contribute to attaining the following objectives formulated by heads of farms in several field studies (see section 2.7):

1) enough production for their own consumption,
2) revenues from sales, (1')
3) the establishment of safety stocks and
4) minimization of risks.

If these objectives are to be considered, it is not immediately evident which decision questions need to be included in the analysis. We will follow a step by step approach. First, we will restrict ourselves to a partial analysis and take into consideration only a part of the important decision questions. On the basis of a comparison of the results of such partial analyses with actual farmers' strategies in practice, we will arrive at a justified extension of the normative analysis.

The set of all decision questions taken into account is called *V*, i.e.:

V =
{ decision questions which are taken into
(2')
consideration in the analysis }

Which factors influence the decisions, and which of them are taken into consideration?

Decisions to be taken at a certain time can be influenced by decisions taken at earlier times and by various exogenous factors. In this section, we will discuss only the influence of exogenous factors; the interrelationship between decisions taken at different times will be discussed in a later section. Exogenous factors can be rainfall and market prices, but also various conditions to be reckoned with in the analysis; for instance, there may be no chemical fertilizer available, or no credit obtainable for purchase of cereals, etc. *Exogenous factors are factors on which the farmers' decisions have no influence*. The set of all exogenous factors which are explicitly taken into account in the analysis, is called *W*. The set *W* can for instance, contain the following exogenous factors as elements:

W = { composition of the farm; size of available area of

land; time of first rainfall; total rainfall in the

(3')

growing season;.....}

Sometimes a factor is considered to be exogenous in a first stage of analysis, in a later stage endougenous; for instance, the level of a grain reserve from the previous year might be considered to be exogenous for a one year planning period, whereas interannual reserves may be endogenous in multi-year planning.

Some of the exogenous factors are of a *stochastic nature*, such as - see (3') - the time of the first rainfall and the total rainfall in the growing season. The other factors are *deterministic*. Sometimes, exogenous factors which are not explicitly included in the set *W*, are there indirectly. Examples are rainfall and soil fertility. These factors have a great influence on crop yields. Let us consider the agricultural production on a certain field. Depending on the depth of analysis, we may instead of rainfall and soil-fertility include crop yields as exogenous factors in *W*.

An important concept in our systems approach is that of *scenario*. A scenario is a realization of exogenous factors, an implementation of the set *W*. For *W* in (3') a scenario could be:

W^* = { the farm consists of 2 men, 3 women and 5 children; the area of the land available for cultivation is 0,5 ha; the time of the first rainfall is the 1st June; ... yield of red sorghum = 600 kg; yield of white sorghum = 620 kg; yield of ground-nuts = 520 kg; ...} (4')

It should be noticed that by considering yields as exogenous factors, it is assumed that the yields on the specified field are not influenced by any of the farmers' decisions. It usually only makes sense to consider rainfall and soil-fertility explicitly as exogenous factors, if the relations between rainfall and soil-fertility on the one hand and yields on the other are known.

At this stage of our systems approach, we need to say more about the concept of *strategy*. Before we define this concept, we will first illustrate with an example: when the first rains fall, the head of the farm will have to decide how much seed he will sow. His decisions might be different according to whether the first rains fall early or late. With early rains he will reserve a part of seeds to anticipate a situation when the rains do not persist and after some time, he will be obliged to resow. Even the choice of the crops (and sometimes of varieties) can change, if the rains appear later or if he has to resow. In fact, the head of the farm will take into account various scenarios (early rainfall, late rainfall) of exogenous factors. He will choose a strategy where he can react adequately to different scenarios. Of course, besides rainfall, other factors can play a role. This example shows the dynamic nature of strategies. A strategy does not refer so much to a fixed sequence of activities to be carried out, but rather to the decisions from which the activities follow.

A strategy is defined here as the set of the decisions to be taken, it means the set of answers to the decision questions of V - see (2').

How do the factors influence the decisions?

We touch here the heart of normative analysis. The decisions are to be taken at various times of the year. We will consider here one *planning period*. It consists of the growing season and the whole year after the growing season. First we take into account the growing season. We divide the growing season into T periods (e.g. weeks, months) which will be numbered t = 1,2,..., T. Without loss of generality, it may be assumed that decisions are only taken at the beginning of each period. The beginning of period t is called time t. Time t = 1 corresponds to the beginning of the growing season, which is assumed to be known. The set V of decision questions - see (2') - consists of T disjoint subsets V_1, V_2,...,V_T with V_t being the set of decision questions to be answered at time t.

If a decision at time t (t ³ 2) follows directly from the decisions at the times 1,2,.., t-1, then we call the decision at time t *passive*. If the decision at time t is different for the different outcomes of the exogenous factors in the periods 1,2,..., t-1, then, we call the decision *conditional.* An example of a passive decision is as follows. Assume that at time t = 1 a.o. the following decision question has to be answered:

V_1 =
{ what is the area of land where white sorghum is
(5')
to be sown?; ....}

and at time t = 2:

V_2 =
{ how much labour should be used in period 2 for
(6')
the cultivation of white sorghum?; ...}

It will be assumed here that the amount of labour necessary to cultivate one ha of white sorghum in period 2 is an exogenous factor. Such an assumption is quite common in farming systems studies. It is, however, not evident. There can be situations when farmers have to decide whether they will put much or little effort per ha in the cultivation of a certain crop, depending on rainfall conditions, the appearance of weeds, diseases etc. Here, this point will not be elaborated further, the labour per ha in period 2 will be considered to be exogenous and deterministic: l manhours per ha. Assume that the answer to the question in (5') is x ha. If we assume that all the land x sown in period 1 is cultivated in period 2 indeed, then it follows that the answer on the question in (6') is lx manhours. The decision which answers question (6') is clearly passive. The assumption that the land will indeed be cultivated in period 2 is called a *decision rule*. Different conditional decision rules are possible as well, for instance:

during period 2 the cultivation of white sorghum is only pursued on plot x if the rainfall in period 1 exceeds a certain level allowing the seedlings grow. Otherwise the land will be available for resowing of white sorghum. (7')

A conditional decision rule corresponds to a conditional ("if-then") decision, the decision to be taken depending on exogenous factors and decisions taken previously. Decision rules can be known and given (for instance on the basis of farmers' experiences) or they can be the subject of study.

In this section we concentrate on the decisions at time $t = 1$. These decisions depend on the exogenous factors e.g. during the growing season. This dependence will be the main point of discussion in the text below. One reason why this dependence is so complicated is the stochastic nature of various exogenous factors.

We will first start with a *given scenario*. This scenario can e.g. be an "expected scenario" (corresponding to "average rainfall", "average yield", "average market prices"), to an "optimistic scenario" ("high yields", "high producer prices") or a "pessimistic scenario" ("low yields", "low producer prices").

We will consider a certain decision question, e.g. the size of the area to be sown with a certain crop on a certain piece of land. It is once more assumed that all conditions of climate and soil on the piece of land are everywhere the same and that one specified method of cultivation is applied. It is recalled - see discussion above - that for a given scenario the yield is known. Therefore, the decision on the size of the area is equivalent to the decision on the amount of produce to be harvested. This decision depends on two questions: how much can we produce and how much do we want to produce.

How much we can produce is predominantly determined by the availability of the production factors, land, labour and capital. In this report land and labour are the most important (see chapter 1). Only these two production factors will be taken into account here. The restrictions are evident: not more land can be cultivated than there is available and during each period $t = 1, 2, ..., T$ no more labour can be mobilized than is available. The formulation of restrictions will be given attention in the next section.

How much we want to produce can be formulated as a requirement, for instance enough should be produced to satisfy the consumption demand. This type of requirement has to be handled with the greatest care. It is not certain that the requirement can be satisfied. Often it has to be reduced to the objective to produce "as much as possible" and deficits will occur. A strategy which satisfies all restrictions and requirements is called a *feasible strategy*.

On the basis of which criteria are the decisions taken?

We will first, as above, deal with the situation where the scenario of exogenous factors is given.

The question of what the good decisions are and what the "best" ones are is difficult to answer. First, we observe that all decisions depend highly on the restrictions and requirements discussed above. We recall again that the farmers try to achieve various objectives - see (1'). Some of these objectives are conflicting, e.g. production for their own consumption and keeping a safety stock reduce the sales.

How should the objectives be weighted? Obviously, there does not exist a blueprint for such a weighting. For various heads of farms on the Central Plateau, this order of objectives coincides with their order of priorities. If their own consumption gets absolute priority, then two situations are possible:

- For the given scenario not enough can be produced, there is a shortage. No surplus is sold on the market (we do not discuss here the important issue - well known on the Central Plateau and in many other parts of Africa - that farmers, even in case of a shortage, sell a part of the produce immediately after harvest and have to rebuy later at much higher prices - see e.g. Yonli, 1988). If financial means are scarce and those have to be used for the purchase of food, no safety stock will be kept for the next year.

- There is a surplus. A weighting has to be made between sales and safety stock. If the revenues from sales can be set aside as "safety stock in cash" to buy food if shortages occur the next year, then the weighting would imply answering the question whether it is preferable to keep reserves in money or in crops. The answer to this question depends among other things on the stochastic nature of prices and on sufficient supply to local markets in the year after the planning year. However, usually revenues from sales are used for urgent expenses. Then the weighting is of a different order. How necessary are the expenses, what are the risks of shortages in the next year? This last question is very much related to the farmers' perception of risks.

Determining a strategy for a given choice of scenarios of exogenous factors is common practice in many (quantitative) farming systems studies. To determine a strategy which is 'good' or 'best', if the scenarios are not (yet) known is, of course, a much more difficult problem. It will be seen in the next section how this problem can be solved approximately by determining strategies which do 'well' or 'the best', if applied to a sample of scenarios, e.g. to a 'pessimistic', an 'average', and an 'optimistic' scenario.

3.2 Systems Approach and Linear Programming

In this section, we shall discuss how mathematical modelling can be applied in normative analysis, identifying some characteristic features. Detailed linear programming models for the "Exploitation Centrale" will be presented in later chapters. We shall discuss the main elements of the systems approach of the previous section point by point.

Decision questions and decision variables

It is necessary that the decision questions can be answered in a unique way. They have to be formulated in such a way that the answer is yes or no or so that the answer can be expressed as quantities.

Each decision question corresponds to a *decision variable*, which takes the value 1 or 0 (answer yes or no) or continuous or integer, often non-negative, values (quantities). The decision variables are chosen in such a way that all decision questions about agricultural methods to be applied, land to be cultivated, dates of sowing etc. can be answered. We shall illustrate how this can be done. It will be assumed that around the compound of the farm a certain number of pieces of land can be distinguished with the property that on one piece of land the conditions of soil and rainfall are everywhere the same. These conditions may differ from one piece of land to the other. The pieces of land are numbered 1, 2, ..., m with m the number of pieces of land to be distinguished. Assume that we are to investigate which areas of each piece of land will be set aside to grow white sorghum, whether the sowing should be done on the 15th or the 30th of June, and whether agricultural method A or B is to be applied. We might then introduce the following decision variables:

x_1 size of the area (in ha) of the land on piece 1, where white sorghum is sown on the 15th of June and agricultural method A is applied.

x_2 dito, but method B is applied. (8')

x_3 size of the area (in ha) of the land on piece 1, where white sorghum is sown on the 30th of June and agricultural method A is applied.

x_4 dito, but method B is applied.

In this way, we obtain in general a certain number, called n, of decision variables x_j, j = 1, 2, ..., n, with x_j being the size of the area of land where a certain crop under specified conditions is cultivated. The land of which x_j is the area is called "plot *j*", the crop which is cultivated on plot *j* is called "crop *j*". The crop *j* may also correspond to mixed cropping or to fallow-land. For other types of decision questions, the choice of decision variables is evident, for instance the amount of sorghum to be sold in the periods *t* etc. A set of values of all decision variables, e.g. x_1 = 0,6 ha, x_2 = 0, ..., is called a solution. A strategy corresponds to a solution.

Exogenous factors and parameters

Many exogenous factors are dealt with by the choice of the decision variables (e.g. which crops are to be cultivated, there is no access to credits etc.). The exogenous factors introduced in (3') correspond to *parameters* in the mathematical model. A scenario W^* - see (4') - corresponds to a choice of values of the parameters. Which parameters are of importance will be discussed below.

Modeling farmers' strategies.

We shall not discuss here all types of constraint which may be part of a linear programming model for farmers' strategies, but select only a few for illustration. Detailed models will be dealt with in later chapters. As was discussed in the previous sections, restrictive conditions of e.g. labour are of importance.

The *labour constraints* can be written as:

$$\sum_{j=1}^{n} l_{tj}\, x_j \leq L_t\,, \quad t = 1,2, ..., T. \qquad (9')$$

For j = 1,2,..., n; t = 1,2, ..., T the parameters l_{tj}, L_t are defined as:

$$(10')$$

- l_{tj} labour required during period t to cultivate one ha of plot *j* in manhours/ha.
- L_t labour available in period *t* in manhours.

Crop rotation, including the system of shifting cultivation leaving land fallow for a period of years before it is cultivated again is one of the difficult aspects of an analysis of agricultural production systems. We shall not elaborate this issue here. In this report we shall focus attention on the land to be left fallow, see chapter 5, rather than on crop succession or crop rotation practices. For a detailed discussion on the handling of multi-year crop rotation requirements in a linear programming model for strategies of *one* growing season reference is made to Schweigman (1985).

Other conditions can also be formulated as constraints, e.g. the requirement that a certain prescribed amount of food has to be produced. In chapter 5 such a constraint will be explicitly taken into consideration. It was argued in section 3.1 that it can be useful to replace such a condition by the objective of producing as much food as possible. If 4 types of cereals are the main food crops, to be indicated by $f = 1,2,3$ and 4, then the objective of producing as much as possible of these cereals can be formulated as:

determine the maximum value of:

$$\sum_{f=1}^{4} \sum_{j=1}^{n} y_{fj}x_j \qquad (11')$$

with: y_{fj} yield of food f on plot j. (12')

Instead of cereal production, we could also maximize the production of calories, vitamins etc.

If the possibility of the sales of a surplus or more generally, the marketing strategy of selling and purchasing food crops is to be studied, then we divide the planning period in small periods of time $t = 1,2,...,T$ and introduce the following new decision variables for $t = 1,2,..., T$:

v_{ft}

the quantity of food f, which is sold in period t.

(13')

a_{ft} the quantity of food f, which is purchased in period t.

A marketing strategy corresponds to values of these decision variables, which have to satisfy the non-negativity conditions.

$v_{ft} \geq 0$,

$f = 1,2,3,4$; $t = 1,2,..., T$

(14')

$a_{ft} \geq 0$, $f = 1,2,3,4$; $t = 1,2,..., T$

We introduce the following parameters:

S_{f0} initial stock of food f available at the beginning of the year. (15')

d_{ft} demand for food f for consumption during period t, $t = 1,2,.., T$.

We recall that the period t=1 corresponds to the first period of the growing season. We assume here that all crops are harvested at one certain time u. In later chapters different harvest times will be used too. In order to determine the surplus, we make use of *storage equations*, in which the following quantities occur:

S_{ft}

the level of the stock of food f at the end of period t.

(16')

If storage losses are left out of consideration, the food storage equations read for f= 1,2,3 and 4:

$$
\begin{aligned}
S_{fu} &= S_{f,u-1} + \sum_{j=1}^{n} y_{fj}x_j + a_{fu} - v_{fu} - d_{fu} \\
S_{ft} &= S_{f,t-1} + a_{ft} - v_{ft} - d_{ft}, \quad t = 1,\ldots, T,\ t \neq u
\end{aligned}
\qquad (17')
$$

Stock levels cannot take negative values, so we have:

$$S_{ft} \geq 0, \quad f = 1,2,3,4;\ t = 1,2,\ldots, T. \qquad (18')$$

If condition (18') is postulated, then we state that the demand for consumption is to be satisfied throughout the whole planning period. If the food supply is not enough, the food must be bought. To verify whether this is possible or not, we need to set up in a similar way a "storage equation" for the financial means. We will not elaborate this equation which includes elements such as revenues from local off-farm employment and livestock, income sent by emigrated relatives, investments, expenses for inputs, etc. Instead, we make a few observations on the formulation of the annual revenues from sales and of the expenses for purchases of cereals. We introduce as parameters the following prices:

c_{ft} kg-selling price of food f in period t (19')

p_{ft} kg-purchase price of food f in period t

The net-revenues can be written as:

$$I = \sum_{t=1}^{T} \sum_{f=1}^{4} \{c_{ft}v_{ft} - p_{ft}a_{ft}\} \qquad (20')$$

The cereal stock level at the end of the planning period equals:

$$S_T = \sum_{f=1}^{4} S_{fT} \qquad (21')$$

with S_{fT} given in (16')

If we want to keep a safety stock level s^* at the end of the year, then the following condition can be imposed:

$$S_T \geq s^* \geq 0 \qquad (22')$$

s^* is a decision variable. Referring to the discussion at the end of the previous section, in case of a surplus, a weighting has to be made between net income I and s^*. Such a weighting can be dealt with as follows. We postulate:

$$p \cdot s^* \geq fr \cdot I \qquad (23')$$

with the fraction fr a chosen parameter and p an average cereal price, for instance at the end of the period. Moreover:

maximize the value of I. (24')

We do certainly not pretend to have discussed all elements of a mathematical model which can be used in a normative analysis of farmers' strategies, neither that the linear programming model (9')-(24') is sufficient to describe properly the farmers' strategies. In fact the simple model (9')-(24') to be worked out in detail for the "Exploitation Centrale" in chapter 5 is not sufficient. At the end of chapter 5 it will be argued what the shortcomings of this model are and a more realistic model will be presented in chapter 6.

3.3 Stochastic nature of yields and sequential decisions

Up to now, we have assumed that the scenario of exogenous factors, i.e. of all parameters in the linear programming model, is known. The stochastic nature of yields and prices has not been taken into consideration. Referring to the previous section, we might deal with it by carrying out the computations for various different scenarios, e.g. an average, optimistic and pessimistic scenario. For each scenario, estimates have to be made of all parameters, in particular of the parameters y_{fj} in (12') and of the prices c_{ft}, p_{ft} in (19'). To different scenarios correspond different "optimal" solutions. Once again, we face the problem of choosing which optimal solution should be considered to be the best one. This depends very much on attitude to risk. Here we make a few remarks on an approach which explicitly takes into account the stochastic nature of e.g. yields. In principle, all parameters y_{fj} in (11') are then stochastic. We do not enter the very difficult problem of estimating the joint probability distribution of all y_{fj} 's. We assume here that we have a sample of ê drawings y_{fjk}, k = 1,2,..., ê for each y_{fj}. The ê drawings y_{fjk}, k = 1,2,..., ê correspond to different scenarios for ê years. Consider the linear programming problem (11') with x_j satisfying (9'). If we try to determine values of x_j, j = 1, 2, ..., n in such a way that on the average over ê years cereal production should be maximal, then we have to solve (9') and (11') with the parameters replaced by:

0 (25')

This is equivalent to the computation of x_j, j= 1,2,.., n for an average scenario. We could also apply different other criteria, e.g. minimizing the probability that during the ê years shortages occur or minimizing the expected shortage over all years. The last objective can be formulated as follows:

$$\text{minimize: } \sum_{k=1}^{ê} \sum_{f=1}^{4} \max\Big(d - \sum_{j=1}^{n} y_{fjk}\, x_j;\ 0\Big) \qquad (26')$$

with:

4

$d =$ Ó$_{f=1}$ d_f , with d_f given in (15') (27')

The optimization problem (26') and (9') can be formulated as a linear programming problem. If the number of decision variables is not too large, then with the aid of existing software such problems can be solved in a reasonable time.

Sequential decisions

At the end of this chapter we return to conditional decision rules introduced in section 3.1. We concentrate on the stochastic nature of the *rainfall* in the first period. It is supposed that the stochastic nature of the rainfall R_1 in the first period is known by its probability distribution (estimated on the basis of observed rainfall data in the past). Let R_{1k}, k=1,2,..., ê be ê drawings from this distribution. For reasons of illustration, it may be assumed that those ê drawings correspond to the rainfall in the first period in ê successive "hypothetical" years. At the beginning of each year the same values of the areas x_j, j= 1,2,..., n are chosen. In the different years the areas to be cultivated in the periods t=2,3,..., T will be different depending on the rainfall in the first period. The following decision variables are introduced for t=1,2,..., T; j=1,2,...,n; k=1,2,..., ê:

x_{tjk}

area for crop j in period t of year k

(28')

It may be written:

x_{1jk} $= x_j$,

j = 1,2,..., n; k = 1,2,..., ê

(29')

If crop 1 refers to white sorghum, the decision rule (7') can be written as:

if $R_{1k} < \beta_1$,

then $x_{21k} = 0$

(30')

$R_{1k} \geq \beta_1$, then $x_{21k} = x_1$.

We assume that the value of the parameter β_1 is known. Of course, many other decision rules can be postulated.

For the other periods we write:

$x_{tjk} = x_{t-1,j,k} = x_{2,j,k}$,

$t = 3,4,..., T$.

(31')

The *labour constraints* (9') have to be changed as follows:

$$\sum_{j=1}^{n} l_{1j}x_j \leq L_1 \tag{32'}$$

$$\sum_{j=1}^{n} l_{tj}x_{2jk} \leq L_t \ , \quad t = 2,3..., T,$$

with l_{tj} and L_t given in (10'). The objective to maximize the average cereal production over the κ years can be formulated as:

maximize 0 (33')

Finally, the following optimization problem is to be solved: (33') with the decision variables x_j, x_{2kj}, $k = 1,2,..., \kappa$; $j = 1,2,..., n$ satisfying constraints such as: (9'), (29') - (32') and

x_j, $x_{2jk} \geq 0$,

j = 1,2..., n; k = 1,2,..., ê.

(34')

This is a linear programming problem in continuous variables and easily to solve, if the number of decision variables is not extremely large. In this way it is possible to investigate the influence of conditional decision rules.

3.4 Final observation on a normative analysis

In a descriptive analysis of farming systems, it is usual to try to describe the actual household situation and farmers' behaviour. The only bias in a descriptive analysis is due to the fact that the researcher and assisting field workers do not observe well enough, have their own preoccupations, do not ask the right questions or do not get the right answers. The normative analysis as described above, which is primarily a tool for the researchers and interested staff workers, has two types of inputs: the results of descriptive analyses and various agricultural, climatic, economic and technical information such as the relation between soil conditions, agricultural methods and yields etc. The strength of a normative analysis is its power to study all important elements influencing farmers' strategies and their interrelationship in a coherent way. But there are also important weaknesses. In a normative analysis biases can occur at two different points. Since results of descriptive analyses are important inputs, the first bias is that mentioned above. The second bias is due to the fact that the model is different from reality because many simplifications, assumptions, choices, and estimates have to be made. We touch here on the important issue of validation. Can we validate the models used? The answer is yes and no. It is not possible to validate the whole model and all assumptions which have been made. But many details of the model can be validated very well. The normative analysis as discussed here will always be an instrument which has to be handled with the greatest care. It is complementary to various other approaches, analyses and insights.

4. Production factors 'land' and 'labour'

4.1 Results of village investigations

Estimates of the cultivated area per head of the rural population can, at an aggregated level, be found in table 2.2. The estimates vary from 0.39 ha/person, for Centre North region, to 0.49 ha/person for the Centre and Yatenga regions. Snijders et al. (1988) present regional data on cultivated area per capita as well. In this study several agriculture statistics covering the Centre, Centre North, Centre West and Yatenga regions on the Central Plateau, over the period from 1970 to 1987 have been analyzed. The estimates of the area cultivated per head of the rural population are considerably lower in this study (see table 4.1).

Similar data collected in village studies vary widely as can be seen in table 4.2.

Table 4.1 Agricultural data related to the Central Plateau.

	Centre	Centre-Est	Centre-Nord	Yatenga	Central Plateau[5]
1975					
- sown area (1000 ha)[1]	354	152	249	216	971
- rural population (1000 inhab)[2]	816	440	687	576	2.519
- area/capita (ha/inhab)[3]	0,43	0,29	0,36	0,38	0,39
1985					
- sown area (1000 ha)[4]	342	186	242	114	884
- rural population (1000 inhab)	1.065	567	799	537	2.968
- area/capita (ha/inhab)	0,32	0,33	0,30	0,21	0,30

Notes:

- The data of 1970 and 1985 related to the planted area have been obtained from the Ministry of Agriculture and Livestock.
- The data related to the resident population have been taken from Konaté (1988), based on the general population census of 1975 and 1985.

1) Only the area on which the cereals sorghum, millet and maize are grown.
2) In the province of Kadiogo in the region Centre the majority of the population lives in Ouagadougou and does not work in agriculture; the rural population in the region Centre has been determined as: the total population - the population of Kadiogo.
3) Area/caput: cultivated area/rural population.
4) 1985 was a bad season (little rain). The areas sown in that year were much less numerous than in the following year.
5) The Central Plateau is defined as the total of the four regions.

Source: Snijders, Djiguemdé, Schweigman, Maatman (1988).

Table 4.2 Data on arable farming acreage, gathered in several village

Studies	N[1]	Surface cultivated per farm	Surface cultivated per inhabitant	Surface cultivated per active
Broekhuyse, 1982: villages studies '80 - '81				
- Tanpooré	8	1.78 (0,32)[3]	0.21	0.47
- Basperiké	8	3.30 (0,64)[3]	0.30	0.56
- Koalma	7	1.92 (0,44)[3]	0.23	0.51
ICRISAT (McIntire, 1983): villages studies 1980				
- Nakamtenga	24 (67% AT[2])	2.56[4]	0.26	
- Nabitenga	20 (55% AT[2])	3.42[4]	0.31	
ICRISAT (Matlon and Fafchamps, 1988) Yako Region: villages studies 1981-1985				
- Kolbila	21	5.6[5]	0.41	
- Ouonon	13	2.9[5]	0.42	
ICRISAT (Prudencio, 1983): villages studies 1981				
- Nonghin	6	1.9	0.29	
Safgrad/FSU (Lang et al, 1984): villages studies 1982 - 1986				
- Bangassé	30 (4 AT[2])	2.1 (0.9)[6]	0.26 (0.1)[6]	0.34
- Nedogo	30 (17 AT[2])	7.1 (3.9)[6]	0.68 (0.3)[6]	1.34

Notes:

- WS: white sorghum, MI: millet, RS: red sorghum, MA: maize, GN: groundnuts

1) The majority of the results refer to samples of farms without animal traction. For mixed samples of farms with and n, each time the proportion between both types of farms is given.
2) AT : Farms with animal traction equipment
   NAT: Farms without animal traction equipment
3) Acreage of individual fields of women in brackets.
4) Acreage of common fields only.
5) Acreage of comon and individual fields together. For the two study-villages together: 70% of the total acreage were individual fields of women and 8% individual fields of men.
6) Standard deviation in brackets

4.2 Plants and soils: land use patterns

This section will deal with some relationships between crops and soils. A more detailed description of soil types on the Central Plateau and their properties is presented in chapter 2 of the original report of Maatman and Schweigman (1995). First, we will discuss the influence of the topography of fields on the choice of crops, next the impact of the distance of fields from the compound dwellings on crop choice and agricultural methods.

4.2.1 Topography and types of crops grown

The position of the lands on the slopes is often referred to as "toposéquence". In figure 4.1 a schematic picture is given of the toposéquence. The change in type of soil from high to low on the slopes ("toposéquence") is, broadly speaking, accompanied by an increasingly falling infiltration capacity and an increasingly rising capacity to retain water. As a result different crops are cultivated by the farmers at the different positions on the slopes. On the lower parts of the slope, where much water is accumulated and the bottom often contains more loam, there is a risk of floods. The higher one gets, the sandier the fields become. The water retaining capacity decreases and the drought risks increase. If there is heavy erosion, the content of organic material also drops considerably, which means that the fertile top layer becomes thinner. Here one also finds the transition between the millet and sorghum fields. In the fields that are situated at a higher altitude the flood danger is remote (apart from a few pools just after a shower) and this benefits the millet which does not like 'wet feet'. Moreover millet has a better resistance to long periods of drought and can produce some harvest, even on very marginal soils (low soil fertility).

Of the cereals sorghum, millet and maize, maize is the most vulnerable. To have a good harvest the field should not be flooded, there should be no drought periods and the field must be sufficiently fertile. As a rule maize fields are therefore well fertilized and maintained. Maize is usually grown round the dwellings. In view of the intensive working of the fields the difference in altitude does not play such a big part, although maize fields are rarely found in rather low (flood danger) or rather high (risk of drought) parts of the slope.

Data on the relation between toposéquence and yield per ha of crops.

Although the great importance of the position on the toposéquence on the crop yield per ha has been pointed out in many publications, still little quantitative information on the subject is available. In Matlon (1984) average yields of crops, and their standard deviations, have been classified in accordance with the position on the toposéquence (see table 4.3). The data were gathered in 1981 in the villages Nakamtenga and Nabitenga on the basis of agronomic experiments which had been carried out by farmers on trial fields. His findings do not supply a great deal of information. Obviously many other factors may have played a part, judging by the large standard deviations.

Figure 4.1: Illustration of the "toposéquence" in Sabouna (Yatenga).

[redacted]

Source: Dugué, 1985 (adapted from Marchal).

[redacted]								
- Observations	0	1	1	1	0	1	1	1
Upper slope								
- Mean yield	268	305	773	605	966	1048	1256	1102
- Standard deviation	268	395	377	473	668	763	480	553
- Observations	8	7	7	12	8	17	9	12
Mid-slope								
- Mean yield	685	311	537	626	1405	915	1369	1197
- Standard deviation	609	376	374	459	763	362	583	454
- Observations	17	16	15	24	17	16	15	24
Lower slope								
- Mean yield	810	516	602	606	1389	1106	1202	1150
- Standard deviation	645	655	313	313	1162	799	1033	588
- Observations	4	6	4	4	4	6	4	7

Notes:
- Low management: no tillage, no fertilizer
- High Management: preplanting, plowing and 100 kg. NPK(14:23:15)/ha.
- E 35-1; 38-3; CSH5 etc.: improved varieties.

Source: Matlon (1984).

Kristjanson (1987) has tried, on the basis of production data provided by ICRISAT village studies, to estimate empirical production functions through regression analysis; with the aid of these results the relative effect of e.g. the toposéquence on the yields per ha can be estimated. As regards the effect of the toposéquence, Kristjanson finds a clearly significant effect of the lower clayey soil on sorghum, compared to the sandy soil at a higher altitude. For sorghum the yields per ha are, relatively speaking, i.e. all other conditions being equal, higher by 110 kg/ha in the lower slope areas; the relative increase for millet is lower, 46 kg/ha and not significant.

In Prudencio (1983), too, production functions are estimated on the basis of data from village studies on the Central Plateau. He has estimated two different types of production functions (a Cobb-Douglas function and a linear function) to "explain" the influence of a large number of variables on the yields. The estimates are hardly ever significant and there are large differences between the Cobb-Douglas and the linear estimates. The analyses do not demonstrate a clear relation between toposéquence and crop yields.

4.2.2 Cultivation in rings

For the Mossi, cultivation methods as far as crop systems and cultivation intensity are concerned, do not only depend on the toposéquence, as we discussed above, but also on the distance between the fields and the dwellings. This means that land use patterns change when the fields are at a greater distance from the dwellings. In order to get a better understanding of the typical cultivating systems of the rainfed agriculture on the Central Plateau, it is useful to use the concept of the 'cultivation in rings' (Pelissier, 1966). Prudencio (1983,1987) has demonstrated that it is possible to identify certain basic rings in the management of land and crops round each dwelling. The management of land and crops refers in particular to the following variables:

(i) the use of fertilizer or manure

(ii) mixed cropping

(iii) the use of fallow land to improve soil conditions

(iv) crop rotation

Prudencio distinguished three "rings":

Ring 1: Near the dwellings the utilization of land is usually the most intensive. Maize and vegetables are grown on a few small fields. To these fields the largest dose organic manure is applied. Since the maize can be harvested a few weeks in advance of the other cereals, these maize fields are of special importance. Towards the end of the growing season the granaries gradually become empty and the maize harvested is sometimes urgently required at that time. Apart from these small fields usually some larger fields are grown with red sorghum, white sorghum and/or millet. In these fields, too, sizeable quantities of organic manure are applied. In this 'first ring' there is hardly any intercropping with cowpea. Animals roaming in the neighbourhood of the compounds might eat the cowpea leaves and so cause a lot of damage to the fields.

Ring 2: At a further distance (second ring) the application of organic manure decreases rapidly. Instead of organic manure sometimes small doses of chemical fertilizer are applied. Occasionally the fields are left fallow. Maize is no longer grown here. Sorghum (both red and white) and millet fields are dominant, but now mainly intercropped with cowpea. Often a few small fields are used to grow groundnuts. Most anti-erosion and soil and water conservation methods are applied in this "second ring".

Ring 3: In the 'third ring', the level of soil management is low. Leaving fields fallow is the main method used to keep up the fertility of the soil. White-sorghum and millet fields dominate, intercropped with cowpea. Anti-erosion measures and soil and water conservation methods are fairly rare phenomena.

The toposéquence and the distance of the fields to the dwellings of the compound have considerable influence on the different cropping systems of the farm. The influence of the toposéquence is explained by its direct relationship with the soil characteristics. It is above all the time taken up in going to the fields and returning to the compound dwellings which explains the reduction of labour intensity when the fields are located further away from the dwellings. Of course, these variations in cropping practices will eventually have a certain impact on the quality of the fields at different distances (see Prudencio, 1983).

In the figure 4.2 a transverse section of a valley is depicted. The compound dwellings are usually constructed on the slopes, somewhat distant from the low lands. In section 5 we will distinguish between lower and higher lands. The higher lands comprise the plateaus and the higher and mid slopes; the lower lands include the low lands and the lower parts of the slope. Furthermore, a distinction will be made between fields who are at a short distance from the dwellings (less than 100 m.), fields between 100 and 1000 m. from the dwellings and fields at a distance of more than 1000 m. from the dwellings. This approaches the distances between the three rings discussed above (Prudencio, 1987). Combining the toposéquence and the distance of the fields, we will distinguish 5 different categories of land, called *S1, S2, S3, S4 and S5*. In this section we shall deal in more detail with the relations between the distance from the dwellings to the fields and the four variables mentioned above, as described in Prudencio's research (1983, 1987).

4.2.3 Application of manure or fertilizer

Within a 'ring' there are also big differences in crops, rotation schemes and soil management methods. Therefore another distinction is made in the table below between some 'sub-rings' within a 'ring'. In table 4.4 some data from an investigation by Prudencio in respect of manuring/ fertilization have been assembled (Prudencio, 1987).

The pattern in this table is clear, with manuring schedules of a decreasing intensity as fields are at a greater distance from the dwellings. What is striking, is the very large quantities of manure administered in the 'sub-rings' 1A, 2A (for Kolbila) and 1 (for Nonghin). The doses organic manure here are 4 to 5 times as big as the doses administered in the other 'rings'. Moreover, practically the entire area in these 'sub-rings' is manured.

Table 4.4 (continuation) Manuring schedules and fallow land methods for the various 'rings' Kolbila (Yako region) and Nonghin (Manga region).

Kolbila -- Yako region --	Ring 1	Ring 2			Ring 3	Total
		A	B	C		
Average distance of fields	25	227	140	456	3024	-
Ring area as a percentage of total cultivated area	2.7	16.4	9.1	10.4	61.4	100
Percentage of ring area that has been fertilized with organic manure	85	62	60	16	0	20
Average amount of farmyard manure applied in fertilized fields (kg/ha)	10500	1550	2200	1250	0	2754
Mean frequency of organic manure application (years of application in all fields during past 6 years)	5	3.6	2.4	1	0	-
Percentage of fields fallowed during past 50 years	35	24	64	56	81	-
Average no. of years since the last fallow occurred	14	18	14	8	6	-
Average length of the last fallow period (in years)	3	6	13	13	5.5	-
Adjusted average intensity of land-use	96	94	80	60	30	50

Notes:
- The results given in this table are average values for the total sample, i.e. for 6 farms without and 19 farms with

Nonghin -- Manga region --	Ring 1		Ring 2		Ring 3		Total
	A	B	A	B	A	B	
Average distance of the fields	18	55	1050	1050	1500	1400	-
Ring area as a percentage of total cultivated area	0.8	13.3	1.5	18	36.5	30	100
Percentage of ring area that has been fertilized with organic manure	97	80	85	48	0	0	21
Average amount of farmyard manure applied in fertilized fields (in kg/ha)	7500	1900	8320	1408	0	0	2288
Average years of application of farmyard manure in all fields during past 6 years	5.9	4.8	3.5	2	1	0	-
Percentage of fields fallowed during the past 50 years	30	33	100	90	100	100	-
Average no. years since the last fallow occurred	40	40	6	13	10	20	-
Average length of last fallow period (in years)	12	15	10	14	10	13	-
Adjusted average intensity of land-use (R)	100	100	50	50	50	30	51

Notes:
- The results given in this table are average values for the total sample, i.e. for 25 farms without and 3 with animal traction.

Source: Prudencio (1987).

These big doses of especially organic manure are only applied to maize fields. According to Prudencio (1983) manuring schedules depend on both the distance, in view of the cost of transporting the manure to the fields, and on the crops or combination of crops that are grown.

On the basis of the data from Prudencio (1987) and Matlon and Fafchamps (1988) and data on average size (in ha) and composition of the farms investigated (partly mentioned in table 2.2) we have calculated how much manure and fertilizer is used on average per farm and per head (table 4.5). It is remarkable that the quantity of manure applied per head does not differ much between the farms in Kolbila and Nonghin, although they differ considerably in average size (number of ha) and composition.

Table 4.5 Average levels of manuring and fertilizing per farm based on data SAT village studies in Yako region (1981-1983) and by Prudencio (1987) in the in and Kolbila (1981).

	N[1]	Number of persons per farm	Cultivated surface area per farm	Manure		Fertilizer	
				per farm (kg)	per head (kg/ head)	per farm (kg)	per head (kg/ head)
ICRISAT (Matlon and Fafchamps, 1988) Studies of villages, 1981-1983							
- Kolbila and Ouonon	34[2]	11.4	4.7	1828	160	52	4.6
ICRISAT (Prudencio, 1987) Studies of villages, 1981							
- Kolbila	25[3]	13.5	5.8	2787	206	101	7.5
- Nonghin	25[3]	7.3	3.2	1763	245	21	2.8

Notes:
1) Number of farms in the sample.
2) Only farms without animal traction.
3) Kolbila: 22 farms without, 3 farms with animal traction.
Nonghin: 6 farms without, 22 farms with animal traction.

Source: Adaptation of Prudencio (1987) and Matlon and Fafchamps (1988).

Data on the effect of manuring on yields per ha.

In Prudencio's (1983) and Kristjanson's (1987) studies an attempt was made to arrive at an estimate of the relative effect of manuring and of chemical fertilizing on the yield of sorghum, millet and maize. Manuring has a significant effect on the yield of both crops. According to the study of Kristjanson (1987), the relative effect is greater in the case of millet than it is in the case of sorghum. The marginal physical product of organic manure is 0.044 kg/ha (per kg/ha manure) for millet and 0.018 kg/ha for white sorghum. A small effect on productivity, which, according to Kristjanson (1987), could explain the non-existence of a market for organic manure. On the other hand, Prudencio states that it is not possible to give a correct estimate of the relative effect of manure on the yield per ha from millet and white sorghum fields, because there is hardly any manuring on these fields and therefore no scope for the necessary observations. Prudencio (1983) confirms, however, that manuring does have an important effect on the yield per ha of red sorghum. At the present input levels the marginal physical product of manure is much higher for red sorghum than for maize, 0.91 kg and 0.02 kg respectively per kg of manure. On the basis of these figures it seems attractive to apply less manure to the maize fields and more to the red sorghum fields. Prudencio (1983) assumes that in particular the high cost of transport of manure (labour-wise) prevents a more intensive manuring of the red sorghum fields, which are situated at a greater distance from the dwellings than the maize fields. Kristjanson reports another problem of assessing the influence of the application of organic manure on crop yields: the soil type variables could be responsible for a large part of it. As a consequence, the influence of organic manuring on crop yields is probably underestimated in the analyses of Prudencio (1983) and Kristjanson (1987).

4.2.4 The intercropping of cereals and cowpea

Of the various types of intercropping, the growing of cowpea in sorghum fields and millet fields is by far the most common on the Central Plateau. Therefore we shall pay special attention to this combination. In the past this practice of cultivating several crops at the same time has often been regarded as outdated and inefficient. It concerns, however, a technique that is widely used in Africa and has a number of advantages including, according to Steiner:

- Better use of limited resources (light, water, nutrients) which results in a better return per land unit and per time unit.
- Increasing the stability of returns in order to limit the chances of a drop in income to a point below subsistence level.
- Reducing production losses caused by weeding, diseases and animals.
- A contribution to the keeping up of soil fertility by means of a reduction in erosion and in the draining off of nutritive material.
- A better balanced repartition of the available labour over the season. (Steiner, 1984: 213).

Research into intercropping on the Central Plateau.

Tests by ICRISAT in the village of Koho, where on certain farms the farmer himself experimented with different types of intercropping on test plots, show an average cowpea yield of 150 kg/ha (low management, 3000 plants/ha). McIntire (1981) analyses the economic consequences of intercropping on the basis of data produced by two village studies, one in Nakamtenga and one in Nabitenga. Intercropping in these villages was particularly practised on the millet and sorghum fields, where mostly cowpeas were sown as secondary crop. In general intercrops produced somewhat higher returns, but in particular the intercropping of maize with red sorghum showed a significant difference in income per hectare (McIntire, 1981: 53). The share in the income attributed to cowpeas was in all cases very minor; not more than 11% of the income per ha of the intercrops of millet and sorghum with cowpeas was produced by cowpeas. Elsewhere, (McIntire, 1983) it is stated that 1980 was a poor year in Nakamtenga and Nabitenga and that in that year the cowpeas had brought an exceptionally low return.

Studies by FSU/SAFGRAD and ICRISAT into the objectives of the farmers have shown that in intercropping maximization of the cereal harvest is the primary objective. The returns produced by the secondary crop is of more or less marginal importance (FSU/SAFGRAD, 1983; Matlon, 1984). Therefore the secondary crop, cowpeas, should hardly have a negative effect on the production of cereals (sorghum or millet).

4.2.5 Using the fallow land system to regenerate the soil

Fallow land and crop sequences are important instruments to maintain the fertility of the soil. Here we shall concentrate on fallow land. The land-use intensity depends on the average length of the fallow period and the average length of the period of cultivation. Different indicators are used to measure the intensity of land-use. (see a.o. Allan, 1965; Ruthenberg, 1980). In this report two indicators will play a role. We define:

L_c

length of period of cultivation
(1)

L_f length of period of fallow

The two indicators are:

- the land-use intensity factor R (from Ruthenberg) given by:

$$R = 100 * L_c/(L_c + L_f)$$

(2)

- the land-use intensity factor I given by:

$$I = L_f/L_c$$

(3)

The definition of these indicators results in

$$I = (100/R) - 1$$
(4)

Following Ruthenberg (1980) often the following land-use systems are distinguished:

Shifting cultivation $R < 33$, i.e. $I > 2$

Fallow system $33 \leq R \leq 66$, i.e. $0.5 \leq I \leq 2$

Permanent cultivation $R > 66$, i.e. $I < 0.5$

An increasing R and the decreasing I correspond to an increasingly intensive land-use.

In table 4.4 an estimate of R has been given for each ring. The method used to estimate Ruthenberg's land-use intensity factor is the following: First the following data are collected for all investigated fields, that is fields that are cultivated: 1) the number of years (L_s) the field has been cultivated continuously, without a fallow period, and 2) the length of the last fallow period (L_d). L_s and L_d are then used as estimates of the average length of cultivation periods (L_c) and the average length of the fallow periods (L_f) of the field. Next the land-use intensity factor R of the field is determined according to the approximative formula $L_s * 100 / (L_s + L_d)$. Next a weighted average is determined of all R's of those fields that are situated within a certain ring (see table 4.4) and of those fields on which the same main crop is grown (see Matlon and Fafchamps, 1988); the weighting coefficient is the fraction given by the surface area of the field over the total of the cultivated area[2].

The estimated average land-use intensity factor lies between 33 and 66 for both villages in table 4.4. From these data it appears that both villages have already made the transition from a 'shifting cultivation system' to a 'fallow system'. When we look at the different rings, we are able to differentiate the above conclusion. In the first 'ring' there hardly seems to be any fallow ($R > 95$). So here we see permanent cultivation. In the second 'ring' fallow system is applied, although the land-use intensity factor R varies greatly between the two villages and between the various 'sub-rings'. In Kolbila the fields in the 'second ring' are cultivated on average for as long as they lie fallow ($R = 50$), in Nonghin the land-use intensity varies between 60% and 95%. The third 'rings' have the least intense cultivation, the land-use intensity in Nonghin on these fields is 50% on average, in Kolbila this lies between 30% and 50%.

The above shows that the use of only one average land-use intensity factor for the entire cultivated area should not be recommended for a 'ring' system such as is applied on the Central Plateau. The ring system is after all characterized by partly permanent, partly semi-permanent and sometimes even extensive land-use with long fallow periods.

Data on the effect of fallow on the yield.

The effect of fallow periods on yield has hardly been studied at all. Also in the regression models of Prudencio (1983) a fallow period has not been included explicitly as an explanatory variable (see appendix 2). The variables "age of the field" and "rings" which are partly related to the fallowing methods have, however, been included in the analyses. The "age of the field", that is the number of years a field has been cultivated without interruption, proves to have only a slight negative effect on the yields of maize, white sorghum and/or millet. It is, however, not significant. The positive effect of the "age of the field" on the red sorghum yields is significant. Prudencio believes this is due to the positive effect of the gradual substitution of the rarely manured white sorghum and millet fields by intensively manured red sorghum fields.

4.3 Production factor 'labour'

4.3.1 The labour calendar

In this section the timing of labour inputs will be discussed. When do the various agricultural activities take place? Sowing strategies will get particular attention.

The labour calendar follows the rhythm of wet and dry season. During the growing season on each field different stages can be distinguished when different activities are carried out. These stages depend to a large degree on the growth-cycle of the plants, see table 4.6.

Table 4.6 Pattern of agricultural activities depending on the growth-stage of the crop.

Stage	Growth-cycle of plant	Activity
1	-	clearing, preparation of land
2	-	sowing
3	-- start of vegetative phase -- germination, emergence	transplantation, resowing
4	-- vegetative and reproductive phase -- panicular initiation, heading, flowering	weeding
5	-- phase of maturation -- pollination, grain filling	last weedings, harvest

Some activities like manuring, anti-erosion measures and methods of conservation of water can be done at various stages, sometimes even in the dry season. When a certain labour activity has to take place depends not only on the growth-cycle of the plant, but also on rainfall and soil conditions (toposéquence). Whether and how intensively agricultural activities are actually carried out depends on other factors as well, for instance on the availability of labour, of manure and seeds and on the relative importance of the various fields.

In table 4.7 the labour calendar, also sometimes called crop calendar, based on the ICRISAT studies in Nakamtenga and Nabitenga, is presented. The labour calendar presented shows a fairly consistent picture of the time scheduling of the agricultural activities on the Central Plateau. During the period of the first light showers the sorghum and millet fields are cleared. In this period there is not much time to plough, the fields have to be seeded as soon as possible.

The sorghum and millet fields are seeded after the first adequate rains (more than 10 to 15 mm). In spite of the urgency, the sowing period appears to be fairly long. According to Matlon and Fafchamps (1988) this reflects the large areas which are sown, the intensity of planting, and the irregular distribution of rainfall at the start of the agricultural season. With regard to the last point, Matlon and Fafchamps (1988) point out that, especially in soils with a low water-retaining capacity, people can sow only during 2 to 3 days after a good downpour. By then the soils are again too dry. So, in the first few weeks of the farming season, when there is only the occasional shower, only a limited part of the time available can be used for sowing (see also e.g. McIntire, 1983; Dugué, 1989).

Only when the main sorghum and millet fields have been seeded, are the other fields, the maize and groundnuts fields, prepared. Usually these fields are ploughed. When the maize and the groundnuts are sown, the weeding of the sorghum and millet fields has to start as well. The first round of weeding takes place 3 to 6 weeks after sowing. This period, from mid June till the end of July, is in general the busiest period (see e.g. Kohler, 1971; FSU/SAFGRAD, 1983; Imbs, 1987; Marchal, 1989). By the end of July, when the last sorghum and millet fields are being weeded, the first weeding round of the groundnuts and maize fields starts. This is a slightly quieter period.

The harvest takes place after the crops have ripened. Maize can be harvested first. The maize harvest may in this period, round September, be crucially important. As has been noted in earlier chapters, the granaries are often almost or even completely empty in this period - the "soudure". In the market there is hardly anything to buy and what there is, is at very high prices.

Table 4.7 Labour calendar for the villages Nakamtenga and Nabitenga, 1980.

	Apr	May	June	July	Aug	Sept	Oct	Nov
WHITE SORGHUM								
clearing								
land prep.								
manure, fert.								
sowing								
resowing								
1st weeding								
2nd weeding								
harvest								
RED SORGHUM								
clearing								
land prep.								
manure, fert.								
sowing								
resowing								
1st weeding								
2nd weeding								
harvest								
MILLET								
clearing								
land prep.								
manure, fert.								
sowing								
resowing								
1st weeding								
2nd weeding								
harvest								
MAIZE								
clearing								
land prep.								
manure, fert.								
sowing								
resowing								
1st weeding								
2nd weeding								
harvest								
GROUNDNUTS								
clearing								
land prep.								
manure, fert.								
sowing								
resowing								
1st weeding								
2nd weeding								
harvest								

Source: McIntire, 1983.

The new maize can bridge the period up to the harvesting of the large millet and sorghum fields in October and November. Also the early millet and red sorghum (varieties with a short cycle) can often be harvested in September or early in October. This harvest too, helps to bridge the "soudure" period. Cowpeas are usually harvested just before the main crops (McIntire, 1983).

Data on the relation between timing of activities and yields.

Prudencio (1983) and Kristjanson (1987) both tried to estimate the relative influence the 'timing' of sowing has on the yields. Prudencio finds a significant positive relation between the sowing date and the yields of white sorghum and millet fields, in that later sowing dates produce higher yields. The yields of red sorghum and maize appear to have a negative, even if not significant, correlation to the sowing dates. Kristjanson, on the other hand, finds a significant negative influence of the sowing date on the yields of millet and white sorghum, i.e. later sowing dates produce lower yields. She does not mention any results for red sorghum and maize.

The analyses by Kristjanson and Prudencio produce results which are barely significant, but are contradictory. This is not surprising. The influence of, for instance, sowing dates on yields also depends on the rainfall pattern and the farming methods applied throughout the growing season. Optimal periods for sowing and weeding not only depend on the rainfall pattern, but also on the soil type and variety (growing cycle, photoperiodicity, also see Mellaart, 1988). Prudencio (1983), for instance, states that farmers seem to go out of their way to weed on time, rather too early than too late. Therefore it seems likely that a negative relation between the yields and the weeding time (in relation to the sowing date) is found, i.e. earlier weeding produces better yields.

4.3.2 Labour time for farming activities

The main theme of this section is the amount of labour that is spent, or should be spent, on various farming activities. The data collected by ICRISAT with regard to labour-input have been elaborately documented in Matlon and Fafchamps (1988). McIntire (1983) gives a survey and an analysis of data collected by ICRISAT in the villages of Nakamtenga and Nabitenga in 1980. Table 4.8 shows a survey of the data on labour-input.

Comparing data on labour-input from several village studies is not an easy task. First of all the data have been collected in different years (different rainfall pattern) and different regions (different soil types, different farming methods). Secondly the farming activities have not always been described accurately. For instance, has the transportation to the granaries been included in the

Table 4.8 Labour hours in hrs/ha for various farming activities and crops, SAT studies conducted in the villages of Nakamtenga and Nabitenga in 1980.

	Total labour input (hrs/ha)			Total labour input (hrs/ha)
Clearing			Resowing	
Millet	23		Millet	11
W. Sorghum	91		W.Sorghum	1
R. Sorghum	33		R.Sorghum	4
Maize	36		Maize	14
Groundnuts	20		Groundnuts	1
Ploughing/Landprep.			1st Weeding	
Millet	0		Millet	276
W. Sorghum	0		W.Sorghum	495
R. Sorghum	1		R.Sorghum	278
Maize	153		Maize	181
Groundnuts	228		Groundnuts	297
Manure (organic man)			2nd/3rd Weeding	
Millet	6		Millet	152
W. Sorghum	41		W.Sorghum	269
R. Sorghum	24		R.Sorghum	238
Maize	114		Maize	10
Groundnuts	1		Groundnuts	10
Chemical fertilization			Harvest	
Millet	1		Millet	75
W. Sorghum	1		W.Sorghum	110
R. Sorghum	0		R.Sorghum	96
Maize	1		Maize	95
Groundnuts	1		Groundnuts	304
Sowing			Total	
Millet	54		Millet	595
W.Sorghum	150		W.Sorghum	1158
R.Sorghum	73		R.Sorghum	746
Maize	83		Maize	687
Groundnuts	133		Groundnuts	996

Notes:
- only labour data from the fields without animal traction (not even partly for a single task)
- When the major crop is cultivated with intercropping, the labour data of the major and
summed. Labour data are only for the communal fields.

Source: McIntire, 1981.

harvesting activities? Moreover, often the distinction made between activities is not the same; in some studies ploughing and preparing the land have been grouped together, in others they have not, etc. It is noted that there are no big differences between the results of Matlon and Fafchamps (1988) and McIntire (1983) regarding the distribution of labour-inputs over the different farming activities for each crop.

In general, it is supposed that the cultivation of maize is the most laborious. According to the results presented by Matlon and Fafchamps (1988) the cultivation of red sorghum (sole cropped!) is the most labour-intensive, closely followed by the cultivation of maize; the results presented in table 4.8 (McIntire, 1983) give a completely different impression, here the cultivation of sorghum (red- and white were taken together) is by far the most labour-intensive. All studies confirm the common opinion, that millet is the least labour-intensive crop. After all, millet is mainly grown on sandy soils (see section 4.2.1) which are easier to work than the more low-lying clayey soils. Besides, millet is especially grown in the outer rings (see section 4.2.2) where less manure is applied and sowing starts later. Sometimes these fields are less well prepared and weeded less meticulously.

Data on the relation between amount of labour and yields.

In general the relations found between labour-input and yields are positive. Singh (1988) only finds a negative relation between yields of maize and the volume of labour-input for the sowing and preparation of the fields, but these relations are not significant. The maize yields prove to be significantly and positively related to the labour-input in respect of both the first and the second weeding rounds. Moreover, the labour-input for weeding appears to have a much greater effect on the yields of maize than on those of millet, sorghum and groundnuts. In addition Singh's analyses show that land preparation has a significant positive influence on the yields of groundnuts. The estimated coefficient for the effect of labour per ha spent on land preparation is higher for groundnuts than for other crops. According to Prudencio (1983) weeding is the most productive for maize, which corresponds with Singh's analysis, with white sorghum and millet coming second and third. Seedbed preparation, so his analyses show, is the most productive for red sorghum, with maize coming second. Finally, Kristjanson, too, finds significant positive relations between labour-input in weeding and yields both for sorghum and for millet. According to her millet yields will vary less than those of sorghum when weeding is more intensive. Weeding, and especially the first weeding round, is often mentioned as an important bottleneck. Therefore, one could expect marginal physical products of weeding labour hours to be relatively high.

4.3.3 Available labour supply and organisation of work

The demand for labour for work in the fields fluctuates in the course of the season (see section 4.3.1). In the peak period as much labour as possible is employed. In general more working hours are used at that period than is normally the case, and outside farming only the most pressing jobs are done. Migrant workers return to the village to help on the land in this period.

In the study of Roth et al. (1986), the quantity of labour available for agricultural work is estimated at 6 hrs per day for male farmers and 4,5 hrs/day for female farmers. They refer for instance to studies of Swanson (1981), Brun et al. (1981) and Bleiberg et al. (1980). The study of Swanson (1981) shows that farmers work on average between 5.3 and 5.7 hrs/day during the peak period (first weeding). Like Imbs (1987), they notice that the amount of time worked varies between male and female farmers. Brun et al. (1981) observed that male farmers worked on average 4.7 hrs/day on weeding activities (including 2nd and 3rd weeding). To perform the same activities female farmers worked on average 3.0 hrs/day (Bleiberg et al., 1980).

Farms rarely hire wage labour (either paid cash or in kind). In most cases, farmers organise work-bees (*sosoaga*) to catch up with cultivation. There is an enormous diversity of work-bees on the Central Plateau. For a detailed discussion on the different types of inter household labour-exchanges and invitations see e.g. Kohler (1971), Imbs (1987) and Fiske (1985, 1991).

The organisation of labour

The head of the household decides on the choice of crops and the planning of activities in the communal fields (see section 2.4). Both the female and the male members of the household participate in the work in the communal fields. There is little difference in the type of activities they carry out in the fields. Land preparation and ploughing of the fields are generally male tasks, whereas sowing and harvesting are mostly done by women. Children tend the herds and guard the fields (in particular to keep birds at a distance). Nevertheless, major differences may exist between different regions and (especially) between different tribes.

5. First attempt of a linear programming model to describe farmers' strategies for the "Exploitation Centrale".

In this section a simple linear programming model is formulated. This model is an initial approach to the analysis of farming strategies for the "Exploitation Centrale" (see chapter 1 and section 2.6).

We recall that all data used in this study are derived from secondary data gathered in studies at village level. Linear programming has been undertaken by several researchers, e.g. by Roth et al. (1986), who use a linear programming model to find out how far certain technical possibilities (especially the mechanical ridge tier) may be successfully applied within the existing farming systems on the Central Plateau. Delgado (1978) and later Jaeger (1984, 1987) have used linear programming models for the study of the use of animal traction in farming. These linear programming studies were aimed at the answering of specific questions. The scope of this study is different and more extensive. We shall investigate how the development of a linear programming model can be employed to analyse the major aspects of farmers' strategies (see chapter 3). In this chapter we make a start.

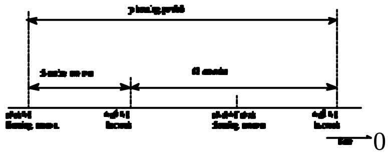
Our models require very detailed information. The data needed can rarely be obtained directly from the above-mentioned studies. Moreover there are big differences between the data collected by the different researchers. For that reason we had to resort to important additional assumptions in order to derive the data needed from those data which were available. For the major part these assumptions are based on qualitative observations discussed in the previous chapters (for instance the effect of soil conditions on yields).

This chapter has been laid out as follows: first, attention will be paid to the setting up of the linear programming model and to the choice of values of parameters in the model, then to computational results and their interpretation.

5.1 Planning period

The linear programming models in this report relate to one farming season. The level of harvested production has consequences for consumption, storage and market strategies during the year following the harvest. In figure 5.1 the time scale has been represented schematically. The period consisting of the farming season and the twelve months following the end of the harvesting time, is called the *planning period*.

Figure 5.1: Schematic representation of the planning period.



This planning period is divided into short periods (of e.g. a few days, a week, a month). In this paper the farming season will be divided in periods of two weeks or one month, which are numbered: *t = 1, 2, ... 10*.

1. the first half of May;
2. the second half of May;
3. the first half of June;
4. the second half of June;
5. the first half of July;
6. the second half of July;
7. the month of August;
8. the month of September; (5)
9. the month of October;
10. the month of November.

The first three months of the farming season are divided in short periods of two weeks for two reasons:

- the months of June and July are the peak periods, in which the first weeding round of sorghum and millet has to take place as well as the soil preparation and sowing of maize and groundnuts (see section 4.3); a division into short periods allows us to study the variations in labour demand during this period in greater depth;

- there is a difference between the yields of a crop when it is, for example, sown in period 1 or in period 2; periods of two weeks allow us to study the influence of differences in sowing dates (see chapter 6).

The 12 months which follow the agricultural season will for the time being be considered as one period. In chapter 6 this latter period will be divided into several parts as well.

5.2 Crops, soils and methods of cultivation.

We distinguish five main crops, namely maize (*MA*), red sorghum (*RS*), white sorghum (*WS*), millet (*MI*) and groundnuts (*GN*) as well as the secondary crop cowpea (*CP*), which will be intercropped with sorghum or millet. The set of these crops is denoted by the symbol P:

$$P = \{ MA, RS, WS, MI, GN, CP \} \quad (6)$$

Further down in this chapter we shall also take the set of cereal crops into account. This set will be indicated by the symbol P_{CER}:

$$P_{CER} = \{ MA, RS, WS, MI \} \quad (7)$$

Apart from growing these crops, the "Exploitation Centrale" may also leave fields fallow. In this example we shall explicitly incorporate fallowing.

A distinction will be made between fields on the higher parts of the toposéquence and fields on the lower parts. In addition, we distinguish 3 "rings" (see section 4.2.2). The relation between the "rings" and the farming strategies refers to crop choice, manuring intensity, fallowing (see section 4.2) and to anti-erosion measures as well. This relation will partly be "explicitly" dealt with in the model, in particular when the decision variables are defined. Moreover the time it takes to walk to and from the fields in a certain "ring" will be taken into account.

The following categories of land are distinguished:

S_1: fields in ring 1 at a short distance from the dwellings (less than 100 m). These fields, mostly small ones, are not situated in the lower parts of the toposéquence (see section 4.2).

S_2: fields on the higher and medium parts of the toposéquence with sandy soil, situated in ring 2 (100m - 1000m from the compound).

S_3: fields on the higher and medium parts of the toposéquence with sandy soil, in ring 3 (at a distance of more than 1000 m from the compound). (8)

S_4: fields on the lower parts of the toposéquence with a relatively high clay content, situated in ring 2.

S_5: fields on the lower parts of the toposéquence with a relatively high clay content, situated in ring 3.

We will refer to these "categories of land" also as "soil types". The set of these five soil types is called set S:

$$S = \{ S_1, S_2, S_3, S_4, S_5 \} \quad (9)$$

The illustration in figure 5.2 corresponds to the illustration in figure 4.2. In the model five different "farming methods" will be distinguished corresponding to five doses of manure to be applied: 0 kg/ha, 800 kg/ha, 2000 kg/ha, 4000 kg/ha and 8000 kg/ha. These values will be our basis, although occasionally bigger doses of manure are applied (see table 4.4). Use of chemical fertilizer is not taken into account here.

A distinction is now made between the following "plots", see also chapter 3: a plot is a piece of land on which one main crop (*MA, RS, WS, MI* or *GN*) is grown, or where sorghum or millet are intercropped with cowpeas (*RS/CP, WS/CP, MI/CP*). The plot belongs to one of the categories of land entered under (8) and (9). Within one plot the same dose of manure is applied everywhere, namely 0, 800, 200, 4000, or 8000 kg/ha.

Representative and alternative decision variables

Not all possible combinations of crop, soil type and dose of manuring will be included in the model. In fact, only those plots will be analyzed, which can be considered meaningful in advance. First of all we shall consider meaningful those combinations of main crop, type of soil and manuring, which are *representative* for the Central Plateau, i.e. which are regularly applied (see section 4.2.2). In addition, we shall include some *alternative combinations,* in order to establish whether these may be feasible and why they might be better. The selection of "alternative" combinations is an important element of a normative analysis (see chapter 3). In table 5.1 will be found an illustration and in appendix 7 an exact indication of the chosen combinations, i.e. plots, which will be included in the linear programming model. We shall define J as the set of "representative" and "alternative" plots that will be considered:

$$J = \{ \text{ all cultivated plots to be considered } \} \qquad (10)$$

The elements of J are indicated as *1, 2, 3* etc. The plots defined in table 5.1 are, for the major part, representative combinations of crop, soil type and doses of manure. Only a few combinations do not occur frequently and can be considered "alternative" plots. In choosing these plots the main considerations were the following:

Table 5.1 Plots included in the linear programming model.

Plots	Crops	Soil type	Manure (kg/ha)
N° 1-10	Maize	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	8000/4000 8000/4000
N° 11-25	Red sorghum	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	2000/800/0 2000/800/0
N° 26-40	Red sorghum/ Cowpea	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	2000/800/0 2000/800/0
N° 41-55	White sorghum	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	2000/800/0 2000/800/0
N° 56-70	White sorghum/ Cowpea	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	2000/800/0 2000/800/0
N° 71-80	Millet	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	800/0 800/0
N° 81-90	Millet/ Cowpea	S_1, S_2, S_3 (High-1, 2, 3) S_4, S_5 (Low-2, 3)	800/0 800/0
N° 91-94	Groundnuts	S_2, S_3 (High-2, 3)	800/0

* Maize: For manuring maize fields, cultivated as monocrop, doses of 8000 kg/ha and 4000 kg/ha are the basic quantities. Data on yields at lower doses are not available in the literature at our disposal. The above doses correspond to those mentioned in Prudencio (1987) and Matlon and Fafchamps (1988), see section 4.2.3. Maize fields are hardly ever intercropped with cowpeas. It is mainly grown on the higher and medium-high parts of the toposéquence. In this example we also examine the possibility of growing maize in the lower fields.

* Red sorghum and white sorghum: The doses of manure applied to red sorghum

and/or white sorghum, cultivated as monocrop or intercropped with cowpeas, are 0 kg/ha, 800 kg/ha or 2000 kg/ha. It could be very interesting to study higher doses, but reliable data on the yields that could be realized with higher doses of manure at farm level, are not available.

* Millet: It is assumed that no manure or a small dose (800 kg/ha) of manure is applied. This corresponds to the results of the various village studies. The possibility of growing millet on the lower fields will be considered, even if in actual practice millet is rarely grown there, among other things because the risks (too much water) are believed to be too big (see section 4.2). Millet can be cultivated as a monocrop or intercropped with cowpeas.

* Groundnuts: Groundnuts are not sown close to the compound, because they are very sensitive to damage caused by small ruminants roaming in the vicinity of the compounds. Moreover groundnuts are not grown on the lower fields. Even more than in the case of millet, groundnut fields are hardly ever manured. In this example we take two possible levels: 0 kg/ha or 800 kg/ha.

For the mathematical analysis of the agricultural planning problem of the "Exploitation Centrale" the following *decision variables* can be defined. Here we shall introduce a somewhat different notation from that used in chapter 3, allowing more insight in the meaning of the variables introduced. We introduce for $j \in J$, see (10):

SUR(j)	surface area of cultivated plot *j*	(11)
FAL(j)	area of fallow land corresponding to cultivated plot *j*.	(12)

In our model to each plot *j* of area *SUR(j)* there corresponds a fallow plot of area *FAL(j)*. The relationship between *SUR(j)* and *FAL(j)* will be elaborated in section 5.4. Apart from the decision variables (11) and (12) other decision variables will be introduced later. Now we shall discuss the availability of the production factors land, manure and labour.

5.3 Availability of land

Before the land constraints are formulated, the following parameters will be defined for $s \in S$, see (9):

$AV(s)$ available area of soil type s, in ha. (13)

Moreover we define for $s \in S$, see (9), the following subsets of J, see (10):

$J(s) = \{ \text{all cultivated plots of soil type } s \}$ (14)

The land constraint is given in equation (15). For all soil types s:

$$\sum_{j \in J(s)} (SUR(j) + FAL(j)) \leq AV(s) \qquad (15)$$

(The size of the total area of the cultivated plots and the corresponding fallow lands of a certain soil type cannot exceed the size of the total area of the land of this soil type on which the "Exploitation Centrale" has users' rights).

In the above equation equality only applies if the area on which the "Exploitation Centrale" has users' rights is either cultivated with one of the above crops, or necessarily lies fallow. Inequality applies if part of the acreage available is not used for arable farming, for instance due to lack of sufficient labour.

The size of the area available per category of land depends on the total land that is available to the "Exploitation Centrale" and on how it is divided between the various categories: see table 5.2. In appendix 1 details are given of the data and assumptions that form the basis of the data in table 5.2. The values of $AV(s)$ are given in the third column of the table. In this chapter all available fields will be considered to be "common" farming fields which are under the control of the head of the farm.

5.4 Fallowing

Table 5.2 The spatial distribution of the available land over the various for the "Exploitation Centrale".

Category of land	Distribution (%)	Surface area (ha)
S_1 (High-1)	5	0,32
S_2 (High-2)	19	1,21
S_3 (High-3)	67	4,29
S_4 (Low-2)	2	0,13
S_5 (Low-3)	7	0,45
Total	100	6,40

It is assumed that, if a plot j is cultivated, some other parcel of land must lie fallow at the same time. We call this parcel the fallow supplement of plot *j*. We define:

$ë_j$ ratio of the area of the fallow supplement of plot *j* to the area of cultivated plot *j*. (16)

So, for each cultivated plot *j* the area of the corresponding fallow parcel equals:

$$FAL(j) = ë_j * SUR(j) \quad (17)$$

(the size of the fallow area belonging to plot *j* is a fraction $ë_j$ of the size of the cultivated plot *j*)

We choose $ë_j$ in such a way that it corresponds to the ratio *I* between the length of the fallow period and the length of the cultivated period of the crop that is grown on plot *j*, see (3) in section 4.2.5. If we define, by analogy with (2):

R_j = land-use intensity factor for plot *j* (18)

then it may be written - see (4):

$$ë_j = (100/R_j) - 1 \quad (19)$$

By this choice of $ë_j$ a rotation schedule can be followed over a number of years, where each year the cultivated area is of the same size and fallow periods (length L_f) can be alternated with periods of cultivation (length L_c). Each year, in the rotation schedule, a (small) part of the cultivated area is laid fallow and a part of the fallow area of the same size is taken into cultivation.

For the determination of the fractions $ë_j$ we have used data on the differences in land-use intensity factors between crops and "rings" from the village studies of Prudencio (1987) and Matlon and Fafchamps (1988), see also section 4.2.3. On the basis of these data we have determined the "average" fractions $ë_j$. These are shown in table 5.3 under scenario 1. In the absence of data we have assumed that the soil type, i.e. location on the toposéquence, does not affect the fraction $ë_j$ "required".

Apart from "average" fractions $ë_j$ per crop and manuring schedule, we shall study the agricultural planning system of "Exploitation Centrale", also in respect of other *scenarios* (see chapter 3). We distinguish between the following two scenarios:

scenario 1: "average" values for $ë_j$

scenario 2:

longer fallow periods with a view to sustainable land-use;

(20)

values of $ë_j$ are higher than the "average" values.

For scenario 2 we have not been able to find adequate data. As regards the fallow periods needed for sustainable agriculture, only some general values are mentioned[3]. We assume that for all crops and manuring schedules a reduction of the "average" R by 20% is necessary for a more sustainable land-use. In this chapter scenario 1 is adopted.

Table 5.3 Ratios $\ddot{e}_j$ of fallow area to cultivated area and land-use intensity R_j scenarios per crop and per manuring schedule.

Culture	Manure (kg/ha)	Scenario 1		Scenario 2	
		$\ddot{e}_j$	R_j	$\ddot{e}_j$	R_j
Maize	8000	0	100	0	100
	4000	0	100	0.25	80
Red sorghum and white sorghum	2000	0.25	80	0.67	60
	800	0.67	60	1.50	40
	0	1.50	40	4.00	20
Red sorghum/cowpea and white sorghum cowpea	2000	0.25	80	0.67	60
	800	0.67	60	1.50	40
	0	1.50	40	4.00	20
Millet	800	0.43	70	1.00	50
	0	1.00	50	2.33	30
Millet/cowpea	800	0.43	70	1.00	50
	0	1.00	50	2.33	30
Groundnuts	800	0.43	70	1.00	50
	0	1.00	50	2.33	30

Notes:
$\ddot{e}_j$ "required" ratio between fallow area and cultivated

R_j "required" land-use intensity factor.

5.5 Availability of manure

First we define the following parameters:

AVMAN available quantity of manure, and (21)

MAN(j) the amount of manure applied per ha on plot j

The "manure constraint" can be formulated as follows:

$$\sum_{j \in J} MAN(j) * SUR(j) \leq AVMAN \tag{22}$$

(the total quantity of manure applied to all plots is less than or equal to the quantity the "Exploitation Centrale" has at its disposal).

In order to estimate the quantity of manure available per farm the data from table 4.5 have been used. We started from the estimated quantity of manure applied on average per person. In the various village investigations this varied from 160 to 250 kg/person. In the absence of any other information we assume here that this quantity is representative for the Central Plateau and, in addition, that it has not changed in the past ten years. In this case we have assumed that the "Exploitation Centrale" has 200 kg. manure per person at its disposal and in total 10 * 200 = 2000 kg. of manure. Details on the quantity of manure applied on a certain plot per ha have already been given in table 5.1. They were part of the definition of a plot.

5.6 Availability of labour

As mentioned earlier in this chapter, the period from the beginning of the growing season to the end of a year following the harvest is divided into short periods, t = 1, 2,...,10. For the periods t in the growing season, see (5), and for $j \in J$, see (10), we define:

AVLAB(t)	the quantity of labour available for agricultural activities in period t (in hours)	(23)
LAB(j,t)	quantity of labour needed in period t to cultivate 1 ha of plot j (in hours).	

For "Exploitation Centrale" we can formulate the labour constraint as follows:
For all periods t in the growing season:

$$\sum_{j \in J} LAB(j,t) * SUR(j) \leq AVLAB(t) \tag{24}$$

(the quantity of labour needed in a period t for the cultivation of the total area of "Exploitation Centrale" is less than or at most equal to the quantity of (family) labour available at the "Exploitation Centrale" during that period).

In order to estimate the quantity of labour available per farm and per month we assume that an active member of 'Exploitation Centrale" can work on average either 7.5 hours a day (man) or 6.5 hrs/day (woman) for 26 days a month on the farm fields (or 13 days for half a month). We suppose that the quantity of labour which is available, is equal during the entire farming season, i.e. the quantity of labour doesn't increase during peak periods and doesn't decrease during less intensive periods. It is labour used which varies. Peak periods, when labour used is close or equal to available labour, receive priority attention in our analysis. We emphasize that the extension of labour availability by inviting extra help or employing paid workers is not introduced in equation (24).

If we make no distinction between efficiency of work done by the different active members (e.g. women, men) and assume that all tasks can be done by all active members, the total availability of labour of "Exploitation Centrale" - *AVLAB(t)* in period t = 1, 2,..., 10 - is given by:

(7,5 hours/day * 2 men + 6.5 hours/day * 3 women) * 13 days =
451 hours for the peak periods (t = 1, 2,..., 6) and
902 hours for the months August, September, October (25)
and November (t = 7, 8, 9, 10)
(of the 5 active members of "Exploitation Centrale", 2 are men, 3
are women, see section 2.6).

The procedure to obtain the estimates of *LAB(j,t)* is the following (see also appendix 4). An agricultural calendar is established on the basis of the agricultural calendars observed in the different village studies, see e.g. table 4.7. Next, for prevailing conditions of cultivation the average labour-input per crop and per activity is estimated on the basis of observed labour-input data per farming activity, see e.g. table 4.8. For new conditions of cultivation the estimates are based on the various observations discussed earlier (section 4.3). Labour-input data per period for the different farming activities are obtained by combining the labour-input estimates with the average labour calendar. Finally, for each month and each plot the time to walk to the plot and return to the compound is calculated on the basis of the average distance of the plot to the compound (dependent on the "ring" in which the plot lies) and the total monthly labour-input required to cultivate the plot.

5.7 Storage equations

In chapter 3 it has already been observed that production and marketing strategies are closely interrelated. It may, for instance, be more efficient to buy part of the cereals that are needed for consumption using the income realized from the sale of e.g. groundnuts. Decisions on production are taken before and during the growing season, purchases and sales usually take place during the twelve months after the harvest, see figure 5.1. Here we formulate the stock balances for the year after the harvest. We introduce the following symbols for elements *p* from the set of products *P*, see (6):

CON(p) consumption of product *p* in the year after harvest (kg) (26)

SAL(p) sales of product *p* in the year after harvest (in kg) (27)

PUR(p) purchases of product *p* in the year after harvest (in kg) (28)

STOCKO(p) stock of product *p* just before harvest (in kg) (29)

STOCKT(p) stock of product *p* at the end of the year after harvest (kg)

(30)

PROD(p) production of product *p* (in kg) (31)

The stock balances or storage equations can now be formulated as follows:
For all products *p*:

$$STOCKT(p) = STOCKO(p) + PROD(p) + PUR(p) - SAL(p) - CON(p) \quad (32)$$

(for each product the final stock equals the total of the initial stock and inputs minus outputs).

In these storage equations storage losses and gifts to and from third parties have not been taken into account. The quantities *CON(p)*, *SAL(p)* and *PUR(p)* are decision variables, that have to comply with:

For all products $p \in P$ - see (6)

$$CON(p) \geq 0; \; SAL(p) \geq 0; \; PUR(p) \geq 0 \quad (33)$$

At the start of the growing season, when the values of the decision variables *SUR(j)* must be set, the value of *STOCKO(p)* can be estimated on the basis of the quantity of products then stocked in the granaries and the expected consumption up to the end of the growing season. *STOCKO(p)* is a parameter. The variable *STOCKT(p)* is determined by the definition equation (32) and should satisfy:

$$STOCKT(p) \geq 0 \quad (34)$$

In chapter 3 storage equations have been formulated for all months. This enables us to study the purchasing and selling strategies in more detail, depending, for instance, on the development of production and consumption prices. Apart from storage equations, income balances will have to be included in the model. This will be dealt with in chapter 6.

In equation (32) the term *PROD(p)* has not yet been described. The following parameters are introduced for $j \in J$, see (10), and $p \in P$, see (6):

YLD(j,p)	yield of product p when 1 ha of plot j is cultivated (in kg/ha)	(35)

The production of product p is given by:

$$PROD(p) = \sum_{j \in J} YLD(j,p) * SUR(j) \qquad (36)$$

The expected yields for the "Exploitation Centrale" are given in table 5.4. The data are based on the results of the various village studies. For observed conditions of cultivation the average yields per crop could be estimated on the basis of observed yield data. For new conditions of cultivation the estimates are based on various observations discussed before. A detailed survey of the various assumptions made for the estimation of the average yields per plot can be found in appendix 2.

Table 5.4 Estimated average yields on the Central Plateau for various crops, evels of manuring.

Crop	Type of soil	Manure (kg/ha)	Yields main crop (kg/ha)	Yields secondary crop (kg/ha)
Maize	S_1, S_2, S_3 (High-1,2,3)	8000 4000	1100 700	
	S_4, S_5 (Low- 2,3)	8000 4000	1210 790	
Red sorghum	S_1, S_2, S_3 (High-1,2,3)	2000 800 0	625 475 360	
	S_4, S_5 (Low-2,3)	2000 800 0	790 618 485	
Red sorghum/ cowpea	S_1, S_2, S_3 (High-1,2,3)	2000 800 0	594 451 342	33 28 25
	S_4, S_5 (Low-2,3)	2000 800 0	751 587 461	39 33 30
White sorghum	S_1, S_2, S_3 (High-1,2,3)	2000 800 0	545 425 345	
	S_4, S_5 (Low-2,3)	2000 800 0	666 531 441	
White sorghum/ cowpea	S_1, S_2, S_3 (High-1,2,3)	2000 800 0	518 404 328	33 28 25
	S_4, S_5 (Low-2,3)	2000 800 0	633 505 419	39 33 30
Millet	S_1, S_2, S_3 (High-1,2,3)	800 0	370 330	
	S_4, S_5 (Low-2,3)	800 0	422 379	
Millet/ cowpea	S_1, S_2, S_3 (High-1,2,3)	800 0	352 314	28 25
	S_4, S_5 (Low-2,3)	800 0	401 361	33 30
Groundnuts	S_2, S_3 (High- 2,3)	800 0	420 400	

5.8 An "optimal" strategy

As we discussed in chapters 2 and 3, a production unit and consumption units can be distinguished within the "Exploitation Centrale". Their interests do not necessarily coincide. Before we deal with the objectives of the production unit, we shall first consider the interests of the "consumption units" of the "Exploitation Centrale". Our point of departure will be a strategy aiming at the *availabil-*

ity of sufficient food for consumption. Restricting ourselves to the consumption of cereals, we postulate that the annual consumption of cereals by members of the "Exploitation Centrale" should at least be equal to the desired annual cereal demand. If we introduce the following symbol:

$DEMCER$ annual cereal demand of the "Exploitation Centrale", (37)

then we can represent the above condition - see also (7) - as:

$$\sum_{p \in P_{cer}} CON(p) \geq DEMCER \qquad (38)$$

(The annual consumption of cereals should at least be equal to the cereal demand)

The annual cereal demand has been estimated at 190 kg per person per year (see e.g. Bakker and Konaté, 1988). So, for the ten members of the "Exploitation Centrale" the total demand for cereals *DEMCER* comes to 1900 kg of cereals per year. In this chapter any preference for the consumption of one of the crops maize, red sorghum, white sorghum or millet, for instance for brewing beer (*dolo*), has not been taken into account. Neither has it been taken into account that maize is especially grown to bridge the period of the "soudure" before the new harvest. When not enough cereals are or can be produced by the "Exploitation Centrale" to meet its own demand, cereals must be purchased (see conditions (32) and (34). In case the cost cannot be covered by the sale of other agricultural products (groundnuts), other sources of income will have to be employed to enable them to buy enough cereals. Which sources of income figure here and whether or not money may have to be borrowed, will not be discussed at this juncture. It will be dealt with in chapter 6.

The main objectives of the production unit are:

- to produce as much cereals as possible for their own food supply;
- to earn as much income as possible from the sale of agricultural products;

- to build up safety-stocks to ensure that poor harvests in the next season can be set off
- to reduce risks.

These purposes match the goals of the farmers who were interviewed by Prudencio (1983), see chapter 2.7. In chapter 3 it was indicated that there are several ways of incorporating a number of objectives in a linear programming model. In this example a high priority is given to the first objective. We assume that in any case the "Exploitation Centrale" wants to produce a major share of the total demand for cereals itself. We define the following parameter:

α the fraction of the cereal demand to be produced by the "Exploitation Centrale" itself. (39)

The first objective is formulated as follows:

$$\sum_{p \in P_{cer}} PROD(p) \geq \alpha * DEMCER \qquad (40)$$

(the production of cereals should at least be equal to a fraction α of the demand for cereals)

In anticipation of a discussion of computing results at the end of this chapter, we point out at this stage that (40) has a considerable effect on the final results. If we left (40) aside, there would be every chance that a strategy would be chosen which would aim at growing crops for selling and at buying cereals for consumption. If one could be certain of sales on the market at the selling prices expected and of the availability on local markets of the cereals that must be bought and of the level of the purchasing prices, this would indeed be an acceptable strategy. However, in actual practice there is no such certainty. There is a big risk that crops can only be sold at lower prices, or that cereals can only be bought at prices that are higher than was expected. In fact, (40) has been included in order to avoid such risks.

The parameter α in (40) plays an important part. $\alpha = 1$ reflects a safe strategy, which, however, may result in a loss of income. In this report we shall take $\alpha = 0.60$ as our guide line, which implies that 60 per cent of the total cereal demand must be grown by the "Exploitation Centrale". A quantity of *(1 - á)*DEMCER* may be purchased. In order to calculate the income from selling and the cost of purchasing we introduce the following parameters for all products *p* belonging to *P* - see (6):

PRS(p) the price the "Exploitation Centrale" expects to receive for the sale of 1 kg of product *p* in the year following the harvest (in FCFA). (41)

PRP(p) the price the "Exploitation Centrale" expects to have to pay when buying 1 kg of product *p* in the year following the harvest (in FCFA). (42)

These "expected prices" require some elucidation. First of all we point out that in the course of the year following the harvest the market prices for cereals generally rise from a low level just after harvesting to a maximum level during the "soudure". Just after harvesting supply is high, during the "soudure" it is low. We base our reasoning on the following situation: The "Exploitation Centrale" is located in the vicinity of a local market. This is the only market where the "Exploitation Centrale" sells and buys. This local market has all the characteristics of a rural market on the Central Plateau; during and just after harvesting the producers (often women) are the suppliers on the market and traders (merchants, retailers) are the buyers. During the "soudure", however, the retailers are usually the suppliers and the producers (consumers) the buyers. In this chapter our point of departure will be that the "Exploitation Centrale" expects that it will only be able to sell on the local market during or just after harvesting. Later in the year the traders are not really interested in buying. For cereals the price *PRS(p)*, here called the producers' price, is therefore the market price just after harvesting.

By the same token we assume that the "Exploitation Centrale" expects that it will only be able to buy from the traders on the local market during the "soudure". The consumer price *PRP(p)* refers to the market price during the "soudure". These assumptions may, in view of the actual practice, seem reasonable, but they do not do justice to a preferred buying and selling strategy, which would enable producers to benefit from low purchasing prices during the harvesting season and high selling prices at the end of the year.

The above assumptions relate to prices of cereals. For the producers' price of groundnuts and cowpea an average annual market price has been taken. The consumers' price for groundnuts and cowpea is of no consequence for the computations in this chapter. It should be noted that the above prices are the prices the "Exploitation Centrale" expects at the moment decisions on production have to be taken, namely before sowing. Expected producers' and consumers' prices are given in table 5.5. The estimates are based on observations of producers' prices during and just after harvesting (October - December) at several rural markets on the Central Plateau and of consumers' prices during the "soudure" (July - September). See appendix 3.

The expected net income from arable farming of the "Exploitation Centrale" can be represented as:

$$REV = \sum_{p \in P} (PRS(p) * SAL(p) - PRP(p) * PUR(p)) \qquad (43)$$

(the net income is equal to the income from the sale of products minus the cost of products bought)

Table 5.5 Estimated selling prices and purchasing prices in CFA/kg.

Crop	Selling price (producers' price)	Purchasing price (consumers' price)
Maize	64	120
Red sorghum	56	96
White sorghum	61	100
Millet	66	107
Groundnuts	108	185
Cowpea	78	235

If the income expected from the sales exceeds the expected cost of purchases, i.e. if the value of (43) is positive, a balance will have to be found between the acquisition of financial income and the building up of a safety stock at the end of the year following the harvest, in view of a possible crop failure in the next year - see also chapter 3. We introduce:

SAFST the volume of the safety stock of cereals at the end of the year following the harvest. (44)

By analogy with chapter 3 we state:

$$\sum_{p \in P_{cer}} STOCKT(p) \geq SAFST \qquad (45)$$

(the final stock of cereals must at least be equal to the safety stock)

In practice the term safety stock is also used with different meanings, for instance, the minimum stock that should be available in a granary or silo at any time to meet the demand in a short period (e.g. 2 months) thereafter. We shall revert to this subject in chapter 6. In this chapter the definition of safety stock as described above is used. *SAFST* is not a parameter, but a decision variable, which must satisfy:

$$SAFST \geq 0 \qquad (46)$$

The weighing up of maximized net income and building up a safety stock can be entered into the linear programming model as follows. We call

PRPMIN

the lowest cereal consumer price per kg.

(47)

It follows from table 5.5 that *PRPMIN* equals the purchase price of red sorghum. The amount *PRPMIN * SAFST* represents the cost of the safety stock, if this would be bought at a purchase price per kg *PRPMIN*. We now formulate the following condition:

$$PRPMIN * SAFST \geq ß * REV \qquad (48)$$

(at least a fraction ß of the net revenues will be spent on building up a safety stock).

In this term *ß* is a parameter. For *ß* we shall choose a value 0.10. The farmers' strategy to acquire as much net income as possible can be translated into the form of a formula as follows:

$$\text{Maximize: } REV \qquad (49)$$

Two important conclusions can be drawn at this stage. It can be shown that in a situation of shortages, when *REV* < 0, it follows that *SAFST = 0*. This corresponds with reality: if there is not even enough money to buy cereals for consumption needs in the current year, a safety stock for the following year will certainly not be built up. Similarly, it can be shown that, when *REV* > 0, *PRPMIN * SAFST = ß * REV*. Only a fraction *ß* of the net proceeds will be spent on the safety stock, not more. To conclude the description of the model under consideration, we note that for all $j \in J$ - see (10) - we have:

$$SUR(j) \geq 0$$

(50)

5.9 Summary of the linear programming model

The strategies of the "Exploitation Centrale" discussed in this chapter are described with the help of the following *decision variables SUR (j), FAL (j), jåJ; CON(p), SAL(p), PUR (p), påP* and *SAFST*. The decision variables *SUR(j), FAL(j)* have been defined in (11) and (12); *CON(p), SAL(p), PUR(p)* in (26) - (28) and SAFST in (44). The sets *P* and P_{CER} have been defined in (6) and (7), *J* has been given in (10), table 5.1 and appendix 7, *J (s)* in (14). The variables *STOCKT(p), PROD(p)* and *REV*, which were defined in (30), (31) and (43), are called *state variables* here. Their values are uniquely fixed by the values of the above-mentioned decision variables. The other variables in the model (51) - (68) are *parameters*. In the following survey the references to their definitions and their values are given:

Parameter	Definition	Value
ë$_j$	(16)	see table 5.3
AV(s)	(13)	see table 5.2
MAN(j)	(21)	see table 5.1
AVMAN	(21)	2000 kg, see section 5.5
AVLAB	(23)	see (25)
LAB	(23)	see appendix 5
STOCKO(p)	(29)	has the value 0 in this chapter
YLD(j,p)	(35)	see table 5.4 and appendix 2
DEMCER	(37)	1900 kg, see section 5.8
á	(39)	0.75; see section 5.8
PRS(p)	(41)	see table 5.5
PRP(p)	(42)	see table 5.5
PRPMIN	(47)	follows from table 5.5
ß	(48)	0.10

Maximize: *REV* (51)

The following conditions must be satisfied:

FAL(j) = ë$_j$ * *SUR(j)*, *j*

$$\sum_{j \in J(s)} (SUR(j) + FAL(j)) \leq AV(s), \qquad s \in$$

$$\sum_{j \in J} MAN(j) * SUR(j) \leq AVMAN \tag{54}$$

$$\sum_{j \in J} LAB(j,t) * SUR(j) \leq AVLAB(t), \qquad t = 1,...,10 \tag{55}$$

$$STOCKT(p) = STOCKO(p) + PROD(p) + PUR(p) - SAL(p) - CON(p), \quad p \in P \tag{56}$$

$$STOCKT(p) \geq 0,$$

$$PROD(p) = \sum_{j \in J} YLD(j,p) * SUR(j), \quad p \in P \tag{58}$$

$$\sum_{p \in P_{cer}} CON(p) \geq DEMCER \tag{59}$$

$$\sum_{p \in P_{cer}} PROD(p) \geq \alpha * DEMCER \tag{60}$$

$$REV = \sum_{p \in P} (PRS(p) * SAL(p) - PRP(p) * PUR(p)) \tag{61}$$

$$\sum_{p \in P_{cer}} STOCKT(p) \geq SAFST \tag{62}$$

$$PRPMIN * SAFST \geq \beta * REV \tag{63}$$

$$SUR(j) \geq 0,$$

$$CON(p) \geq 0,$$

$$SAL(j) \geq 0,$$

$$PUR(p) \geq 0,$$

$SAFST(p) \geq 0,$

The simultaneous objectives of the "Exploitation Centrale" (see section 5.8), are covered in particular by the constraints (59), (60) and (62) and the objective (51).

5.10 Discussion of computational results

The model is defined by (51) - (68). The optimal strategy for this model is given by:

No. plot	Crop	Soil type	Manure (kg/ha)	Cultivated area (ha)	Fallow area (ha)
J11	RS	S_1 *(high-1)*	2000	0.26	0.06
J14	RS	S_2 *(high-2)*	2000	0.74	0.19
J21	RS	S_4 *(low-2)*	800	0.01	0.00
J22	RS	S_4 *(low-2)*	0	0.05	0.07
J25	RS	S_5 *(low-3)*	0	0.18	0.27
J84	MI/CP	S_2 *(high-2)*	0	0.14	0.14
J86	MI/CP	S_3 *(high-3)*	0	2.15	2.15
				3.52	2.88

Total: 6.40 ha

Crop	Production (kg)	Sales (kg)	Purchases (kg)	Consumption (kg)	Safety stock (kg)
MA	-	-	-	-	-
RS	748	-	434	1182	-
WS	-	-	-	-	-
MI	718	-	-	718	-
GN	-	-	-	-	-
CP	57	57	-	-	-

Net revenues: -37.205 FCFA

The "subsistence" cereal production which the households is able to produce is equal to 1466 kg, which is 77% of the cereal demand. The "Exploitation Centrale" sells his cowpea production and purchases the remaining cereal demand. He makes a debt of 37.205 FCFA in order to cover this demand. 55% of the available land is cultivated and 45% is left fallow.

Before examining the results in more detail, the concept of duality will be discussed briefly. This concept is important for a better understanding of the influence of certain constraints, and is very important in linear programming. Each linear programming model (called the primal) is associated with another linear programming model, called the dual. The decision variables in the dual correspond with the constraints of the primal. The dual variables corresponding to the constraints concerning the use and availability of production resources have a special importance and interpretation. The optimal values of these variables express the implicit value of these resources for the "Exploitation Centrale", in the neighbourhood of the optimal solution. For each resource, this implicit value measures the contribution, in terms of the objective function (i.e. in the first example above in net revenues, FCFA), which will be acquired when one extra unit of this resource is made available. They are also called shadow prices. The shadow prices are identical to the marginal values of production in conventional economic theory. Clearly, the shadow price is 0 when the constraint is not restrictive; one extra unit of a resource which is already only partly used adds nothing to the household's revenues. The shadow prices of the resources land, manure and labour are:

Constraint	Shadow price
Land:	
- S_1: Highlands, Ring 1	4.064 FCFA/ha
- S_2: Highlands, Ring 2	2.473 FCFA/ha
- S_3: Highlands, Ring 3	1.136 FCFA/ha
- S_4: Lowlands, Ring 2	3.541 FCFA/ha
- S_5: Lowlands, Ring 3	1.885 FCFA/ha
Manure	10 FCFA/kg
Labour	
- 1: Begin May	0 FCFA/hour
- 2: End May	0 FCFA/hour

Constraint	Shadow price
- 3: Begin June	0 FCFA/hour
- 4: End June	0 FCFA/hour
- 5: Begin July	0 FCFA/hour
- 6: End July	256 FCFA/hour
- 7: August	0 FCFA/hour
- 8: September	0 FCFA/hour
- 9: October	0 FCFA/hour
- 10: November	0 FCFA/hour

In the optimal solution, labour is restrictive in period 6, i.e. the second half of July, as well as the quantity of manure. Land is restrictive for all soil types. Red sorghum is cultivated with the application of 2000 kg/ha of manure on the higher fields and hardly any manure on the lower fields. Millet, intercropped with cowpea, is cultivated on higher fields without the application of manure.

The shadow prices, as presented above, cannot be compared easily because the units are different (FCFA/ha for land, FCFA/kg for manure and FCFA/hour for labour). However, we can present all shadow prices approximately in the same unit, for example FCFA/ha. Labour required in period 6 (end of July) to cultivate one hectare varies between 101 hour/ha and 389 hour/ha (see appendix 7). So, the shadow price of labour in period 6 in FCFA/ha varies between 256 FCFA/hour * 101 hour/ha = 25.856 FCFA/ha and 256 FCFA/hour * 389 hour/ha = 99.585 FCFA/ha, dependent on crop, soil type and quantity of manure applied. Likewise, the shadow price of manure in FCFA/ha varies between 8.000 FCFA/ha and 80.000 FCFA/ha, dependent on the crop and the quantity of manure applied. When comparing all these shadow prices, we can conclude that the one from labour in period 6 (end of July) is highest and the one from land of soil type S_3 the lowest. This brings us to the conclusion that it is most efficient for the "Exploitation Centrale" to cultivate the crops with the highest labour productivity. The optimal strategy, as presented above, does indeed corresponds to the highest labour productivity. If manure is applied, the labour productivity of red sorghum is highest on higher fields (a dose of 2000 kg/ha); if no organic manure is applied, the highest labour productivity comes on the lower fields from red sorghum and on the higher fields from millet intercropped with cowpeas.

We concentrate especially on the shadow price for labour in period 6 (end of July). This price of 256 FCFA/hour seems to be high. For example Singh (1988) has calculated marginal values of production between 5 and 9 FCFA/hour for the first weeding round and between 4 and 9 FCFA/hour for the second weeding round of millet, sorghum, maize and groundnut. These values are very low, even lower than the estimated values for sowing these crops. This reflects according to Singh (1988) the low value of additional labour (see section 4.3). In Prudencio (1983) we find higher values: 379 FCFA/hour for maize, -29 for red sorghum, 109 for white sorghum and millet and 119 FCFA/hour for all cereals together. Also Kristjanson finds higher values (expressed in kg/hour, see section 5.2) than those given by Singh (1988). However, the marginal values of production of the first weeding round of these three studies are in general much lower than the values found here for labour required in the second half of July, in which the first weeding round absorbs most of the labour. On the other side, it is remarkable that the studies of Jaeger (1987) and Roth et al. (1986), which both used linear programming, also found high marginal values of production, which are comparable with our estimation of 256 FCFA/hour. The shadow price of labour in the first 2 weeks of the sowing period and the first weeding round is equal to 365 FCFA/hour in Roth et al. (1986); shadow prices in Jaeger (1987), calculated per week, are 150 FCFA/hour to 370 FCFA/hour between June and July; in the last week of July the shadow price even reaches 620 FCFA/hour.

It is difficult to draw conclusions on the basis of this information. Nevertheless, we estimate that the marginal value of production found in our model is a little overestimated. One reason can be that there exist in reality several possibilities of better distributing required labour. We take the following options into account:

1. apply different sowing periods for cereals, and especially attempt to sow very early, in order to distribute labour demand for the first weeding round of cereals over several periods;

2. postpone the beginning and/or decrease the labour time of the first weeding round (i.e. less intensive weeding, weed quicker) for some of the plots.

In chapter 6 we discuss these options.

6. An improved Linear Programming model of farmers' strategies

6.1 Marketing of agricultural produce: incomes and expenditures

In general, farmers from the Central Plateau sell their groundnuts and other cash crops (for instance cotton[4]) immediately after the harvest. They prefer not to sell their cereals (except for rice and in some cases red sorghum, see chapter 2.1).

Cereal production, basically millet and white sorghum, is generally intended for consumption and for security stock. Nevertheless, when incomes from cash crops are not sufficient to cover emergency expenses, the farmer may be obliged to sell cereals. Many farmers then have to go back to the market later in the year to (re)buy cereals to meet their food needs. The nature of the local market gradually changes during the year. "Collectors" partly become traders who sell cereals and farmers become buyers. If after the harvest, market prices are essentially producer prices, during the soudure they are rather consumer prices. Prices rise in the course of the year from one harvest to the next, for several reasons. First, prices (both producer and consumer prices) show a 'reasonable' increase in order to cover investment costs in stocks, storage costs, and losses of stocks. Yonli, Schweigman and Jongkamp (1993) estimate this increase to be between 32% and 39% for the Central Plateau. Secondly, consumer prices at the end of the year are higher because of traders' profits and transport costs (if cereals are imported from other regions). During the scarcity period, as Yonli (1988) stresses, traders respond to the needs of purchasers, who lack financial resources: they sell small quantities and provide credit facilities for purchasing cereals. Sometimes the farmers sell in advance part of the next season's cereal harvest. According to the results of the University of Michigan/Wisconsin village studies, many of the households sell cereals (see table 6.1). The quantities sold do not exceed 25 % of the foodcrops. Nevertheless, the results differ a lot from one village to another.

Many anthropological studies conducted in Burkina Faso have mentioned the fact that farmers are particularly reluctant to sell certain cereals, such as white sorghum and, especially, millet, notably in areas of chronical shortage (for instance Broekhuyse, 1983, 1988; Fiske, 1985; Mccorkle, 1987).

Table 6.1: Sales and purchases data for different products in village studies kina Faso by the Universities of Michigan/Wisconsin: 1983 - 1984.

		Cereals annual gross sales		Cereals annual gross purchases	
		Number of households	Total sales volume (kg)	Number of households	Total purchases volume (kg)
Mene	Red Sorghum	0	0	6	433
	White Sorghum	2	32	40	8493
	Millet	4	404	42	12989
	Maize	2	700	33	4445
	Rice	1	39	31	1032
	Aid1	-	-	3	180
	Aid2	-	-	22	2768
Bougoure	Red Sorghum	0	0	2	59
	White Sorghum	5	40	39	9348
	Millet	1	28	9	462
	Maize	0	0	12	306
	Rice	1	7	24	303
	Aid1	-	-	16	1845
	Aid2	-	-	35	6098
Bare	Red Sorghum	46	21510	29	7594
	White Sorghum	13	4523	16	2069
	Millet	6	446	10	739
	Maize	14	3464	10	431
	Rice	2	59	37	4320
Tissi	Red Sorghum	8	1085	26	8766
	White Sorghum	13	458	30	11802
	Millet	6	298	17	1395
	Maize	0	0	8	190
	Rice	3	202	33	2011
Dankui	Red Sorghum	1	144	33	5344
	White Sorghum	3	362	38	8597
	Millet	0	0	13	1001
	Maize	0	0	9	543
	Rice	0	0	14	90

Notes:
- Aid1: food aid (cereals) from the Catholic Relief
  Aid2: food aid in sorghum.

Source: Szarleta (1987)

According to table 6.2, and at first sight contrary to what we said previously, cereal sales and purchases take place all the year round. The sales do not seem to be concentrated on the post-harvest period (the periods 11 October -

December and January - March). However, when one considers the second part of the table, it appears that most households which sold over 25 kg of cereals, sell the greater part in the two post-harvest periods (56 out of 69 households). Cereal purchases gradually increase throughout the year. It appears that a large number of the households (which bought over 50 kg) bought the largest parts in the soudure period (July - October); nevertheless, a large number of the households bought the largest parts in the period between January and March and between April and June. To summarize, the studies conducted by the Universities of Michigan/Wisconsin provide only little support for the assumption that farmers buy (at a high price) during the soudure and sell (at a low price) in the post harvest periods. Nevertheless, due to big disparities between the villages located in the South and North of the region of study, it is difficult to interpret their results: for example, two thirds of the households which sold over 25 kg of cereals are located in Baré.

6.2 Financing cereal purchases

Farmers from the Central Plateau buy more cereals than they sell. Cereals often account for most of their overall expenses (see also table 6.3). According to Thiombiano et al. (1988), more than 60 % of farm expenses in the shortage areas is spent on food purchases: partly for buying ingredients (especially meat, 20% of food expenses), agro-industrial products (e.g. sugar, oil and butter, 16 %), local drinks (dolo), colanut and tobacco (10 %), agricultural produce processing (2%); the rest which accounts for about 52 % is used to buy cereals. Livestock is often referred to as the most important income source for the purchase of foodcrops. However there are large disparities between the site villages. Income diversification i.e. non-crop production incomes shares are, according to Reardon et al. (1992), the highest in the Sahelian and Guinean zones and the lowest in the Soudanian zone where the largest part of the Central Plateau is located. Livestock and temporary migrations provided most of the household incomes in the Sahelian zone, while extra-agricultural activities related to crop production (products processing,...) were the most developed in the Guinean and Soudanian zone. Such dependance is dangerous in the

Table 6.2: Data on seasonal cereal sales and purchases in the village studies s of Michigan/Wisconsin in Burkina Faso 1984

	Jan. - March	April - June	July. - 10 Oct.	11 Oct. - Dec.
Kilograms				
Sales[1]	9,520	4,885	6,347	7,811
Purchases[1]	25,366	35,846	57,158	12,085
Number of households with highest sales and purchases volume in each three months[2]				
Sales[1]	21	5	8	35
Purchases[1]	45	61	64	7

Notes:
- Data collected in the Mene, Bougoure, Bare, Tissi and Dankui villages.
1. Sales:sorghum, millet, maize
   Purchases:Sorghum, millet, maize, food aid, various foods.
2. Data used by households which sold over 25 kg and bought over 50 kg.

Source: adapted from Ellsworth and Shapiro, 1989.

Soudanian zone, since agricultural production is very variable here with frequent large shortages. Furthermore, the poorest households were everywhere more dependant on crop production, probably because they lacked the financial means to diversify.

Apart from cereal sales and purchases, there is little information on the variations of expenses and incomes during the year. According to Thiombiano et al. (1988), purchases of livestock mainly occur during the post-harvest period, while cattle are mainly sold during the soudure period. Also social expenses and even health expenses are focused on the post-harvest period. On the Central Plateau, vegetable-gardening is widely practised in the post-harvest period (December - February). Because of storage problems, vegetable-gardening produce is sold immediately after harvest. It is often difficult for farmers to sell all their produce at a good price.

Table 6.3: Data on farms' monetary expenses and revenues derived from CEDRES, University of Ouagadougou in the north of the Central Plateau, 1984.

Revenues	Gourcy	Rom	Thiou	Nomo	Tamas-sogo	Barsa-logho	Kon-goussi	Loagha	Total (in %)
Cowpea, Voandzou, vegetable gardening	0	9692	346	0	12063	0	109742	8435	14.5
Livestock	111-934	11635	108-444	33173	15469	7123	28815	32627	36
Handicraft	91192	769	14923	9515	0	169	18300	20905	16.5
Small trade	0	6346	19423	5278	2431	2980	2653	3731	4.5
Retirements and pensions	131-692	0	26692	0	43077	0	0	0	20
Other revenues	3846	34038	0	0	10576	846	13846	17308	8.5
Total (in CFA)	338-664	62480	169-828	47966	83616	11118	173356	833-006	100

Notes:
- Data computed on the basis of data provided in table III.2 (p. 108). In this table, the overall illage sample) are supplied. The data presented here are obtained by dividing the total revenues by the ouseholds (13 in each village).

Expenses (in percentages)	Deficit areas[1]	Surplus areas[1]
Food consumption expenses	62	48
Agricultural production and livestock expenses	18	9
Social expenses	14	28
Non-food consumption expenses	4	11
Other expenses18	4	3
Total	102	99

Notes:
1. Deficit areas: 8 site villages north of the Central Plateau (Bam, Yatenga, Passore, Sanmatenga, 13 lage).
Surplus areas: villages in the Comoe and Black Volta areas (8 villages), 13 households per village.
Appendix 10 contains a brief survey of these village studies as well as maps showing the location villages.

Source: adapted from Thiombiano et al., 1988.

6.3 Storage and seed reserves

In this paragraph we are going to discuss data available on storage losses. We note that losses induced by threshing are not discussed here. These losses are accounted for in the production figures (yields, data on dry weight of grains per ha)[5]. Then, seed selection for the next growing season will be dealt with. Seeds for sowing as well as storage losses will be included in the formulation of the linear programming model (see section 6.5).

6.3.1 Storage losses

Storage losses comprise reductions in weight of produce stored for some time due to insect infestation and damage caused for example by rats and mice. There is little information on the quantity of storage losses at farm level on the Central Plateau. Cereal storage losses in traditional granaries are often estimated not to be very large (Eicher and Baker, 1982). According to Yonli et al. (1987), annual cereal storage losses account for 3 to 5% (per year) in the Soudano-Sahelian zone. He stresses the importance of post-harvest losses caused by operations performed before storing, like drying, threshing and transport. All post-harvest losses together can account for a yearly rate of 10 to 14%. According to Nagy, Ohm, Sawadogo (1989), white sorghum can be stored for about 3 to 4 years as opposed to millet which can be stored for 1 to 2 years. Cowpeas are especially difficult to store, since annual losses - especially due to insect infestations - may rise to 35 - 40 % (Eicher and Baker, 1982).

6.3.2 Next season's seed selection

Immediatly after harvest, part of the production is selected and reserved as seeds for the next growing season. The quantity the farmer must put aside for a certain crop (variety) depends on the area he expects to sow during the next growing season, on the amount of seeds to be used per hectare and on the number of times he wants to be able to resow with the same crop or to substitute another crop for this particular one (variety).

According to Matlon et Fafchamps (1988) the quantities of seed used for cereal cropping is lowest for millet (7.8 kg/ha), then for white sorghum (11.5 kg/ha), red

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[5] According to a study conducted in Nigeria, losses due to threshing (grains which remain in the ears, grains scattered or buried during threshing) vary between 1.5% and 8.5 % for sorghum (Ohiagu,

sorghum (13.1 kg/ha) and the highest for maize (47.9 kg/ha). Cereal seed quantities decrease (a little) when cereals are intercropped with cowpeas. For groundnuts 84.5 kg/ha seeds were used.

6.4 Nutritive requirements and nutritional consumption value of foodcrops.

In this section we will deal with nutritive requirements. Energy and protein needs will be estimated for the various categories of the population on the Central Plateau. The contribution of cereals and other crops to these needs will be estimated for each individual crop, by taking into account consumption patterns.

6.4.1 Nutritive requirements

The human body needs energy, protein, vitamins and mineral salts. One needs energy to fulfil the basic metabolic functions (vital exchange, breathing, heart pulsating, keeping of the body temperature), for physical activities and for growth. These needs vary from one region to another (climate, i.e. temperature) and from one individual to another according to age, sex, body weight and physical activities. For a woman, these needs also depend on her reproductive state (Bakker, Konate, 1988). Proteins are building and maintenance elements. They ensure for instance the constitution and maintenance of the tissues. In the present report, we will focus on energy and protein needs since these nutrients are largely provided by foodcrops (cereals, groundnuts, cowpeas) which are the focus of our model.

1987).

Table 6.4: Average energy and protein requirements per person per day.

	Individual energy need (kcal)	Individual protein need[1] (g)
Children		
Under one year	820	13.5
1 to 4 years	1350	15.5
Men		
5 to 9	1975	24
10 to 14	2300	38.5
15 to 19	2750	54
20 to 29	2830	45
30 to 59	2780	45
60 and over	2300	45
Women		
5 to 9	1775	24
10 to 14	2025	40
15 to 19	2150	44
20 to 29	2230	37.5
30 to 59	2320	37.5
60 and older	2050	37.5

Notes:
1) Protein needs are expressed in grammes of reference protein (NPU = 100). NPU (Net Protein sses efficiency with which proteins are used by the body. For millet and sorghum, the NPU value is 50; and groundnut, the NPU value is 45.

Source: adapted from Bakker and Konate (1989) who complied with FAO/WHO/UNU standards (1985).

Bakker and Konate (1988) computed required intakes for energy and protein for the population on the Central Plateau (see table 6.4). Table 6.4 shows that energy needs increase to 2830 kcal per day for men (age group 20-29 years) and to 2320 kcal per day for women (age group 30-59 years). Furthermore, energy expenses depend on the type of physical activities carried out. In June, July and August, i.e. the "peak" period (sowing maize and groundnut fields, weeding of cereals), energy consumption is highest. Protein needs do not vary according to the season.

6.4.2 Nutritional value of food plants consumption

Table 6.5 provides the nutritional values of different foodcrops. The values are taken per kilogram of dry grains, since foodcrop production (cereals, groundnuts, cowpeas) is measured in kilograms of dry grains. The nutritional value of agricultural produce varies according to the ways of preparing the food for consumption. To estimate these values, we based ourselves, for each crop, on the most common way of consumption. "*Tô*" made of cereal flour, constitutes the traditional meal on the Central Plateau. Millet and sorghum are used for preparing *tô* and many other meals; maize is used especially when it is fresh (broiled) in the soudure period; red sorghum is used especially for preparing beer; cowpeas and groundnuts provide ingredients for sauces for the *tô*. The different meal preparation stages may cause losses in the nutritive values of the agricultural produce used (which are not taken into account in table 6.5).

6.5 Presentation of the model and discussion of the results

Table 6.5: Composition table of foodcrops consumed (per 100g)

	Calories (kcal)	Proteins (g)	Calcium (mg)	Iron (mg)	Vitamins A (g)	Vita-mins C (mg)	Water (%)
Maize -Dried full grains	357	9.4	16	3.6	5	traces	11.6
Millet -Dried full grains	351	10.4	22	20.7	traces	traces	12
White Sorghum -Dried full grains	343	9.8	40	5.8	10		11
Red Sorghum -Dried full grains	339	9.8	30	15.6			11.5
Shelled groundnuts	546	23.2	49	3.8	15	1	6.5
Cowpeas	342	23.1	101	7.6	70	1	10.8
Cowpeas (leaves)	44	4.8	295	6	3774	60	84.4
Okra	36	1.9	70	1.3	95	25	88.6

Source: adapted from Bakker and Konaté (1988).

The present section is devoted to the construction of a more elaborate linear programming model of farmers' strategies on the Central Plateau, extending the model discussed in chapter 5.

6.5.1 Planning period: re-examined

We recall that the planning period consists on the one hand of the growing season and on the other hand of the period in which the harvested produce is consumed, marketed and stored. We call this last period the target consumption year (see figure 6.1). The farmers' production strategies are related to the growing season, their consumption, marketing and storage strategies are related to the target consumption year. There is an essential difference between the planning periods introduced in chapter 5 and chapter 6. In chapter 5 we assumed that all products were harvested at one moment, at the end of the growing season. So the growing season and the target consumption year were clearly separated. The target consumption year consisted of the 12 months after harvest. In the present chapter we make a distinction between different harvesting periods, the months of September, October and November. Now it is not certain whether the harvest during the months of September, October and November will be allocated to the year after harvest or has to satisfy consumption requirements - at least partially - during the three-month harvest period as well. To put it differently, the start of the target consumption year is not evident. However, we define the 12 months period <u>after the beginning</u> of the harvest as the <u>target consumption year</u>, see figure 6.1. The stocks immediately before harvest, i.e. the initial stocks at the beginning of the target consumption year, play an important role in our analysis.

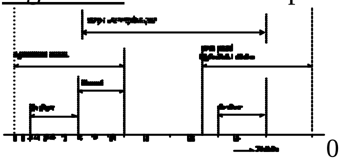
The planning period is divided into 13 short periods as follows:

1. First half of May	8. September	
2. Second half of May	9. October	
3. First half of June	10. November	(69)
4. Second half of June	11. December - February	
5. First half of July	12. March - May	
6. Second half of July	13. June - August	
7. August		

These periods are numbered t = 1, ...13. The agricultural production decisions are taken before or during the agricultural season (t=1,...,10), while the trade, storage and consumption strategies refer to the target consumption year (t=8,...,13), see figure 6.1.

To clarify the changes in the consumption, storage and marketing strategies in the year following the harvest, several periods are distinguished. We have taken maximum periods of three months to allow better estimation of storage losses and capital accumulation in each period.

Figure 6.1: Schematic representation of the planning period



6.5.2 Soils and farming methods

In this chapter a difference is made between common fields and women's individual fields. Individual fields, allocated by the head of farm to women of the household, are usually not the best ones. Imbs (1987) observed that in Kumtaabo, for instance, no individual field was found on lower situated fields. We also assume here that individual fields are not located on these lower parts.

The following categories of land are added to the set of soil types, S, see (8)

S_6: Individual fields near the compound (at less than 100 m);

S_7: Individual fields on the higher and medium parts of the topo-séquence with sandy soil, situated in ring 2 (100 m - 1000 m from the compound);

(70)

S_8: Individual fields on the higher and medium parts of the topo-séquence with sandy soil, situated in ring 3 (over 1000 m from the compound).

The set of all soil types now becomes:

$$S = \{S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8\} \quad (71)$$

Where S_1 to S_5 correspond to soil types of the common fields, as defined in (8).

The size of the area available for each soil type, *AV(s)*, see (13), depends on the total area of land that is available to the "Exploitation Centrale" (6.40 ha), as well as on its division over the various categories (see chapter 5). For individual fields, we assume that about 15 % of the fields of the household on the highlands are individual fields. The values AV(s) are (0.27 1.01 3.58 0.13 0.45 0.05 0.20 0.71), for soil types in order (see (71)). These values are based on data from village studies on cultivated areas per farm, land-use intensity of cultivated fields, field distribution according to toposequence and rings. Data derived from agricultural statistics (cultivated areas, arable land, population density) have also been taken into consideration (see table 5.2 and appendix 1).

A distinction has been made between various sowing periods for the cultivation of red sorghum, white sorghum and millet; they are the periods t = 1, 2, 3, 4 and 5. Two levels of weeding intensity have been distinguished for all the cereals in the model. The first level, called intensive, is based on a very good field management, i.e. weeding on time before weeds cause too many problems, and by employing enough labour in order to remove all weeds. The second level of clearing called extensive is based on a lighter field management. Weeding begins a little later, and is carried out faster, i.e. with less labour.

Now the definitions of the plots changes. A plot is a parcel of land where a certain crop (*MA, RS, WS, MI, or GN*) or a combination of crops (*RS/CP, WS/CP* or *MI/CP*) is grown. The plot corresponds to one of the categories of land (71). On a plot a quantity of organic fertilizer of 0, 800, 2000, 4000, or 8000 kg/ha is applied. For the crops *RS, WS* and *MI* as well as for the intercropping of these crops with cowpea (*RS/CP, WS/CP, MI/CP*) the plot is sown in one of the periods 2, 3, 4 or 5 for higher fields and in one of the periods 1, 2, 3 or 4 for lower fields (see (69) and table A4.2 in appendix 4). The plots where maize or groundnuts are cultivated are sown in an "average" period. The plots cultivated with groundnuts are weeded at an "average" level. The plots cultivated with the other crops are weeded at an in- or extensive level.

6.5.3 Labour availability

In addition to (23), defined in chapter 5, we define for the periods in the growing season, and for $j \in J$, see (10) and t = 1, 2, ..., 10:

AVLABC (t)
Available labour in period t for farming
(72)
activities (in hours) on common fields

AVLABI (t)

Available labour in period t for farming

(73)
activities (in hours) on individual fields,

Here, to simplify the notation, it is suitable to divide the set J, see (10), into two sets JC and JI separated as follows:

JC = {all the plots corresponding to common fields}
(74)

JI = {all the plots corresponding to individual fields}
(75)

JC contains the plots of the categories of fields S_1, S_2, ... S_5. JI contains the plots of the categories S_6, S_7, S_8, see (70). For the "Exploitation Centrale", labour constraints are formulated as follows; for all periods t of the growing season, i.e. t = 1..., 10 holds:

$$\sum_{j \in JC} LAB(j,t) * SUR(j) \le AVLABC(t) \qquad (76)$$

where *JC* is defined in (74)

$$\sum_{j \in JI} LAB(j,t) * SUR(j) \le AVLABI(t) \qquad (77)$$

where *JI* is defined in (75).

Labour distribution between common fields and the individual fields is subject to strict rules on the Central Plateau. There is little information on such social rules, and they seem to vary a lot from one region to another. At the beginning of the farming season, labour generally seems to be concentrated on common fields. (Kohler, 1971, Imbs, 1987) Individual fields are not yet sown in May (periods 1 and 2 in the model). We assume that women can work 30 % of their time on individual fields, which is about 2 hours/day, during peak periods 3, 4, 5, and 6 (June -July), and 40 % of their time in periods 7, 8, 9 and 10 (August, September, October and November). We emphasize that in the model labour distribution is strict, i. e. it is not possible to transfer labour from individual fields to common fields or the other way round.

To prepare and sow the land, the soil has to be wet, and this depends primarily on rainfall. One may sow 2 to 4 days after heavy rain ($\geq$ 20 mm), depending on the intensity of the rain, soil initial moisture and soil type (Dugue, 1989). In this section, we are going to formulate new constraints for the preparation and sowing of the land at the beginning of the farming season. It is required that these activities be carried out only in days favorable for them. Concerning the beginning of the farming season, we recall that we have defined the sowing season from period 1 to period 5 (from May till the first fortnight of July).

The new constraints have the same form as (76) and (77). For periods t = 1, 2, 3, 4, 5 of the farming season, we define for $j \in J$, see (10) and t = 1,..., 5:

SOWDAYS (t)
Favourable days in period *t* for preparing
(78)
and sowing fields (in days),

DUR (t)

Duration (in number of days) of period *t*

(79)

LABSOW(j,t)
Labour required in period t for preparing
(80)
and sowing 1 ha of plot j (in hours),

For all periods t = 1, 2, ..., 5 we have:

$$\sum_{j \in JC} LABSOW(j,t) * SUR(j) \leq SOWDAYS(t) * AVLABC(t)/DUR(t) \qquad (81)$$

$$\sum_{j \in JI} LABSOW(j,t) * SUR(j) \leq SOWDAYS(t) * AVLABI(t)/DUR(t) \qquad (82)$$

where *JC* and *JI* are defined in (74) and (75).

The values of *SOWDAYS(t)*, i.e. the total number of favourable days in the periods 1, 2, 3, 4 and 5 (early May - early July), are taken to be respectively 2.5; 3.5; 5; 7 and 8.5 (days). These figures are computed on the basis of the relation between rainfall and the number of days when crops can be sown. Such data are obtained by

Jaeger (1987) and Dugué (1989) in their village level studies; see appendix 6. The ratios *AVLABC(t)/DUR(t)* and *AVLABI(t)/DUR(t)* are equal to the hours per day the members of the household can work, respectively, on the common fields and individual fields in period *t*. The value of *DUR(t)* is 13 in each period *t*, *t* = 1, 2, 3, 4, 5, which follows from the definition of the periods in (69) and the number of working days per month (see also section 5.6).

6.5.4 Agricultural production and seeds

Harvesting takes place in September, October and November. We define the following variables and parameters for $p \in P$, see (6), t = 8, 9, 10 and $j \in J$, see (10):

PROD(p,t)
Harvest of product *p* in period *t* (in kg)
(83)

YLD(j,p,t)
Yield in period *t* of product *p* per hectare of plot *j* (in kg/ha)
(84)

Note that this is different from the definition in chapter 5. The production of product $p \in P$ in period *t* = 8, 9, and 10 is given by

$$PROD(p,t) = \sum_{j \in J} YLD(j,p,t) * SUR(j) \qquad (85)$$

Obviously, the values of *PROD(p,t)* are 0 for *t* = 1, 2,...,7, 11,...,13 (periods outside the harvest periods). Yields are based on the results of all village studies we have considered. In this chapter, yields depend on crop, soil type, fertili-zation level, sowing date and weeding intensity. Whether the plot is common or individual does not influence yields. The yields of all plots are given in appendix 7. In the model of chapter 5 yields did not depend on *t*. The time dependance of the yields in (84) is dictated by the period of harvesting.

During the harvest period, part of the production is selected and saved for next year's seeds. Here, we presume that part of the production is put aside for this goal in each harvest period. We have estimated an average quantity of a certain crop to be reserved for sowing 1 ha with this crop. These quantities are 50 kg/ha for maize, 20 kg/ha for red sorghum, 15 kg/ha for white sorghum, 10 kg/ha for millet, 85 kg/ha for groundnuts and 3 kg/ha for cowpea (intercropped). The estimations of these values are based on the data of Matlon and Fafchamps (1988); we have taken resowing into account. We suppose that each plot *j* where product *p* is cultivated needs the same amount of seeds per ha of product *p*. In order to facilitate the description of the selection of seeds for the next year, in the model we assume that in each month of the harvesting period a part of the total required quantity is put aside, dependant on the agricultural calendar of plot *j*. So, we define for *j* å *J*, see (10), *p* å *P*, see (6) and *t* = 8, 9, 10:

ã(j,p,t)
Quantity of product *p* to be reserved per hectare
(86)
of plot *j* in period *t*.

The portion of the harvest of product *p* of plot *j* which must be put aside as seeds for next year's farming season equals the above mentioned values for product *p* multiplied by the area of plot *j*. In order to estimate the values of the parameters *ã(j, p, t)* in (86) we need the crop calendar (for the harvest) presented in Appendix 4. The estimates are given in Appendix 7. Now we define for *p* å *P*, see (6), *t* = 8, 9 and 10:

SEEDS(p,t)
quantity of product *p* to be kept aside in period
(87)
t as seeds for the next season,

SEEDS(p,t) = Ó *ã(j,p,t) * SUR(j)*

(88)

jåJ

Now we can determine the portion of the agricultural production available for consumption or sale in the target consumption period. We first define:

PROD'(p,t)
harvest of product *p* (in kg) in period *t*,
(89)
available for consumption or sale in the
target consumption period

For all products *påP* and periods *t*=8,...,13, we have:

PROD'(p,t) = *PROD(p,t)* -
SEEDS(p,t) for *t* = 8, 9, 10
(90)
PROD'(p,t) = 0 for *t* = 11, 12, 13

6.5.5 Stock balances

We now move to equations dealing with agricultural produce stocks. We recall that the storage strategies correspond to the target consumption year (see paragraph 6.5.1), i.e. to the periods *t* = 8,..., 13 (see figure 6.1). We introduce, for all *p* å *P* and *t* = 8,..., 13, the following variables:

CON(p,t)

Consumption of product p in period t (in kg)

(91)

SAL(p,t)

Sales of product p in period t (in kg)

(92)

PUR(p,t)

Purchases of product p in period t (in kg)

(93)

STOCK(p,t)

Stock of product p at the end of period t (in kg)

(94)

We also define, for *påP*, see (6):

STOCK(p,7)

Stock of product p at the end of period 7

(95)

(beginning of the harvest period, see figure 6.1),

Farmers' strategies, as well as the solution of the linear programming model to be developed, depend to a large extent on the expected levels of the initial stocks at the beginning of the target consumption year, i.e. the values of *STOCK(p,7)*. In this section, these initial stocks are treated as parameters. Other parameters which are used in the storage equations are, for *p* å *P*, see (6), and *t* = 8, 9, ..., 13.:

f(p,t) Fraction of the stock of product *p* lost in period *t*

due to storage losses

(96)

Annual losses are estimated on the basis of some available data, see section 6.3. The following annual fractions are assumed: for red sorghum 6 % per year; for white sorghum 8 % per year and millet 10 % per year; for groundnut 15 % and for cowpeas 30 % per year. Maize is not often stored for long. We assumed 10% per year. In addition, it is assumed that storage losses are constant throughout the year. Now we can formulate stock balances, for *p* å *P*, see (6), and *t* = 8, ..., 13.:

$$STOCK(p,t) = (1 - f(p,t)) * STOCK(p,t-1) + (1 - f(p,t)/2) * (PROD'(p,t) + PUR(p,t) - SAL(p,t) - CON(p,t)) \quad (97)$$

The fraction *f(p,t)/2* is explained as follows. If we suppose that the supply of produce and purchases to the granaries, and the decrease of the granaries by sales and consumption are distributed equally over period *t*, then the quantities transfered stay in the granaries for about half of the period.

The decision variables *CON(p,t), SAL(p,t), PUR(p,t)* and the variables *STOCK(p,t)* must satisfy the following requirements, for $p \in P$, see (6), and *t* = 8, 9, ..., 13:

$$CON(p,t) \geq 0 \quad (98)$$

$$SAL(p,t) \geq 0 \quad (99)$$

$$PUR(p,t) \geq 0 \quad (100)$$

$$STOCK(p,t) \geq 0 \quad (101)$$

Stocks at the end of period 13 are of special importance. These stocks may serve for consumption in the harvest period of the next year's farming season. Moreover, these stocks may serve to meet consumption requirements after this period, if e.g. next year's harvest proves disappointing. We call the stock reserved at the end of period 13 to cover the food requirement after next year's harvest the safety stock of the "Exploitation Centrale". We define:

STOCKR(p)
Volume of the stock of product *p* (in kg) saved at
(102)
the end of period 13 to contribute to food needs
in the harvest period of next farming season.

SAFST(p)

Volume of the safety stock of product *p* (in kg) re-

(103)

served at the end of period 13 to meet food requirements after the harvest period of the next farming season, if the harvest proves disappointing.

Now we define for *p* å *P*, see (6):

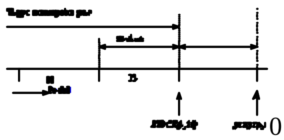
STOCK(p,13) = STOCKR(p) + SAFST(p) (104)

It will be shown in section 6.5.8, where the objectives of the "Exploitation Centrale" will be discussed, why it is useful to divide the *STOCK (p,13)* in the two stocks (102) and (103). These stocks are illustrated in figure 6.5. The decision variables *STOCKR(p)* and *SAFST(p)* must satisfy the following requirements:

STOCKR(p) ³ *0*
(105)

SAFST(p) ³ *0*
(106)

Figure 6.2: Representation of the stocks at the end of period 13 and at the end of the next years' harvest period.



6.5.6 Financial balances

We recall that in the present report, not all financial matters of the "Exploitation Centrale" will be considered. Production costs are not dealt with merely because they are very low for farmers on the Central Plateau where usually no chemical fertilization is applied and no animal traction is used. Here the incomes of the "Exploitation Centrale" are composed of revenues from sales of agricultural produce and incomes from livestock and non-agricultural (on- and off-farm) activities. Expenses refer to purchases of cereals for consumption and other daily expenses. Financial balances are considered in the same periods as the agricultural produce stock balances, i.e. the target consumption year. We now move to the formulation of financial balances. For periods $t = 8$ ..., 13, and products *p* å *P*, we introduce the following variables:

FIN (t)

Financial resources (FCFA) at the disposal of the

(107)

"Exploitation Centrale" at the end of period *t*.

And the following parameters; for *p* å *P*, see (6), and $t = 8, ..., 13$:

FIN (7)

Financial resources (FCFA) at the disposal of the

(108)

"Exploitation Centrale" at the end of period 7.

NCI(t) Non-cropping

"Exploitation Centrale" during period *t*

NFE(t) Non-food exp

Centrale" during period *t*.

ñ (t)

Interest rate on the capital deposited in period *t*

(111)

We refer to section 5.8 and section 6.1 in which the farmers' selling and purchasing strategies on the Central Plateau are discussed. We recall that farmers usually sell only after the harvesting season and buy only in the period before the new harvest period. That's why here we also assume that the "Exploitation Centrale" expects to sell its cereals on the local market only after the harvesting season (*t* = 11), since later the traders/retailers are no longer interested in buying them. The cereal price *PRS(p)*, see (41), is therefore the producer price realized right after the harvest period. By the same token, we assume that the farm expects to buy cereals from the traders/retailers only in the pre-soudure and soudure season (*t* = 8, 12, 13). The cereal price *PRP(p)*, see (42), is therefore the purchasing price paid in these periods. In the harvest periods *t* = 9 and 10, households buy nor sell. For all products *p* å *P*, see (6) we have:

PUR (p,t) = 0

for t = 9, 10, 11

(112)

SAL (p,t) = 0

---

[6] In this model the non-cropping income is defined as the net revenues from livestock and non-agricultural activities (on-farm and off-farm) of the habitants of the farm-household, including the amounts of money sent by migrants.

[7] In this model the non-food expenditures are defined as all the expenses of the farm-household habitants, except the expenses for non-agricultural (on- and off-farm) and livestock activities and the purchases of food crops (maize, sorghum, millet, groundnuts, cowpea) to meet consumption needs.

for t = 8, 9, 10, 12, 13 (113)

The above-mentioned assumptions are related to cereal prices. For producer prices of groundnuts and cowpeas, we assume mean annual market prices. Consumer prices of groundnuts and cowpeas play no role in this chapter. Producer price and consumer price estimates, *PRS(p)* and *PRP(p)*, are presented in table 5.5. It is assumed that the "Exploitation Centrale" does not buy cowpeas or groundnuts in the lean season, see also section 6.1. The financial balances can be formulated as follows, for periods t = 8, ..., 13:

$$FIN(t) = (1 + \rho(t)) * FIN(t-1) + (1 + \rho(t)/2)\,(NCI(t) - NFE(t) + \sum_{p \in P} PRS(p) * SAL(p,t) - \sum_{p \in P} PRP(p) * PUR(p,t)) \qquad (114)$$

$$FIN(t) \geq 0 \qquad (115)$$

In these balances, the interest rates, $\rho(t)$, are estimated on the basis of an annual interest rate of 0.10. Anticipating the discussion of the results of our computations, it is appropriate to emphasize the importance of the values of the parameters *NCI(t)* and *NFE(t)*. Nevertheless, there are few data on incomes and expenses of farm activities on the Central Plateau (see section 6.2). We presume the following values of *NCI(t) - NFE(t)* for t = 8, ... 13 respectively: (7500, 7500, 0, - 25000, 20000, 20000 FCFA). Although non-food expenditures can, of course, differ a lot from one household to the other, the magnitude of the chosen values and their distribution in time seems to be realistic. Note that in period 11 (the post-harvest period), non-food expenses are higher than non-cropping incomes. This requires the farmer to sell part of his crops to meet his financial needs. We define:

REV net revenues during the target consumption year (in FCFA). (116)

and write:

REV = FIN (13) - FIN (7)
(117)

We start from the hypothesis that:

FIN (7) = 0 (118)

6.5.7 Nutritional consumption values and food balances

In this model we will focus on energy (KC) needs measured in 1000 kilocalories and protein (PR) needs measured in 1000 grams. We define N as the set of nutrients taken into account:

N = {KC, PR}
(119)

The following parameters are introduced, for *t* = 8, 9, ..., 13, *n* å *N*, see (119) and *p* å *P*, see (6):

DEM(n,t)

Demand of nutrient *n* by the "Exploitation Centrale"

(120)
during period *t*

VAL(p,n)
The contents of nutrient *n* of 1 consumed kg of product *p*
(121)

Food demand for the different members of the "Exploitation Centrale" in each period is given in table 6.6. These figures are based on the values provided by

Bakker and Konate (1988) and Agbessi and Dos Santos (1987, see paragraph 6.4). See appendix 5 for the estimation of figures given in table 6.6.

Table 6.6: Energy and protein demand for each member of the "Exploitation Centrale" in period *t*

	Energy (in 1000 Kcal)			Proteins (in 1000 grams)		
	Men	Women	Children	Men	Women	Children
Period 8 (Sept)	87.35	69.67	53.23	1.460	1.217	0.730
Period 9 (Oct)	87.35	69.67	53.23	1.460	1.217	0.730
Period 10 (Nov)	87.35	69.67	53.23	1.460	1.217	0.730
Period 11 (Dec-Feb)	222.74	198.55	159.69	4.380	3.651	2.190
Period 12 (March-May)	235.85	202.04	159.69	4.380	3.651	2.190
Period 13 (June-August)	301.36	229.90	159.69	4.380	3.651	2.190

For the caloric and protein values of the different agricultural produce, see table 6.7. These values, expressed in nutritional units per kg of dry grains include nutritional losses during meal preparation (see section 6.4.2).

Table 6.7: Contents of effective nutrient intake[1] by the human body per kg consumed[2].

	Maize	Red Sorghum	White Sorghum	millet	Groundnut	Cowpea
1000 kilocalories	3.57	3.39	2.57	3.41	5.46	3.42
proteins (grams)	42	49	37	52	104	104

Note:
1. Protein requirements (see table 6.6) are expressed in grammes of reference protein (NPU = 100). NPU (Net Protein Utilization) expresses efficiency with which proteins are used by the body. For millet and sorghum, the NPU value is 50; for maize, cowpea and groundnut, the NPU value is 45. Effective protein intake of e.g. the consumption of one kg maize equals 0.45(NPU)*9.2(see table 6.5)*10.
2. The nutritive values are based on consumption habits (including nutritive losses during the preparation of meals).

In chapter 5, only cereal consumption was taken into account. Here, we also take into consideration groundnut and cowpea consumption. Apart from products $p \in P$, see (6), the members of the "Exploitation Centrale" also eat other crops such as sorrel, sesame, okra and baobab leaves. According to the region, fruits such as sheanuts, grapes, tamarins and mangoes may also be eaten. The spices used in meals like *soumbala* contain nutrients (and vitamins). Finally, meat is eaten from time to time. Hardly any fish is eaten. Meat consumption is very low on the Central Plateau, and often limited to special events, such as traditional and religious celebrations, funerals and marriages. These observations imply that only part of the food demand is met by the consumption of the products p å P. For this reason, we introduce the following parameter, for *p* å *P*, see (6), and *n* å *N*, see (119):

È$_1$*(n)*

fraction of the demand of nutrient *n* by of the

(122)

"Exploitation Centrale" to be satisfied by consuming

products *p*,

We choose È$_1$*(n)* equal to (0.80; 0.70). These values are adapted from the study by Bakker and Konate (1988) in which it is assumed that a satisfactory energy consumption is achieved when about 75 % of food requirements are covered by the consumption of staple cereals (especially white sorghum and millet). Cereals constitute the largest part of the consumption of products *p* å *P* of the "Exploitation Centrale"; the percentage for the satisfaction of the protein requirements is a little lower, given the fact that cereals are primarily energy sources.

Food deficits play an important role in our model. In chapter 5, we simply postulated that cereal consumption should meet "cereal demand". If the "Exploitation Centrale" did not produce enough, food was bought. Here, we follow another approach which is more realistic. In short, we assume that the "Exploitation Centrale" first tries to minimize food deficits in the target consumption year, before proceeding with other objectives, see section 6.5.8. The following (definition) variables are introduced, for *n* å *N*, see (119), and *t* = 8,...,13.:

CONS(n,t)

Consumption of nutrient *n*, in period *t*

(123)
DEF(n,t)
Deficit of nutrient *n* in period *t*
(124)

We compute the consumption of nutrient $n \in N$, see (119), for each period $t = 8, ..., 13$ as follows:

$$CONS(n,t) = \sum_{p \in P} CON(p,t) * VAL(p,n) \qquad (125)$$

Nutrient deficit is 0 if consumption exceeds the nutrient requirements and equals the difference between requirement and consumption. If the consumption is not sufficient:

$$DEF(n,t) = max(0;\ \Theta_1(n) * DEM(n,t) - CONS(n,t)) \qquad (126)$$

where $n \in N$, see (119) and $t = 8, ..., 13$.

Since food deficits are minimized (see (143) in section 6.5.8), it is possible to substitute formula (126) for the following linear conditions:

$$DEF(n,t) \geq \Theta_1(n) * DEM(n,t) - CONS(n,t) \qquad (127)$$

$$DEF(n,t) \geq 0 \qquad (128)$$

We recall that the deficit defined above corresponds only to the consumption of products $p \in P$, see (6).

We recall the discussion on the target consumption year. Suppose that the "Exploitation Centrale" can choose strategies that satisfy all nutritional requirements during the target consumption year, i.e. all deficits $DEF(n,t) = 0$, $t = 8,...,13$. In that case they can choose to reach also other objectives. Another objective of the "Exploitation Centrale" is the minimization of food "deficits" in the harvesting period of the next farming season. Here, we are not dealing with food deficits in the same way as we used them for the target consumption year. They are not yet true deficits since the harvests of the next farming season can always meet part of these "deficits". Nevertheless, it may be of interest to the "Exploitation Centrale" to optimize stocks at the end of period 13 (right before the harvest of the next farming season) to reduce the dependency on harvesting of early varieties in the next farming season. The discussion on objectives of the "Exploitation Centrale" will be continued in section 6.5.8; here, we focus on the definition of food "deficit" in the harvesting period of the next growing season. First of all, we define the following parameter, for $n \in N$, see (119):

DEMR(n)	Demand of nutrient *n* by the "Exploitation Centrale" during the harvesting period of the next growing season.	(129)

The values of parameter *DEMR(n)* are given in table 6.6. Demand during the next harvest equals the demand in the harvest period of the current farming season. We define for $n \in N$ the following variable:

DEFR(n)	Deficit of nutrient *n* during the harvest period of the next farming season, if the consumption of the "Exploitation Centrale" was based only on the agricultural stocks at the end of period 13,	(130)

Figure 6.3 shows the difference between *DEF(n,t)* and *DEFR(n)*.

We can compute these "deficits" as follows, for $n \in N$, see (119):

$$DEFR(n) = max\ (0\ ;\ \Theta_1(n) * DEMR(n) - \sum_{p \in P} STOCKR(p) * VAL(p,n)) \quad (131)$$

Figure 6.3: Representation of the periods in which shortages can occur.

0

Analogous to (126) - (128), we can replace (131) by the following conditions:

$$DEFR(n) \geq È_1(n) * DEMR(n) - \sum_{p \in P} STOCKR(p) * VAL(p,n) \qquad (132)$$

$$DEFR(n) \geq 0 \qquad (133)$$

We recall the predominance of red sorghum in the farming and food strategies of the "Exploitation Centrale" in chapter 5. However, as we have already pointed out, red sorghum consumption is not very high on the Central Plateau; it is generally limited to the consumption of the local beer, *dolo*[8]. Hardly any data exist on *dolo* consumption. The consumption study of IFPRI/ICRISAT shows that red sorghum consumption comprises 2 to 9% of households' consumption (in kilocalories). When using the daily consumption figures per adult equivalent (AE) in kilocalories, of Reardon and Matlon (1989), we can calculate the fractions of red sorghum consumed. According to the calculations, between 50 and 200 kilocalories per day per adult equivalent for the different household types come from red sorghum consumption, i.e. between approximately 18000 and 73000 kilocalories per AE per year, which equals a quantity between 5 and 21 kg of red sorghum per AE per year. When using the figures on red sorghum consumption per AE per year, the "Exploitation Centrale" (which comprise 7.5 AE) consumes between 40 and 160 kg

[8] Note that dolo consumption is limited to a non-muslim population. In this example, we restrict

of red sorghum. Note that the village studies of IFPRI/ICRISAT have been executed during a very bad year, with, probably, a low *dolo* consumption[9]. We suppose here that the "Exploitation Centrale" does not consume more than 150 kg of red sorghum. Clearly, more red sorghum can be produced to sell[10]. *Dolo* is drunk throughout the year. In the farming season, the women of the compound (or of the district) prepare *dolo*. *Dolo* consumption is highest in the post-harvest period when women have ample time to prepare (and sell) *dolo* and consumers also have ample time to drink. *Dolo* is indispensable for celebrations, funerals and marriages in this period. In this model, a constraint is formulated to restrict red sorghum consumption to an "average" level. We define for *t*=8,..., 13:

MAXRS(t)
Maximum red sorghum quantity which can be
(134)
consumed per period *t*

and postulate:

CON(RS, t) £ MAXRS(t) (135)

The values of *MAXRS(t)* are (8 8 9 50 50 25) for *t* = 8, 9, ...13, respectively. These values are based on the above mentioned discussion regarding quantities of *dolo* consumed (note that the "Exploitation Centrale" is made up of 10 persons). Similarly, stocks at the end of the target consumption period meant for consumption in the next harvest season or as safety stock should not include more red sorghum than what is usually consumed in the harvest period. This gives rise to the following condition:

STOCK(RS, 13) £ MAXRS(8) + MAXRS(9) + MAXRS(10) (136)

---

ourselves (thus) to a non-muslim farm.

9 Note that red sorghum is sometimes consumed as *tô*, especially during periods when food is rationed.

10 The data on red sorghum production on the Central Plateau show the following scheme: between 0 and 10% of the area is cultivated with red sorghum; the average yields is about 475 kg/ha (see appendix 2). If we use these figures for the "Exploitation Centrale" (whose cultivated area doesn't exceed 4 ha, see chapter 5) the red sorghum production will be between 0 and 190 kg.

If one focuses on nutritional demand, one runs the danger of achieving a meal composition which is justified in terms of nutrition, but which is far away from the usual meal pattern, i.e. nobody will accept such a solution. This phenomenon is widely known in the literature (see e.g. Schweigman, 1979). A constraint must be introduced in such a way that cereals WS, MI and MA will be the basic constituents for meals (and not groundnuts or cowpeas). Red sorghum is not taken into consideration since it is consumed in the form of *"dolo"* (as a drink). Apart from *the consumption of nutrient n by the consumption of all products* $p \in P$, we introduce *the consumption of nutrient n by the consumption of the staple cereals WS, MI and MA*. Like *CONS(n,t)* introduced above, we define, for $n \in N$, see (119) and $t = 8, ..., 13$:

CONS'(n,t)
Consumption of nutrient n by the consumption of
(137)
the staple cereals WS, MI and MA during period t,

we can write for $n \in N$, see (119), $t = 8, ..., 13$, and for *Pcer*, see (7):

$$CONS'(n,t) = \sum_{\substack{p \in Pcer \\ p \neq RS}} CON(p,t) * VAL(p,n) \qquad (138)$$

To ensure that daily meals should mainly consist of staple cereals, we impose the following conditions:

$$CONS'(n,t) \geq È_2(n) * (CONS(n,t) - CON(RS,t) * VAL(RS,n)) \qquad (139)$$

where $n \in N$, see (119), $t = 8, ..., 13$, *Pcer* is defined in (7).

$\grave{E}_2(n)$ are parameters. We estimate the values (0.85; 0) respectively. So we require that 85% of the energy value of the consumption of agricultural produce *MA, WS, MI, GN* and *CP* comes from the first three products. We focus on the energy value because of the importance of cereals for energy intake. The value 85 % seems to be a little lower than in reality on the Central Plateau. Farmers' meals on the Central Plateau are basically made of "*tô*" (done with staple cereals), accompanied by a little sauce; sometimes "*tô*" is eaten with just a little water. For a normative analysis of farmer strategies, it is justified to set the values of parameters $\grave{E}_2(n)$ a little lower than the "average" values on the Central Plateau, in view of an analysis of the possibilities offered by diversification. It is especially interesting to study the nutritional and economic consequences of a larger groundnuts and cowpea consumption.

We assume that the consumption of the two nutrients is in no period below a critical minimum level, i.e.

$$CONS(n,t) \;³\; \grave{E}_3(n) * DEM(n,t) \qquad (140)$$

Where: *n* å *N*, see (119) and *t* = 8,..., 13.

We have chosen for $\grave{E}_3(n)$ the values (0.60; 0.50) based on IFPRI consumption studies (see Reardon and Matlon, 1989) carried out in an extremely poor year following the big 1984 drought.

6.5.8 "Optimal Strategy"

In section 5.8, we discussed the objectives of the "Exploitation Centrale". We started with a strategy based on an availability of food which was sufficient for consumption. Nevertheless, as we have seen from studies on consumption models on the Central Plateau, the level of consumption is often below the standards of the FAO, WHO, etc. (see section 6.4). In this chapter, we no longer require the "Exploitation Centrale" to consume in conformity with these standards, even if that results in debts. We start here from the hypothesis that the "Exploitation Centrale" cannot get too far into debt (i.e. take credits that cannot be reimbursed). The aim is rather, to minimise food deficits, using their own financial resources.

In section 5.8, we also discussed the objectives of the production unit of the "Exploitation Centrale". The objective of producing as many cereals as possible for their own consumption was considered as extremely important and as a priority. Similar to the procedure followed in that section, we assume that the "Exploitation Centrale" intends to produce at least a major part of their own cereal demand. In section 5.8, we defined the parameter α, see (39), and pointed out its importance. The condition for "subsistence" cereal consumption is formulated as follows:

$$\sum_{\substack{p\in Pcer \\ p\neq RS}} \sum_{t=8..10} PROD'(p,t) \geq \alpha * \sum_{\substack{p\in Pcer \\ p\neq RS}} \sum_{t=8..13} CON(p,t) \qquad (141)$$

where *Pcer* is defined in (7).

If expected revenues exceed expected expenses, so the value of (117) is positive, two options are possible: to obtain a financial income or to build up a reserve (safety stock) at the end of the year following the harvest to make up for a possible failure of the next year's harvest. The choice between the two options, i.e. net income maximization and safety stock build-up, has been introduced in this linear programming model in the same way as in chapter 5. We formulate the following condition:

$$\sum_{p\in Pcer} PRP(p) * SAFST(p) \geq \beta * REV \qquad (142)$$

where *Pcer* is defined in (7).

In this expression, *ß* is the same parameter as defined in (48).

The strategy of the "Exploitation Centrale" primarily aims at preventing or minimizing food deficits during the target consumption year; if they avoid a deficit, then the strategy aims at maximizing stocks at the end of the target consumption year in order to meet food requirements during the harvest period of the next farming season (which corresponds to the minimization of the variables *DEFR(n)*, see (132) and (133). If these objectives are achieved as well, they will try to acquire maximum net income. The combination of these objectives will be formulated as follows:

$$\text{Maximize: } REV - \underset{nåN}{Ó} \; \underset{t=8..13}{Ó} \; ù(n) * DEF(n,t) - \underset{nåN}{Ó} \; ù_r(n) * DEFR(n) \quad (143)$$

One must choose high values for *ù(n)* to ensure that the objective of achieving food self-sufficiency in the target consumption year will be a priority. The values $ù_r(n)$ must also be sufficiently high, but less high than parameters *ù(n)*. The choice of high values of parameters *ù(n)* and $ù_r(n)$ implies that incomes are maximized only in the case where deficits *DEF(n,t)* and *DEFR(n)* are 0. If the quotient *ù(KC)/ù(PR)* is higher than 1, the energy (in 1000 kilocalories) is considered more important than proteins (in 1000 grams). The specific choice of *ù(KC)/ù(PR)* is difficult to justify on the basis of a weighing of the importance of energy and proteins for the human body. However, it appears that the precise ratio *ù(KC)/ù(PR)* is not very important, i.e. the solution of the linear programming models does not differ very much as this ratio varies. We have chosen the following approach. We choose *ù(KC)/ù(PR)* = 1/66 based on the relationship between the value in (1000) kilocalories and the value in (1000 grammes) proteins of one kg of millet, a staple consumption product on the Central Plateau (see table 6.7). The values we have finally chosen are (1000, 66000) for parameters *ù(n)* and (100, 6600) for parameters $ù_r(n)$.The value of the quotient *ù(KC)/ù(PR)* and the absolute value of the coefficients *ù(n)* and $ù_r(n)$ are not very important. It is rather the order of magnitude that counts, i.e. $\grave{u}(n) >> \grave{u}_r(n) >> 1$.

We emphasize that we assume in this model global objectives for all farm-level activities. Differences between the objectives of the head of farm and those of women are not explicitly taken into account. We only analyze the implications of a more or less rigid distribution on the Central Plateau of labour on women's individual fields and labour on common fields, while preserving the conception that agricultural production on individual as well as common fields are in line with the same "priority" objectives as discussed above. This is not in compliance with the results of numerous anthropoligical studies we have consulted, which mention notable differences in the women's objectives and in those of the head of farm (see also section 2.7). Such differences in the objectives primarily result from separate responsibilities: if men are responsible for meeting most of the farm members' cereal consumption and for settling most of the financial obligations, women are responsible for meeting the food requirements of their own consumption unit for the remaining part (or period) by providing ingredients for the sauce and by satisfying petty cash needs. However, the distribution of responsibilities at farm level may vary a great deal from one area to another, and even within the same village, e.g. from one ethnic group to another. So, the evolution of the responsibilities under the influence of the socio-economic changes on the Central Plateau seems considerable. As far as we know, there are no detailed studies on the issue[11]. To take into account these different responsibilities in this model, individual physical and financial estimates should be included, thus immediately making the model very complex indeed. We have therefor decided to restict ourselves to global objectives for all farm-level activities.

[11] The INERA/RSP North-Western team started such a study whose results are at the moment being analyzed (see Gué, 1995).

6.5.9 Summary of the linear programming model

The strategies of the "Exploitation Centrale" discussed in this chapter are described with the help of the *decision variables* discussed in chapter 5 and 6. The decision variables *SUR (j), FAL (j), jåJ; CON(p,t), SAL(p,t), PUR (p,t), påP* and *t = 8,...,13* are defined in (11), (12), (91), (92) and (93); and *STOCKR(p)* and *SAFST(p), p å P*, in (102) and (103).

The sets *P* and P_{CER} have been defined in (6) and (7), *J* has been given in (10), table 5.1 and appendix 7, *J (s)* in (14).

The *state variables*, whose values are uniquely determined by the values of the above-mentioned decision variables are *PROD(p,t), SEEDS(p,t), STOCK(p,t)* and *PROD'(p,t), p å P, t = 8,...,13* as given in (83), (87), (94) and (89); *FIN(t), t= 8,...,13*, and *REV* as given in (107) and (116), and *CONS(n,t), DEF(n,t), DEFR(n)* and *CONS'(n,t), n å N, t = 8,...,13*, as defined in (123), (124), (130) and (137). The set *N* is defined in (119). The *parameters* and the references to their definitions and their values values are:

Parameter	Definition	Value
$ë_j$	(19)	see table 5.3
AV(s)	(13)	see § 6.5.2
MAN(j)	(21)	see table 5.1
AVMAN	(21)	2000, see § 5.5
AVLABC(t)	(72)	see § 6.5.3
AVLABI(t)	(73)	see § 6.5.3
LAB(j,t)	(23)	see appendix 7
SOWDAYS(t)	(78)	see appendix 6
DUR(t)	(79)	see § 6.5.3
LABSOW(j,t)	(80)	see appendix 7
YLD(j,p,t)	(84)	see appendix 7
ã(j,p,t)	(86)	see § 6.5.4

STOCK(p,7)	(95)	see § 6.5.5
f(p,t)	(96)	see § 6.5.5
FIN(7)	(108)	see (118)
NCI(t)	(109)	see § 6.5.6
NFE(t)	(110)	see § 6.5.6
PRS(p)	(41)	table 5.5
PRP(p)	(42)	table 5.5
$\rho(t)$	(111)	see § 6.5.6
DEM(n,t)	(120)	see table 6.6 and appendix 5
VAL(p,n)	(121)	see table 6.7
$\theta_1(n)$	(122)	see § 6.5.7
DEMR(n)	(129)	see table 6.6
MAXRS(t)	(134)	see § 6.5.7
$\theta_2(n)$	§ 6.5.7	see § 6.5.7
$\theta_3(n)$	§ 6.5.7	see § 6.5.7
α	(39)	here the value is 0.6
β	(48)	here the value is 0.1
$\omega(n)$	§ 6.5.8	see § 6.5.8
$\omega_R(n)$	§ 6.5.8	see § 6.5.8

$$\text{Maximise: } REV - \sum_{n \in N} \sum_{t=8..13} \omega(n) * DEF(n,t) - \sum_{n \in N} \omega_R(n) * DEFR(n)(1$$

$$\sum_{j \in J(s)} (SUR(j) + FAL(j)) \le AV(s), \qquad s$$

$$FAL(j) = \lambda_j * SUR(j),$$

$$\sum_{j \in J} MAN(j) * SUR(j) \le AVMAN \qquad (147)$$

$$\sum LAB(j,t) * SUR(j) \le AVLABC(t), \qquad t$$

$= 1,\dots,10$ (148)

$$\sum_{j \in JI} LAB(j,t) * SUR(j) \le AVLABI(t), \qquad t = 1,\dots,10 \qquad (149)$$

$$\sum_{j \in JC} LABSOW(j,t) * SUR(j) \le SOWDAYS(t) * AVLABC(t)/DUR(t) \qquad t = 1,\dots,5 \qquad (150)$$

$$\sum_{j \in JI} LABSOW(j,t) * SUR(j) \le SOWDAYS(t) * AVLABI(t)/DUR(t) \qquad t = 1,\dots,5 \qquad (151)$$

$$PROD(p,t) = \sum_{j \in J} YLD(j,p,t) * SUR(j) \qquad p \in P,\ t = 8, 9, 10 \qquad (152)$$

$$SEEDS(p,t) = \sum_{j \in J} ã(j,p,t) * SUR(j) \qquad p$$

$$PROD'(p,t) = PROD(p,t) - SEEDS(p,t) \qquad t = 8, 9, 10 \qquad (154)$$

$$PROD'(p,t) = 0$$

$$STOCK(p,t) = (1-f(p,t)) * STOCK(p,t-1) + (1 - f(p,t)/2) * (PROD'(p,t) + PUR(p,t) - SAL(p,t) - CON(p,t)) \qquad p \in P,\ t = 8,\dots,13 \qquad (156)$$

$$STOCK(p,13) = STOCKR(p) + SAFST(p), \qquad p \in P \qquad (157)$$

PUR(p,t) = 0,

SAL(p,t) = 0,

*FIN (t) = (1 + ñ(t)) * FIN (t-1) + (1 + ñ(t)/2) (NCI (t) -* (160)

NFE (t) + S *PRS(p) * SAL(p,t) -* S *PRP(p) * PUR(p,t))*

p å P *p å P* *t* = 8,...,13

REV = FIN(13) - FIN(7) (161)

CONS(n,t) = O *CON(p,t) * VAL(p,n),* *n*
å N, t = 8,...,13
(162)
påP

DEF(n,t) ³ *È₁(n) * DEM(n,t) - CONS(n,t)* *n*
å N, t = 8,...,13
(
163)

DEFR(n) ³ *È₁(n)*DEMR(n) -* Ó *STOCKR(p) * VAL(p,n),n å N* (164)
påP

CON(RS,t) £ *MAXRS(t),* *t*

STOCK(RS,13) £ *MAXRS(8) + MAXRS(9) + MAXRS(10)* (166)

CONS'(n,t) = O *CON(p,t) * VAL(p,n),* *n*
å N, t = 8,...,13
(
167)
påPcer
p ¹ *SR*

CONS'(n,t) ³ *È₂(n)*(CONS(n,t) - CON(RS,t)*VAL(RS,n))* (168)
n å N, t = 8,...,13

CONS(n,t) ³ *È₃(n) * DEM(n,t),* *n*

$$\sum_{\substack{p=Pcer \\ p \neq SR}} \sum_{t=8..10} PROD'(p,t) \geq \alpha * \sum_{\substack{p=Pcer \\ p \neq SR}} \sum_{t=8..13} CON(p,t) \qquad (170)$$

$$\sum_{p \in Pcer} PRP(p) * SAFST(p) \geq \beta * REV \qquad (171)$$

$$\begin{aligned}
&SUR(j) && \geq 0,\\
&CON(p,t) && \geq 0,\\
&PUR(p,t) && \geq 0,\\
&SAL(p,t) && \geq 0,\\
&STOCK(p,t) && \geq 0,\\
&STOCKR(p) && \geq 0,\\
&SAFST(p) && \geq 0,\\
&FIN(t) && \geq 0,\\
&DEF(n,t) && \geq 0,\\
&DEFR(n) && \geq 0,
\end{aligned}$$

6.5.10 Discussion of results

The model that is presented here has been developed step by step. Through developing the models and analyzing the results we arrived at an extension which was more in line with the real situation. Some elements in the model are clearly the results of this interactive process. We refer, to the different sowing periods, the restricted time available for labour and sowing, the distinction between intensive and extensive weeding, etc.

The results of our calculations in the model defined in (144) to (181), which correspond to an 'average' scenario, have been given in table 6.8. In general the results seem to describe the real situation quite well. The levels of agricultural production and of consumption correspond well to the average levels observed in the village studies on the Central Plateau. A remarkable feature in this study is the heterogeneity of agricultural strategies, i.e. the cultivation of different crops, sometimes 'pure', sometimes intercropped, on different soil types and using a great diversity of growing methods (different sowing periods, with different quantities of organic manure, intensive and extensive weeding). The great diversity in agricultural activities, in response to a complex range of objectives and constraints, is a key element of the farmers' strategies on the Central Plateau. So they grow, for instance, maize (and groundnuts) to meet their consumption needs in the month of September and early October. Other results that conform to observations made in field studies are the small part of the harvest that is sold and the necessity to buy back cereals later in the year. Sales of part of the groundnuts production are necessary to meet urgent needs in the period after harvest. That farmers only engage in the commercialization of their agricultural products after the harvest, corresponds with the findings of Sherman et al. (1987) and Thiombiano et al. (1988).

In a normative analysis one does not only expect results that conform to reality, on the contrary, diverging results may show some important perspectives. There are some diverging results: for instance, maize cultivation on the lower fields rather than on the fields near to the compound, the absence of white sorghum, i.e. the predominance of millet, the small area where intercropping is applied, the sales of cowpeas and the quantities of groundnuts that are consumed.

We will now discuss the reasons for these divergences. Let us start with the last point. Because of the higher nutritional value of groundnuts (energy and protein values) it is apparently more effective to consume groundnuts rather than selling them and buy cereals in return. Bakker and Konaté (1988) and Agbessi Dos Santos and Damon (1987) also stress the importance of the consumption of non-cereal products such as groundnuts in order to get away from ill-balanced nutrition.

The absence of white sorghum is explained by the losses in nutritional value during the preparation of *tô* using white sorghum. These losses (estimated at 25% of the total weight of the grains) have a strong effect on the results. In fact, sensitivity analysis (see Maatman and Schweigman, 1996) shows that without these losses more white sorghum would be grown (replacing millet), and the nutritional value of the total package of agricultural products would improve considerably. Mills that would be able to grind whole grains of white sorghum could make an important contribution to the food security of the households.

The dominant position of millet on the higher fields is therefore the result of the low nutritional value of white sorghum compared with that of millet. Moreover, millet demands less minerals and water, which explains its dominance on the higher fields, in particular in the northern district of the Central Plateau.

Table 6.8 Some results of the linear programming model

Crop	Soil type	Owner	Manure (kg/ha)	Sowing period	weeding intensity	Cultivated area (ha)	Fallow area (ha)
Maize	high-1	common	8000	average	intensive	0.127	0.000
Maize	low-2	common	4000	average	intensive	0.011	0.000
R.Sorghum	low-2	common	2000	1	intensive	0.095	0.024
R.Sorghum	low-3	common	800	1	intensive	0.147	0.098
Millet	high-3	common	0	4	intensive	0.391	0.391
Millet	high-3	common	0	5	intensive	0.499	0.499
Millet/Cowpeas	high-1	common	800	2	intensive	0.100	0.043
Millet/Cowpeas	high-2	common	800	2	intensive	0.688	0.296
Millet/Cowpeas	high-3	common	0	2	intensive	0.054	0.054
Millet/Cowpeas	high-3	common	0	3	intensive	0.173	0.173
Millet/Cowpeas	high-3	common	0	3	extensive 0.174	0.174	
Millet/Cowpeas	low-3	common	0	1	intensive	0.102	0.102
Groundnut	high-2	common	0	average	average	0.013	0.013
Groundnut	high-3	common	0	average	average	0.499	0.499
Millet	high-1	indiv.	0	4	intensive	0.025	0.025
Millet	high-3	indiv.	0	4	intensive	0.126	0.126
Millet	high-3	indiv.	0	5	intensive	0.173	0.173
Groundnut	high-2	indiv.	0	average	average	0.100	0.100
Groundnut	high-3	indiv.	0	average	average	0.056	0.056
						3.55	2.85

	t=8	t=9	t=10	t=11	t=12	t=13
Production (kg)						
- Maize	129	43	0			
- R.Sorghum	0	110	110			
- W.Sorghum	0	0	0			
- Millet	0	465	465			
- Groundnut	88	179	0			
- Cowpeas	21	21	0			
Consumption (kg)						
- Maize	124	41	0	0	0	0
- R.Sorghum	0	8	9	50	50	25

- W.Sorghum	0	0	0	0	0	0
- Millet	0	80	122	325	332	396
- Groundnut	7	14	13	36	37	44
- Cowpeas	12	0	0	0	0	0
Sales (kg)						
- R.Sorghum				43		
- Groundnut				49		
- Cowpeas				24		
Purchases (kg)						
- Millet	0				0	378
	t=8	t=9	t=10	t=11	t=12	t=13
Stocks of products (kg)						
- Maize	0	0	0	0	0	0
- R.Sorghum	0	99	197	102	51	25
- W.Sorghum	0	0	0	0	0	0
- Millet	0	372	698	361	24	6
- Groundnut	62	188	173	83	44	0
- Cowpeas	7	25	25	0	0	0
Finances (FCFA)						
- NCI-NFE	7500	7500	0	-25000	20000	20000
- Sales				9570		
- Purchases	0				0	40480
- Financial resources[1]	7530	15120	15241	0	20240	0
Consumption						
- in 1000 kilocalories	520	520	520	1472	1501	1673
- in proteins (1000gr)	7	8	8	23	24	26
Food shortage						
- in 1000 kilocalories	0	0	0	0	0	0
- in proteins (1000 gr)	0	0	0	0	0	0

Annual net revenues: 0 FCFA

Note:
[1] For the calculation of the level of financial resources at the end of period *t*, see (114).

Maize cultivation on the lower fields is not common practice on the Central Plateau, in spite of the fact that the soil is quite suitable for the growing of maize[12], which is probably due to the problems of transportation of large quantities of organic manure to these fields (they need, for instance, a cart). In addition, the fields close to the compound can more easily be guarded, to protect them against theft and damage (for instance by animals).

The results show that intercropping should be practised on only 36% of the

[12] There is still a risk of inundation in the lower fields. Maize cannot stand inundation.

cultivated area. But on the Central Plateau in general 70% of the cultivated area is used for intercropping. One can think of several reasons for this. The values taken for the yields of cowpeas could be too low and/or the reduction in the yields of the principal crops too high (note that our estimates are based on village studies carried out to a large extent in years of drought[13]). In fact, an increase in the yield of cowpeas by 25% is sufficient to arrive at a solution with intercropping on more than 70% of the cultivated area. Besides, some elements that are often mentioned as advantages of intercropping are not included in this model. We refer in particular to residual effects of intercropping (cowpeas fix nitrogen) and increased stability of yields; and to the drop in labour time spent on weeding (see for instance, Norman, 1974; Steiner, 1984).

The prognoses of the models do not hide the fact that the situation on the Central Plateau is delicate. Investments (purchase of inputs, animal traction) do not seem possible except at the expense of food security (already weak). The production of cereals by the "Exploitation Centrale" reaches a total of 1322 kg, equal to 132 kg/person. By combining effectively the factors of production, land, labour and capital (i.e. especially organic manure), under average conditions, the crop production system of the "Exploitation Centrale" meets roughly 99% of the annual energy needs of the household, including the energy values of the production of groundnuts and cowpeas. Only 3.5% of the cereal production is sold immediately after the harvest to cover direct expenses. The majority of agricultural revenues come from the sale of groundnuts and cowpea.

In table 6.9 the shadow prices for the means of production are given. These figures express the implicit values which these means of production have for the "Exploitation Centrale", in terms of the objective function, see (143). It is not difficult to express the values of the shadow prices approximately in FCFA, see Maatman and Schweigman, 1996. The marginal revenues of labour found in this

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[13] McIntire (1981) has found that cowpea contributes only modestly to the revenues per hectare of the intercropped crops (data from the village studies of the ICRISAT).

model are much lower than those found in other studies based on linear programming models on the Central Plateau (see for instance, Jaeger (1987) and Roth et al. (1986a), who find values between 150 and 620 FCFA/hour in the 'peak' periods). On the other hand, the results correspond with the study by Singh (1988), who used production functions to estimate the marginal revenues of labour.

The disparity of these results can be explained by the fact that a large number of technical alternatives were taken into consideration (sowing in different periods, intensive and extensive weeding, several levels of fertilization) for the same crop and the same soil type. Since the results in this model are more detailed and accurate where the agricultural activities are concerned, they are probably more reliable.

Table 6.9 Shadow prices of production resources[1] in the model

	Shadow price (in FCFA equivalents)[2]
Land:	
- High lands, ring 1, common fields	8674 (in FCFA/ha)
- High lands, ring 2, common fields	7672
- High lands, ring 3, common fields	6319
- Low lands, ring 2, common fields	14021
- Low lands, ring 3, common fields	12156
- High lands, ring 1, individual fields	10572
- High lands, ring 2, individual fields	10693
- High lands, ring 3, individual fields	9638
Organic manure	13 (in FCFA/kg manure)
Labour[1]	
- Common fields: period 4	40 (in FCFA/hr)
- Common fields: period 5	66
- Common fields: period 6	46
- Common fields: period 7	20
Labour for sowing[1]	
- Common fields: period 1	24 (in FCFA/hr)
- Common fields: period 2	26
- Individual fields: period 4	97
- Individual fields: period 5	64

Notes:
1) This table contains only the production resources from which the shadow price is higher

than 0.
2) Based on the purchase of millet in required quantities.

The results show, contrary to those of for instance Roth, that technology essentially oriented towards the reduction of labour in the peak periods, does not (no longer?) have great value for growth in agricultural production on the Central Plateau. This argument gains even more strength when the dynamics of the agricultural systems on the Central Plateau are considered (a growing rural population, saturation of arable land), which will lead to a larger number of active members per hectare in the future (see Matlon, 1987, 1990).

Technology for the development of land resources seems to be more promising. This has, for instance, to do with anti-erosion measures, such as agro-forestry and stone walls constructed during the dry season. Reclaiming of eroded fields, for example by application of *zaï*, is of importance as well. Maintaining the fertility of the soil (physically and chemically) is crucial to a sustainable agriculture. In a cultivation system which becomes more and more intensive (shorter fallow periods), the availability of organic manure and the effectiveness of its application equally gain in importance. This role is even more apparent, if scenario 2, described in section 5.4, is considered. In this scenario the strategies for a more permanent agricultural production are analyzed, by imposing longer fallow periods (of course, depending on the crop and the quantity of manure applied). The results of the calculations on the basis of the second scenario show important food deficits. In fact, for the "Exploitation Centrale" to stay at roughly the same level of food security a double quantity of organic manure is required (4000 kg instead of 2000 kg). These results show the importance of a better integration of agriculture and animal husbandry, even more important if one considers the poor chances the farmers have to buy chemical fertilizers. Extensive studies, which should closely involve the rural population, on possibilities and problems of better integration of animal husbandry into agriculture, are necessary to correct the voids in the knowledge about this subject (management and quality of grasslands, fodder needed for animals, possibilities of fodder cultivation, ...).

On the individual fields millet and groundnuts are grown. The growing of sorghum or maize is less effective because manure is not available. The marginal revenues of labour are not as big on the individual fields as they are on the common fields (table 6.9). The area where groundnuts are grown is 0.67 hectare, of which 23% is cultivated on individual fields. This result (23%) lies a little below the results for the majority of village studies consulted. Nevertheless, relatively more groundnuts are grown on individual fields than on common fields. This is particularly explained by the revenues the women can obtain from this production, or by the responsibility the women have to provide the ingredients for sauces. The analyses show yet another reason. In view of the distribution of labour among the members of the household, and especially the low availability of labour for the individual fields at the start of the season, the demands on labour for the growing of groundnuts correspond with the availability of labour for the individual fields.

Price variations for the agricultural products, while maintaining the same ratio between selling and purchasing prices, do not seem to have a big influence on the agricultural production strategies and the commercialization of agricultural products (see table 6.10). This result confirms that the farmers react to the prices only marginally. And yet, when the price of groundnuts increases relatively compared to the price of cereals, the strategies change: the production of groundnuts goes up and sales of groundnuts replace the sales of cereals. The opposite occurs when the price of cereals shows a relative increase compared to the price of groundnuts. However, when the sales of cereals have replaced the sales of groundnuts, an additional increase in the price of cereals will reduce the quantities sold. These reverse relations between price and supply of cereals are also found in the studies of the University of Ouagadougou (see Thiombiano, 1987). Moreover, a drop in the price of cereals seems to be interesting for the "Exploitation Centrale".

Table 6.10 Some results of the linear programming model for different prices.

Sales and purchase price		Value of the objective function[2]	Production[3]			Sales[3]			Purchases[3]	
CER[1]	GN[1]		CER	GN	CP	CER	GN	CP	CER	GN
-	-	-276,705	1322	267	42	43	49	24	378	-
-	+20%	-264,296	1289	292	38	-	82	-	388	-
+20%	-	-377,334	1428	195	31	131	-	10	316	-
+20%	+20%	-357,728	1295	272	46	-	60	19	316	-
+50%	+50%	-515,174	1361	217	53	35	23	25	251	-
-	-20%	-277,380	1468	140	58	119	-	37	318	44
-20%	-	-213,183	1261	308	53	-	78	38	492	-
-20%	-20%	-234,717	1300	292	40	52	68	23	470	-

Notes:
1. CER = Cereals (Maize, Red Sorghum, White Sorghum and Millet); GN = Groundnut; CP =
2. see (1).
3. Total of the production of one growing season; totals of sales and purchases in one target
r.

7. Conclusions

If we are to take the results of our models prudently, it is clear that there is no simple way to attain higher and more sustainable food security levels. In fact, sensitivity analysis seems to indicate that it will be difficult, even impossible, for most households in the Central Plateau of Burkina Faso to meet the need for food of the members of the household and to preserve the natural resources (land, water, vegetation) without help from outside. Intensification of agriculture (i.e. increasing yields) is necessary to meet the needs of the rural (and urban) population in the future. Such intensification can only be achieved by stopping erosion of the soil and by improving its fertility significantly. The investments necessary (for instance, construction of permeable dikes, transport of stones for anti-erosion works, chemical fertilizers, carts, animal traction and equipment for ploughing and ridging,....) do not seem to be within the reach of the farmers.

The challenge which agricultural research can take up is working out not only techniques to improve the agricultural production in the short term, but also scenarios for a sustainable intensification of agriculture in the long term. Intensification of the current farming systems can only be based on improvement (or intensification) of the 'traditional' techniques (integrated agriculture - animal husbandry, agro-forestry, local methods of preserving water and soil, ...) and the careful introduction of other techniques such as chemical fertilization. Agricultural research should not concentrate on technical questions only. The intensification of production systems is also, and maybe first of all, a matter of organizing the local population (including organization of credit systems, supply of inputs). This is the reason why in all studies the cooperation of the rural population is of vital importance. A lesson we learned from the past is that we must not make any plans without involving the rural population. By discussing the various options and by sharing the knowledge of everyone involved it will be possible to arrive at ideas for more permanent agricultural development and food security.

The linear programming models presented in this document are the means used to investigate and analyze the farmers' strategies. They represent an important means to profit from secondary data collected in several village studies and offer great possibilities of analysis at the household level. This type of model which has been used for thirty years in agricultural research in Africa (Eicher and Baker, 1982) has only recently been introduced in the national agricultural research programme in Burkina Faso (Ouédraogo, 1995).

The linear programming models defined seem to describe in a fairly satisfactory manner the average socio-economic conditions in the households on the Central Plateau, the farming methods and techniques available to the farmers and the factors and criteria steering and limiting their production strategies. Nevertheless, there are many important factors that have not been included in this model. The study of farmers' strategies and food security is very complex and can only be approached by integrated studies of an interdisciplinary nature (Schweigman et al., 1990; Maatman et al., 1992). This study is only one component of such an approach. The results of the calculations should be interpreted with great caution. In our opinion they are not the most important results of the present study. When formulating a linear programming model the researchers are compelled to reflect profoundly on the concepts to be used (for instance, what exactly is a strategy), the decisions that have to be taken into account, the relations between decisions and factors etc. During this process, step by step, a better understanding of the food security problems is obtained indeed. For that reason linear programming seems to be an adequate instrument for analyzing the study of food security problems and for the search for appropriate solutions.

Yet, it should be noted that horticultural cultivation is gaining ground. It is practised in the dry season, around water reservoirs (dams).

The approximation of L_c through L_s gives a bias, for L_s may be lower than L_c.

'Sustainable' fallowing schedules at present low levels of manuring are estimated at 15 to 20 years after 3 to 5 years of cropping (R between 15% and 3
g. Hammond, 1966.

Cotton is no longer widely grown on the Central Plateau (see chapter 2.1, volume I).