COMPETING FOR LIMITED RESOURCES:

THE CASE OF THE FIFTH REGION OF MALI

REPORT 2

PLANT, LIVESTOCK AND FISH PRODUCTION

N. van Duivenbooden, P. A. Gosseye & H. van Keulen (*Eds*)

CABO-DLO, Wageningen, The Netherlands
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Etude sur les Systèmes de Productions Rurales en 5ème
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PREFACE

This report is written in the framework of the 'Mopti project', officially designated 'Development of a land use plan for the 5th region of Mali (Region Mopti + Cercle de Niafunké)', a joint activity of the Centre for Agrobiological Research (CABO, Wageningen, the Netherlands) and a multidisciplinary team based in Mali (ESPR, Equipe chargée de l'étude sur les Systèmes de Production Rurales en 5ème Région). The project is jointly financed by the Directorate-General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs and the Government of Mali (in the framework of the second 5-year plan for the 5th region, financed by the World Bank).

The aim of the project is to assess the possibilities for regional agricultural development, based on a quantitative description of agricultural production activities (arable crops, livestock and fisheries), both those currently practiced and potential ones. The project should result in suggestions for technically feasible development options for sustainable agricultural land use of Mali's Fifth Region. Within the present project, use is made of a linear programming model that combines information on possible activities in the region with information on the regional resources.

The general title of the report is 'Competing for limited resources: The case of the Fifth region of Mali'. It is subdivided in four interdependent reports.

Report 1, titled 'Ressources naturelles et population' (Cissé & Gosseye, 1990) presents a general survey of the environmental and human conditions of the Region.

Report 2 with the title 'Plant, livestock and fish production' (van Duivenbooden, Gosseye & van Keulen, 1991; van Duivenbooden & Gosseye, 1990) describes quantitatively the various agricultural activities required for the optimization model.

Report 3, titled 'Formal description of the optimization model MALI5' (Veeneklaas, 1990), describes the Linear Programming model used in the study.

Finally, Report 4 is a synthesis of the three preceding ones and presents the results of the optimizations and the conclusions. It is titled 'Development scenarios' (Veeneklaas *et al.*, 1991; Veeneklaas *et al.*, 1990).

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1. ACTIVITIES, LABOUR REQUIREMENTS AND SUSTAINABILITY

(N. van Duivenbooden)

1.1 Agricultural production techniques

1.1.1 Definition of systems, activities and production techniques.

For application of the Multiple Goal Linear Programming model (Report 3) a quantitative description of all possible agricultural production systems in the Region (Fifth Region and the Cercle de Niafunké; Figure 1.1) is required. Such a description specifies the production of a system as a function of the degree of exploitation of limited resources, both human and natural, and of the use external inputs. Three agricultural production systems are distinguished: *(i)* crop systems, *(ii)* livestock systems and *(iii)* fisheries. Each of these production systems can be interpreted as a mix of activities. Activities are defined as well-defined agricultural production techniques with specified and quantified inputs and outputs.

Figure 1.1. Mali, and in black the Region (Fifth Region and Cercle de Niafunké).

Activities may take place in principle anywhere in the region, i.e. in any of the agro-ecological zones distinguished (Report 1, Chapter 3), unless specified otherwise. All production techniques defined are assumed to be sustainable, i.e. their yield potential is not jeopardized in the long run (Section 1.3). In addition, the crop and livestock activities are defined in a **target-oriented way**, i.e. the production (output) per hectare or per animal is defined first and the requirements (inputs) to realize that production are derived subsequently. Outputs comprise e.g. grain, meat, milk or manure, whereas inputs consist of e.g. land, labour, oxen, chemical fertilizer or manure. Note that outputs of one activity can be inputs into another (e.g. manure). As a rule, technical coefficients for inputs depend only on activity, i.e. are independent of the agro-ecological zone. An exception, however, is the amount of fertilizer, which is a function of yield, and hence varies with agro-ecological zone. The technical coefficients for outputs of cropping activities, however, vary according to rainfall zone. In addition, the activities are quantified for the two distinguished weather regimes, i.e. the so-called "normal" and "dry" years with respect to rainfall and flood, as defined in Report 1, chapter 4. Activities are finally summarized in input-output tables, units of parameters are according to the SI-system (e.g. Monteith, 1984; Taveirne, 1990).

The various production techniques comprise *(a)* existing or current, *(b)* alternative and *(c)* potential techniques. Alternative techniques refer to practices applied in similar natural environments, but not yet common in the region; potential techniques refer to intensified production techniques not practiced in the region at present (e.g. millet cultivation with high input of chemical fertilizer).

Agricultural production systems comprising various techniques, are presented shortly in Subsection 1.1.2. In Part I arable crops are discussed in more detail, whereas Part II deals with livestock and Part III with fisheries.

As labour availability can be an important constraint for the level of intensity of agricultural activities (see also Report 4, Subsection 4.1.2), it is discussed in more detail in Subsection 1.2.

1.1.2 Defined production techniques

In the LP-model three crop types are considered: rainfed crops, flood retreat crops and irrigated or inundated crops. These are further classified by crop species, such as: millet, rice, sorghum, fonio, groundnut, cowpea, onion and the so-called 'other vegetables' (comprising among others tomatoes, tobacco, cassava and cabbage). Other crops, like e.g. maize, cotton and sesame, can be grown in the region, but their prospects are limited on a regional scale. An additional simplification has been introduced: in the actual situation several flood retreat crops are grown, such as sorghum, millet, cowpea and vegetables, but in the LP-model, flood retreat sorghum is considered representative for all these flood retreat crops.

Each of the crops included can be grown with a specific technology, comprising different techniques, differentiated on the basis of four criteria: *(i)* fallow periods, *(ii)* oxen traction, *(iii)* application of farmyard manure and *(iv)* application of chemical fertilizer (Table 1.1).

Table 1.1. Defined arable cropping activities with various technologies in the LP-model. OP-rice: Outside polder rice; P-rice: polder rice IR-rice: irrigated rice. -: no use; +: use of.

ACTIVITY CODE	CROP/ TECHNOLOGY[a]	INTENSITY	TRACTION	MANURE	FERTI-LIZER	FALLOW
i1 -i5	Millet/1	extensive	-	-	-	+
i6 -i10	Millet/2	extensive	-	+	-	-
i11-i17	Millet/3	extensive	+	-	-	+
i18-i24	Millet/4	extensive	+	+	-	-
i25-i28	Millet/5	semi-intensive	+	+	+	-
i29-i32	Millet/6	intensive	+	+	+	-
i33	Fonio	extensive	-	-	-	+
i34	Sorghum/1	extensive	-	-	-	+
i35	Sorghum/2	semi-intensive	-	-	+	-
i36	Groundnut/1	semi-intensive	+	-	+	+
i37	Groundnut/2	intensive	+	-	+	-
i38-i42	Cowpea/1	semi-intensive	+	-	+	+
i43-i45	Cowpea/2	intensive	+	+	+	-
i46	Shallot	intensive	-	+	-	-
i47	Vegetables	intensive	-	+	-	-
i49-i51	Fodder crop	intensive	+	+	+	-
i52	Bourgou	semi-intensive	+	+	+	-
i54-i56	OP-rice	extensive	+	-	-	+
i57	P-rice/1	semi-intensive	+	+	+	-
i59	P-rice/2	semi-intensive	+	+	+	-
i58	IR-rice	intensive	+	+	+	-
i48,53	vacant					

[a]) indicates intensification level.

A crop activity is defined as the specific combination of a soil type and a technology. The combination of a crop and a soil is made on the basis of physical characteristics of the soil (water holding capacity; Section 2.1). It is assumed in this study that arable fields are within a 6 km radius from permanent water points. The unit for definition of the technical coefficients of a crop activity is one hectare [ha].

In addition, three intensity levels are distinguished: *(i)* extensive, *(ii)* semi-intensive and *(iii)* intensive. Extensive refers to techniques without any external nutrient inputs (chemical fertilizer), intensive to techniques with high levels of such inputs and semi-intensive to intermediate levels. In addition, intensive techniques include a high degree of innovative practices. Application of farmyard manure is considered extensive, because it is a transfer of fertility within a certain area. Fallowing can be interpreted as transferring arable fields towards the surrounding pastures and manure application as transferring fertility towards arable fields by exploitation of the surrounding pasture by animals (Quilfen & Milleville, 1983; Tourte, 1963). Vegetable growing falls outside this schematization and is considered intensive due to its high inputs of pesticides and manure.

The degree of differentiation depends on the relative importance of a crop species. For instance, for millet as the main crop of the region, 6 techniques are distinguished, whereas for fonio (a minor crop) one technique is described only. Table 1.1 presents the crops and technologies included. One can derive, for instance, that for semi-intensive millet cultivation (i25-i28, millet/5) animal traction is used, farmyard manure and fertilizer is applied, but no fallowing.

For livestock systems twenty two production techniques are distinguished, based on four criteria: *(i)* animal species (cattle, sheep, goats, donkeys, and camels), *(ii)* main production objective (meat and/or milk or traction/transport), *(iii)* mobility of animals (migrant, semi-mobile or sedentary) and *(iv)* animal target production level (low, intermediate and high) (Table 1.2). The technical coefficients are expressed per Tropical Livestock Unit [TLU].

Table 1.2. Defined livestock activities in the LP-model.

ACTIVITY CODE	SPECIES	MAIN PRODUCT	MOBILITY	PRODUCTION LEVEL
B1	cattle	traction	sedentary	intermediate
B2	cattle	meat	semi-mobile	low
B3	cattle	meat	semi-mobile	intermediate
B4	cattle	meat	migrant	low
B5	cattle	meat	migrant	intermediate
B6				vacant
B7	cattle	milk	sedentary	intermediate
B8	cattle	milk	sedentary	intermediate
B9	cattle	milk	migrant	intermediate
B10	cattle	milk	migrant	intermediate
B11	cattle	milk	sedentary	semi-intensive
B12	cattle	milk	sedentary	semi-intensive
B13	sheep	meat	sedentary & semi-mobile	low
B14	sheep	meat	sedentary & semi-mobile	intermediate
B15	sheep	meat	migrant	low
B16	sheep	meat	migrant	intermediate
B17	sheep	meat	sedentary	high
B18	goats	meat & milk	sedentary & semi-mobile	low
B19	goats	meat & milk	sedentary & semi-mobile	intermediate
B20	goats	meat & milk	migrant	low
B21	goats	meat & milk	migrant	intermediate
B22	donkeys	transport	sedentary	intermediate
B23	camels	transport	migrant	low

For fishery 3 production techniques are distinguished, based on two criteria: *(i)* whether fisheries is the primary or secondary occupation and *(ii)* mobility of fishermen (Table 1.3). The technical coefficients are expressed per household.

Table 1.3. Defined fishery activities in the LP-model.

ACTIVITY	ABBREVIATION	OCCUPATION	MOBILITY
V1	MMF	primary	migrant
V2	MSF	primary	sedentary
V3	SSF	secondary	sedentary

1.2 Labour requirements

1.2.1 Periods of specific labour demands

Labour requirements are defined as the number of man-days required to complete an operation including the necessary travelling time. One man-day [mnd] is defined as the amount of work accomplished by a male adult during one working day. In analogy, one animal-team-day [At, "atelage"] is the work accomplished by a pair of oxen during one working day. It is assumed in this study that only oxen are used for animal traction.

Labour requirements are defined separately for six different periods of the year, to account for the occurrence of periods with peak labour demands. In such periods, labour supply may become a constraint in agricultural activities. The length of each period is given to indicate the number of days available to complete the operation(s). The periods are:

1 Land preparation and sowing time of millet (duration 20 d);
2 First weeding (duration 15 d);
3 Remainder of the growing season of millet till harvest (duration 55 d);
4 Harvest time of millet (duration 10 d);
5 Harvest time of wet season rice (duration 10 d);
6 Remainder of the year (duration 255 d).

In each period the total labour requirements (for arable farming plus animal husbandry plus fisheries) may not exceed the local supply per subregion expressed in adult equivalents. Hence, temporary migration between subregions is excluded.

Labour requirements for transport (e.g. equipment or chemical fertilizer) and for travel to and from the fields are not explicitly included in this study, except those for transport of produce and farmyard manure, as described in the following subsection.

1.2.2 Labour requirements dependent on input or output

For some operations labour requirements are also a function of the level of input or output. For instance, the labour requirements for transport and application of farmyard manure are a function of the amount of manure required (input), which in turn is a function of the target yield (output). Furthermore, the labour requirements for harvest, transport of produce, threshing and winnowing are directly a function of yield. The same activity taking place in different rainfall zones varies in yield with the associated consequences for the labour requirements.

This problem could be solved by defining the labour requirements as a function of yield, but that would drastically increase the number of matrix cellules in the LP-model. Hence, as an alternative, the highest labour requirements for a specific task, i.e. those of the wettest rainfall zone (i.e. RZ I, Table 2.2, page 27) is selected and those for the other zones are derived from that value, using a correction factor. For labour requirements for transport and application of manure such a correction factor is not applied, as a preliminary analysis has shown that labour availability in the period for those tasks is not limiting, i.e. labour requirements for these tasks are not binding.

If the labour requirements for harvest would be exactly proportional to grain yield, the correction factors for extensive techniques would be 0.76, 0.50 and 0.37, those for semi-intensive techniques 0.81, 0.62 and 0.35 and those for intensive techniques 0.82, 0.64 and 0.35, for rainfall zone II, III and IV, respectively. However, it can be argued that at lower yields, more time per kg grain is required, resulting in higher values for the correction factors. Hence, the correction factors are set at 0.80, 0.60 and 0.45, for rainfall zone II, III and IV, respectively, independent of system intensity.

1.3 Sustainability

The concept of sustainability has received ample attention recently. Certainly any development or land use plan should consider (only or as far as possible) sustainable agricultural production systems. A special task force of the consultative Group on International Agricultural Research (CGIAR) defined sustainability as: 'the successful management of resources for agriculture to satisfy changing human needs, without degrading the environment or the natural resource base on which agriculture depends' (TAC, 1989). Evidently, degradation of the natural resource base can take many different forms. Of particular importance for the Region are the chemical exhaustion of soils, the disappearance of perennial grasses from the flood plains, the mortality of shrubs and trees on the rangelands, soil crusting and sealing and degradation of the rangeland (i.e. changing species composition or decreasing cover leading to lower forage availability) on loamy substrate's and increased wind erosion.

For operational purposes in this study, sustainability for arable crop systems has been defined as an equilibrium situation for the nutrient balances of the macro-elements (Subsection 1.3.1). For livestock systems, sustainability refers to a stable herd of each animal species, based on sustainable forage production. In addition to the condition of chemical equilibrium, only a fraction of the total pasture biomass production can be used (Subsection 1.3.2). For fisheries, sustainability refers to a maximum quota of fish that can be caught, given the level of the flood of the river Niger.

Water is another natural resource, whose exploitation should be sustainable. In the present study, the locations of permanent water points have been used to calculate the surface area that can be exploited by the animals during the dry season. The assumption made, is that a permanent water point supplies enough water both for human needs and for the animals that can be fed within a radius of 15 km of that water point.

1.3.1 Sustainability in terms of nutrient elements

Sustainability of the arable crop systems is defined here in such a way that the total amount of nutrient elements in the soil remains constant in the long run. This criterion was selected, as in addition to uncertain, variable and low rainfall, low soil fertility (in terms of nutrient element availability) is a major constraint for crop production in West Africa (Penning de Vries & Djitèye, 1982; Piéri, 1989). If the soil can not supply sufficient plant nutrients to satisfy crop demand, the yield level is determined by the amount of the limiting element that can be taken up. This constraint can be removed by fertilizer application, provided it is takes place in the right way, in the right form and at the right time. This results in increasing yields with increasing nutrient availability, until another growth factor (e.g. water, radiation) becomes limiting. Hence, for definition of sustainable crop systems, soil fertility and fertilizer effects play a key-role. Moreover, the dynamics of nutrient elements within the production system should be known. Figure 1.2 shows in a schematized way these dynamics, used as the basis for our calculations.

This definition of sustainability implies that all nutrient elements taken up by the crop (1) (numbers refer to processes in Figure 1.2), lost by surface runoff and erosion (2), or lost otherwise from the system (3) must be covered completely by inputs from natural sources (4) and external inputs (5 & 6). The analysis is restricted to nitrogen, phosphorus and potassium, due to lack of quantitative information on other elements. In our study, losses due to erosion and run-off, and inputs by run-on and dust have been neglected under the assumption that for these processes an equilibrium situation exists in the Region. However, erosion losses may be considerable under certain conditions, as described by Stoorvogel & Smaling (1990).

As no quantative information is available on the availability of nutrient elements from natural sources in the various soil types in the region, calculations are made from target yield towards requirements of fertilizer and manure. In some production techniques, however, neither of these inputs are applied, hence in that case soil fertility must be maintained by fallowing for different periods. In the calculation procedure the following steps have been used, as described in more detail by van Duivenbooden (1991).

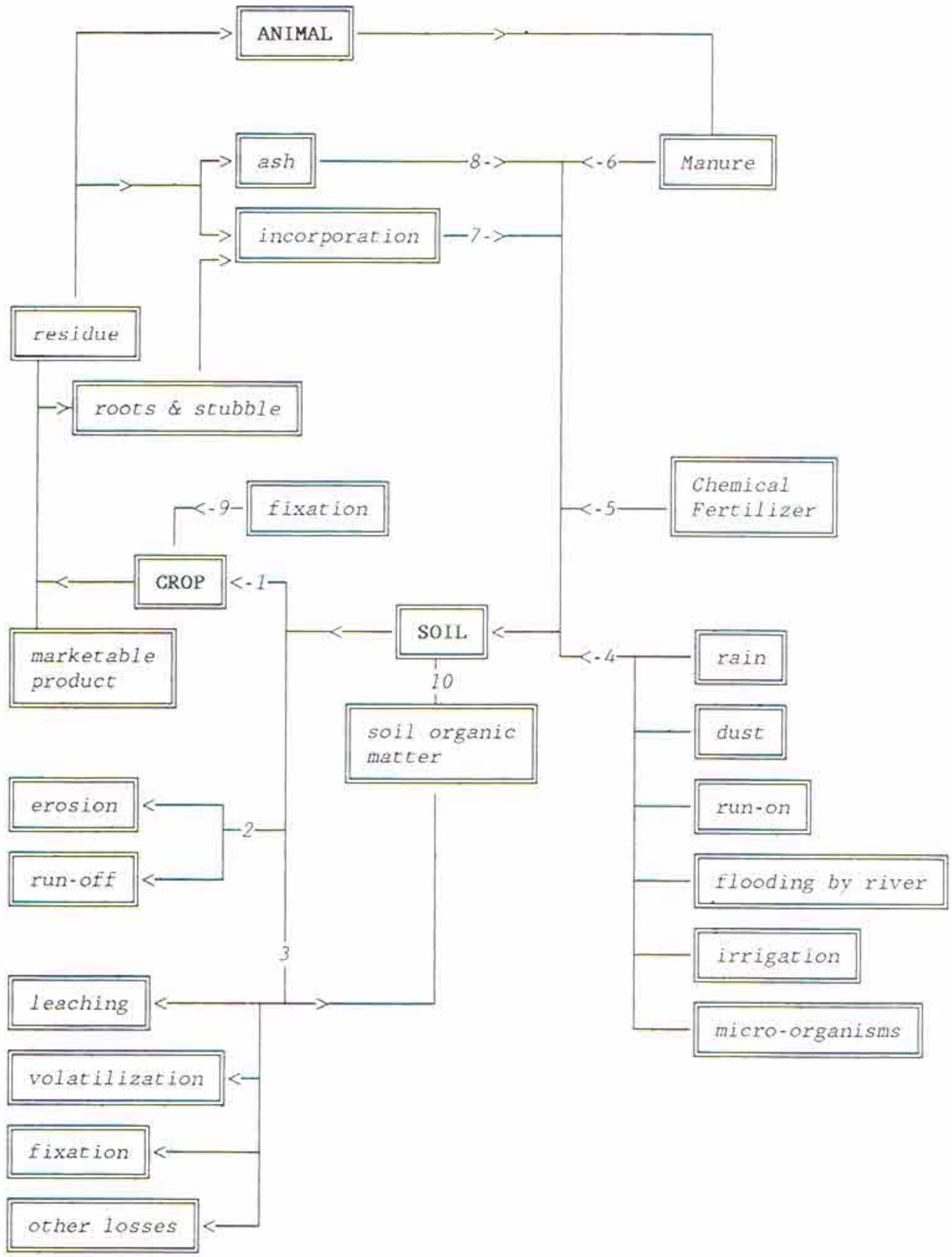


Figure 1.2. Schematized dynamics of macro nutrient elements (nitrogen, phosphorus and potassium) in the production system.

1.3.1.1 Uptake of N, P and K

1. Target yield and total above-ground biomass

Potential yields (under optimum supply of water and nutrients, and in the absence of weeds, pests and diseases) and yields under water-limiting conditions can be obtained from simulation models. These models are, however, as yet not adequate in situations where crop growth may be limited by either water or nutrient shortages at different periods during the growth cycle and moreover, variable yield reductions due to pests and diseases may occur. Therefore, reported yields from the Fifth Region are used for these conditions. Harvest and post-harvest losses, estimated at 20%, are taken into account in the LP-model to calculate net yield.

Total above-ground biomass is calculated on the basis of simulation model results if possible, or alternatively on the basis of harvest indices available from literature.

The biomass production of roots and stubble is calculated on the basis of fixed shoot-root ratio's (SRR), with values a function of technique. For cereals these values are set at 4, 4 and 6 for the extensive, semi-intensive and intensive techniques, respectively, and for leguminous species at 5, 5 and 7.

2. Minimum concentrations of N, P and K

Values of concentrations for both marketable product and crop residues for the various crops were derived from fertilizer experiments in West Africa as reviewed by van Duivenbooden (1991). However, as nutrient elements are practically never diluted to these minimum concentrations due to the negative effects of other growth reducing factors, a multiplier is introduced defined as a function of technique intensity. For extensive and semi-intensive techniques the multiplier is 1.2 and 1.3 for grains and straw, respectively. For the intensive technique the values are 1.4 and 1.7, respectively. Due to the low number of observations for onions and other vegetables, no multiplier is applied for these crops.

3. Total uptake of N, P and K

Subsequently, the required uptake of N, P and K for each production technique is calculated as the product of biomass of marketable product and crop residues (including roots and stubble), their respective concentrations and the relevant multiplier.

1.3.1.2 Sources of N, P and K

1. Nutrient availability from natural sources

In addition to nutrients originating from mineralization during decomposition of old soil organic matter (Figure 1.2, No 10), nutrients from other natural sources are available, such as rainwater, dust, irrigation water, river water in flood-retreat crops and micro-organisms (free living bacteria's) (4). All processes affecting natural fertility of the soil (in terms of availability of nutrient elements in the absence of fertilizer or manure application, including processes of weathering) have been quantified. As indicated earlier, no actual data on natural fertility of the various soil types are available. Hence, natural fertility is defined as the ratio of the required uptake of the nutrient element and the fraction allocated to soil organic matter. In other words, the amount of fertilizer nutrients lost on the one hand due to allocation to old soil organic material, becomes available from that source on the other hand (equilibrium situation).

2. Nutrients available from crop residues

Nutrients from last year's crop residues come available to the soil *(i)* through the animal, i.e manure (6), *(ii)* by incorporation (7), *(iii)* in the form of ash (8) and *(iv)* by micro-organisms associated with roots. Two categories are distinguished *a)* root & stubble and micro-organisms and *b)* straw left on field, partly buried in the soil and partly as ash. It is assumed here that the quantity of nutrient elements absorbed by roots and stubble one year will become available in the following year.

3. Nutrient available from the crop itself

Nitrogen can be fixed by some crops (groundnut & cowpea) (9), reducing thus the input required.

1.3.1.3 Quantification of the various soil processes

To calculate the required amount of fertilizer, the recovery fraction, i.e. the fraction of the applied fertilizer taken up by the crop, must be established. This fraction is determined on the basis of an assumed distribution of the applied N, P and K among the various processes illustrated in Figure 1.2 (3). For each combination of soil type and nutrient element that distribution has been assessed (Tables 1.4 & 1.5), e.g. for nitrogen in soil type B1, the assumed fractions are: incorporation in soil organic matter 0.3, leaching 0.15, volatilization 0.15, denitrification 0.10 and hence apparent recovery (plant uptake) 0.30. This distribution assumes an equilibrium situation, hence if a soil has to be improved in terms of nutrient availability, the various fractions may change considerably.

It is assumed that nutrient elements behave in the soil independent of their source (chemical fertilizer, manure, crop residues).

Table 1.4. Distribution of nitrogen, phosphorus and potassium among the various processes for the various soil types of the 5th region of Mali, as applied for rainfed crops.

PROCESS	SOIL TYPE A	B1	B2	C1,2	D1	D2	E1	E2	F1	F3	G
NITROGEN											
Incorporation	0.30	0.30	0.30	0.35	0.25	0.20	0.30	0.20	0.30	0.35	0.40
Leaching	0.25	0.15	0.15	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.05
Volatilization	0.15	0.05	0.15	0.10	0.05	0.05	0.10	0.20	0.05	0.05	0.05
Denitrification	0.00	0.10	0.10	0.10	0.15	0.15	0.20	0.20	0.25	0.25	0.30
Plant uptake	0.30	0.40	0.30	0.35	0.45	0.50	0.30	0.20	0.30	0.25	0.20
PHOSPHORUS											
Incorporation	0.30	0.30	0.30	0.35	0.25	0.25	0.30	0.20	0.30	0.30	0.35
Fixation	0.30	0.30	0.30	0.35	0.30	0.40	0.25	0.45	0.30	0.30	0.30
Residual	0.20	0.20	0.20	0.15	0.20	0.20	0.15	0.15	0.15	0.15	0.20
Plant uptake	0.20	0.20	0.20	0.15	0.25	0.15	0.30	0.20	0.25	0.25	0.15
POTASSIUM											
Incorporation	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.15	0.20	0.20	0.25
Leaching	0.20	0.20	0.20	0.10	0.10	0.10	0.10	0.15	0.10	0.10	0.10
Fixation	0.15	0.15	0.15	0.10	0.10	0.10	0.05	0.10	0.05	0.05	0.10
Plant uptake	0.50	0.50	0.50	0.60	0.60	0.60	0.65	0.60	0.65	0.65	0.55

Table 1.5. Distribution of nitrogen among the various processes for rice cultivation. For phosphorus and potassium see Table 1.4.

PROCESS	SOIL TYPE E1	E2	F3
NITROGEN			
Incorporation	0.30	0.25	0.35
Leaching	0.05	0.10	0.05
Volatilization	0.05	0.10	0.00
Denitrification	0.35	0.35	0.40
Plant uptake	0.25	0.20	0.20

1.3.1.4 Fertilizer requirements

1. N, P and K requirements

The requirements of each nutrient element are calculated separately by:

$$REQ_e = \frac{UPT_e - FIX_e}{FPU_e} - NAT1_e - NAT2_e - CRR1_e - CRR2_e \qquad (1)$$

with,

REQ_e = Required input of element e [kg ha^{-1}]
UPT_e = Uptake of element e by crop [kg ha^{-1}]
FIX_e = Nitrogen fixation by crop, for P & K: 0 [kg ha^{-1}]
$NAT1_e$ = Natural soil fertility of element e [kg ha^{-1}]
$NAT2_e$ = Remainder of element e available from natural sources [kg ha^{-1}]
$CRR1_e$ = Availability of element e from crop residues of preceding year (roots & stubble) [kg ha^{-1}]
$CRR2_e$ = Availability of element e from crop residues of preceding year (straw & ash) [kg ha^{-1}]
FPU_e = Apparent recovery for element e [-]

Equal to:

$$REQ_e = \frac{UPT_e - FIX_e}{FPU_e} - \left(\frac{UPT_e - FIX_e}{FPU_e} * FOM_e\right) - NAT2_e - CRR1_e - CRR2_e \qquad (2)$$

or

$$REQ_e = \left(\frac{UPT_e - FIX_e}{FPU_e} * (1 - FOM_e)\right) - NAT2_e - CRR1_e - CRR2_e \quad (3)$$

with,
FOM_e = Fraction of element e applied allocated to soil organic matter [-]

Note that for the same agro-ecological zone the required input of fertilizer N, P and K is a function of soil type.

2. Farmyard manure and chemical fertilizer requirements

Availability of nitrogen and other nutrient elements from applied farmyard (organic) manure for plant uptake depends on one hand on its rate of decomposition and on the other hand on its quality the two of which are interrelated, but the actual quantitative relationships are poorly understood and need more research as discussed by de Ridder & van Keulen (1990). The quality, i.e. defined in general terms of absolute and relative nutrient element content, is a function of *a)* the type of animal, *b)* the quality of its diet and *c)* the time between excretion and application in the field. For definition of a generally applicable value, based on the available experimental evidence, the 50% probability level of nutrient concentration as calculated from the available data has been used. These concentrations are 12.7, 2.8 and 13.0 g kg^{-1} on DM basis for N, P and K, respectively. As said before, it is assumed for the time being that nutrients originating from manure in terms of losses and availability behave similarly to those from chemical fertilizers.

The fraction of the total nutrient requirements to be met from manure depends on both crop and technique intensity. The amount of manure required is calculated for N, P and K separately:

$$MAN_e = \frac{REQ_e * FMM}{CON_e} \quad (4)$$

with,
MAN_e = Manure requirements [kg ha^{-1}]
FMM = Fraction met by manure [-]
CON_e = Concentration of element e in manure [kg kg^{-1}]

In the LP-model the maximum of the three values is used as input. The remainder of the total nutrient requirements is to be met from chemical (inorganic) fertilizer:

$$FER_e = REQ_e - (MAN_m * CON_e) \qquad (5)$$

with,
FER_e = Chemical fertilizer requirements of element e [kg ha^{-1}]
MAN_m = Manure requirements used in LP-model [kg ha^{-1}]

1.3.1.5 Ratio years of fallow/year of cultivation

The fraction of the vegetation not consumed by animals during fallow periods contributes to an input of nutrient elements to the soil. In the present study that contribution is estimated on the basis of the N_b-formula for an equilibrium situation (de Wit & Krul, 1982), which also takes into account inputs through rain, fixation by leguminous species and algae. Note that algae are assumed to be active under fallow only and not under ploughed conditions. Application of this approach is justified by the assumption of sustainability in terms of nutrients, which is equivalent to an equilibrium situation. The original equation reads:

$$N_b = \frac{0.0085 * PR}{1.025 * F - (0.02 * L + 0.038)} \qquad (6)$$

with,
N_b = Total amount of nitrogen in above-ground biomass [kg ha^{-1}]
PR = Precipitation [mm]
F = Fraction of N lost from the vegetation [-]
L = Contribution of leguminous species to vegetation [%]

For natural pastures it has been assumed that a fraction of 0.3 to 0.5 of the peak amount of nitrogen in the biomass is lost each year in the equilibrium situation, e.g. by grazing and volatilization (Chapter 11). For fallow fields the grazing pressure is assumed to be half of that of natural pastures, but taking into account some selective grazing behaviour, a value of 0.3 has been used. Furthermore, the contribution of leguminous species is estimated at 5%. Hence, the N_b-formula becomes:

$$N_b = \frac{0.0085 * PR}{0.1695} \qquad (7)$$

In that situation the amount of nitrogen lost is thus:

$$N_e = F * N_b \quad (8)$$

with,
N_e = Amount of nitrogen lost from fallow fields [kg ha^{-1} yr^{-1}]

For sustainable systems, this amount of nitrogen should be at least be covered by the input of N from fallow. Quantitative data on this topic are scarce, and the net input is ambiguous: slightly positive (Stoorvogel & Smaling, 1990; Poulain, 1980) or negative (van de Pol, 1990). At clearing after fallow, trees and bushes are removed from the field, with its associated consequences for the N, P and K balances. In this study it is assumed that the net annual input during fallow equals 1.3 times the amount of nutrient lost:

$$FI = 1.3 * N_e \quad (9)$$

with,
FI = Net amount of element added to the soil [kg ha^{-1} yr^{-1}].

Application of the above mentioned value of 0.3 for F and Equation 7, e.g. for nitrogen this results in:

$$FI_N = 0.020 * PR \quad (10)$$

with,
FI_N = Net amount of nitrogen added to the soil [kg ha^{-1} yr^{-1}].

Note that for a flood retreat crop (sorghum) this amount is augmented with the amount of nutrients sedimented by the river.

For example this means for a fallow field in rainfall zone I a net nitrogen input of 10.6 kg ha^{-1} yr^{-1}, which is of the same magnitude as the net input calculated on the basis of 5 times a millet crop (yield 500 kg ha) and a 20 year period of fallow.

In this study it is assumed that the amounts of phosphorus and potassium added to the soil system are 0.12 and 1.0 times those of nitrogen, respectively. These assumptions are based on rather flimsy evidence, and more research is needed to substantiate them.

As these equations hold for an equilibrium situation, where losses and contributions from natural sources implicitly have been taken into account, years of fallow per year of cultivation is calculated separately for each nutrient element:

$$YFYC = \left(\frac{UPT_e - FIX_e}{FPU_e} - CRR1_e\right) * \frac{1}{FI_e} \qquad (11)$$

with,
YFYC = Years of fallow/year of cultivation [yr yr^{-1}]
FI_e = Input of element e during fallow [kg ha^{-1} yr^{-1}]

In a few cases (fonio, groundnut), it appeared that the maximum years of fallow per year of cultivation was obtained for phosphorus. As the length of the fallow period could be reduced substantially by a small input of chemical P-fertilizer, this was assumed to be practiced.

An example of this method for two millet activities is presented in Table 1.6. Note, however, that these calculations are based on rather crude assumptions with respect to the nutrient cycles in the soil-plant system and more accurate and detailed experimental data are required to substantiate the results obtained.

Table 1.6. Example of the calculation method for fertilizer/manure requirements or ratio of fallow years/year of cultivation for activity i1 & i6, i.e. millet, extensive technique on a B1 soil in rainfall zone I.

PARAMETER	UNIT	VALUE		
Target yield	[kg ha^{-1}]	500		
Straw	[kg ha^{-1}]	2750		
Total	[kg ha^{-1}]	3250		
shoot-root ratio	[-]	4		
Root & stubble	[kg ha^{-1}]	813		
fraction straw left on field	[-]	0.30		
fraction straw burnt	[-]	0.50		
Straw buried in soil	[kg ha^{-1}]	1225		
UPTAKE REQUIREMENTS		N	P	K
Minimum content grain	[g kg-1]	13.0	1.8	10.0
Minimum content straw	[g kg-1]	3.0	0.3	4.0
multiplier grain	[-]	1.2	1.2	1.2
multiplier straw	[-]	1.3	1.3	1.3
uptake above-ground biomass	[kg ha^{-1}]	18.5	2.15	20.3
uptake roots & stubble	[kg ha^{-1}]	3.2	0.32	4.2
Total uptake	[kg ha^{-1}]	21.7	2.47	24.5
AVAILABILITY FROM REMAINDER OF NATURAL SOURCES				
rainwater	[kg ha^{-1}]	3.5	0.37	2.7
river water	[kg ha^{-1}]	0.0	0.00	0.0
irrigation water	[kg ha^{-1}]	0.0	0.00	0.0
micro-organisms org. mat.	[kg ha^{-1}]	0.3	0.03	0.0
AVAILABILITY FROM CROP RESIDUES				
root & stubble	[kg ha^{-1}]	3.2	0.32	4.2
micro-organisms roots	[kg ha^{-1}]	0.3	0.03	0.0
straw left on field	[kg ha^{-1}]	1.2	0.12	1.7
ash from straw	[kg ha^{-1}]	0.5	0.10	1.0
Recovery fraction	[-]	0.40	0.40	0.50
Fraction nutrients to soil OM	[-]	0.30	0.30	0.15
REQUIREMENTS	[kg ha^{-1}]	29.0	3.38	32.2
MANURE REQUIREMENTS (i1)				
Fraction req. met by manure	[-]	1.0	1.0	1.0
Manure requirements	[kg ha^{-1}]	2282	1206	2475
Requirements used in LP	[kg ha^{-1}]	2480		
FALLOW/CULTIVATION (i6)				
Input from fallow	[kg ha^{-1} yr^{-1}]	10.6	1.3	10.6
Ratio fallow years/year cultivated	[-]	4.8	4.6	4.2
Ratio used in LP-model	[-]	5		

1.3.2 Sustainability in terms of production

For livestock production techniques, sustainability is related to the production of both animals and forage, as described in detail by Breman & de Ridder (1991).

To assure biological survival of the herds, a minimum reproduction rate is used that results in a constant herd. This means for cattle that the quality of the diet should attain or exceed a lower limit, allowing heifers to grow 25 kg yr^{-1}. This minimum quality has been applied for all livestock.

Sustainability of fodder production systems, as far as crop residues are concerned, is treated as for arable crops. For rangelands, sustainability is taken into account in calculating forage availability from total forage production. The following assumptions were used:

- Annual production of the herb layer is first corrected for losses due to fire, after which 50% of the remaining biomass is regarded available for intake in case of grazing during the rainy season only and for regrowth of perennial grasses after fire in the dry season. This fraction is reduced to 35% in case of both grazing during the dry season and continuous grazing.
- In case of dominance of perennial grasses, only 50% of the annual production is regarded available, to assure maintenance of their nutrient stock, and this fraction has been reduced as mentioned above.
- Availability of browse is calculated on the basis of green foliage, accessible in the dry season, plus annual fruit production. The maximum amount of browse to be grazed may not exceed 15% of the total browse production in a normal year.
- If mowing is part of the production technique, the nutrients that are removed from the field with the fodder should be replaced by fertilizer application.

These precautions may not be sufficient to avoid further degradation of the rangelands on the more loamy soils, i.e. soil types C2, D1, D2 and F2. The amount of biomass required to protect their soil surfaces against physical degradation (crusting and sealing) exceeds their annual biomass production (Penning de Vries & Djitèye, 1982). Hence, if sustainability were to be included in the model in the sense of its original definition, it would imply no grazing at all of the rangelands on these soil types. In the present version of the model, however, this criterion has not been applied.

PART I. PLANT PRODUCTION

2. MILLET

(N. van Duivenbooden & P.A. Gosseye)

2.1 Introduction

The term 'millet', as used here, refers to *Pennisetum americanum ssp. americanum* (syn. *P. typhoides, P. typhoideum, P. glaucum*). Other vernacular names in English are: pearl millet, bulrush millet, cattail millet and spiked millet (Purseglove, 1975) and in French: petit mil, mil perlé, mil à chandelles, mil pénicillaire, millet (Pernès *et al.*, 1980; Baudet, 1981).

Millet is grown throughout the Region on rainfed land, preferably on light to medium-textured soils. The crop is highly resistant to drought, high temperatures and high levels of radiation. In addition, it can be grown on a wide range of soil types, and tolerates a range of pH-levels and moderate levels of salinity (Rassel, 1958; Jacquinot, 1971; Kassam & Kowal, 1975; Kurian, 1976; Rachie & Majmudar, 1980). Its requirements in terms of rainfall correspond to rainfall levels within the Region.

The primary target of this rainfed cereal crop is to produce grain for human consumption, as millet accounts for up to 95% of the producers' diet (Catherinet *et al.*, 1963; Martin, 1982; 1985; PIRT, 1983). Millet is the eighth most important cereal produced worldwide (Baudet, 1981) and forms the staple diet of the inhabitants of semi-arid regions in Africa and Asia, where low rainfall prevents cultivation of other sources of carbohydrates (Ferraris *et al.*, 1973; 1974; Rachie & Majmudar, 1980).

The stubble is used to feed livestock, mainly cattle (Dicko *et al.*, 1983; Quilfen & Milleville, 1983). In the last few years this has become an important practice in the Region, as in the whole of Mali. It was once common practice at harvest to break the stalks with a stick to bend them, collect the ears and simply leave the stubble in the field as fodder for passing animals (stubble grazing) or as part of an agreement between livestock owners and farmers. At present, it is much more usual to see shocks of millet cut at the stem base with a hoe. After the ears have been harvested, the stover is collected and stacked in circular or square ricks, with the stem base to the outside. The stover is used to feed the own animals or sold as fodder for periods of low forage availability. In addition to serving as fodder, the stubble is used as fuel, building material for enclosures and roofs and, after burning, in the manufacture of potassium salt for cooking and soap products.

The husks are used, among others, for potassium salt making, for construction in banco and as a mulch for vegetables. In some areas, we have observed that they are returned to the fields.

In the Region, millet is grown under a wide range of cultivation methods, that could all be described in detail. However, given the aims of this study and the specific requirements of the LP-model, only six major sustainable millet production techniques have been defined, on the basis of the four discriminating criteria

(Subsection 1.1.2), i.e. use of animal traction, use of farmyard manure, chemical fertilizer application and use of fallow.

A. Use of animal traction

This first criterion refers to the level of technical development. Use of animal traction stimulates exploitation of the soil nutrient reserves, thus leading, in the short term, to increased yields of the order of 20%. Unfortunately, however, this leads in the long term to more rapid exhaustion. To maintain fertility, therefore, compensatory measures are required, either increasing the ratio of fallow years to cultivated years or adding nutrient elements from external sources (Subsection 1.3.1).

B. Application of farmyard manure

This second criterion, as the next two, strictly refers to the way in which soil fertility is maintained in the long-term, or in other words, how sustainability of the production techniques is guaranteed (Subsection 1.3.1). Farmyard manure serves to sustain both chemical fertility and physical properties of cultivated soils in the long term. Although the use of organic manure implies a transfer of fertility (Quilfen & Milleville, 1983), it is assumed in this study that manure cannot cross the border of the Region nor that of an agro-ecological zone and that at the sub-regional level demand should not exceed supply.

C. Chemical fertilizer application

Chemical fertilizer is mainly used to increase the level of nutrient availability (a means of correcting any nutrient imbalances and compensating for plant nutrient uptake). Hence, fertilizer application means a net import of nutrients into the Region. It should, however, always be applied in combination with organic manure to maintain the physical properties of the soils.

D. Fallowing

As mentioned in Subsection 1.3.1, fallowing is another way of maintaining soil fertility in the long term, by lowering exploitation pressure, whereas application of manure or fertilizer allows continuous use. It is realised that continuous use of fertilizer may eventually lead to soil tiredness (yield reduction due to soil-borne pests and diseases), but no specific allowance is made for this fact in this study (rotation constraint) and it is assumed that the use of fallowing, or organic manure, counterbalances that effect.

The six techniques selected for our study can be classified in three categories, depending on the level of intensification:

Extensive technique

Four extensive production techniques can be distinguished, that are currently practiced, exploiting the natural fertility level of the soil:

1. No animal traction, no manure nor fertilizer application. Sustainability of the production technique is ensured by fallowing;
2. No animal traction, no fallowing nor fertilizer application. Sustainability of the production technique is ensured by farmyard manure application;
3. Animal traction, no farmyard manure nor fertilizer application. Sustainability of the production technique is ensured by fallowing;
4. Animal traction, no fallowing nor fertilizer application. The sustainability of the production technique is ensured by farmyard manure application (Figure 2.1).

Figure 2.1. Illustration of the extensive production technique no 4 of millet: application of manure.

Semi-intensive technique

The semi-intensive technique (no 5), hardly practiced at present, relies on increased nutrient availability to the crop by farmyard manure and chemical fertilizer application and is based on current production methods: use of animal traction, but without fallowing. Sustainability of the production technique is ensured by manure application and chemical fertilizer.

According to Barry (pers. comm., ODEM) and Tembély (pers. comm., ORM), chemical fertilizer application is already practiced by farmers in Cercle de Bankass and Cercle de Koro (Sourou and Séno Bankass): if the prospects for the rainy season are favourable, they try to obtain fertilizer in time for the growing season.

Intensive technique

The intensive technique (no 6), which is not practiced at present, relies on a substantial increase in nutrient availability to the crop and uses improved production methods: e.g. animal traction with a better quality plough. Fallowing is not used and sustainability of the production technique is ensured through organic manure and fertilizer application. The intensive technique is considered potential, but is certainly technically feasible in the Region.

2.2 Environment

The optimum rainfall zone for millet is between 250 and 700 mm yr^{-1}. In Africa and Asia, millet is the dominant cereal crop below 500 mm yr^{-1} (Catherinet *et al.*, 1963; Siband, 1981; Lambert, 1983). The Region, from South to North, is located between 600 and 200 mm yr^{-1}, as shown in Report 1, Chapter 4.

The Region is divided into 11 agro-ecological zones (Figure 2.2) on the basis

Table 2.1. Listing of the 72 geographical reference localities in the Region. The numbering corresponds with the underlined numbers in Figure 2.2.

NO	NAME	NO	NAME	NO	NAME
1.	Ambiri	25.	Kami	49.	Ouo
2.	Bandiagara	26.	Kani Bonzon	50.	Ouro-Mody
3.	Banikané	27.	Kanigogouna	51.	Pel
4.	Bankass	28.	Kara	52.	Sah
5.	Baye	29.	Kendié	53.	Sangha
6.	Boni	30.	Konio	54.	Saraféré
7.	Boré	31.	Konna	55.	Ségué
8.	Diafarabé	32.	Koporokendié-Nah	56.	Sendégué
9.	Dialassagou	33.	Korientzé	57.	Sofara
10.	Dialloubé	34.	Koro	58.	Sokoura
11.	Diankabou	35.	Kouakourou	59.	Sossobé
12.	Dinangourou	36.	Koumaïra	60.	Soufouroulaye
13.	Diondiori	37.	Léré	61.	Soumpi
14.	Diongani	38.	Madougou	62.	Soyé
15.	Dioura	39.	Mondoro	63.	Taga
16.	Djenné	40.	Mopti-ADRAO	64.	Ténènkou
17.	Dogo	41.	Mopti-Aérodrome	65.	Toguéré-Goumbé
18.	Douentza	42.	Mopti-OMM	66.	Toroli
19.	Dourou	43.	Mougna	67.	Youwarou
20.	Fatoma	44.	N'Gorkou	68.	Macina
21.	Gathi-Loumo	45.	N'Gouma	69.	Nampala
22.	Goundaka	46.	Niafunké	70.	San
23.	Guidio-Saré	47.	Ningari	71.	Tombouctou
24.	Hombori	48.	Ouenkoro	72.	Tonka

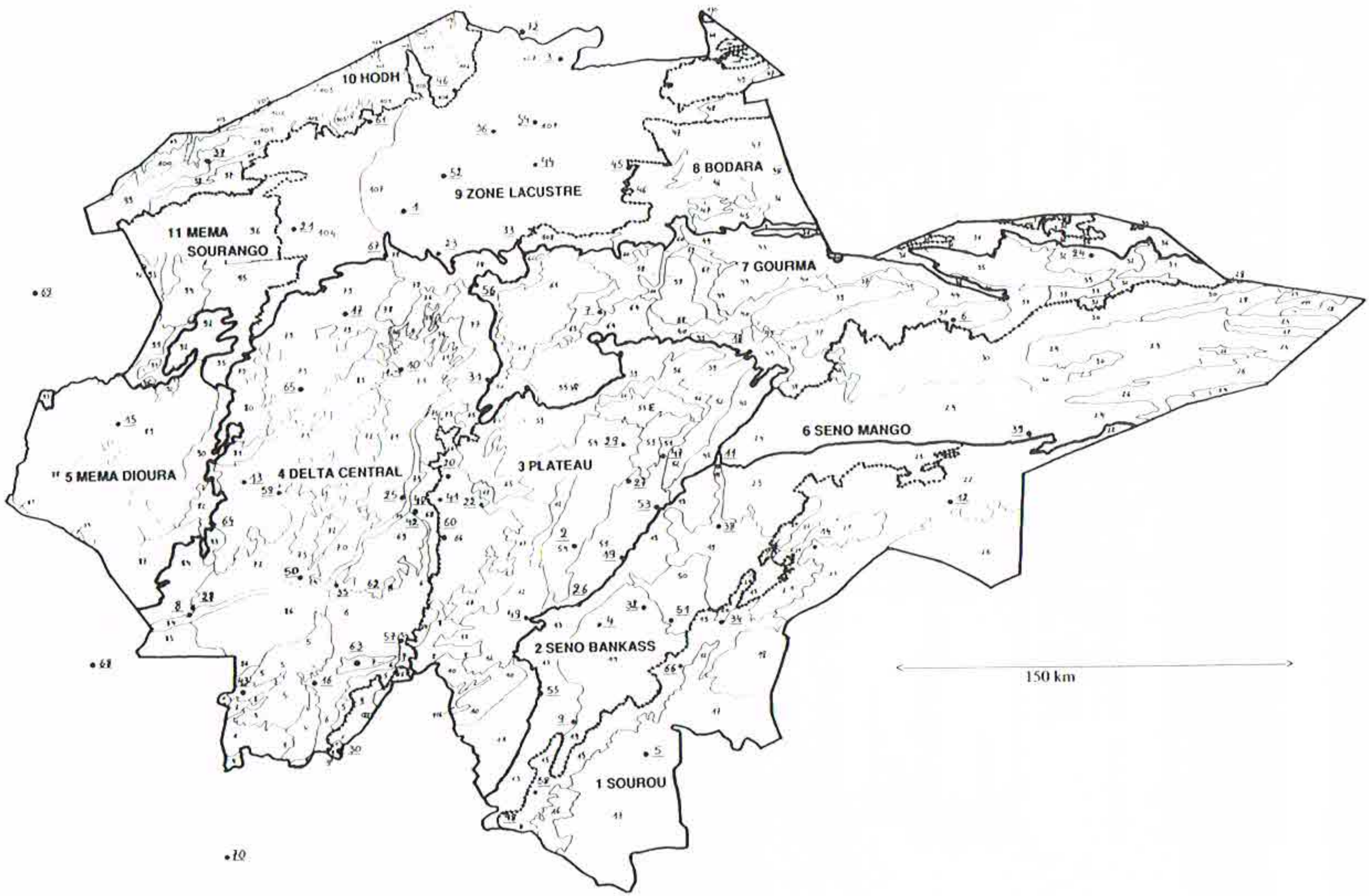


Figure 2.2. The Region and its 11 agro-ecological zones. The thin lines are the limits of the 116 PIRT basic map units which are identified by the small numbers. The underlined numbers are the 72 localities of geographical reference given in Table 2.1.

of soil criteria, each zone constituting the basic physical territorial unit for the LP-model (Report 1, Chapter 3).

In terms of rainfall, these 11 zones are divided into 4 rainfall zones as shown in Table 2.2. We have used the rainfall data from May to October in 'normal' and 'dry' years between 1959 and 1988 (Report 1, Chapter 4).

Table 2.2. Annual rainfall [mm yr^{-1}] and rainfall from May till October [mm] for dry, normal and wet years in the four rainfall zones regrouping the 11 agro-ecological zones. Average values for 1959-1988.

AGRO-ECOLOGICAL ZONE	MAY - OCTOBRE			ANNUAL		
	normal	dry	wet	normal	dry	wet
Rainfall Zone I						
Sourou	530.5	362.5	683.0	544.5	368.1	689.0
Séno Bankass						
Rainfall Zone II						
Plateau	457.3	302.4	653.2	460.9	305.6	662.7
Delta Central						
Rainfall Zone III						
Méma Dioura	376.4	236.7	501.7	379.3	237.0	512.1
Séno Mango						
Gourma						
Rainfall Zone IV						
Bodara	255.0	153.1	356.0	256.6	153.1	356.9
Zone Lacustre						
Hodh						
Méma Sourango						

Source: Report 1, Chapter 3.

In normal years, millet can be cultivated in all four zones, as annual rainfall varies between 545 and 257 mm (531 to 255 mm between May and October). In dry years millet can still be grown in the two southern rainfall zones, which comprise four agro-ecological zones, where annual rainfall varies between 368 and 306 mm (363 to 302 mm between May and October). Millet, however, is a marginal crop in the two northern rainfall zones, which comprise 7 agro-ecological zones where, in dry years, annual rainfall varies between 237 and 153 mm (237 to 153 mm between May and October). From 1959 to 1988, avarage annual rainfall in the 11 agro-ecological zones varied from south to north between 536 and 233 mm, while from 1979 to 1988, it varied between 469 and 137 mm (Report 1, Chapter 4).

Millet tolerates an unfavourable soil structure and although it can be grown on heavy soil (loam and clay), it is mainly cultivated on light (sand and loamy sand) and medium-textured soils (sandy loam). Before discussing the various soil types cultivated with millet, it is important to briefly consider two factors affecting the choice of soil, leaving aside possible sociological and social restrictions. These two factors are also taken into account in the simulation models (Erenstein, 1990; van Duivenbooden, 1990a).

1. Constraints related to water

- Millet is sensitive to waterlogging. Heavy soils are therefore best avoided, since they are prone to waterlogging during heavy rains. This sensitivity to waterlogging is also one of the reasons why millet is sometimes cultivated on ridges;
- The first rains are important from the point of view of germination. Heavy soils are therefore avoided because they require too much water (pF curve) at the start of the rainy season to trigger germination, thereby further reducing the already very short growing season;
- Heavy soil retain a substantial proportion of the water that cannot be used by plants (wilting point, pF curve), thus aggravating drought when rainfall is low.

Heavy soils are used, however, if the combination of rainfall and topographic position is such that it ensures a better supply of water due to run-on, while waterlogging is avoided. This combination is often used in the Region: the crops 'climb' towards the upper parts of the micro-relief, on lighter soils, when the prospects for rainfall are favourable. Conversely, they 'descend' into the depressions of the micro-relief, on heavier soils, when the prospects are unfavourable. By covering heavy soil with sand, more favourable conditions for germination during the first rains can be created, while the soil is also easier to work.

In the northern part of the Region, where rainfall is low and the soils are sandy, the topographic position is also used to increase water availability to millet by growing it at the foot of sand dunes where not so much run off water, but infiltrated water is used, with the dune serving as a 'collector'.

2. Labour constraint

Whether a given soil can be worked (ploughing and additional tillage operations) depends, among others, on available labour and tehnical means (hoe/manual, plough/oxen). Therefore, a naturally tendency exists towards choosing fairly light soils that are quicker and easier to work. This more extensive technique also decreases risks.

Yet another constraint is that pertaining to the 'scarcity of land'. The less land is available, the greater the variety of soils used. On the Plateau, for example, cultivation can be observed even on filled-in diaclases and rocky scree.

These three constraints, and the exploitation of specific rainfall-topography combinations, results in, at least partial, cultivation of soils that are apparently unsuitable for farming. For quantification of the area that can be cultivated with millet, an utility index is defined. The value has been determined on the basis of literature information (PIRT, 1983; 1984; 1986; 1987; 1989) and field studies.

In the LP-model, the soils defined potentially suitable for cultivation of millet per agro-ecological zone are:

- loamy sand, soil type B1 (CABO-classification = D5 and D6 PIRT-classification; Report 1, Chapter 3) found in Séno Bankass (Figure 2.2) with a surface of 2 477 km^2, in Séno Mango (4 430 km^2) and in Hodh (25 km^2);
- loamy sand with a shallow ground water table (B2 = D7) found in the Delta Central (64 km^2), Méma Dioura (391 km^2), Bodara (5 km^2), Zone Lacustre (4 312 km^2), Hodh (7 km^2) and Méma Sourango (265 km^2);
- sandy loam (C1 = DA1, DA2, DA3, DA4, DA5, PS2 and PS3) found in Sourou (2 327 km^2), Séno Bankass (3 866 km^2), Plateau (1 814 km^2), Delta Central (375 km^2), Méma Dioura (2 319 km^2), Séno Mango (884 km^2), Gourma (800 km^2), Bodara (1 006 km^2), Zone Lacustre (278 km^2), Hodh (1 657 km^2) and Méma Sourango (57 km^2). These soils include sand dunes cultivated occasionally;
- gravelly sandy loam (C2 = TR2 and TR6) found in the Plateau (3 354 km^2) and Gourma (1 491 km^2). The TR1 soils in the Gourma, also gravelly sandy loams, have been excluded;
- clay loam (D1 = PL4 and PL6) found in Sourou (367 km^2 = 15% of PL6), the Plateau (102 km^2 = 100% of PL4), Méma Dioura (594 km^2 = 100% of PL4 and PL6) and Gourma (208 km^2 = 15% of PL4). Soil types PL4 and PL6 in Séno Mango have been excluded, as well as PL4 in Bodara, Hodh and Méma Sourango. Soil type TH5 in the Delta Central, Gourma and Hodh which is also a clay loam, has also been excluded;
- fine clay loam/loamy clay (upland soil) (E1a = PA3 and TI5) found in the Plateau (46 km^2 = 100% PA3), Gourma (58 km^2 = 15% PA3), Hodh (3 km^2 = 100% TI5) and Méma Sourango (27 km^2 = 100% TI5). Soil type PA3 of Séno Mango has been excluded. Soil type TH4 in Méma Dioura, Zone Lacustre, Hodh and Méma Sourango as well as TH8 in the Delta Central, also fine clay loam/loamy clays, have been excluded;
- fine clay loam/loamy clay (upland soil) with a low level of fertility (E2a = PL7) can be fully exploited in Sourou (147 km^2), the Delta Central (204 km^2) and Méma Dioura (567 km^2). It cannot be used in either the Gourma or Méma Sourango. Soil type TH1 in the Gourma, also upland fine clay loams, have been excluded;
- loamy clay (F1 = PL9 and TH7) can be fully exploited in Sourou (138 km^2), the Plateau (1 304 km^2) and Gourma (109 km^2). In the Delta Central and Méma Dioura however, it cannot be cultivated. Soil types TH3 and TH8, which are also loamy clays, have been excluded.

2.3 Yields

The target yields of millet are based on the one hand on data collected in the region and on the other hand on simulation results. Field data refer to extensive techniques with yields varying from year to year and within the region from 400 to 700 kg ha^{-1} (OMM, 1988). Average yield over the period 1976-1986 in the regions Koro and Bankass was about 500 and 550 kg ha^{-1}, respectively (de Frahan & Diarra, 1987).

Target yields in normal years for extensive techniques without animal traction (techniques 1 and 2) in the 4 rainfall zones are set at 500, 375, 250 and 190 kg ha^{-1}, respectively. With the use of animal traction (techniques 3 and 4) target yields are supposed to be on average 20% higher, as the effects of animal traction are substantially initially (yield increases of 67% compared to manual labour), but decrease afterwards (Chopart & Nicou, 1989).

Simulation results have been used to derive target yields for the intensive and semi-intensive production techniques. The first step is the calculation of water-limited yields (i.e. yields determined by water availability only, the supply of nutrient elements assumed to be optimum), on the basis of soil characteristics (pF-curve, Report 1, Chapter 3) and observed rainfall for the period 1959-1988 of 7 meteorological stations in the region. As no quantitative information on runoff and runon for the study area was available, and assuming that on a regional scale of hundreds of km^2 the positive and negative effects compensate each other, all rain was supposed to infiltrate. The simulation results, described in detail by Erenstein (1990) and van Duivenbooden (1990a), are illustrated for millet on two soil types in Figure 2.3, which shows that in addition to rainfall, soil characteristics are important.

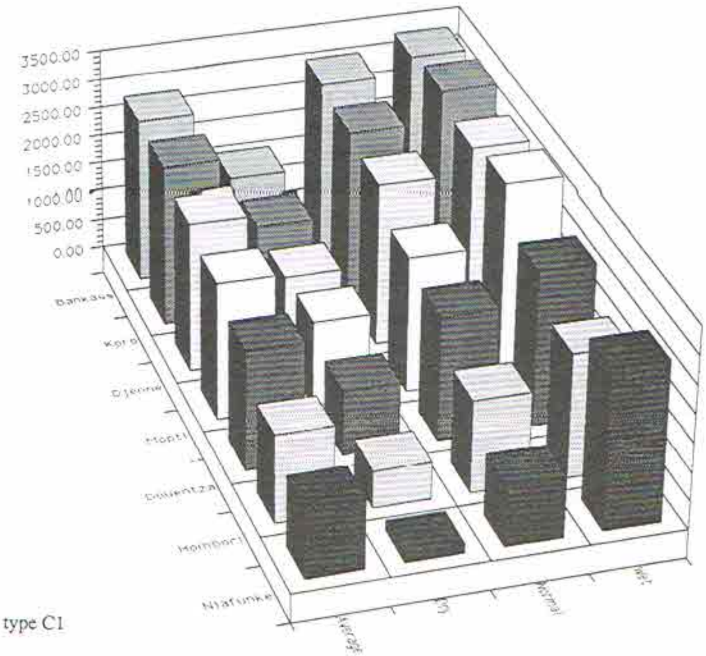
The assumption of optimum nutrient supply implies a high external input of nutrient elements (chemical fertilizer), as the supply from natural sources only covers a small fraction of the demand. In addition, even under optimum nutrient supply, lack of timeliness, pests and diseases, weeds, etc. lead to 'unavoidable' yield reductions, which imply waste of external inputs. Hence, in this study, thetarget yields in normal years for the intensified technique are set at 80% of the simulated water-limited yield. The values range from 840 to 2 390 kg ha^{-1}, depending on soil type and rainfall zone.

The target yields for the semi-intensive technique are set at 40% of those for the intensive technique, i.e. 32% of the simulated water-limited yield, resulting in a range from 360 to 1 000 kg ha^{-1}. This level is somewhat lower than reported by OMM (1988) for their 'stade 4', i.e. 700 to 1 400 kg ha^{-1}.

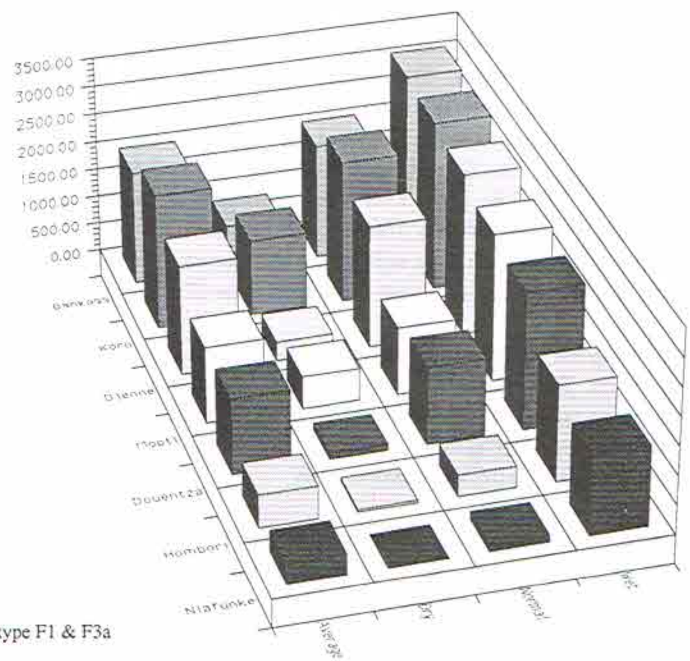
Note that the combinations of soil type and intensive technique are not identical to those of soil type and semi-intensive technique (Table 2.5).

Target yields for dry years (Section 2.2) have been calculated on the basis of simulation results. The ratio of average simulated yield in dry years and in normal years has been calculated for each combination of rainfall zone and soil type. The target yield in a dry year is then obtained by multiplying the target yield in a normal year by that rainfall zone-specific ratio.

As crop residue production depends on crop production technique, soil type and rainfall, no fixed value can be used. Hence, the simulated crop residue production was plotted against simulated grain yield for normal and dry years over the 30-year period for each soil type in rainfall zone I. An example for three soil types is given in Figure 2.4. Subsequently, for each target yield of an activity (i.e. for each rainfall zone), crop residue production was derived from that curve. As in the LP-model only linear relations can be included, a linear regression line has been calculated relating crop residue production to target yield (Stover = a * target yield + c). Hence, in the LP-model total crop residue production has both a yield-



Millet, soil type C1



Millet, soil type F1 & F3a

Figure 2.3. Average simulated water-limited yields of millet on two soil types as function of type of rainfall year and meteorological station in the region.

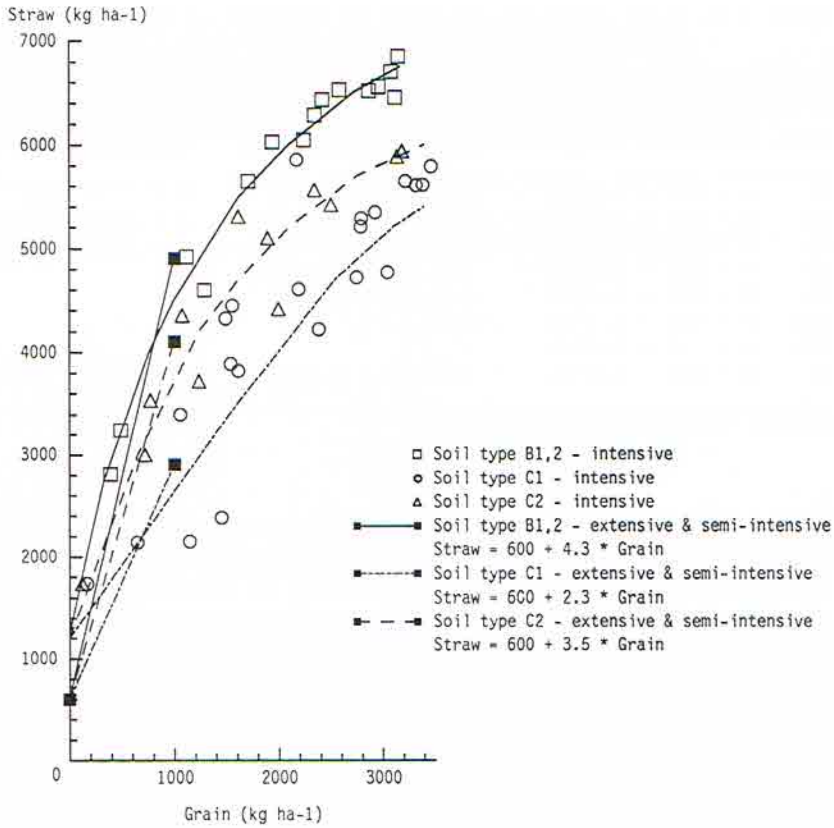


Figure 2.4. Straw production as function of target grain yield for millet on three soil types (van Duivenbooden, 1991).

dependent and an area-dependent component. However, these regression lines can not be applied for the extensive and semi-intensive techniques, as the harvest indices (ratio of yield and total above-ground biomass production) are generally lower. As pertinent information was not available, the regression lines have been adapted on the basis of common sense, such that the intercept with the yield axis (c) has been reduced and the slope of the line (a) somewhat increased (Table 2.3).

To estimate animal consumption of the by-products of millet their composition has to be known as organs differ in quality. On the basis of the results used to validate the model of Jansen & Gosseye (1986; average of 51 values, all treatments combined), the above-ground biomass of millet, without the grains, can be subdivided into: laminae: 25%, stems (stalks + sheaths): 49%, stem bases (top of the root and bottom of the stalk): 10% and cobs (ears minus grains): 16%. It is assumed that stem bases and cobs cannot be consumed, as the former are too hard and the latter too rough (due to the hairs). Hence, that leaves laminae and stems. According to Quilfen & Milleville (1983), 100% of the laminae are consumed and 98% of the

Table 2.3. Straw yield [S, kg ha^{-1}] as function of yield [Yt, kg ha^{-1}] for the various millet activities.

SOIL	TECHNIQUE EXTENSIVE (1-4)	SEMI-INTENSIVE (5)	INTENSIVE (6)
B1	S = 600 + 4.3*Yt	S = 600 + 4.3*Yt	S = 2.7*Yt
B2	S = 600 + 4.3*Yt	S = 600 + 4.3*Yt	S = 3300 + 1.3*Yt
C1	S = 600 + 2.3*Yt	S = 600 + 2.3*Yt	S = 1700 + 1.2*Yt
C2	S = 600 + 3.7*Yt	S = 600 + 3.7*Yt	-
D1	S = 300 + 3.0*Yt	S = 300 + 3.0*Yt	-
E1a	S = 100 + 2.7*Yt	-	-
E2a	S = 80 + 2.8*Yt	-	-
F1	S = 200 + 3.5*Yt	S = 200 + 3.5*Yt	S = 1830 + 1.3*Yt

Source: van Duivenbooden (1991).

stems, i.e. completely consumable, given that 2% is lost in the soil in the form of small fragments. Consequently, 74% of the above-ground biomass, apart from the grains, can be consumed by animals, set at 75% in the model. It is assumed that after harvest, 100% of the millet residues are accessible to the animals, but some losses, estimated at 10%, are taken into account.

Prices of the marketed products refer in principle to those just after harvest. The producer price of millet is set at 55 FCFA kg^{-1}. Straw is not priced in this study.

2.4 Nutrient requirements

Based on the results of an extensive literature review (van Duivenbooden, 1991), the minimum concentrations on a dry weight basis of nitrogen, phosphorus and potassium are set at: 3.0, 0.3 and 10.0 g kg^{-1} for straw and 13.0, 1.8 and 4.0 g kg^{-1} for grain, respectively.

Based on these concentrations the required length of the fallow period, or the manure and fertilizer requirements have been calculated, following the method described in Chapter 1, as presented in Tables 2.4 and 2.5.

2.5 Crop calendar and labour requirements

Sowing takes place after the first effective rains (Dancette & Hall, 1979), generally about mid-July; harvest time is in the first half of October. Labour requirements for the various operations, under the different techniques, are discussed below.

1. Cleaning the field

Cleaning the fields comprises removal and burning of crop residues of the preceding year or removal of trees and bushes after a long fallow period. It is not clear whether the reported labour requirements of 5 mnd ha^{-1} (OMM, 1988) refer to the former, to the latter or to the combination of these two operations. Hence, labour requirements for the former operation are estimated at 1 mnd ha^{-1} (techniques 2 and 4) and for the latter at 5 mnd ha^{-1} (techniques 1 and 3).

2. Transport and application of manure

Except for the extensive techniques 1 and 3, all techniques use farmyard manure as input. Manure is transported to the field in the months before the onset of the rainy season, either by man with a calabas (6 trips at 10 kg each per day), with a donkey (4 trips at 40 kg each per day) or with a 2-wheel donkey chart (3 trips at 100 kg each per day).

For the extensive techniques it is assumed that 25% is done by man, 65% by donkey and 10% by chart, hence about 150 kg mnd^{-1}. For both the semi-intensive and intensive techniques these values are 0, 20 and 80%, respectively, hence, about 270 kg mnd^{-1}. The amount of manure required depends on soil type and target yield (Table 2.5).

Manure is evenly spread over the field before ploughing. If time permits, crushing of large pieces is practiced. It is assumed that per man-day 400 kg DM of manure can be processed. The labour requirements for this operation are presented for each activity in Table 2.5.

The total labour requirements for transport and application of manure for extensive techniques, varying from 15 to 23 mnd ha^{-1} (Table 2.5), slightly exceed the requirements of 15 mnd ha^{-1} reported by OMM (1988).

3. Basic dressing

In the semi-intensive and intensive techniques chemical (inorganic) fertilizer composed of nitrogen, phosphorus and potassium is assumed to be applied on the field just before land preparation. The reported labour requirements are 1 mnd ha^{-1} (OMM, 1988; ORM, pers. comm.).

4. Land preparation

Land preparation can be done by hand, requiring 5 (van Heemst *et al.*, 1981) to 12 mnd ha^{-1} (PIRT, 1983). In the techniques 1 and 2 this operation takes place, but as the farmers use the ridges originating from the weeding operation of the preceding year, labour requirements for this operation are set at 3 mnd ha^{-1}. Alternatively, land preparation is by oxen traction in the form of ridge ploughing. Labour requirements are (4 mnd + 2 At) ha^{-1} (OMM, 1988; PIRT, 1983), comparable to (3.5 mnd + 2 At) ha^{-1} reported by van Heemst *et al.* (1981). The first labour requirements are used for the techniques 3 to 5. Note that in the case of ridge ploughing only half the area is ploughed effectively. If a sowing machine is used (technique 6), first a complete land preparation is executed (8 mnd + 4 At) ha^{-1}, followed by ridge ploughing, in total (12 mnd + 6 At) ha^{-1}.

5. Sowing

Sowing is done in seed-holes and labour requirements range from 2 (PIRT, 1983) via 5 (OMM, 1988) to 10 mnd ha^{-1} (van Heemst *et al.*, 1981). The value of OMM is applied for both the extensive and semi-intensive techniques. In the intensive technique a sowing machine is used, which requires (2 mnd + 1 At) ha^{-1} (Mbenque, 1987).

6. First weeding

Reported total labour requirements for manual weeding are reported 22 (PIRT, 1983) or 26 mnd ha^{-1} (OMM, 1988), and for weeding with animal traction (10 mnd + 2 At) ha^{-1} (PIRT, 1983) or (13 mnd + 4 At) ha^{-1} (OMM, 1988). In terms of labour requirements, the first weeding demands over half of the total time spent on weeding (OMM, 1988). Hence, labour requirements for the first weeding are set at 15 mnd ha^{-1} and (10 mnd + 2 At) ha^{-1} for manual and animal traction, respectively.

Earthing up, requiring (5 mnd + 2 At) ha^{-1} (PIRT, 1983), coincides with weeding. Hence, this operation is not considered separately.

Application of herbicides is as yet not common in millet cropping systems, but may be an attractive alternative in the future for the time-consuming weeding. In the present version of the model, however, this option is not included.

7. First top dressing

The first top dressing, i.e. making a hole for the fertilizer and covering it afterwards, requires 4 mnd ha^{-1} for the semi-intensive and intensive techniques.

8. First spraying of insecticides

For the intensive technique, spraying against pest and diseases is required. According to our information it takes about 1 hour to spray one hectare (effective work). If transport of water and materials is included, the requirement is estimated at 0.5 mnd ha^{-1}.

9. Second weeding

Although OMM (1988) reports use of animal traction for the second weeding, generally the danger of crop is damage is considered too high. Hence, the second weeding is assumed to be carried out by hand, the residual labour requirements for manual weeding being applied: 12 mnd ha^{-1} (OMM, 1988) for all millet techniques.

10. Second top dressing

The second top dressing is only applied in the intensive technique, and requires 4 mnd ha^{-1}, like the first dressing.

11. Second spraying

As for the first spraying, 0.5 mnd ha^{-1} is required for the intensive technique.

12. Harvest

Harvest is done manually in the extensive techniques with a millet knife and in the semi-intensive and intensive techniques with an improved knife. No detailed data on labour requirements as a function of yield are available. It is assumed in this study that labour requirements are a function of yield and of the number of panicles to be harvested, as weight of grains per panicle is a function of the rate of fertilizer application (van Duivenbooden & Cissé, 1989; Gosseye, pers. obs). Labour requirements for harvest (MdO-R) are calculated as:

$$\text{MdO-R} = \frac{Y}{GPP} * \frac{1}{VR} \qquad (12)$$

with,
Y = Yield [kg ha^{-1}]
GPP = Grain weight [kg $panicle^{-1}$]
VR = Harvest rate [panicle mnd^{-1}]

Based on a number of 38 000 panicles ha^{-1} (Gosseye, pers. obs.) and reported labour requirements of 5 mnd ha^{-1} (OMM, 1988), the harvest rate for the extensive techniques is approximated at 8 000 panicles mnd^{-1}. For the semi-intensive and intensive techniques it is set at 10 000 panicles mnd^{-1}, based on the use of the improved knife and the higher panicle density. For the extensive techniques and the more intensive techniques the weight of grain per panicle is set at 12 and 19 g, respectively (Gosseye, pers. obs.). Substitution of these estimates in Equation 12, yields:

$$\text{MdO-R} = B * Y \qquad (13)$$

with,
B = 0.010 for the extensive techniques [mnd kg^{-1}]
0.005 for the semi-intensive technique [mnd kg^{-1}]
0.005 for the intensive technique [mnd kg^{-1}]

13. Transport of panicles, threshing and winnowing

In the Region, threshing and winnowing are seldom carried out directly after harvest (OMM, 1988), though it is observed in Méma Dioura. Generally, the panicles are bundled and transported from the field to the farm. However, especially in the south of the Region, the straw is increasingly transported to the farm as well. In the present version of the model threshing in the field and transport of straw has not been included.

The labour requirements for transport, threshing and winnowing are a function of yield (number of panicles and grain weight per panicle) and of the means of transport used. For calculating the values presented in Table 2.5, the following considerations have been applied.

From own observations it was estimated that each bundle, requiring about 0.25 h for two persons to assemble, contains about 1 350 panicles.

It was assumed that one person can make 4 trips a day carrying one bundle on the head (including its construction). By donkey, 3 bundles can be transported four times a day, with a donkey chart 6 bundles three times a day and with an improved chart 10 bundles three times a day. For the extensive techniques 1 and 2 (without animal traction) transport is manually only at a rate of 65 kg mnd^{-1}. For the extensive techniques 3 and 4 transport is assumed to be 50% by donkey and 50% by oxen-chart, at a rate of 240 kg mnd^{-1}. For the semi-intensive technique transport is by charts only (460 kg mnd^{-1}), and for the intensive technique by improved chart only (770 kg mnd^{-1}).

Threshing and winnowing are time-consuming activities. PIRT (1983) estimates that 40 to 60 kg mnd^{-1} can be processed. For threshing only, van Heemst *et al.* (1981) reported 9.4 mnd t^{-1} (= 106 kg mnd^{-1}). The average value of PIRT has been applied in this study.

Labour requirements for storage of the harvested product have not been included in this study.

The total labour requirements for extensive technique 1 on soil type C1 of 61.5 mnd ha^{-1} (Table 2.4) are similar to the requirements reported by PIRT (1983), but are somewhat higher then the value of 49 reported for Burkina (Roth, 1986). The value for technique 3 with animal traction of (55.5 mnd + 4 At) ha^{-1} for the human component slightly exceeds the (50 mnd + 8 At) ha^{-1} (PIRT, 1983), but is lower for the animal component. Furthermore, the manure application assumed in this study increases total labour requirements substantially.

The labour requirements are distributed over the various periods of the year (Subsection 1.2.1), as given in Table 2.4 for millet production techniques on soil type C1. For other soil typesvalues can be derived from Table 2.5.

2.6 Monetary inputs

2.6.1 Capital charges

1. Plough

The required number of ploughs defined in the LP-model is the maximum value calculated for any particular period. For instance, the time required for land preparation in the extensive techniques 3 and 4 and the semi-intensive technique (2

At ha^{-1}) and the time span in which land preparation should be completed (20 d), results in a requirement of one plough for each 10 ha. Similarly, in the period of first weeding the plough requirements are 1 for each 7.5 ha. Hence, the latter value is applied in the LP-model. For the intensive technique, however, the maximum ratio applies to the period of land preparation, i.e. one plough per 3.33 ha.

Furthermore, accessibility of ploughs can be a problem. This is mimicked in the LP-model by prohibiting exchange of ploughs between agro-ecological zones. In addition, within a zone exchange is assumed to be limited, hence, the required number of ploughs is increased by 25%.

Applying the purchase price and life expectancy as given in Annex 1 (Table A1.1), the depreciation rate for techniques 3, 4 & 5 and 6 amounts to 1 670 and 5 260 FCFA ha^{-1} yr^{-1}, respectively.

2. Small equipment

The small equipment for millet production techniques comprises different kinds of hoes, a knife and a special millet knife. The purchase price of each item is given in Table A1.1 (Annex 1) and its total depreciation is estimated at 500 (PIRT, 1983) to 700 FCFA ha^{-1} yr^{-1} (OMM, 1988), the latter being applied in this study for extensive techniques. For the semi-intensive and intensive technique it is estimated at 1 000 and 1 500 FCFA ha^{-1} yr^{-1}, respectively, due to differences in quality of the material used.

3. Sowing machine

In the intensive technique a sowing machine is used. Given the time restrictions on sowing, one sowing machine is assumed to be required for each 5 ha. On the basis of its purchase price and life expectancy (Table A1.1) and the 25% increase for accessibility, the depreciation rate is 1 600 FCFA ha^{-1} yr^{-1}.

4. Sprayer

In the intensive technique a sprayer is used. It is assumed that each household has one sprayer for every 5 ha. Hence, on the basis of its purchase price and life expectancy (Table A1.1), the depreciation rate is 1 200 FCFA ha^{-1} yr^{-1}.

2.6.2 Operating costs

1. Seeds

According to CRD (1985) about 2% of the yield is retained as seed for the subsequent growing season, which exceeds the quantity of 10 kg ha^{-1} reported by PIRT (1983), if yield exceeds 500 kg ha^{-1}. However, this seems too high, considering the normal practice in extensive techniques of 4 to 5 seeds per seed-hole, about 12 500 seed-holes ha^{-1} (plant density of 0.9 * 0.9 m) and a 1 000-seed weight

Table 2.4. Input-output table of millet production techniques on soil type C1.

CARACTERISTIC	EXTENSIVE				SEMI-INTENSIVE	INTENSIVE
	1	2	3	4	5	6
Animal traction	–	–	+	+	+	+
Manure	–	+	–	+	+	+
Chemical fertilizer	–	–	–	–	+	+
Fallow	+	–	+	–	–	–
INPUTS [ha^{-1} yr^{-1}]						
FALLOW/MANURE/FERTILIZER						
Ratio fallow years/ year cultivated*	5	–	6	–	–	–
Manure [kg DM]*	0	1 930	0	2 290	2 530	1 930
Fertilizer N [kg]*	0	0	0	0	12	96
Fertilizer P [kg]*	0	0	0	0	0	12
Fertilizer K [kg]*	0	0	0	0	0	56
LABOUR[a] [mnd]						
6 Cleaning the field	5	1	5	1	1	1
6 Transport and appl. of manure*	–	17.5	–	21	15.5	12
1 Basic dressing	–	–	–	–	1	1
1 Land preparation	3	3	4.+ 2 At	4.+ 2 At	4.+ 2 At	12.+ 6 At
1 Sowing	5	5	5	5	5	2.+ 1 At
2 Weeding 1	15	15	10.+ 2 At	10.+ 2 At	10.+ 2 At	10. + 2 At
2 Top dressing 1	–	–	–	–	4	4
2 Pesticide spraying 1	–	–	–	–	–	0.5
3 Weeding 2	12	12	12	12	12	12
3 Top dressing 2	–	–	–	–	–	4
3 Pesticide spraying 2	–	–	–	–	–	0.5
4 Harvesting*	5	5	6	6	5	12
6 Transport, threshing & winnowing*	16.5	16.5	13.5	13.5	19.5	46
Total	61.5	75	55.5 + 4 At	72.5 + 4 At	77.+ 4 At	117.+ 9 At

.../...

Table 2.4. Continued.

CARACTERISTIC	EXTENSIVE				SEMI-INTENSIVE	INTENSIVE
	1	2	3	4	5	6
MONETARY INPUTS [FCFA]						
Capital charges						
Small equipment	700	700	700	700	1 000	1 500
Plough	-	-	1 670	1 670	1 670	5 260
Sowing machine	-	-	-	-	-	1 600
Sprayer	-	-	-	-	-	1 200
subtotal	700	700	2 370	2 370	2 670	9 560
Operating costs						
Seeds	60	60	60	60	60	60
Pesticides	100	100	100	100	250	6 500
subtotal	160	160	160	160	310	6 560
Total	860	860	2 530	2 530	2 980	16 120
OXEN [ox]	-	-	0.33	0.33	0.33	0.75
OUTPUTS [ha^{-1} yr^{-1}][b]						
Grain [kg DM]*	500	500	600	600	960	2 390
Straw [kg DM]*	1 750[c]	1 750[c]	1 980[c]	1 980[c]	2 800[c]	4 570[d]

a) Numbers in front of operations refer to the period of the year (Subsection 1.2.1).
b) In a normal year in rainfall zone I (average precipitation in May-October: 530 mm).
c) Average N-content is 3.9 g kg^{-1}.
d) Average N-content is 5.1 g kg^{-1}.
*) Varies as function of activity, see Table 2.5.

Table 2.5. Target yields of millet grain and corresponding crop residues [kg DM ha^{-1}], requirements of farmyard manure [kg DM ha^{-1}], chemical N, P and K fertilizer [kg ha^{-1}] and ratio of fallow years per year cultivated (RJC) for the various millet activities on different soil types. In addition, labour requirements [mnd ha^{-1}] for transport and application of manure (MdO-TEF), for harvesting (MdO-R) and for transport, threshing and winnowing (MdO-TBV).

TECHNIQUE 1							
Activity	i1	i2	i3	i4	i5		
Soil type	B1	B2	C1	C2	D1		
Grain[a]	500	250	500	340	500		
Straw[a]	2 750	1 680	1 750	1 850	1 800		
Manure	0	0	0	0	0		
N	0	0	0	0	0		
P	0	0	0	0	0		
K	0	0	0	0	0		
RJC	5	5	5	5	4		
MdO-TEF	0	0	0	0	0		
MdO-R	5.0	2.5	5.0	3.5	5.0		
MdO-TBV	16.5	8.5	16.5	11.5	16.5		
TECHNIQUE 2							
Activity	i6	i7	i8	i9	i10		
Soil type	B1	B2	C1	C2	D1		
Grain[a]	500	250	500	340	500		
Straw[a]	2 750	1 680	1 750	1 850	1 800		
Manure	2 540	1 840	1 930	1 640	1 700		
N	0	0	0	0	0		
P	0	0	0	0	0		
K	0	0	0	0	0		
RJC	-	-	-	-	-		
MdO-TEF	23.5	17.0	17.5	15.0	15.5		
MdO-R	5.0	2.5	5.0	3.5	5.0		
MdO-TBV	16.5	8.5	16.5	11.5	16.5		
TECHNIQUE 3							
Activity	i11	i12	i13	i14	i15	i16	i17
Soil type	B1	B2	C1	D1	E1a	E2a	F1
Grain[a]	600	300	600	600	600	600	600
Straw[a]	3 180	1 890	1 980	2 100	1 720	1 760	2 300
Manure	0	0	0	0	0	0	0
N	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
RJC	6	6	6	4	6	8	6
MdO-TEF	0	0	0	0	0	0	0
MdO-R	6.0	3.0	6.0	6.0	6.0	6.0	6.0
MdO-TBV	13.5	6.5	13.5	13.5	13.5	13.5	13.5

.../...

Table 2.5. Continued.

TECHNIQUE 4							
Activity	i18	i19	i20	i21	i22	i23	i24
Soil type	B1	B2	C1	D1	E1a	E2a	F1
Grain[a]	600	300	600	600	600	600	600
Straw[a]	3 180	1 890	1 980	2 100	1 720	1 760	2 300
Manure	3 010	2 150	2 290	2 060	2 830	5 290	3 280
N	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
RJC	-	-	-	-	-	-	-
MdO-TEF	28.0	20.0	21.0	19.0	26.0	48.5	30.0
MdO-R	6.0	3.0	6.0	6.0	6.0	6.0	6.0
MdO-TBV	13.5	6.5	13.5	13.5	13.5	13.5	13.5

TECHNIQUE 5				
Activity	i25	i26	i27	i28
Soil type	B1	B2	C1	F1
Grain[a]	940	650	960	1 000
Straw[a]	4 630	3 400	2 800	3 700
Manure	3 210	3 040	2 530	3 880
N	14	15	12	21
P	0	0	0	0
K	18	2	0	0
RJC	-	-	-	-
MdO-TEF	20.0	19.0	15.5	24.0
MdO-R	4.5	3.0	5.0	5.0
MdO-TBV	19.0	13.0	19.5	20.0

TECHNIQUE 6				
Activity	i29	i30	i31	i32
Soil type	B1	B2	C1	F1
Grain[a]	2 340	1 630	2 390	1 810
Straw[a]	6 230	5 500	4 570	4 260
Manure	2 020	2 150	1 930	2 020
N	102	107	96	102
P	10	5	12	6
K	102	72	56	36
RJC	-	-	-	-
MdO-TEF	12.5	13.5	12.0	12.5
MdO-R	11.5	8.0	12.0	9.0
MdO-TBV	45.0	31.5	46.0	35.0

a) In a normal year in rainfall zone I.

of about 7 g (= 0.44 kg ha^{-1}) (Gosseye, pers. comm.). Taking into account the possibility of seedling death due to drought, so that reseeding is required, 1 kg of seed is assumed as input for all techniques, valued at 60 FCFA ha^{-1} yr^{-1}.

2. Pesticides

The most common insect pests in millet are: *Raghuva albipunctella* (spike worm), *Acigona ignefusalis* and *Sesamia calamistis* (stem borers). Relatively important diseases are: *Sclerospora graminicola* (downy mildew), *Tolysporium penicillariae* (head smut) and *Claviceps fusiformis* (ergot) (Gahukar, 1989). However, in the Region treatment against these pests and diseases is not common.

For desinfecting seeds, PIRT (1983) reported an input of 23 FCFA ha^{-1} and OMM (1988) 100 FCFA ha^{-1}. As the former value is considered inadequate, the value is set at 100, 250 and 500 FCFA ha^{-1} yr^{-1} for the extensive, semi-intensive and intensive techniques, respectively.

In the intensive technique spraying in the course of the season is assumed to be practiced, the costs being estimated at 6 000 FCFA ha^{-1} yr^{-1}.

Costs of pesticides during storage are not included in this study.

Consequently, total costs of pesticides are 100, 250 and 6 500 FCFA ha^{-1} yr^{-1} for the extensive, semi-intensive and intensive techniques, respectively.

Total monetary inputs are 860, 2 530, 2 980 and 16 120 FCFA ha^{-1} yr^{-1} for the extensive (1 and 2), extensive (3 and 4), semi-intensive and intensive production techniques, respectively (Table 2.4).

2.7 Oxen requirements

As a consequence of the use of animal traction for land preparation and weeding in the production techniques 3, 4, 5 and 6, and the use of an animal-drawn sowing-machine in technique 6, oxen are required as input. As for plough requirements, oxen requirements are quantified on the basis of the highest ratio of oxen-team requirements in a certain period to time span available. Consequently, the oxen requirements during that period are twice the team requirements. For the techniques 3, 4 and 5 and 6 these requirements are 0.33 and 0.75 ox ha^{-1}, respectively.

2.8 Input-output table

Inputs and outputs of the defined millet production techniques for the LP-model are quantified in Table 2.4. For other soil types, values can be derived from Table 2.5.

3. RICE

(N. van Duivenbooden)

3.1. Introduction

In the fifth region of Mali rice is cultivated with a range of the depth of the water layer. Three rice types can be distinguished:

a. Shallow water rice (depth of water layer 0-0.25 m);

b. Medium-deep water rice (depth of water layer 0.25-1.0 m), which is further subdivided into:

   b1. Intermediate-deep water rice (0.25-0.50 m) and

   b2. Semi-deep water rice (0.5-1.0 m);

c. Deep water rice (depth of water layer > 1.0 m). Special varieties known as 'floating rice' are also included in this type, with water depths reaching 6 m (Courtois, 1988, Diarra, IER-Mopti, pers. comm.).

Two species of rice are cultivated, *Oryza sativa* and *Oryza glaberrima*. Floating rice can be either *O.sativa* or *O.glaberrima*, whereas for the other types only *O.sativa* is used.

About 25 varieties of *O.glaberrima* are available in the Region (ADRAO, 1985). According to Diarra (pers. comm.) many of the floating rice varieties are originally *O.sativa* cultivars introduced in the 16th century, explaining the relatively high yields (Annex 2, Table A2.1). As grain shedding at maturity is very high (up to 50%, Diarra, pers. comm.) risks of crop losses are considered too high so that *O.glaberrima* is not included in this study.

Varieties of *O.sativa* mainly used by farmers are BH2, DM16, Khao Gaew, D52-37 and FRRS43-3 (Diarra, pers. comm.) with DM16 being preferred above Khao Gaew (de Frahan *et al.*, 1989). Growth cycles vary from 120 to 170 days (ADRAO, 1986; ADRAO, 1985; ADRAO, 1980; Gosseye, 1982), with the shorter cycles in the north (about 120 d; Schreurs, 1989). In this study the growth cycle is set at 140 days, as the basis for the formulation of the working calendar. For irrigated conditions, IR 15-29 and IR 15-61 are advised (ORM, quoted by de Frahan *et al.*, 1989). However, one of the constraints in rice cultivation in the Region is the availability of seed (e.g. of DM16, de Frahan *et al.*, 1989; ESPR, 1988c).

In the Region five methods of rice cultivation can be distinguished:

1. Outside polder rice: without water control, purely based on the flood of the river (Viguier, 1938a);
2. Polder rice: semi-controlled water management;
3. Irrigated rice: completely controlled water management, generally practiced in small irrigation schemes;
4. Rainfed rice: in depressions where run-on is considerable, allowing cultivation of short-cycle rice;
5. Flood retreat rice: depending on the flood of the lakes susceptible to floods.

As the latter two types of rice cultivation are relatively minor, both in acreage and in production in the Region and even in the Sahel (Bono & Marchais, 1966), only the first three rice production techniques are included in this study (Sections 3.2, 3.3 and 3.4, respectively).

3.2 Outside Polder Rice

3.2.1 General description

In this production technique, also called non-controlled rice cultivation, long cycle rice is grown on deeper laying soils, the so-called 'rizières basses' (relative to flood height), while short cycle rice is grown on higher laying soils ('rizières hautes') to satisfy food requirements when the stock of rice is finished and long cycle varieties cannot yet be harvested. Farmers notice that the deep water rice in the northern part of the Region (N'Gouma and Korientzé) is increasingly replaced by irrigated rice (de Frahan *et al.*, 1989).

Growth of rice is dependent on rainfall until the flooding starts, which can, however, be too late or too fast (exceeding 5 cm d^{-1}) (de Frahan *et al.*, 1989). Water levels vary from less than 1 m for the high laying fields to 1 to 3 m for the deeper laying fields (Bidaux, 1971), but farmers aim at a maximum water level of 1.5-2 m (Viguier, 1938a). For more detailed information about all types of outside polder techniques, reference is made to Viguier (1937, 1938a, 1938b).

Soil fertility is maintained by fallow periods (shifting cultivation). In the past these fallow periods lasted 1 or 2 years after 3 to 5 years of cultivation (Viguier, 1937), but according to Andriesse & Fresco (1990), these fallow periods are non-existent at present in West Africa. Nevertheless, fallow is included in this study and consequently, this technique is considered extensive.

3.2.2 Environment

Outside polder rice cultivation is practiced generally in the southern part of the Niger delta, only to a limited extent in the north and not at all in the western part. Therefore, the outside polder rice technique has been defined for soil type E1b in rainfall zones II, III and IV, soil type E2b in zones II and III and soil type F3b in zone II.

3.2.3 Yields

Yields of outside polder rice vary considerably, depending on species, variety used (*O.sativa* or *O.glaberrima*) and agricultural practices. Yields of 500 to 700 kg ha^{-1} are often reported, e.g. 675 kg ha^{-1} (World Bank quoted by de Jong *et al.*, 1989). That is much lower than the yields of 700 to 1 500 kg ha^{-1} reported in the past (Viguier, 1938a). In this study, the target yield in a normal year (Report 1, Chapter 4) is set at 600 kg ha^{-1}. To account for the yield decrease and the reduction of area harvested in a dry year, the same reduction factor as for the polder rice semi-intensive technique 1 (Subsection 3.3.3) is applied. Hence, the target yield in a dry year is 80 kg ha^{-1}.

As no quantitative information is available on straw production, it is estimated on the basis of the harvest index, which is set equal to that of the polder rice (semi-intensive technique 1) at 0.20. The fraction of straw not consumable by animals is set at 10%, but taken into account that only about 70% is really offered to animals (remainder used as fuel or for fabrication of bricks), straw availability as fodder is 63% of total straw production.

The producer price of rice is set at 90 FCFA kg^{-1}, whereas straw is not priced in this study.

3.2.4 Crop calendar and labour requirements

Sowing takes place in the period end of July/beginning of August and harvest is in December to January. The labour requirements for the various operations are treated below.

1. Land preparation

Land preparation, formerly done by hoe (Viguier, 1938a), is at present principally carried out by oxen traction, before the onset of the rainy season.

According to ORM (1989a) land preparation with a oxen plough requires (8 mnd + 4 At) ha^{-1}. PIRT (1983) estimates the labour requirements at (10 mnd + 5 At) ha^{-1}. Both estimates are about twice as high as those of ESPR (1988a), which are considered too low. Hence, the labour requirements as given by ORM are applied here.

2. Sowing

Broadcast sowing is practiced, which requires about 1 mnd ha^{-1} (ORM, pers. comm.). The labour requirements of 2 mnd ha^{-1} reported by CRD (1985) are considered too high.

3. Weeding

Weeding is not always practiced because of labour shortage (labour requirements in the rainfed cultures are high at the same time); 51% of the farmers weeded the rice fields at the arrival of the water (Diarra, 1988). Weeding twice is recommended, but due to risks of flooding farmers are not reluctant to comply. At least one weeding is required, and taking into account the labour requirements for weeding in rainfed cultures, it should take place in the period of 28 to 42 days after emergence (Diarra, 1988). Labour requirements for weeding of outside polder rice are estimated at 20 mnd ha^{-1} (PIRT, 1983).

In this study, the labour requirements are set at 50% of these requirements: 10 mnd ha^{-1}.

4. Bird scaring

No data are available on the labour requirements for bird scaring in the Region. Van Heemst *et al.* (1981) reported a labour requirement of 126 hr ha^{-1}. For the Region it is supposed that the job is mainly carried out by children. Furthermore, it is assumed that only 25% of the fields are effectively protected, hence the labour requirements are set at 1 mnd ha^{-1}.

5. Harvest

Harvest of rice should be carried out as soon as possible after ripening to prevent losses. ORM (1988a; 1988b) reported a range in the length of the harvest period of one hectare of 6 to 15 days, but the latter seems inappropriate as recommendation. Hence, in this study a length of the harvest period of 10 days is assumed.

This activity comprises the actual cutting, but also binding and formation of ricks. Assuming labour requirements identical to those for harvest of irrigated rice (Subsection 3.4.4), i.e. 13 mnd 1 000 kg^{-1}, the labour requirements for the target yield (Subsection 3.2.3) are 8 mnd ha^{-1}.

6. Threshing, winnowing & filling of sacs

Manual threshing is done twice, but can only be carried out for a few hours a day and requires thus a long time. Including winnowing and filling of sacs these labour requirements are 40 mnd 1 000 kg^{-1} (ORM, pers. comm.). For the present technique, taking into account harvest losses of 10%, the labour requirements are 21.5 mnd ha^{-1}. These requirements exceed the requirements reported in literature, ranging from 2 (CRD, 1985), via 6 (PIRT, 1983) to 8 mnd ha^{-1} (ESPR, 1988b).

7. Transport

It is assumed that the average distance to be covered is 6 km and that transport is carried out by donkeys only: 3 trips at 70 kg each per day, thus equivalent to 210 kg mnd^{-1}. Hence, the labour requirements are 2.5 mnd ha^{-1}, i.e. higher than the labour requirements of (1 mnd + 1 At) ha^{-1} (PIRT, 1983) and of 1 mnd ha^{-1} as reported by others (ESPR, 1988a; ORM, pers. comm.).

8. Land preparation at end of cycle

Land preparation at the end of the growing season to prevent growth of rhizomes of weeds is only carried out by about 25% of the farmers (Diarra, 1988). Although a higher frequency is considered useful, the value of 25% is used in the present version of the model, hence, labour requirements of (2 mnd + 1 At) ha^{-1}.

The total labour requirements of 54 mnd ha^{-1} (Table 3.1, Section 3.6) fall within the range reported in the literature: 37 (ESPR, 1988b; 1988c), 48 (CRD, 1985), 53 (PIRT, 1983) and 65 mnd ha^{-1} (World Bank quoted by de Jong *et al.*, 1989). The labour requirements are distributed over the various periods of the year

(Subsection 1.2.1), as given in Table 3.1 (page 61).

3.2.5 Monetary inputs

3.2.5.1 Capital charges

1. Plough

Given the oxen-team requirements for land preparation (4 At ha^{-1}) and the length of the period in which land preparation should be completed (20 days), the required number of ploughs per hectare is 0.2. As for millet production techniques, plough accessibility in the Region has been taken into account by increasing the requirements with 25%. Given the purchase price (Annex 1, Table A1.1) and the life expectancy of 5 years, the depreciation rate equals 3 500 FCFA ha^{-1} yr^{-1}.

2. Small equipment

Small equipment comprises e.g. a hoe, a sickle and a knife. Prices are given in Annex 1, Table A1.1, but as no detailed information is available on the number of these tools per farmer or per hectare, depreciation costs of small equipment are estimated, as for irrigated rice (Paragraph 3.4.5.1), at 500 FCFA ha^{-1} yr^{-1} (PIRT, 1983).

3.2.5.2 Operating costs

1. Seed

Sowing density for broadcast sowing is 70 kg ha^{-1} (de Frahan *et al.*, 1989; ADRAO, 1986), which is far less than the 120 kg ha^{-1} reported by PIRT (1983), or 100-140 kg ha^{-1} (Bidaux, 1971). ORM (pers. comm.) estimates that 90% of the farmers use 70 kg ha^{-1} and the remainder 120 kg ha^{-1}, hence on average 75 kg ha^{-1}. As the price of seed is 100 FCFA kg^{-1} (ORM, pers. comm.), this input is equivalent to 7 500 FCFA ha^{-1} yr^{-1}.

2. Biocides

Although no data are available on the actual application of biocides, it is assumed that they are applied on the soil just after seeding. The costs are, as for the extensive millet techniques estimated at 100 FCFA ha^{-1} yr^{-1}.

Hence, the total costs for this production technique are 11 600 FCFA ha^{-1} yr^{-1} (Table 3.1).

Nutrient element requirements and oxen requirements for this technique are discussed in Section 3.5 and 3.6, respectively.

3.3 Polder Rice

3.3.1 General description

In total 15 ORM polders (designated thus because they are managed by ORM) exist with a total area of 44 140 ha (including dikes, ponds, roads, canals and soils that cannot be flooded), of which 33 156 ha can be used for rice cultivation. In addition, three polders are used as pasture (Annex 2, Table A2.2).

The advantage of this type of cultivation is the possibility of flood control, under the condition that the flood is high enough and at the right time. A disadvantage, however, is that the polders have not been levelled, hence the water level may vary. This has consequences when the flood is not high enough for the area sown and the rice variety used. The ratio of area sown and area available varied between 48 and 70% in the period 1972-1988, with averages of 62 and 58% for a low flood (dry year) and a normal flood (normal year), respectively (Table A2.3, Annex 2). As flood height may be insufficient, the ratio of harvested and sown area also varies, with averages of 16 and 75% for a dry and a normal year, respectively (Table A2.2). Hence, of the available area is harvested only 10 and 43% in a dry and normal year, respectively.

The water level under favourable conditions is from 0.6 to 1.3 m for the deeper laying soils and from 0.3 to 0.6 m for the higher laying soils. The ratio of the areas cultivated is about 2.5:1 (ORM, pers, comm.). Farmers apply about 100 kg ha^{-1} of NP-fertilizer just before land preparation and 50 kg ha^{-1} of urea later (ORM, pers. comm.).

In this study, two semi-intensive polder rice techniques (PR1 and PR2) are defined, with different target yields and consequently different inputs (e.g. labour requirements and chemical fertilizer).

3.3.2 Environment

Polder rice is mainly concentrated in the central and southern part of the Niger delta, and is not practiced in the northern and western parts (de Frahan *et al.*, 1989). In this study, polder rice techniques are defined for soil type F3b in rainfall zone II, but for the Delta Central only.

3.3.3 Yields

Yields of polder rice vary considerably, as a function of variety, soil texture, soil fertility, flood level and management. The weighted average of the number of experiments of available experimental yields (paddy) at the ADRAO station for the various species varied between 2 480 (BH2) and 3 720 kg ha^{-1} (D52-37) (Table A2.4, Annex 2; van Duivenbooden, 1989b). In farmers fields the range was between 1 880 (Khao Gaew) and 2 540 kg ha^{-1} (DM16), i.e. appreciably higher than the values of about 770 (range 0-1 500) and 1 280 (931-1 818) kg ha^{-1} reported by ORM for dry years and normal years, respectively (Table A2.3). The difference may be explained by the difference in amount of fertilizer applied.

Yield for the first semi-intensive technique (PR1) is mainly determined by natural fertility of the soils with some chemical fertilizer application. The target yield for a normal year is based on the average yield derived from ORM data (Table A2.3), and is approximated at 1 300 kg ha^{-1}. The target yield in a dry year, taking into account the lower yield per hectare and the lower percentage of sown area harvested (Table A2.4), is set at (800/1 300 * 16/75 * 1 300 =) 170 kg ha^{-1}.

Target yield for the second technique (PR2) is based on the highest weighted average yield of the various varieties (based on experiments with fertilizer application) for three water levels. For deep, medium and shallow water level, varieties with the highest yields were FRRS-43-3, FRRS-43-3 and DM16, with yields of 3 190, 3 540 and 3 830 kg ha^{-1}, respectively (Table A2.4), or on average 3 520 kg ha^{-1}. As the target yield level under farmers conditions is presumably lower than that obtained on the experimental station, it is set at 80% of the calculated average. This target yield of about 2 800 kg ha^{-1} in a normal year is somewhat higher than reported farmer's yields (Table A2.4). Assuming the same factor as for the technique PR1 to account for decrease in yield and reduction of the area harvested, the target yield for a dry year is set at 370 kg ha^{-1}.

Based on the results of a literature review by van Duivenbooden (1991), the harvest index is set at 0.20 and 0.25 for the techniques PR1 and PR2, respectively.

3.3.4 Crop calendar and labour requirements

Sowing takes place in the period end of July/beginning of August (ADRAO, 1986; Koli *et al.*, 1983) and harvest is in December/January. The labour requirements of the various operations are discussed below.

1. Maintenance of dikes

At present, maintenance of dikes is the responsibility of ORM, for which the farmers have to pay (Subsection 3.3.5). Hence, no labour requirements of farmers are attributed to this operation.

2. Basic dressing

Just before land preparation a chemical fertilizer comprising nitrogen and phosphorus is applied broadcastly. The labour requirements for both techniques are 1 mnd ha^{-1}, in accordance with the labour requirements for millet (Section 2.5).

3. First land preparation

This first land preparation is done entirely by draught oxen, hence the same labour requirements as for outside polder rice are applied (8 mnd + 4 At) ha^{-1}.

4. Transport and application of manure

It is assumed that the average distance to be covered is 8 km and that in the technique PR1 70% of the transport is carried out by donkeys and 30% by donkey carts, and in the technique PR2 entirely by carts. Each trip takes about the same time for both means of transport, but because of differences in time of loading and unloading, two trips for a cart and three trips for a donkey are assumed per working day. Hence, the estimated amount of manure transported per day varies for the two techniques: 150 kg and 600 kg mnd^{-1} for PR1 and PR2, respectively. Consequently, the labour requirements are 7.5 and 7 mnd ha^{-1}, respectively.

Labour requirements for spreading of manure are calculated in agreement with millet, at a rate of 400 kg mnd^{-1}. Given the amounts of manure required as calculated in Section 3.5 and presented in Table 3.1, the labour requirements are 3.0 and 10.5 mnd ha^{-1} for PR1 and PR2, respectively.

Consequently, total labour requirements for these operations are 10.5 and 17.5 mnd ha^{-1} for the techniques PR1 and PR2, respectively.

5. Sowing

In the past a sowing machine was used, but as the unit was inappropriate because of its too light weight in relation to the soil structure and surface, it is not used any more (ORM, pers. comm.). In the present version of the model an improved sowing machine is not opted for. Hence, as for outside polder rice, the labour requirements for broadcast sowing are used (1 mnd ha^{-1}).

6. Harrowing

After sowing the soil is harrowed by oxen traction; the labour requirements are (1 mnd + 0.5 At) ha^{-1} (ORM, pers. comm.).

7. First weeding

The degree of weed control is an important determinant of yield. Weeding is required around 35 days after emergence and again around 65 days after emergence (ADRAO, 1986). However, at present not all farmers carry out the first weeding. For the present study it is assumed that for the technique PR1 the first weeding is not carried out, because of the high labour requirements in the rainfed cultures.

Weeding of upland rice (shifting cultivation) requires from 15-30 to 49 (Ivory Coast, Courtois, 1988), 30 (Mali, Vallee, 1980), 31 (Sierra Leone, Courtois, 1988), 32 (Liberia, Courtois, 1988) to 53 mnd ha^{-1} (Nigeria, Courtois, 1988). For polder rice labour requirements were 20 mnd ha^{-1} in the period without water on the land and at 10 mnd ha^{-1} in the period with water (ORM, pers. comm.). ESPR (1988a) estimates the labour requirements at 21 mnd ha^{-1}, comparable to the 20 mnd ha^{-1} reported by CRD (1985).

For the present study the labour requirements for the first weeding for the technique PR2 are set at 20 mnd ha^{-1}.

8. First top dressing

The first top dressing requires for both techniques also 1 mnd ha^{-1}.

9. Second weeding

For the technique PR1 the labour requirements for this operation are very high, as in fact it is the first weeding: the requirements are estimated at 35 mnd ha^{-1}. For the technique PR2 the labour requirements are set at 10 mnd ha^{-1}. For both techniques it includes cutting of weeds below water surface, which is carried out on 10% of the fields.

10. Second top dressing

In the first technique (PR1) no second top dressing is applies. For the technique PR2 the labour requirements are set at 1 mnd ha^{-1}.

11. Bird scaring

As for outside polder rice, bird scaring is practiced. Application of the same labour requirements for all fields, results in 3 mnd ha^{-1}.

12. Harvest

This operation comprises the actual cutting, but also binding and formation of risks. Harvest and transport of upland rice (shifting cultivation) requires 30-36 (Ivory Coast), 47 (Liberia), 82 (Nigeria) and 84 mnd ha^{-1} (Sierra Leone) (Courtois, 1988). For polder rice, ESPR (1988a) reported labour requirements of 10 mnd ha^{-1}, whereas CRD (1985) reported 23 mnd ha^{-1}. Assuming labour requirements identical to those for irrigated rice (Subsection 3.4.4) of 13 mnd 1 000 kg^{-1} and the defined target yields (Subsection 3.3.3), result in the labour requirements of 17 and 36.5 mnd ha^{-1} for the techniques PR1 and PR2, respectively.

13. Threshing, winnowing and filling of sacs

Threshing is done manually or by a simple threshing machine (Monoplace). The fraction of yield threshed manually is estimated at 30% (ORM, pers. comm.) and 0%, for the techniques PR1 and PR2, respectively. Hence, taking into account harvest losses of 10%, and labour requirements of 40 mnd 1 000 kg^{-1}, the labour requirements for the technique PR1 are 14 mnd ha^{-1}.

The fraction threshed by a threshing machine is thus 70 and 100% for the techniques PR1 and PR2, respectively. The capacity of the threshing unit is 70 kg h^{-1} (ORM, pers. comm.) or 560 kg d^{-1}. It is assumed that one person is required to operate this machine and another person must fill the machine. Consequently, taking into account harvest losses of 10%, the labour requirements are 3 and 9 mnd ha^{-1} for the techniques PR1 and PR2, respectively.

Hence, the total labour requirements for threshing are 17 and 9 mnd ha^{-1} for the techniques PR1 and PR2, respectively.

14. Transport

Assuming the same characteristics as for transport of manure, but due a higher ratio weight/volume, the amount of paddy transported per day is estimated at 210 kg and 800 kg mnd^{-1} for PR1 and PR2, respectively. Consequently, the labour requirements are 4.5 and 3 mnd ha^{-1} for the techniques PR1 and PR2, respectively.

15. Land preparation at end of cycle

Two types of land preparation at the end of the growing season can be distinguished: 'labour fin de cycle' and 'labour de réprise'. The labour requirements are identical to those for the first land preparation, but as these operations are practiced by only 50 and 15% of the farmers, respectively (ORM, pers. comm.), the labour requirements are adjusted to (4 mnd + 2 At) ha^{-1} and (1 mnd + 0.5 At) ha^{-1}, respectively. The total labour requirements of (5 mnd + 2.5 At) ha^{-1} are applied for both techniques.

The total labour requirements of 104 and 117 mnd ha^{-1} for the techniques PR1 and PR2, respectively (Table 3.1, page 61), are higher than those reported in the literature, varying from 41-42 mnd ha^{-1} (ESPR, 1988a; 1988c) via 90 mnd ha^{-1} (de Jong *et al.*, 1989) to 92.5 mnd ha^{-1} (ORM, pers. comm.). The difference is probably due to differences in the labour requirements for weeding and for transport and spreading of manure.

The labour requirements are distributed over the various periods of the year (Subsection 1.2.1), as given in Table 3.1.

3.3.5 Monetary inputs

3.3.5.1 Capital charges

1. Dike

Construction of the main dike for a 80 ha polder with a net cultivable area of 75% required 5 800 mnd, or expressed per cultivated area about 97 mnd ha^{-1} (Filleton & Monimart, 1989). Construction costs were about 76 000 FCFA ha^{-1} while the life-span of the dike is about 5 years (Filleton & Monimart, 1989), hence a depreciation rate of 15 200 FCFA ha^{-1} yr^{-1}. The construction costs of an ORM polder were 150 000 FCFA ha^{-1} in 1978 (ORM, pers. comm.) and taking into account inflation (5%, World Bank) this is equivalent to about 300 000 FCFA ha^{-1} at present. Under good management and proper maintenance, the life expectancy can be set at 10 years and results in a depreciation rate of 30 000 FCFA ha^{-1} yr^{-1}. This sum is assumed to be charged to the farmer, because, although ORM is responsible the required money should come from somewhere.

2. Plough

In analogy to outside polder rice, the depreciation rate for ploughs is 3 500 FCFA ha^{-1} yr^{-1}.

3. Harrow

Given the oxen-team requirements for harrowing (0.5 At ha^{-1}) and the length of the period available for harrowing (5 days) 0.1 harrow per hectare is required. Given the purchase price of 20 000 FCFA with a life expectancy of 5 years (Table A1.1), the depreciation rate is 400 FCFA ha^{-1} yr^{-1}.

4. Small equipment

The depreciation rate for small equipment costs is in analogy with irrigated rice (Paragraph 3.4.5.1) 500 FCFA ha^{-1} yr^{-1}.

3.3.5.2 Operating costs

1. Seed

As for outside polder rice, seed rate is set at 75 kg ha^{-1}, equivalent to 7 500 FCFA ha^{-1} yr^{-1}.

2. Biocides

Although no data are available on the actual application of biocides, it is assumed that they are applied on the soil just after seeding. The costs are, as for the semi-intensive millet techniques estimated at 250 FCFA ha^{-1} yr^{-1}.

3. Threshing

For mechanized threshing, carried out by ORM, 6 FCFA kg^{-1} is charged (ORM, 1988a), and consequently the operating costs are 2 100 and 15 000 FCFA ha^{-1} yr^{-1} for the techniques PR1 and PR2, respectively.

4. Maintenance of dikes

This work, carried out by ORM, is charged to the farmer, who should pay for this service. It is estimated, rather arbitrarily at 5 000 FCFA ha^{-1} yr^{-1}.

Hence, the total costs of are 49 250 and 62 250 FCFA ha^{-1} yr^{-1} for the polder rice production techniques PR1 and PR2, respectively (Table 3.1).

Nutrient element requirements and oxen requirements for both techniques are treated in Section 3.5 and 3.6, respectively.

3.4 Irrigated rice

3.4.1 General description

Cultivation of irrigated rice takes place in small irrigation schemes around the village, in the so-called 'PPIV' (= Petits Périmètres Irrigués Villageois). The area of an irrigation scheme varies form 2 to 40 ha, with an average of about 18 ha. The total area in the Region is about 434 ha (Table A2.5, Annex 2), of which 90% can be used for rice cultivation (390 ha). The water level in those schemes varies from 0.15 to 0.25 m. One of the constraints of irrigated rice production is availability of ploughs in the Region (ORM, pers. comm.).

Although in this cropping technique rice cultivation is sometimes carried out in rotation or in combination with groundnut (ORM, 1989a), the latter crop is not included in this study.

Chemical fertilizers are generally applied, e.g. a basic ammonium phosphate dressing of 100 kg ha^{-1} (N-P-K = 18-20-0 or N-P_2O_5-K_2O = 18-46-0) and twice top dressings of urea at a rate of 75 kg ha^{-1} each: ORM, pers. comm.). Farmyard manure is sometimes applied, for example at a rate of 1 140 kg ha^{-1} as reported by ORM (1989a).

3.4.2 Environment

Irrigated rice is mainly cultivated in the central part, to a small extent in the southern and northern part and not at all in the western part of the Niger delta (de Frahan *et al.*, 1989). In the surroundings of Mopti the irrigation scheme is often in a polder, e.g. PPIV of Kouna (ORM, 1989c) (Table A2.2).

The irrigated rice production technique is defined for soil type F3b in rainfall zone II and in the Delta Central only. As the soil types of the schemes and their acreages located in Zone Lacustre are unknown, these schemes are considered part of the Delta Central.

3.4.3 Yields

Data on yield of irrigated rice in the Region are available only to a limited extent (Table A2.6, Annex 2). Reported yields for the first season are relatively low for a number of reasons, one of which is the low dose of chemical fertilizer (especially nitrogen) applied (ESPR, 1988c). No explanation is provided for the very low yield of 450 kg ha^{-1} (de Jong & Harts-Broekhuis, 1989), hence it has not been taken into account for calculation of the weighted average. On the basis of the reported yields and taking into account that the maximum yield of the rainy season exceeds that of the dry season, the (paddy) target yield in a normal year is set at 4 000 and 5 000 kg ha^{-1} for the rainy and the dry season, respectively, hence a total of 9 000 kg ha^{-1} yr^{-1}. In a dry year, total yield is maintained at the same level.

Based on the results of a literature review by van Duivenbooden (1991), the harvest index is set at 0.43, which is used to calculate straw yields.

3.4.4 Crop calendar and labour requirements

The start of the working season varies with year and place, e.g. for the rainy season cultivation from the end of June (ORM, 1988a) till the middle of August (ORM, 1989b). June is considered in this study as starting month for rainy season cultivation and January for dry season cultivation. Labour requirements of the various operations are described below, applicable to both seasons.

1. Seed-bed

This operation consists of dike construction of the seed-bed, farmyard manure application (at a rate of about 2 700 kg ha^{-1}, ORM, 1989a), land preparation, soil levelling, watering and seeding, probably carried out before the onset of the rains. For one ha of rice a seed-bed of about 0.04 ha is required (ORM, 1988b). As plants over 45 days of age cannot be transplanted, seeding is done three times with 7-10 day intervals between sowing dates. Alternatively, transplanting begins earlier, but not before 20 days after emergence. One weeding is performed in the seed-bed after about 35 days.

Reported labour requirements range from 6 (ORM, 1988b) to 10 mnd ha^{-1} (van Heemst *et al.*, 1981; RFMC, 1977), the former being applied in this study. Labour requirements for soil levelling and watering, and basic dressing before transplanting are set at 12 and 1 mnd ha^{-1}, respectively.

2. Land preparation of the main field

This operation comprises ploughing, maintenance of dikes, watering and application of basic dressing. CRD (1985) reported labour requirements of 21 mnd ha^{-1}, against 40 mnd ha^{-1} plus 10 mnd ha^{-1} for soil levelling by RFMC (1977). According to ORM (1988a), maintenance takes place during the growing season. Land preparation with a hoe takes about 12 mnd ha^{-1} (ORM, pers. comm.). Although the requirements differ considerably from those reported by van Heemst *et al.* (1981), the value of ORM is applied in this study.

Taking into account the labour requirements for land preparation as defined before and a ratio of land preparation by hoe and by plough of 0.3:0.7 (ORM, pers. comm.), the labour requirements are (9.5 mnd + 3 At) ha^{-1}.

Labour requirements for maintenance of dikes before the onset of the rains (wet season cultivation) are estimated at 15 mnd ha^{-1}. The remaining 15 mnd are spent later in the season, distributed among the various periods of the year proportional to the length of the period.

3. Transplanting

After about 30 days (between 20 and 45) of growth in the seed-bed, rice plants are transplanted to the main field. Reported labour requirements for this operation are 20-25 (Asia, 8 h mnd^{-1}; Navasero *et al.*, 1986), 30 (RFMC, 1977), 35 (van Heemst *et al.*, 1981) or 25-55 mnd ha^{-1} (Viguier, 1938b). Planting of upland rice (shifting cultivation) required 20-24 (Ivory Coast), 30 (Nigeria), 37 (Liberia) or 42 mnd ha^{-1} (Sierra Leone) (Courtois, 1988). The reported labour requirements of 163 and 270 mnd ha^{-1} for the rainy season and the dry season, respectively (ORM, 1988a: 1988b) include dike maintenance, soil levelling and 'mis en boue'. The labour requirements of 123 mnd ha^{-1} (ORM, 1989a) seems relatively high, but probably includes other activities as well. As labour requirements above 120 mnd ha^{-1} are very high in comparison with the other values reported, labour requirements for transplanting are set at 35 mnd ha^{-1}.

4. Transport and spreading of manure

It is assumed that transport only takes place by means of an improved chart, and the average distance to be covered is about 2 km, so that five trips per day can be made. Hence, labour requirements for transport are 1 mnd 1 200 kg^{-1}, equivalent to 2 and 2.5 mnd ha^{-1} for the rainy and dry season rice cultivation, respectively.

In agreement with the labour requirements for spreading of manure (Section 2.5), the labour requirements for this operation are 6 and 7.5 mnd ha^{-1} for the rainy and dry season rice cultivation, respectively.

Consequently, the total labour requirements for these operations are 8 and 10 mnd ha^{-1} for the rainy and dry season rice cultivation, respectively.

5. Irrigation

According to ORM (1988a) the fields should be irrigated once each 6 days in the dry season, but in practice this has been 1 in 4 days, whereas in the rainy season this has been 1 in 7 and 1 in 13 days (ORM, 1989a; ORM, 1988b).

Irrigation requires about 5-6 and 11 mnd ha^{-1} in the rainy season and the dry season, respectively (ORM, 1989a; 1988a; 1988b). In this study, these values are applied and distributed among the various periods of the year proportional to the length of the period. Although no information is available with regard to maintenance of the pump, it is supposed to be included.

6. First weeding

This operation should take place within 30 days after transplanting. Navasero *et al.* (1986) reported total labour requirements for weeding of irrigated rice of 44-50 mnd ha^{-1}, whereas ORM (1988a; 1988b) reported 26 (rainy season) to 29 mnd ha^{-1} (dry season).

As for polder rice, labour requirements for the first weeding are set at 20 mnd ha^{-1}.

7. First and second top dressing

In agreement with data reported before, these operation requires each 1 mnd ha^{-1}.

8. Second weeding

As for polder rice, this operation requires 10 mnd ha^{-1} .

9. First and second biocide spraying

As for the intensive millet technique, each spraying requires 0.5 mnd ha^{-1} and two sprayings are assumed per season.

10. Watchman

ORM (1989a) reported that one watchman is contracted during the growing season (for a 19 ha irrigation scheme), i.e. for each growing season labour requirements of 5 mnd ha^{-1}, distributed among the various periods of the year proportional to the length of the period.

11. Bird scaring

As for polder rice, the labour requirements for bird scaring are set at 3 mnd ha^{-1}.

12. Harvest

Navasero *et al.* (1986) reported labour requirements for harvest in Asia of 15 to 20 mnd ha^{-1}, whereas van Heemst *et al.* (1981) 12 mnd ha^{-1} and RFMC (1977) reported 40 mnd ha^{-1}. ORM (1988a; 1988b) reported 50 and 60 mnd ha^{-1} for the rainy season and the dry season, respectively (including formation of ricks). No explanation is given for the observed difference. As the values of ORM are related to yield, the labour requirements are equal to 10 and 16 mnd per 1 000 kg paddy, respectively. The average is used in this study, resulting in labour requirements for harvest of 52 and 65 mnd ha^{-1} in the rainy and the dry season, respectively.

13. Threshing and winnowing

Threshing is entirely by a threshing machine. Given its characteristics (Subsection 3.3.4) and assuming 10% harvest losses, the labour requirements are 13 and 16 mnd ha^{-1} for the rainy and dry season cultivation, respectively.

14. Transport

In agreement with the transport of manure to and of paddy from polders, it is assumed that 2 500 kg can be transported per man-day. Hence, labour requirements for transport are 1.5 and 2 mnd ha^{-1} for the rainy and dry season rice cultivation, respectively.

The total labour requirements of 214 and 237 mnd ha^{-1} for the rainy and dry season rice cultivation, respectively (Table 3.1), differ from data cited in the literature, varying from 175-189 (von Braun *et al.*, 1989) via 200 (de Jong *et al.*, 1989) via 261 (rainy season) (ORM, 1988b) to 360 mnd ha^{-1} (dry season) (ORM, 1988a). As the values cited by ORM have been explained by the high requirements for dike maintenance, no reason exist to reject our calculated requirements.

The labour requirements are distributed over the various periods of the year (Subsection 1.2.1), as given in Table 3.1 (page 61).

3.4.5 Monetary inputs

3.4.5.1 Capital charges

1. Irrigation scheme

Investments in establishing irrigation schemes (construction of canals, land levelling, etc.) in Africa are about 15 000 to 20 000 USD ha^{-1} (1986, FAO quoted by von Braun *et al.*, 1989) equivalent to 4.5-6.0 million FCFA and they require a labour input of about 610 mnd ha^{-1} (Filleton & Monimart, 1989). For an irrigation project in the Gambia, land levelling costs were about 2 million FCFA ha^{-1} and miscellaneous costs for civil works about 0.5 million FCFA ha^{-1} (von Braun *et al.*, 1989). De Jong *et al.* (1989) estimated costs at 1.5 million FCFA ha^{-1} when local labour is involved and 2.5 million FCFA ha^{-1} without local labour. ORM (pers. comm.) estimated the costs at 1.5 million FCFA ha^{-1} and local contribution at about 0.65 million FCFA ha^{-1} (ORM, 1988b). Taking into account price increase, investments are estimated at 3 million FCFA ha^{-1}. With a life expectancy of 10 years, this results in a depreciation of 300 000 FCFA ha^{-1} yr^{-1} or 150 000 FCFA ha^{-1} for rainy and dry season rice cultivation each.

2. Motor pump

The purchase price of a motor pump (STORK, 25 HP, 380 m^3 h^{-1}) is about 4 000 000 FCFA (1988, Filleton & Monimart, 1989). ORM (1988a) reported depreciation costs of 500 000 FCFA yr^{-1} (for an irrigation scheme of 19 ha), equal to 26 300 FCFA ha^{-1} yr^{-1}, whereas a depreciation rate of 56 000 ha^{-1} yr^{-1} is also reported (ORM, pers. comm.). A depreciation rate of 50 000 FCFA ha^{-1} yr^{-1} is used in this study.

3. Plough

Given the oxen-team requirements for land preparation (70% of 4 = 3 At ha^{-1}) and the length of the period available for land preparation (15 days), 0.20 plough per hectare is required. As for the other production techniques, a correction has been made for the inaccessibility of ploughs in the Region. Given its purchase price (Table A1.1) and life expectancy, the depreciation rate is set at 3 500 FCFA ha^{-1} yr^{-1} or 1 750 FCFA ha^{-1} yr^{-1} for rainy and dry season rice cultivation each.

4. Small equipment

Small equipment costs are estimated at 5 000 FCFA season^{-1} for an irrigation scheme of 20 ha (ORM, 1989a; 1988a; 1988b), hence the depreciation rate is 500 FCFA ha^{-1} yr^{-1}.

5. Sprayer

As for the intensive millet technique, it is assumed that one sprayer is available for every 5 ha. Hence, given its purchase price and its life expectancy (Table A1.1), the depreciation rate is 1 200 FCFA ha^{-1} yr^{-1}.

3.4.5.2 Operating costs

1. Seeds

Seed rates range from 29 to 32 kg ha^{-1} at a price of 100 FCFA ha^{-1} (ORM, 1989a; 1988a), but 41 kg is also reported (ORM, 1988a). In this study the seed requirements are set at 35 kg per season, hence for two crops per year equivalent to 7 000 FCFA ha^{-1} yr^{-1}.

2. Fuel and maintenance of motor pump

Fuel costs are about 40 000 FCFA ha^{-1} yr^{-1} (Filleton & Monimart, 1989). In the dry season it is 59 000 FCFA ha^{-1} (ORM, 1988a), and in the rainy season from 20 000 to 34 000 FCFA ha^{-1} (ORM, 1989a; 1988b). Total costs are set in this study at 86 000 FCFA ha^{-1} yr^{-1}.

Maintenance costs comprise 9 600 FCFA ha^{-1} yr^{-1} for large reparations and 6 400 FCFA ha^{-1} yr^{-1} for oil and oil filters (ORM, pers. comm.), hence in total 16 000 FCFA ha^{-1} yr^{-1}.

The total costs of 102 000 FCFA ha^{-1} yr^{-1} is split up equally among the two crops.

3. Biocides

Sometimes biocides are applied during the growing season (e.g. Carbufuran, Furandan SG) at a rate of 3 kg ha^{-1} (ADRAO, 1986). As for the intensive millet technique, these costs are estimated at 6 000 FCFA ha^{-1} season^{-1}. In addition, biocides before sowing are assumed to be applied, with the same price as for the intensive millet technique of 500 FCFA ha^{-1}. Hence, total costs are 13 000 FCFA ha^{-1} yr^{-1}.

4. Threshing

Threshing is done mechanically at a price of 6 FCFA kg^{-1} (ORM, 1988a), hence 48 600 FCFA ha^{-1} yr^{-1}.

5. Dike and irrigation scheme maintenance costs

As no specific quantitative information is available, costs are as for polder rice estimated at 5 000 FCFA ha^{-1} yr^{-1}.

The total costs, approximated at 530 000 ha^{-1} yr^{-1} (Table 3.1), substantially exceed the amount reported by Deneve & Reinder (quoted by de Jong *et al.*, 1989) who calculated in 1986 the running costs at 140 000 FCFA ha^{-1} yr^{-1}. No explanation can be given for the differences, as the latter is not described in sufficient detail.

3.5 Nutrient requirements

Based on the results of the literature review by van Duivenbooden (1991), the minimum concentrations on a dry weight basis of nitrogen, phosphorus and potassium applied for all production techniques are 10.0, 1,3 and 3.6 g kg^{-1} for grain and 4.0, 0.3 and 10.0 g kg^{-1} for straw, respectively. Based on these concentrations the required length of the fallow period, or the manure and fertilizer requirements have been calculated, following the method described in Chapter 1 (Table 3.1).

Due to a relatively low nitrogen recovery fraction (processes causing losses are relatively important), the required input of nitrogen is considerable, especially for irrigated rice where about 600 kg ha^{-1} of nitrogen is required for 2 crops a year. Note moreover, that the calculated ratio of fallow years per year of cultivation is about 5 times higher than practiced in the Region. This is entirely due to the restriction of sustainability in terms of nutrient elements. As mentioned before, these calculations are based on rather crude assumptions with respect to the nutrient cycles in the soil-plant system and more accurate and detailed experimental data are required to substantiate the results obtained.

3.6 Oxen requirements

As a consequence of plough requirements for land preparation and weeding, it means that the oxen requirements are two times higher, 0.5 ox ha^{-1} for all production techniques.

3.7 Input-output table

Inputs and outputs of the defined rice production techniques for the LP-model are given the following table.

Table 3.1. Input-output table for the five rice production techniques. Outside polder on soil type E1b and the others on soil type F3b.

CHARACTERISTICS	OUTSIDE POLDER	POLDER		IRRIGATED	
		PR1	PR2	RAINY	DRY
Animal traction	-	+	+	+	+
Manure	-	+	+	+	+
Chemical fertilizer	-	+	+	+	+
Fallow	+	-	-	-	-
INPUTS [ha^{-1} yr^{-1}]					
FALLOW/MANURE/FERTILIZER					
Ratio fallow years/ year cultivated [-]	5[d]	-	-	-	-
Manure [kg DM]	-	1 130	4 220	2 340	2 970
Fertilizer N [kg]	-	129	214	268	339
Fertilizer P [kg]	-	8	10	20	26
Fertilizer K [kg]	-	68	88	72	97
LABOUR[a] [mnd]					
6 Seed-bed	-	-	-	6	6
6 Dike maintenance	-	-	-	15	15
6 Basic dressing	-	-	-	1	1
6 Manure transp. & appl.	-	-	-	8	10
6 Land preparation 1	-	-	-	9.5 + 3 At	9.5 + 3 At
6 Soil levelling	-	-	-	12	12
6 Irrigation, dike maint. & watchman	-	-	-	7	-
1 Basic dressing	-	1	1	-	-
1 Manure transp. & appl.	-	10.5	17.5	-	-
1 Land preparation 1	8.+ 4 At	8.+ 4 At	8.+ 4 At	-	-
1 Sowing	1	1	1	-	-
1 Harrowing	-	1.+ 0.5 At	1.+ 0.5 At	-	-
1 Transplanting	-	-	-	35	35

.../...

Table 3.1. Continued.

CHARACTERISTICS	OUTSIDE POLDER	POLDER		IRRIGATED	
		PR1	PR2	RAINY	DRY
1 Weeding 1	-	-	-	7	-
1 Irr., maint. & watchman	-	-	4	-	
2 Weeding 1	10	-	20	13	20
2 Top dressing 1	-	1	1	1	1
2 Pesticide spraying 1	-	-	-	0.5	0.5
2 Irr., maint. & watchman	-	-	-	3	-
3 Weeding 2	-	35	10	10	10
3 Top dressing 2	-	-	1	1	1
3 Pesticide spraying 2	-	-	-	0.5	0.5
3 Irr., maint. & watchman	-	-	-	10	-
4 Bird scaring	1	3	3	3	3
4 Irr., maint. & watchman	-	-	-	2	31
5 Harvesting	8	17	36.5	52	65
6 Threshing, winnowing	22	17	9	13	16
6 Transport	2.5	4.5	3	1.5	2
6 Land preparation 2	2.+ 1 At	5.+ 2.5 At	5.+ 2.5 At	-	-
Total	54.5 + 5 At	104.+ 7 At	117.+ 7 At	214.5 + 3 At	238.+ 3 At
MONETARY INPUTS [FCFA]					
Capital charges					
Plough	3 500	3 500	3 500	1 750	1 750
Small equipment	500	500	500	250	250
Harrow	-	400	400	-	-
Dike	-	30 000	30 000	-	-
Irrigation scheme	-	-	-	150 000	150 000
Motor pump	-	-	-	25 000	25 000
Sprayer	-	-	-	600	600
subtotal	4 000	34 400	34 400	177 600	177 600

.../...

Table 3.1. Continued.

CHARACTERISTICS	OUTSIDE POLDER	POLDER		IRRIGATED	
		PR1	PR2	RAINY	DRY
Operating costs					
Seeds	7 500	7 500	7 500	7 000	7 000
Dike maintenance	-	5 000	5 000	2 500	2 500
Threshing	-	2 100	15 100	21 600	27 000
Fuel & main. pump	-	-	-	51 000	51 000
Pesticides	100	250	250	6 500	6 500
subtotal	7 600	14 850	27 850	85 100	90 500
Total	11 600	49 250	62 250	262 700	268 100
OXEN [ox]	0.50	0.50	0.50	0.50	0.50
OUTPUTS [ha^{-1} yr^{-1}][b]					
Grain [kg]	600	1 300	2 800	4 000	5 000
Straw [kg][c]	2 400	5 200	8 400	4 890	6 110

[a]) Numbers in front of operations refer to the period of the year (Subsection 1.2.1) for all techniques, except the irrigated dry season cultivation: all labour requirements are during the period 6.

[b]) In a normal year in rainfall zone I.

[c]) Average N content is 5.2 g kg^{-1} for all techniques, except the irrigated rice: 6.8 g kg^{-1}

[d]) Other soil types are E2b and F3b, with same inputs and outputs as E1b, except the ratio fallow years/ year cultivated is 7.

4. FLOOD-RETREAT SORGHUM

(P.A. Gosseye)

4.1 Introduction

Sorghum is the general name for *Sorghum bicolor* (syn. *S. vulgare*). Other vernacular names are great millet, Guinea corn, sorgo (Cérighelli, 1955; Purseglove, 1975), and in French: gros mil, grand millet, millet d'Inde, blé de Guinée.

The cultivars used for flood-retreat cultivation presumably are very old and highly adapted to this type of production. According to Guillaume (1960), growth cycles vary from 150 to 250 d between sowing or transplanting from mid-February to mid-May, and harvest from the end of August to the end of October. According to the same author, the flood-retreat sorghum cultivars from the valley of the Senegal river are not suitable for the valley of the Niger, because they must be sown from November to December for harvesting in March to April (different growing temperature and photoperiod).

In this chapter, strictly rainfed cultivation of sorghum will not be discussed. In the Region, sorghum is at the northern limit of its extension as that crop, in fact, dominates above 1 000 mm yr^{-1} of rainfall; it is gradually replaced by millet as rainfall decreases and the latter dominates below 600 mm yr^{-1} and disappears below 400 or 450 (Guillaume, 1960; Charreau & Poulain, 1963; Arnon, 1972; Rao & Willey, 1980). In a normal year, rainfall in the Region varies from south to north between 545 and 255 mm yr^{-1} (Table 2.2, page 26). It is, nevertheless, possible to grow sorghum on a small scale in depressions receiving run-off water or on soils with a shallow groundwater table (Guillaume, 1960; Stoop & Pattanayak, 1979; Quilfen & Milleville, 1983). However, field surveys have indicated that this type of cultivation is limited and not always successful (double risk: excess or lack of water). Although it may be important from the viewpoint of the individual farmer, this production technique is considered marginal, hence, it is not included in the LP-model but is implicitly included in the millet production techniques on heavy soils.

On the other hand, in the north of the Region, especially in the Zone Lacustre, sorghum is cultivated on flood plains (alluvial deposits along rivers or at lake shores, that are cultivated after retreat of the flood), exploiting both floodwater and rainfall. This cultivation technique is not only practiced for sorghum, but also for millet and other crops. This chapter deals with the cultivation of the flood plains, known as 'flood-retreat cultivation' and not with wet season crops that exploit, on the basis of topographical features, non-flooded soils such as for example in Lake Niangaye.

Based on statements from those interviewed (Boura, Cissé, Sanou, Sidibé, villagers of Koundioum and N'Gouma) and available literature (Guillaume, 1960; WIP, 1980; Gadelle, 1986; Hesse & Thera, 1987; Aalbers, 1988), a distinction is made in the Region between crops grown on levees along the river and crops grown in lakebeds.

1. Riverbank crops

Cultures on steep slopes forming the banks of rivers and temporary streams: at the top of the banks as the water recedes, we find first very limited areas of cassava (*Manihot esculenta*), followed by sweet potato (*Ipomoea batatas*) for 3 months and finally, towards March, sowing of groundnut (*Arachis hypogaea*) being harvested 3 months later; lower down we find forage crops of bourgou (*Echinochloa stagnina*); at the high water margin we find vegetable crops irrigated by calabash, especially shallot (*Allium cepa var. cepa*) and tobacco (*Nicotiana tabacum*).
For this study, these production types have not been considered as flood-retreat crops, but have been included in vegetable production techniques (Chapter 8). Cultivated bourgou is treated in Chapter 9 and natural stands in Chapter 11.

2. Lakebed crops

Lakebed crops, and to a lesser extent, crops in the beds of temporary streams on gentle slopes: from top to bottom and as the water recedes, we first find cassava followed by sweet potato and sorghum or millet and finally groundnut, cowpea (*Vigna unguiculata*), maize (*Zea mays*), roselle (*Hibiscus sabdarifa*) and gumbo (*Hibiscus esculentus*). The crops are harvested in reverse order according to maturity and the flood.
Calabash (*Cucurbita* sp.) and water melon (*Citrullus vulgaris*) are normally cultivated in association with cassava and sweet potato. However, they have not been cultivated to any extent since the beginning of the drought period: water resources seem to be reserved for crops considered more useful. Cassava cultivation, as observed at Lake Aougoundou, is practised at the high-water limit and even above that, if capillary rise guarantees sufficient water supply; however, the crop is not grown in the rainy season to avoid termite attacks. Cassava cuttings are planted in small holes in December and January and harvested either according to the needs of the grower, say from August onwards, or depending on anticipated and actual flood levels. However, the plants may remain in the field for up to 5 years, serving as wood reserve (source of cuttings) and harvested roots are used to manufacture starch for clothing.

Flood-retreat cultivation is always combined with cultivation of millet on the upland loamy sands (Section 2.2, CABO soil type B2 = PIRT D7); sometimes indicated as 'dune culture', with very erratic yields. The degree of success of combinations with other flood-retreat crops or with rainfed crops depends on flood level and rainfall and on economic incentives (Guillaume, 1960). As that author concludes:

'Despite their apparent simplicity, the flood-retreat crops in the valley of the Niger are riddled with difficulties. Their success depends on the flood regime of the river for the first part of their development and on the rainfall pattern for the second part. They suffer from the irregularities of both regimes, which are virtually independent. The variability in flood-retreat production is very high, because both the cultivated area and the production per unit area vary parallelly. The flood-retreat crops only serve as a supplement to the winter crops with a very low production under rainfall of less than 400 mm yr^{-1}.'

To avoid too much complexity in the LP-model, this production technique, in reality very complex, must be reduced to something more manageable. To achieve that objective, we have schematized all flood-retreat crops to the cultivation of flood-retreat sorghum, which, based on our experience in the Region may be referred to as 'the flood-retreat sorghum and millet production technique'.

Flood-retreat sorghum cultivation is very important in the Zone Lacustre. According to WIP (1980), it supplies up to 80% of the total cereal production in this agro-ecological zone. Sorghum straw has the same functions as millet straw, and is moreover suitable for wickerwork and basketmaking.

The production techniques used for flood-retreat sorghum are apparently simple and include many minor variations depending on the specific cultivation conditions, which is not surprising, given its dependence on flooding regime, rainfall and soil type. This cultivation technique is based on thorough knowledge of the local environment; yet it is dependent upon a forecast of future events that are hard to anticipate. For the LP-model, it is necessary to reduce this diversity to major techniques of flood-retreat sorghum production, taking into account the constraint of sustainability. On the basis of the four criteria defined before (Section 2.1), two sorghum production techniques have been selected.

Fallowing of land used for flood-retreat cultures, however, is more complex than that used for millet (Guillaume, 1960). On the one hand, 'dry' fallowing is practiced, i.e. fallowing after flood retreat, when the land is cultivable, and on the other hand 'flood' fallowing, i.e. during the period that the land is flooded; this has an influence on the structure of the soil and on its fertility through the influx of silt and organic matter, even at small amounts.

The two techniques selected for the LP-model can be classified according to their intensity level:

Extensive technique

Under the extensive technique (currently widely practised), the natural soil fertility is exploited. Animal traction is not used and manure nor chemical fertilizer are applied. Sustainability is ensured by the use of 'dry' and 'flood' fallowing.

Semi-intensive technique

Under the semi-intensive technique (not practised at present), nutrient availability is increased, but only current means of production are used: no animal traction, no application of manure nor use of 'dry' fallowing. Sustainability of the production technique is based on the use of 'flood' fallowing and external inputs of chemical fertilizer. At this technological level the availability of manure is assumed to be limited to the extensive dune agriculture; it replaces formations of the Egyptian doom palm (*Hyphaene thebaica*) and since sustainability is not considered, exploitation during arable farming is often exhaustive, leaving fallow land of very low production capacity. This level of technology implies that infrastructures for flood control should be created.

4.2 Environment

In the Region, cultivation of flood-retreat sorghum is mainly practised in the Zone Lacustre in rainfall zone IV, with annual rainfall in normal years of 255 mm and in dry years of 155 mm (Table 2.2, page 26), and to a limited extent in rainfall zone III with an average annual rainfall of 380 mm in normal years and 235 mm in dry years. In fact, water availability for this culture cannot be directly estimated on the basis of rainfall given its various origins. In the dry season, after the flood has receded, germination takes place in the moist, if not saturated, soil. The start of the vegetative phase and the survival of the seedlings are assured under these rather harsh conditions by stored soil moisture and capillary rise from shallow water tables, the rate of upward movement being largely dependent on soil type. During the rainy season, the water required for completion of the vegetative phase and for the reproductive and grain filling phases originates directly from the rain and indirectly from run-on from higher areas. In fact, the crop is topographically situated in the lower parts of the slightly undulating landscape. It should be noted that small bunds are sometimes constructed to retain the surface water, but anaerabiosis should be avoided. These bunds, and sometimes actual dykes, are also used to avoid to early flooding. However, these protective measures against high and/or early flooding may result in total absence of flooding in case of low water levels (as with the disputed dyke at Koundioum).

According to Gadelle (1986), the cultivated flood plains should be situated on the medium to high margins of the flooded area, and be covered by at least 20 cm of water for a minimum of two months to restore the available water reserve (available water is the storage capacity between field capicity and wilting point), but according to Guillaume (1960), the actual flood levels depend very much on the hydraulic properties of the soil and the crop should be sown on the basis of the flood level reached before February 15 assuming that the crop will not be submerged subsequently. The successive submergence and drying of the flood plain as a result of the contributions from successive high or low floods modified by losses due to evaporation and infiltration is not treated, as this phenomenon is not well understood (Guillaume, 1960; Gadelle, 1986; Aalbers, 1988).

According to Guillaume (1960), the soils used for this type of agriculture are the beds of lakes and temporary streams with strongly sloping features. The topographical sequence from bottom to top consists texturally of clay, clay loam, loam, sandy loam, loamy sand and sometimes sand. This sequence is the result of the sedimentation of fine particles in the lower part of the landscape, and of aeolien and colluvial deposits of coarse material from dunes, at the higher parts. At the bottom of the depressions we find loamy and sandy clay and on the slopes fine sandy clay and clayey sand. Accumulation of organic matter and humus occurs predominantly in the lower parts, i.e. flooded for a long time. The typology of the soils is thus highly complex as witnessed by the many vernacular terms used. Field surveys confirm this diversity which can sometimes be observed as stratified profiles, while also sand deposits may occur. The combination of three spatially and temporally variable factors - flood, rain and soil texture - allows a certain flexibility of management, but thorough knowledge of the environment is required, which precludes a general approach in suggesting interventions.

The heavier the soils (clayey and/or loamy), the higher the storage capacity for available water and the contribution from capillary rise, but also the higher the risk for saturation and anaerobiosis. The lighter the soil (sandy) the lower the natural fertility level. Sorghum is grown on heavy soils: it requires more water than millet to complete its growth cycle, and is less sensitive to excess water. Millet, on the other hand, is grown on lighter soils or heavier soils covered by a sand layer; the same holds for cowpea (Gadelle, 1986). The ratio of sorghum to millet also depends on the prevailing rainfall and flooding regimes.

Flood-retreat cultivation allows exploitation of environments less suitable for rainfed crops, better utilization of the rain because rooted plants are present from the onset, broadening of the spectrum of potential crops, minimizing of the risks through 'extensification', i.e. sowing larger areas, and use of labour when it is not in great demand by other agricultural activities.

Inclusion in the LP-model of the complete range of soils briefly described above is not possible to keep it manageable. Schematically therefore, only part of the alluvial loams (CABO G = PIRT TI7 + TI4; Report 1, Chapter 3) has been selected. The alluvial loams of the levees upstream of Lake Débo (TI4) have not been included, because they are on the one hand too steep and on the other hand too much influenced by the fluctuations of the river floods upstream of Lake Débo, hence the timing of flooding, recession and rain is not suitable for this type of agriculture. The virtually flat alluvial loamy soils (TI7) of the north of the Delta Central, also upstream of Lake Débo, have also been excluded because of synchronization problems (Guillaume, 1960). The loamy soils downstream of Lake Débo are considered suitable for cultivation, but not all of these can be exploited.

In fact, land suitable for flood-retreat cultivation is limited to specific flood plains whose position and area constantly vary as a result of the variability in flooding conditions. The inconvenience of having to adapt constantly to this variability, is partly 'offset' by the fact that the technique is sustainable because of the 'forced' fallowing (extensive technique). This is no longer the case when flood control is introduced (Guillaume 1960; Gadelle 1986) and only 'flooded' fallowing remains, as that is insufficient to maintain chemical soil fertility in the long run. Then, application of chemical fertilizers is indispensable (semi-intensive technique). The relationship between the intensity of flooding (i.e. height and duration) and the area that can be sown to flood-retreat crops is not known, and no dynamic model covering several years seems to exist that links flooding height to the flooded area and to natural or cultivated vegetation. Finally, for the Zone Lacustre we cannot mimic the annual effects of the floods due to the scarcity of available data (Report 1, Chapter 5).

In the LP-model, it is assumed that the suitable surface area represents 25% of soil type TI7 downstream of Lake Débo, i.e. 30 km^2 in the Gourma and 210 km^2 in the Zone Lacustre in a normal year. In a dry year the flooded area is smaller, but as quantitative information is lacking, the same values have been applied.

4.3 Yields

Biomass production of the crops using groundwater reserves in the dry season, i.e. between sowing, following the recession of the flood and the first rains, is low according to our information. It is estimated at 300 kg DM ha^{-1} for the extensive technique and 400 for the semi-intensive technique. According to Hesse & Thera (1987), the growth of crops during the dry season until the first rains is controlled by grazing. No other written sources have been found, but it is confirmed by one verbal source. It raises, however, certain questions. In fact, the vegetative material of sorghum conta32 dhurrine or dhurroside a cyanogenic heterocide giving at hydrolysis hydrocyanic acid, 0.5 g of which is enough to kill an adult cow (Cérighelli, 1955; Purseglove, 1975; RFMC, 1980; Göhl, 1982). The dhurrine content of a sorghum plant is cultivar-specific and depends on age, and growth conditions. Young plants, young leaves and regrowth contain the highest levels; they decrease with age and are very low at maturity, while it is not present in grains. The toxin is destroyed by drying or during silage. The levels are higher in plants under drought stress or with abundant nitrogen supply. Each cultivar has its own characteristic levels; Cérighelli (1955) quoting Dumas and Viguier, suggests that the levels in the sorghum cultivars of the French Soudan are very low. To our knowledge, farmers in the Region are aware of the toxicity of sorghum to animals, but that does not prevent accidents from happening. It appears that certain flood-retreat sorghum cultivars in the Zone Lacustre are very low in the toxin: animals are taken deliberately to the fields to graze, thus reducing above-ground biomass, and transpiration and hence minimizing losses of useful water reserves. In other words, the chances for survival of the plants until the first rains are increased. This technique could equally well be applied to flood-retreat millet planted on lighter soils with a smaller store of available water and hence more susceptible to drought. In the process the seedlings are trampled which promotes tillering, a technique long practised on cereal fields in Europe. Since no data are available on the extent of this practice in the Region nor on all characteristics of the flood-retreat sorghum cultivars used, we have for the purposes of the model assumed that the fields are not grazed at all in the Zone Lacustre.

According to Guillaume (1960), flood-retreat sorghum grain yields vary from 1 500 to 2 000 kg ha^{-1} under optimum conditions. The average figure is 700 to 800 kg ha^{-1}, varying between 400 and 1 200.

For the LP-model, target yields in a normal year have been estimated on the basis of simulation results. These are 600 kg ha^{-1} for the extensive system and 1 000 for the semi-intensive system. Stover yields are estimated at 4 650 and 5 450 kg ha^{-1}, respectively. For dry years a reduction in yields of flood-retreat sorghum is applied similar to that of rainfed millet, resulting in yields of 360 and 600 kg ha^{-1} for the extensive and semi-intensive production technique, respectively.

For millet, it was estimated that 75% of all crop residues after harvest are consumed by the herds (Chapter 2). For sorghum, it is estimated that 45% of the residues after harvest can be consumed by animals: first, total stover yield of sorghum at harvest is very similar to that of millet (Erenstein, 1990); secondly, according to Quilfen & Milleville (1983), 100% of the laminae but only 40% of the stems can be consumed because of their structure and it is estimated that stem bases and cobs are also inedible. In addition, not all sorghum residues are accessible, due to partial or complete flooding of the harvested fields. If it is assumed that 50% of the residues are accessible to the animals, only 22.5% of the residues from flood-retreat sorghum can be consumed by the animals.

4.4 Nutrient requirements

On the basis of the results of a literature review by van Duivenbooden (1991), the minimum contents [g kg^{-1}] of N, P and K in the dry matter of grain and stubble are set at 11.0, 1.6 and 2.5, and 3.0, 0.2 and 6.0, respectively.

On the basis of these concentrations and applying the method described in Chapter 1, the required length of the fallow period and the requirements for chemical fertilizer have been calculated for each technique as presented in Table 4.1.

4.5 Crop calendar and labour requirements

According to Guillaume (1960) and Gadelle (1986), flood-retreat sorghum is sown between mid-February and mid-May and harvested between the end of August and the end of October, depending on cultivar. As the cultivated area is very variable due to the variability in flood levels, additional outside labour is hired in good years when large areas have to be planted. The various operations involved in the two production techniques are discussed below.

1. Cleaning the fields

Cleaning of the fields is not practised, since normally the floodplains do not carry vegetation. In fact, one of the features of soil type TI7 is the virtual absence of vegetation, but it is not clear whether that is an intrinsic characteristic of this unit, or the result of degradation under the influence of natural and anthropogenic factors. If the fields had been cultivated the preceding year, the flood will have destroyed all signs of cultivation; anyway, since this cultivation is not based on the use of the plough, there is no need to clean the fields of residues that could hamper ploughing. According to Guillaume (1960), if after harvest the stubble of sorghum is not destroyed by flooding or other processes and provided they grow in soils with a favourable water supply, there may be a second harvest from a ratoon crop.

Hence, field cleaning has not been included.

2. Transport and application of manure

If manure would be applied, the method of cultivation would prevent incorporation in the soil and, left on the surface, it would be useless to plants and carried away by the first rains (soil surfaces are rather smooth and always sloping). Even after incorporation in the top soil it would be of no use to the plants until the onset of the rains, as the upper soil layers are desicated. However, the long term maintenance of the physical proporties of the flood-retreat soils is ensured at least by 'flood' fallowing.

Hence, in neither of the two techniques manure is applied.

3. Basic dressing

If chemical fertilizer is applied at the beginning of the cycle in such a way that it is accessible to the roots in view of the moisture availability, the seedlings could benefit while water is still available. However, available water would also be more quickly exhausted, thus increasing the risk of killing the plants before the end of the dry season. Since the objective is to have living plants that are well-rooted at the onset of the rains, no fertilizer should be applied at the beginning of the cycle to reduce growth and consequently conserve soil water on the one hand and on the other hand to reduce the ratio of above-ground to belowground biomass, as in poor soils root growth is stimulated (functional equilibrium: van Keulen *et al.*, 1988).

For neither technique therefore, basic dressing with chemical fertilizer is applied.

4. Land preparation

According to Guillaume (1960) and Gadelle (1986), no land preparation is practised, as sowing is carried out as the waters recede and the soil is still too wet. We have, however, observed ploughing at Lake Aougoundou on light soil just prior to millet sowing, although this was probably rather a 'pre-sowing weeding' to destroy weeds already present.

Soil preparation has therefore not been included in the LP-model.

5. Sowing

According to Guillaume (1960) and our own observations, before sorghum is sown, small pits are dug about 80 to 100 cm apart. At the bottom, small holes are made with a dibber (a pointed stick with a weighted head known as 'chukawal') in which seeds are placed, resulting in very deep sowing. The pits are not always dug. Alternatively, plants are sown in irrigated seed-beds above the flood line, followed by transplanting when 20 to 30 cm high as the floods recede. This allows phasing of the harvest as transplanted plants mature a little later. The purpose of digging the pits is first to reach the moist soil, if the surface is already dry and secondly, to lower the level of the plants to allow their roots to be in contact with the soil water as long as possible. If the soil is light or medium-textured, the seeds are covered with the same soil. If the soil is heavy, however, the seeds are covered with sandy soil brought in from elsewhere, to prevent rotting of the seeds.

For neither technique, transplanting from seed-beds has been considered and the labour requirements for sowing in situ are estimated at 10 mnd ha^{-1}, which is relatively high, but includes digging the pits, making holes, placing the seeds, collecting and transporting the sandy soil and covering the seeds.

6. Thinning and transplanting

According to Guillaume (1960), thinning of flood-retreat sorghum is not practised. According to our verbal information however, the flood-retreat sorghum may indeed be thinned and transplanted. During the phased-out sowing following the recession of the flood, plants from the first sowing are uprooted above and transplanted lower down.

Since this operation is not systematically practised, however, the time allotted to thinning and transplanting has been fixed at 4 mnd ha^{-1} for both production techniques.

7. First weeding

According to Guillaume (1960) and our verbal information, a first weeding is practised during the dry season, and according to that author, if the fields are too heavily infested, they are abandoned. This first weeding is very important to prevent loss of available water, but it is not practised systematically over the whole area of the field. This rapid weeding takes between one third and one quarter of the time necessary for millet weeding.

For the two techniques therefore, the labour requirements for first weeding have been set at 4 mnd ha^{-1}.

8. Top dressing

Chemical fertilizer is applied in the semi-intensive technique at the beginning of the rainy season while the plants are still young, but well-rooted and may benefit from the additional water to complete their cycle.

As the fertilizer is placed, i.e. a hole is made, the fertilizer inserted and the hole filled in again, the labour requirements for this operation are set at 4 mnd ha^{-1}.

9. Second weeding

According to Guillaume (1960), a second weeding takes place at the beginning of the rainy season. According to verbal information, this second weeding is not always practised, either because the land is infested too heavily or the necessary labour is not available because it is monopolized by the rainfed cultures. When practised, this second weeding takes place after the first weeding of rainfed millet and is more thorough than the first one, since it also involves a certain degree of hoeing and harrowing, and the labour requirements are therefore set at 6 mnd ha^{-1} for both techniques.

10. Harvesting

Sorghum is harvested similarly to millet (Section 2.5, point 10), but a little more rapidly. The estimated harvesting rate for millet without improved implements is 100 kg mnd^{-1}. If we assume that sorghum harvest takes 75% of the time required for millet, the rates are 135 kg mnd^{-1} for the extensive technique and 145 kg mnd^{-1} for the semi-intensive technique, assuming that the working efficiency is higher when yields are higher. Most of the flood-retreat sorghum is harvested before the rainfed crops, so there is only a slight overlap between the two harvests.

For the extensive technique harvesting time is set at 4.5 mnd ha^{-1} and for the semi-intensive technique at 7.0.

11. Transport of panicles

Sorghum products are transported in the same way as those of millet (Section 2.5, point 11) except that flood-retreat sorghum is also transported by 'pirogue' (canoe). According to verbal information, in a normal year 40% of the total production is transported by donkey, 20% by cart, 20% by canoe and 20% is carried on the head.

If we assume that the transport capacities for panicles of sorghum and millet are identical, i.e. 65 kg mnd^{-1} on the head, 200 kg mnd^{-1} by donkey, 300 by cart - extensive technique - and 460 by cart - semi-intensive technique (same cart and same volume transported, but heavier panicles) - and that the carrying capacity of an average canoe is the same as that of a cart -semi-intensive technique - the required transport times are 245 kg mnd^{-1} or 2.5 mnd ha^{-1} for the extensive technique, and 275 kg mnd^{-1} or 3.5 mnd ha^{-1} for the semi-intensive technique. Transport of the panicles of flood-retreat sorghum coincides with harvest of rainfed crops.

12. Threshing and winnowing

Sorghum is threshed and winnowed in the same way as millet (Section 2.5, point 12), except that for flood-retreat sorghum both take less time.

For threshing and winnowing we have assumed that the rate is 75 kg mnd^{-1} or equivalent to a labour requirement of 8 mnd ha^{-1} for the extensive technique and 13 for the semi-intensive technique without improved implements. In a normal year, threshing and winnowing of flood-retreat sorghum takes place when the products are required, which means that it is postponed until after harvest of the rainfed crops.

The total labour requirements for flood-retreat sorghum are 39.0 mnd ha^{-1} for the extensive technique and 51.5 for the semi-intensive technique (Table 4.1). The labour requirements are distributed over the various periods of the year (Subsection 1.2.1) as given in Table 4.1.

4.6 Monetary inputs

4.6.1 Capital charges

The costs of infrastructures to control flooding have not been included. These infrastructures should avoid both lack of water and excess water, which complicates their design and increases the costs (WIP, 1980; Gadelle, 1986). For both techniques annual capital charges on infrastructures have also not been taken into account.

The equipment used in the cultivation of flood-retreat sorghum is restricted to light equipment whose annual costs are estimated at 700 FCFA ha^{-1} yr^{-1} for the extensive technique and 1 000 for the semi-intensive technique.

4.6.2 Operating costs

1. Seeds

It is assumed, that the average planting distance is 90 * 90 cm with 5 seeds per seed hole, hence 61 730 seeds ha^{-1}. According to Purseglove (1975), the 1 000-seed weight ranges from 14 to 40 g. In this study, it has been set at 30 g, hence the seeding rate is 1.85 kg ha^{-1} at a cost of 55 FCFA kg^{-1}. In the model a value of 150 FCFA ha^{-1} yr^{-1} has been applied.

2. Pesticides

Costs of pesticides are estimated at 100 FCFA ha^{-1} for the extensive technique and at 250 for the semi-intensive technique.

4.7 Input-output table

Inputs and outputs of the defined flood-retreat sorghum production techniques for the LP-model are quantified in Table 4.1.

Table 4.1. Input-output table for two flood retreat sorghum production techniques on soil type G.

CHARACTERISTIC	EXTENSIVE	SEMI-INTENSIVE
Animal traction	-	-
Manure	-	-
Chemical fertilizer	-	+
Fallow	+	-
INPUTS [ha^{-1} yr^{-1}]		
FALLOW/MANURE/FERTILIZER		
Ratio fallow years/ year cultivated [-]	13	-
Manure [kg DM]	-	-
Fertilizer N [kg]	-	105
Fertilizer P [kg]	-	15
Fertilizer K [kg]	-	59
LABOUR[a] [mnd]		
6 Seeding	10.0	10.0
6 Transplanting	4.0	4.0
6 Weeding 1	4.0	4.0
1 Top dressing	-	4.0
3 Weeding 2	6.0	6.0
3 Harvesting	4.5	7.0
4 Transport	2.5	3.5
6 Threshing & winnowing	8.0	13.0
Total	39.0	51.5
MONETARY INPUTS [FCFA]		
Capital charges		
Small equipment	700	1 000
Operating costs		
Seeds	150	150
Pesticides	100	250
subtotal	250	400
Total	950	1 400
OXEN [ox]	-	-
OUTPUTS [ha^{-1} yr^{-1}][b]		
Grain [kg DM]	600	1 000
Straw [kg DM][c]	4 650	5 450

a) Numbers in front of operations refer to the period of the year (Subsection 1.2.1).

b) In a normal year.

c) Average N% is 3.9 g kg^{-1}.

5. FONIO

(P.A. Gosseye)

5.1 Introduction

Fonio is the vernacular name for *Digitaria exilis*. Other vernacular names are fundi and hungry rice (Portères, 1955; Purseglove, 1975; Baudet, 1981) and in French fonio blanc, fundi and petit mil.

According to Portères (1955), cultivation of fonio is confined to West Africa and is supposed to be a very ancient practice, but for various reasons, it is declining. In the zones where fonio cultivation is concentrated, i.e. the Fouta Djalon and the Senegalo-Nigerian high basin, a wide range of cultivars is available, adapted to various soil textures and levels of soil fertility. The lengths of their growth cycles vary from very short to very long, i.e. from 60 to 150 d. Outside these zones the choice is more limited: south of the 12th parallel N there are still a number of cultivars, mainly late ones, while to the north, the choice is limited to early or very early cultivars, ranging from 60-90 d. However, the length of the growth cycle depends on the date of sowing, as fonio is a short day plant, i.e. sensitive to day lengths between 11 h 50 and 11 h 30. In the north to which the Region belongs, only one to four cultivars are available. We have assumed that only one cultivar is grown in the Region and that the heaviest rains do not affect fertilization of this cereal because it is cleistogamic (Cérighelli, 1955; Portères, 1955).

The main aim of cultivating this rainfed cereal is to produce grain for human consumption. According to Portères (1955) and Purseglove (1975), fonio is a main crop in the areas where cultivation is concentrated, whereas in other zones it is a secondary or companion crop. Between 12 and 15° N, fonio serves as an 'emergency' crop, grown in situations of imminent starvation (Portères, 1955). Note that fonio is a cereal exceptionally rich in methionine (Baudet, 1981). In the Region, fonio is mainly cultivated in the south as a secondary crop.

Among other things, the straw is used as forage in the field or after storage, as a source of potassium salt after incineration, as a material for stuffing mattresses and as an additive to bricks made from unfired clay (Portères, 1955; Purseglove, 1975).

In this study, the possible cultivation technique with animal traction is not considered, although that seems to have been tried between the years 1905 and 1933 (Portères, 1955). For the purpose of the LP-model only one fonio production technique has been defined, on the basis of the four basic criteria defined earlier (Section 2.1).

The selected technique, currently practised, is considered extensive and exploits the natural soil fertility. Animal traction is not considered. Organic manure nor chemical fertilizer are applied and sustainability of the technique is ensured by the use of fallowing.

5.2 Environment

According to Portères (1955), the zones where fonio cultivation is concentrated are located between the isohyets of 900 and 1 000 mm yr^{-1} with 4 or 5 months of rain. In mountainous regions, ranging in altitude from 1 400 to 1 500 metres, fonio is cultivated between the isohyets of 1 000 and 2 000 mm yr^{-1}. South of the 12^{th} parallel N, fonio cultivation descends till the forest, while in the north it extends as far as 14° N. This author found that when going north, cultivation of fonio is increasingly concentrated in depressions. He considers the northern limit of the cereal at the isohyet of 500 mm yr^{-1}. Purseglove (1975), however, considered a value of 400 mm yr^{-1}. Hence, despite its reputation as a drought-resistant crop, it seems that fonio is a crop for relatively rainy regions.

In the Region, it is grown in Sourou and Séno Bankass, in other words in rainfall zone I where average annual rainfall is 545 mm in a normal year and 368 mm in a dry year (Table 2.2, page 26). It is also grown on the Plateau, but almost absent in the Delta Central, i.e. rainfall zone II with average annual rainfall of 461 mm in a normal year and 306 mm in a dry year. Fonio also occurs in Méma Dioura and Séno Mango, i.e. rainfall zone III with 379 mm yr^{-1} in a normal year and 237 mm yr^{-1} in a dry year, and it is even found further north. However, cultivation in rainfall zones III and IV is not considered in the LP-model, because of the high risks of complete or almost complete crop failure. Hence, fonio is considered to be cultivated only in rainfall zones I and II.

According to Cérighelli (1955) fonio grows well on soils of low fertility provided they are permeable. According to Portères (1955), the crop is grown on sandy to clayey soils in zones where the crop is grown widely and a range of cultivars is available. Differences among cultivars exist with respect to their suitability for different environmental conditions, and growers try to match the qualities of the cultivar with the local ecology. In general, however, clay soils are less suitable since fonio prefers sandy to loamy soils irrespective of their location and stoniness. In most cases, it is cultivated on well-drained sandy or loamy sand or sandy loam soils. According to RFMC (1980), it can grow in soils ranging from light to heavy-textured and from very poor to rich. According to Purseglove (1975), fonio can be grown on soils that are light, poor, skeletal and rocky. Results of fertilizer experiments are not conclusive, nitrogen tends to induce lodging and to result in a higher proportion empty grains. It seems that on a rich soil the harvest index decreases.

Portères (1955) suggests that in zones where fonio cultivation is concentrated a wide range of cultivars is available, suitable for a wide range of soils with regard to texture and soil fertility. In general, however, fonio is not grown on fertile soils unless these are first exhausted by other, more nutrient-demanding crops, since most fonio cultivars tend to produce more straw and less grain in fertile soil. In other words, the crop will not be grown at the start of a rotation.

Outside these zones fonio is more an emergency crop grown in unfavourable times. Viguier, quoted by Portères (1955), notes that cultivation of the crop expands following a series of poor harvests, a fact confirmed by de Jager (KIT, pers. comm.) and Tembély (ORM, pers. comm.). The area under fonio therefore expands not only to provide for dry years, but also in response to empty barns following a series of drought years. The aim is to produce something and not to achieve high yields. Fonio is suitable for this role, since the available cultivars range from early to very early and have been selected for their hardiness rather than their productivity. That hardiness enables them to perform in relatively poor soils, the more fertile soils being used for crops which are more nutrient-demanding or regarded as essential (primary or staple crops). The low fertility of soils cultivated with fonio is either natural, temporary at the end of normal crop rotation cycles, or permanent following a long and serious imbalance between the lengths of the fallow periods and the cultivation periods. According to Portères (1949; 1955), fonio is even capable of performing reasonably well in soils where millet, although considered a crop low in nutrient requirements, is unable to produce. This hardiness also enables fonio cultivation under an extensive technique with low labour requirements. However, these advantages, when abused, may become drawbacks: fonio is frequently cultivated outside any normal crop rotation system as a continuous crop until it does not yield anymore, in other words, until the soil is totally exhausted. In addition, it is very widely cultivated following bush fires, stubble clearing and stubble burning, the latter two being particularly destructive.

The cultivar selected for the Region, is chosen for its hardiness and not for its yield; it should therefore be cultivated on soils that are not too fertile so as not to affect the harvest index unfavourably, and should not be given organic or mineral fertilizer. Sustainability of the technique is ensured by fallowing. For the present study, it has been assumed that fonio is a part of the normal rotation of millet under technique 1 at the extensive level, i.e. it is cultivated at the end of the rotation or as a continuous crop. For the LP-model exhaustive practices are not considered, even though they may be actually practiced.

5.3 Yields

According to Cérighelli (1955), yields of hulled grain, i.e. with the husk (in DM), range from 800 to 2 000 kg ha^{-1}. Portères (1955) gives an average yield for West Africa of 400 kg ha^{-1} and 250 kg ha^{-1} for the French Soudan, as derived from official statistics. In the following, a brief review of results cited by Portères (1955) is given.

- In a research station using animal traction, Renoux & Dumas measured yields of husked grain between 800 and 1 000 kg ha^{-1} for late cultivars;
- In a research station using animal traction, Bidaut measured a yield of 783 kg ha^{-1} for a medium-duration cultivar;
- Boyd gives yields for continuous cropping of 168 kg ha^{-1} yr^{-1} on average over a period of five years in stony soil, 175 kg ha^{-1} yr^{-1} over three years in sandy soil and 162 kg ha^{-1} yr^{-1} over seven years on a heavy soil in a depression;
- Crieg obtained 3 600 kg ha^{-1} on an experimental station;
- Rae recorded only 57 kg ha^{-1};
- Dapoigne obtained 200 kg ha^{-1} using animal traction and 500 kg ha^{-1} with simple hoeing; another reported value is 166 kg ha^{-1};
- Froment recorded yields of 172, 195 and 204 kg ha^{-1} using animal traction;
- Faulkner & MacKie reported 600 kg ha^{-1}.

Portères (1955) concluded that, under normal farming practice expected yields do not exceed 200 kg ha^{-1}, irrespective of rainfall conditions, but that with well-tended late varieties it is possible to achieve 500 or even 1 000 kg ha^{-1}. Cissé (1975) quoting Johnson gives 400 to 600 kg ha^{-1} with a maximum of 1 000 kg ha^{-1}; quoting Gaudy he gives 500 kg ha^{-1} and concludes a compilation of statistical data with average yields of 366 kg ha^{-1} for Burkina Faso, 400 kg ha^{-1} for Mali, 181 kg ha^{-1} for Niger, 330 kg ha^{-1} for Senegal and 355 kg ha^{-1} on average for the eight West-African countries examined. Purseglove (1975) gives yields of 150 to 200 kg ha^{-1} on poor soils and 600 to 800 kg ha^{-1} on soils of average fertility. He also points out that yields exceeding 1 000 kg ha^{-1} have been recorded. In Mali, SRCVO (1988) working on a research station, applying 50 kg ha^{-1} of 'complex cotton' fertilizer, and using 11 Guinean and one 'local' cultivar, in 1987 measured an average yield of 904 kg ha^{-1} ranging from 633 to 1 183 at Sotuba, an average of 639 kg ha^{-1} ranging from 379 to 850 at Cinzana and negligible yields at Koro (in the 5th Region) where rainfall was 231 mm yr^{-1} according to DRA. Under the same conditions, SRCVO (1989) in 1988 measured an average of 1 204 kg ha^{-1} ranging from 1 000 to 1 295 at Cinzana and at Koro an average of 263 kg ha^{-1} ranging from 105 to 710, with the rainfall for Koro being 489 mm yr^{-1} according to DRA. SRCVO concludes that the 'local' cultivar has the best performance.

According to Portères (1955), the yield of unhulled fonio grain is 80 to 85% of the hulled grain, i.e. 15 to 20% husks.

On the basis of the literature review summarized above, yields under normal farming practise are of the order of 200 to 400 kg ha^{-1}.

In the LP-model therefore, the target yields for a normal year for rainfall zones I and II have been set at 375 and 250 kg ha^{-1} of hulled grain, respectively, i.e. 300 and 200 kg ha^{-1} of unhulled grain. As no growth simulation for fonio has been carried out, the reduction in production in a dry year has been set equal to that for millet, i.e. 48 and 45% in rainfall zones I and II, respectively. In a dry year therefore, target yields of fonio in RZ I and II are 195 and 140 kg ha^{-1} of hulled grain, or 156 and 112 kg ha^{-1} of unhulled grain, respectively.

Froment, quoted by Portères (1955), gives ratios of grain to straw in kg ha^{-1} of 172/350, 195/460 and 204/570, yielding harvest indices (HI) of 0.33, 0.30 and 0.26. Under controlled conditions (phytotron), Cissé (1975) measured an average HI of 0.3, ranging from 0.23 to 0.45 on sandy soil, an average of 0.26 ranging from 0.18 to 0.37 on loamy soil and on clay soil an average of 0.27 ranging from 0.18 to 0.36. In the LP-model the value is set at 0.30 and given the target yields, straw production is 875 and 585 kg ha^{-1} for rainfall zones I and II, respectively in a normal year and 455 and 300 kg ha^{-1} , respectively in a dry year.

The farm-gate price for hulled grain is set at 70 FCFA kg^{-1}.

5.4 Nutrient requirements

On the basis of the results of a literature review by van Duivenbooden (1991), the minimum contents of N, P and K on a dry matter basis of (unhulled) grain are

12.3, 2.1 and 2.8 g kg^{-1} and those of straw 8.7, 0.3 and 12.0, respectively.

Based on these values it is possible to calculate (Subsection 1.3.1) the time required for fallowing, which appears seven years for each year of cultivation.

5.5 Crop calendar and labour requirements

According to our observations, fonio is sown at the end of July or the beginning of August at about the time of the first weeding of millet. According to Purseglove (1975), the crop is harvested from September to October and according to our own observations always before the millet harvest.

According to our knowledge, no or virtually no recorded information is available on labour requirements for fonio cultivation, and the values given below have been derived mainly on the basis of verbal information collected during the present study and comparison with the cultivation of millet.

1. Cleaning of the fields

If fonio is included in a normal rotation of millet, the labour requirements for this operation are 1 mnd ha^{-1}. If fonio is grown continuously instead of millet (technique 1), labour requirements for cleaning the fallow land at the start of the rotation are 20 mnd ha^{-1} and the crops that follow require only superficial cleaning, requiring 1 mnd ha^{-1}.

Similarly to millet (Section 2.5), the average labour requirements for cleaning a normal cycle of fonio are set at 5 mnd ha^{-1}.

2. Transport and application of manure and basic manure

As no manure nor chemical fertilizer are applied in the selected production technique, no labour is required for these operations.

3. Land preparation

Disregarding the experiments with animal traction, land preparation as such is not practiced for fonio. Just prior to sowing the land is lightly hoed by hand (top two to three centimetres of soil). This superficial hoeing seems to be adequate, especially if the land has already been worked. For fonio, shallow planting is always practiced (Portères, 1955). According to the same author, hoeing immediately precedes sowing and is carried out directly after the first rains or shortly before. According to Purseglove (1975), hoeing takes place in June to July. Our own information indicates that hoeing is done between sowing of millet and its first weeding.

The labour requirements for hoeing are estimated at 4 mnd ha^{-1} (van Heemst *et al.*, 1981), being applied in the LP-model.

4. Sowing

Fonio is always sown broadcast, except on research stations. According to Portères (1955), cleaning, soil preparation and sowing combined require 20 to 25 mnd ha^{-1}. Sowing takes place immediately following hoeing, towards the first weeding of millet. Sowing is sometimes, but not always, followed by very light manual harrowing with branches.

Labour requirements for sowing are estimated at 1 mnd ha^{-1}.

5. Weeding

Portères (1955) reports that fonio is generally not weeded, but states that one weeding would be preferable in case of dense planting and two for lower plant densities, which would require 20 to 30 mnd ha^{-1}. According to Purseglove (1975), fonio is usually not weeded as dense sowing generally prevents competition. According to our own observations, weeding would be very difficult (unless fonio is sown in rows), although manual weeding would be conceivable if absolutely necessary.

For the defined fonio production technique, however, weeding is not justified. If hoeing is done well after the start of the rainy season, it not only loosens the surface of the soil to prepare the seed-bed, but also destroys any vegetation that might have already germinated. In any case, the densely sown crop will prevent further germination of weeds. Hence, labour requirements are set to zero.

6. Harvesting

All details of harvesting techniques reported by Portères (1955) are not discussed here. According to our observations, fonio is harvested in much the same way as rice, except that, when mature, fonio very often lodges which hampers harvesting and makes mowing tests, both manual and mechanical, inconclusive (Renoux & Dumas, quoted by Portères, 1955). After the panicles have been cut with a knife or bill-hook, the loose bundles are piled into stooks close to the harvest site to dry. Given the susceptibility dehiscence of the caryopses, it is preferable to handle fonio panicles while still wet to avoid grain loss (Cissé, 1975), but that requires drying under good conditions - hence stooks and not ricks - to prevent fermentation affecting the quality, and occasionally, the quantity of the product (Portères, 1955).

Labour requirements for harvesting are estimated at 8 mnd ha^{-1}.

7. Transport, threshing and winnowing of panicles

For detailed information on transport, threshing and winnowing, reference is made to Portères (1955). According to our own observations, fonio panicles are not transported before storage or threshing. Threshing and winnowing take place near the stooks erected during harvest and are very similar to the same processes for rice. Portères states (1955) that threshing floors are always carefully prepared to avoid contamination of grains with soil particles. According to our observations, however, there are no special precautions and it is up to the winnowers to provide a clean product which, however, is never free of sand. The same author also refers to a process of trampling to remove the grains, but in Mali we have never seen this technique used for fonio, nor for any other cereal, except for millet being tumbled on a lorry. The hulled grains are stored and are dehulled by mortar and pestle as and when required. At markets, the grain is sold either hulled or dehulled. Portères (1955) states that harvesting, threshing, winnowing and transport together require about 20 mnd ha^{-1}.

Fonio is threshed, winnowed and transported shortly after harvest from the beginning of October to mid-October. Labour requirements for threshing and winnowing are estimated in the LP-model at 15 mnd ha^{-1} and for transport at 2 mnd ha^{-1}, hence in total 17 mnd ha^{-1}.

Total labour requirements for the cultivation of fonio range according to Portères (1955) from 60 to 75 mnd ha^{-1}, while from the above reported requirements a total of 35 mnd ha^{-1}, is obtained (Table 5.1). The difference is explained by weeding operations included by Portères and the difference in soil preparation, which in our study was assumed to be very superficial.

The labour requirements are subdivided according to the various periods of the year (Subsection 1.2.1) as given in Table 5.1.

5.6 Monetary Inputs

5.6.1 Capital charges

For fonio cultivation the only annual capital charge is the cost of small equipment, estimated at 700 FCFA ha^{-1} yr^{-1}.

5.6.2 Operating costs

1. Seeds

According to Cérighelli (1955), Portères (1955), Cissé (1975) and Purseglove (1975), the 1 000-seed weight of fonio ranges from 0.4 to 0.7 g. The sowing rate according to Cérighelli (1955) is 35 kg ha^{-1}. According to Portères (1955) the rate is 15 to 20 kg ha^{-1} for late cultivars and 30 to 40 or as much as 50 kg ha^{-1} for early cultivars, but rates of 25 up to 120 kg ha^{-1} have been reported; the same author estimates that, for properly managed crops using animal traction, sown in rows and with two weedings, rates of 3 to 5 kg ha^{-1} should be sufficient; for manual cultivation, rates of 10 to 20 kg ha^{-1} should suffice. According to Purseglove (1975), the seed rate is 10 to 20 kg ha^{-1} and SRCVO (1988; 1989) applies a rate of 15 kg ha^{-1}. Very high sowing rates of the order of 40 kg ha^{-1} have been reported by the project KIT/Mali-Sud (de Jager, pers. comm.).

Cérighelli (1955) indicated a sowing depth of 1 cm. Portères (1955), studying the germination conditions of fonio, found that the optimum conditions were 2 cm deep and 30 °C, is such that germination is favoured by sunlight. The shoot/root ratio of young seedlings and that, the conditions in light, poor soils are most favourable. He also found that the growth rate in the juvenile phase is very low which reduces its competitiveness with weeds. According to that author and our own information (de Jager, pers. comm.), high sowing rates ensure a very rapid cover of the soil by fonio seedlings which suppresses weeds, compensate for the heavy seed losses due to birds and other predators given the shallow sowing depth, and ensure successive waves of germination after sudden droughts, given the dormancy of the seeds.

In the LP-model the sowing rate is set at 35 kg ha^{-1} at a cost of 90 FCFA kg^{-1}, an estimate based on the fact that the price of fonio follows that of rice (Cissé, pers. comm.). Hence, seed costs are 3 150 FCFA ha^{-1}.

2. Pesticides

Fonio's pests and predators are essentially a cryptogam (*Phyllacora sphaerosperma,* syn. *Sphaerodothis sphaerosperma*), birds, the African ground squirrel, monkeys and striga. The latter are semi-parasitic *scrophulariaceae* (Portères, 1955). To quote from Portères (1949) :

'the strigas (*Striga hermontica* and *S. senegalensis*) are only facultative parasites and live easily as autotrophic organisms. They react very strongly to the condition of the host plant. That condition reflects the interactive effects of edapho-climatic and cultural conditions. Infestations of *Panicum* (millet), sorghum, maize, rice, fonio, etc. are only observed on crops under unfavourable conditions. The poor condition of the crop is not the result of the strong infestation with striga but its cause which in turn encourages spreading of the parasite.'

According to the same author the main cause of infestation is overexploitation leading to soil exhaustion. Drought, mineral imbalances and poor husbandry practices also encourage the parasite by leading to poor crops. Control measures include fallowing, cultivated fallowing (*Cassia occidentalis*) and the application of manure by penning or transport. Cultivar differences in susceptibility exist. Without going into details, we can confirm that fallowing and manure application are effective control measures as has been demonstrated by growers of the village of Dalonguébougou (Doyura District, 4th Region). Since overexploitation is not included in the LP-model, this parasite is not considered, even though in reality it is often present.

In the LP model we have estimated the costs of phytosanitary treatment of the seed at 100 FCFA ha^{-1}.

The total monetary input for the production technique described amounts to 3 950 FCFA ha^{-1} yr^{-1} (Table 5.1).

5.7 Input-output table

Inputs and outputs of the defined fonio production technique for the LP-model are quantified in Table 5.1.

Table 5.1. Input-output table of fonio production technique on soil type C1.

CHARACTERISTIC	EXTENSIVE
Animal traction	-
Manure	-
Chemical fertilizer	-
Fallow	+
INPUTS [ha^{-1} yr^{-1}]	
FALLOW/MANURE/FERTILIZER	
Ratio fallow years/ year cultivated [-]	7
Manure [kg DM]	-
Fertilizer N [kg]	-
Fertilizer P [kg]	-
Fertilizer K [kg]	-
LABOUR[a] [mnd]	
6 Field cleaning	5
2 Land preparation	5
2 Seeding	1
3 Harvesting	8
3 Threshing & winnowing	15
3 Transport	2
Total	36
MONETARY INPUTS [FCFA]	
Capital charges	
Small equipment	700
Operating costs	
Seeds	3 150
Pesticides	100
subtotal	3 250
Total	3 950
OXEN [ox]	-
OUTPUTS [ha^{-1} yr^{-1}][b]	
Grain [kg DM]	375
Straw [kg DM][c]	875

a) Number in front of operations refers to the period of the year (Subsection 1.2.1).
b) In a normal year in rainfall zone I (530 mm).
c) Average N-content is 11.3 g kg^{-1}.

6. COWPEA

(P.A. Gosseye)

6.1 Introduction

Cowpea in this study refers to *Vigna unguiculata ssp. unguiculata* (syn. *V. sinensis*, *V. catjang*). Other vernacular names are black-eye pea, southern pea, China pea, black-eye bean, catjang and lubia and in French: haricot, haricot kundé, haricot mongette, haricot dolique, dolique, dolic, dolique de Chine, dolique mongette, catjang and caupi. (Cérighelli, 1955; Van Den Abeele & Vandenput, 1956; Arnon, 1972; Purseglove, 1974; Westphal, 1974; Maréchal *et al.*, 1978; RFMC, 1980; Wien & Summerfield, 1984).

According to Maréchal *et al.* (1978), cowpea originates from Africa and has been domesticated in West-Africa. On the basis of the above mentioned authors, it is assumed that all the cultivars used in the Region are of the cv-gr. *unguiculata*. Arnon (1972) regards cowpea the most widely cultivated legume in Africa, while according to Purseglove (1974) it is second to haricot bean (*Phaseolus vulgaris*). According to both authors and Sinha (1980), cowpea is a crop grown in hot, wet to semi-arid regions (20 to 35 °C average daily temperature). It is considered drought-resistant and suitable for a wide range of soil conditions, but it can not stand waterlogging.

The crop is grown both for grain for human consumption and fodder for livestock (Arnon, 1972; Purseglove, 1974; FAO & DANIDA, 1977; RFMC, 1980; Sinha, 1980). As this is a legume, the protein content in grains and crop residues is high, making it of particular interest. Cowpea seeds are also farinaceous (dry legumes), i.e. rich in carbohydrates and, moreover, low in lipids. Leaves and young shoots may also be consumed fresh or dry as a leafy vegetable. The crop can also be used as a green manure or as a covering plant.

'Traditionally' non-improved cultivars are grown in the Region. They should ideally have a growth cycle of approximately 75 d (with 50% flowering at 50 days after sowing), i.e. between 65 and 80 d. Cultivar choice under the local growing conditions should also take into account the production target. The cultivars may be subdivided into grain types, fodder types and dual-purpose types. Of all rainfed grain legumes tested (*Cajanus cajan, Cyamopsis tetragonoloba, Lablab purpureus, Phaseolus acutifolius, Tylosema esculenta, Vigna aconitifolia, Vigna mungo, Vigna radiata, Vigna unguiculata* and *Vigna vexillata*) in a rainfall zone similar to the Region, cowpea has so far been the most promising, but more thorough screening may widen the range of possibilities. Potential grain cowpea cultivars for the Region would be 'CSIRO 45 581', 'CSIRO 45 587', 'TVx 1836-90E', 'TVx 3236-01G' and 'TVx 4661-07D'; forage cultivars would be 'TVu 4945', 'TVu 4949' and 'TVx 3871-02F'; and dual purpose cultivars 'KN 1' et 'TN 88-63' (RFMC, 1980; Hulet, 1983b; 1984b; 1985c; 1985d; Hulet *et al.*, 1986; de Frahan *et al.*, 1989).

For the LP-model, the dual purpose cultivar is assumed to be grown, with a cycle length of less than 90 days, the actual length being a function of environmental conditions in the Region.

Intercropping

In the Region, cowpea cultivation is closely linked to that of millet, but it is only regarded as a secondary crop, with the main emphasis on the staple crop. As a consequence yields may be very low, of the order of 50 kg ha^{-1} of grain (RFMC, 1980; de Frahan *et al.*, 1989).

Before defining cowpea production techniques as used in the LP-model, it is necessary to explain briefly why mixed crops are not considered in the present study, although it is not the purpose to discuss here in detail the differences between mono and mixed cropping systems. In summary, mixed cropping may be advantageous, but it should be considered in relation to the production objective i.e. to distinguish between the main crop and the companion crop and to define the purpose of the mixed crop. It is then necessary to define the conditions necessary for successful implementation, avoiding the implicit assumption of synergism and the application of hypotheses and generalisations. Finally, it is necessary to examine whether the necessary conditions, with respect to climate (an uncontrollable factor apart from irrigation), edaphic factors, variety used and production technique can be realized. That will not always be easy, if only for the erratic nature of rainfall conditions in semi-arid regions.

Among the various types of mixed cropping, competition effects are least if crops are separated in time and/or space. Relay intercropping is difficult to practice in semi-arid zones (200 to 600 mm yr^{-1}) because of the short growing season. One of the most promising practices in mixed cropping seems to be strip intercropping. This is in fact a close spatial arrangement of monocultures in which interactions occur, but leaves open the possibility of specific cultivation methods for each crop. Another interesting possibility is alley cropping which is a variant on row intercropping or multi-storey cropping, comprising a combination of a woody species and an herbaceous species, usually a cereal. However, although certain types have been shown promising in sub-humid zones, in the semi-arid zone more research is needed (Cissé, ILCA, pers. comm.) (Annex A3.1).

Our experience, as confirmed by de Frahan *et al.* (1989), leads to the conclusion that a rotation of monocultures facilitates management of the various crops with respect to the choice of variety, cultural operations (especially during harvest), fertilization and phytosanitary measures. It is becoming increasingly clear that, to promote intensification, this is the best solution, if not intellectually the most challenging (de Wit, 1960; de Wit & van den Bergh, 1965; de Wit *et al.*, 1966; Norman, 1975; Gosseye & Le Houérou, 1979; Gosseye *et al.*, 1979, 1983; Spitters, 1980; 1983a; 1983b; Hulet & Gosseye, 1982; 1984; 1986; BOSTID, 1983; Hulet, 1983a; 1984a; 1985a; 1985b; 1986; Gosseye & Hulet, 1984; Nair, 1984; Hien & Zigani, 1987; INRAN *et al.*, 1987; Kang & Wilson, 1987; Steiner, 1985; Genotte, 1987; Kang, 1989; Reynolds *et al.*, 1989; Alzouma, 1990).

For the LP-model it is assumed that cowpea is grown as a monoculture.

Continuous cultivation of leguminous species generally leads to problems. In addition, cowpea appears a suitable crop in rotation with millet, since it stimulates the germination of striga without being very sensitive to this pest.

For the LP model, three production techniques could have been selected, on the basis of the four criteria defined earlier (Section 2.1).

Extensive technique

Under the extensive technique, cowpea is cultivated without animal traction, without application of organic manure or fertilizer and by using fallow to guarantee sustainability of the technique in terms of nutrient elements. This production technique is currently practised, both as a monoculture and in mixed cropping.

However, this technique has not been included in the LP-model, because of the required length of the fallow period: seven years for each year of cultivation on the basis of the crop's phosphorus requirements and the inputs of P from natural sources (van Duivenbooden, 1991). In actual practice such a fallow period will not be applied. Moreover, as continuous cultivation of cowpea is not feasible, it is normally grown in rotation with millet (which is not explicitly taken into account in the LP-model). That, however, leads to nutritional imbalances for millet (phosphorus) which remains the main crop.

Semi-intensive technique

Under the semi-intensive technique, cowpea is cultivated using animal traction and chemical fertilizers (phosphorus), and with application of a very short fallow period without manure application.

This technique, selected for the LP-model, is primarily aimed at reducing the length of the fallow period and at preventing exhaustion of the soil phosphorus reserves which therefore are available for the main crop. The calculated length of the fallow period for sustainable production in this case is three years for each year of cultivation. However, this is a 'theoretical' value since cowpea is normally grown in rotation with millet (which is not explicitly taken into account in the LP-model).

If this technique is applied for the first crop in the rotation we can reasonably assume some nitrogen fixation, albeit minimal. This nitrogen input is partly recovered by the following crop (Jones, 1974). Most of the nitrogen fixed is exported at harvest of the cowpea and at the end of the cycle the only nitrogen left in the soil is in dead roots and nodules. This residual nitrogen is available to the following crop without creating a phosphorus imbalance and without depleting the soil nutrient reserves. As manure is not used for this technique it is available for the main crop.

The production target for this technique is both grain for human consumption and hay for livestock.

Intensive technique

Under the intensive technique, cowpea is cultivated using animal traction, manure, and chemical fertilizer, without a fallow period.

In this technique, which has been included in the model, relatively large quantities of chemical fertilizer as well as organic manure are applied and it is normally practiced in rotation with millet. The production target is high yields of grain and hay. The hay provides a high quality fodder, especially at the end of the dry season.

6.2 Environment

Cowpea is considered resistant to water shortages. Its behaviour however, is in fact drought-avoiding. During the vegetative phase it responds to drought stress by increased stomatal resistance, followed by a change in leaf orientation and finally by a reduction in leaf area, i.e. leaf shedding and cessation of growth. During this phase the crop can recover from water stress. During the reproductive phase the water requirements of cowpea are high and the crop is very sensitive to water shortages which may cause dramatic yield reductions (Arnon, 1972; Purseglove, 1974; Sinha, 1980; Akyeampong, 1986; Wien & Summerfield, 1984; Alzouma, 1990).

According to Sinha (1980), cowpea is cultivated between the 250 and 1 000 mm yr^{-1} isohyets, according to RFMC (1980), from 300-400 mm yr^{-1} to over 1 000 mm, with the main area between 500 and 800 mm yr^{-1}. According to Alzouma (1990), cowpea prefers humid and warm conditions, the cultivars producing both human food and animal fodder being grown mainly in areas with annual rainfall below 400 mm, the forage cultivars in areas with rainfall between 750 and 1000 mm yr^{-1}. In actual practice, cowpea appears a very flexible crop, that, depending on the origin of a specific cultivar (Hulet et al., 1986), is cultivated over a wide range of rainfall regimes (Westphal, 1974; Maréchal *et al.*, 1987; Hulet, 1983b; 1984b; 1985c; 1985d). Hence, instead of discussing the requirements of cowpea in general terms, it is better to identify a cultivar or group of cultivars suitable for a given rainfall regime and production objective, for example 'TN 88-63' as a dual-purpose cowpea for the Region. According to Dancette (1979), a 75 d-cowpea needs 320 mm of available water to complete its growth cycle which means that rainfall must exceed this level.

Cowpea can be grown on soils ranging in texture from light to heavy. Although, differences in this respect exist among cultivars, the best results are obtained on well-drained soils. Waterlogging, even for a very short period of time (3 or 4 days), has a disastrous effect on production (Arnon, 1972; Purseglove, 1974; FAO & DANIDA, 1977; Sinha, 1980; Alzouma, 1990).

In a normal year, the loamy alluvial soils of lakebeds and temporary open water surfaces (G = TI7) are partially planted with flood-retreat crops, including cowpea. This type of cultivation is dealt with in Chapter 4. When this soil type (TI7) is not flooded, i.e. following a sequence of dry years, rainfed crops (including cowpea) are grown, to profit from the additional water supply (run-on and capillary rise: Sections 2.1 and 4.1). Although these techniques are applied in actual practice, and may be important in the current situation, they have not been included in this study. At the level of aggregation of this study, it is impossible to do justice to all these farming practices, if only for the fact that they depend on the specific features of a small area.

In the LP-model, the soils defined potentially suitable for cultivation of cowpea in the various agro-ecological zones are:

- loamy sand with a shallow groundwater table (B2 = D7) found in the Delta Central (64 km^2), Méma Dioura (391 km^2), Bodara (5 km^2), Zone Lacustre (4 312 km^2), Hodh (7 km^2) and Méma Sourango (265 km^2);
- sandy loam (C1 = DA1, DA2, DA3, DA4, DA5, PS2 and PS3) found in Sourou (2 327 km^2), Séno Bankass (3 866 km^2), the Plateau (1 814 km^2), the Delta Central (375 km^2), Méma Dioura (2 319 km^2), Séno Mango (884 km^2), Gourma (800 km^2), Bodara (1 006 km^2), Zone Lacustre (278 km^2), Hodh (1 657 km^2) and Méma Sourango (57 km^2);
- gravelly sandy loam (C2 = TR2 and TR6) found in the Plateau (3 354 km^2) and Gourma (1 491 km^2). The TR1 soils in the Gourma, also gravelly sandy loams, have not been included;
- clay loam (D1 = PL4 and PL6) found in Sourou (367 km^2 = 15% of PL6), the Plateau (102 km^2 = 100% of PL4), Méma Dioura (594 km^2 = 100% of PL4 and PL6) and Gourma (208 km^2 = 15% of PL4). Soil types PL4 and PL6 of Séno Mango have not been included, neither PL4 in Bodara, Hodh and Méma Sourango. Soil type TH5 in the Delta Central, Gourma and Hodh which is also a clay loam, has not been included either;
- loamy clay (F1 = PL9 and TH7) can be fully exploited in Sourou (138 km^2), the Plateau (1 304 km^2) and Gourma (109 km^2). In the Delta Central and Méma Dioura however, it cannot be cultivated. The soil types TH3 and TH8, which are also loamy clays, have not been included.

6.3 Yields

The target yields of cowpea (in shelled grains) for a normal year, are given in Table 6.1. These values have been derived from crop growth simulation models (Erenstein, 1990; van Duivenbooden, 1990a). Note that for rainfall zone IV on soil types D1 and F1 the simulation results give average yields of about 50 kg ha^{-1} which in the LP-model have been ignored. In fact, total rainfall would be sufficient for reasonable yields in Rainfall zone IV on heavy soils, but unfavourable rainfall distribution frequently results in complete crop failure.

The ratio of grain to grain plus shells is estimated at 0.6 and 0.7 for the semi-intensive technique and the intensive technique, respectively (van Duivenbooden, 1991).

Table 6.2 gives yields of shelled grain in a dry year in relation to those in a normal year.

As for millet, crop residue production is calculated on the basis of grain production. For a normal year and for the intensive production technique (optimum nutrient supply, water limitation only), a linear relation between simulated grain and hay production has been established. For the semi-intensive technique, for which no quantitative information was available, it has been assumed that less hay is produced at zero grain production, and that the harvest index is lower than for the intensive production technique. Table 6.3 shows the equations of these linear regressions.

Table 6.1. Target yields of shelled grains [kg DM ha^{-1}] of the eight cowpea activites in a normal year for the four rainfall zones.

Activity	Soil	RZ I	RZ II	RZ III	RZ IV
Semi-intensive					
i 38	B2	.	500	250	130
i 39	C1	750	500	250	130
i 40	C2	.	450	230	.
i 41	D1	750	500	250	0
i 42	F1	750	500	250	0
Intensive					
i 43	B2	.	1 440	1 080	530
i 44	C1	1 540	1 260	860	350
i 45	F1	1 160	660	300	0

Sources: Erenstein, 1990; van Duivenbooden, 1990a.
0: value negligible, too small, trace.
.: value impossible.

Table 6.2. Grain yields of the eight cowpea activities in a dry year, as percentage of grain yield in a normal year.

Activity	soil	RZ I	RZ II	RZ III	RZ IV
Semi-intensive					
i 38	B2	.	48	43	35
i 39	C1	54	41	32	25
i 40	C2	.	37	30	.
i 41	D1	50	31	24	100
i 42	F1	34	17	7	5
Intensive					
i 43	B2	.	.	43	35
i 44	C1	54	41	32	25
i 45	F1	34	17	7	5

Sources: Erenstein (1990); van Duivenbooden (1990a).
.: value impossible.

Table 6.3. Hay yield [s, kg DM ha^{-1}] as function of target yield of shelled grain [Yt, kg DM ha^{-1}] for the two cowpea techniques.

SOIL	SEMI-INTENSIVE	INTENSIVE
B2	S = 300 + 3.0 * Yt	S = 1700 + 1.3 * Yt
C1	S = 200 + 2.0 * Yt	S = 770 + 1.2 * Yt
C2	S = 300 + 2.8 * Yt	.
D1	S = 90 + 2.9 * Yt	.
F1	S = 50 + 2.7 * Yt	S = 700 + 1.7 * Yt

Source: van Duivenbooden (1991).

The calculated values of crop residue production for a dry year in relation to those in a normal year are given in Table 6.4.

The producer price of shelled grains is set at 75 FCFA kg^{-1}.

Table 6.4. Hay yield of the eight cowpea activites in a dry year, as percentage of hay yield in a normal year.

Activity	soil	RZ I	RZ II	RZ III	RZ IV
Semi-intensive					
i 38	B2	.	70	63	56
i 39	C1	79	60	52	51
i 40	C2	.	66	53	.
i 41	D1	60	35	18	100
i 42	F1	50	34	21	17
Intensive					
i 43	B2	.	.	63	56
i 44	C1	79	60	52	51
i 45	F1	50	34	21	17

Sources: Erenstein (1990); van Duivenbooden (1990a).
.: impossible value.

6.4 Nutrient requirements

Cowpea belongs to the family of *Fabaceae* (*Leguminosae*) and to the subfamily of *Faboideae* (*Papilionoideae*), and hence can establish a symbiosis with aerobic bacteria of the genus *Rhizobium* which are nitrogen-fixing. The effectiveness of the symbiosis depends, among other things, on the genome of the plant and that of the bacteria (strain). This does not seem to be a problem for cowpea. At the beginning of symbiosis (nodulation), i.e. at the start of the growth cycle, the bacteria is in the parasitic phase which delays growth of the host plant by creating a nitrogen shortage. Application of small amounts of nitrogen at the start of the cycle (starter fertilizer) can alleviate this nitrogen shortage, but it also delays the start of fixation. Under unfavourable growing conditions, either edaphic or climatic, the bacteria remains in the parasitic phase and does not fix any nitrogen, hence fertilizer nitrogen application is necessary. If very high yields are aimed at, it will be necessary to cover part of the crop's nitrogen requirements by fertilizer application as fixation alone is inadequate (Arnon, 1972; FAO & DANIDA, 1977; Summerfield *et al.*, 1977; Maréchal *et al.*, 1978; Sinha, 1980).

In addition to nitrogen, phosphorus, which is essential for effective symbiosis, is often reported deficient in semi-arid regions; potassium is also essential and although it is rarely in short supply, the soil reserves should not be depleted. Micro elements and trace-elements are also important, particularly to achieve effective symbiosis (Gros, 1967; Arnon, 1972; FAO & DANIDA, 1977; Haverman, 1986).

Manure application positively affects the growth of cowpea, not only through the addition of nutrient elements but also by improving the physical properties of the soil. In addition, organic matter application favourably affects nodulation and effective fixation (Arnon, 1972; FAO & DANIDA, 1977; RFMC, 1980; Sinha, 1980).

On the basis of a literature review (van Duivenbooden, 1991), the minimum concentrations on a dry matter basis of N, P and K grain are set at 35.0, 3.0 and 12.0 g kg^{-1}, respectively; those in the shells at 11.0, 0.7 and 8.0, respectively, and in the hay at 13.0, 0.9 and 6.8, respectively

Based on these concentrations, the required length of the fallow period, or the manure and fertilizer requirements as presented in Table 6.5 have been calculated, following the method described in Chapter 1.

6.5 Crop calendar and labour requirements

The growth cycle of cowpea coincides with that of millet, so that the timing of the various operations also coincides. To avoid the loss of leaves at the end of the growth period, under the influence of water shortage, however, it is preferable to harvest cowpea before millet, say between the middle and end of September. This means that cultivars with a cycle length of less than 90 d must be used. This early harvest safeguards fodder yields and avoids competition for labour during harvest of millet. Delaying the harvest of cowpea will not necessarily lead to higher grain yields, as the growing conditions at the end of the season are not favourable for grain filling because of water shortage. In our experience, that also means that part of the forage is lost through leaf shedding, which is often sudden and very rapid. Finally, delayed harvest frequently leads to the entire labour force being invested in the main crop. Hence, once the main crop has been harvested, the hay is lost and only the unopened pods can be harvested. The pods are in fact dehiscent and tend to open when dry, especially in direct sunlight. Monocultures facilitate harvest.

1. Field cleaning

The time required for clearing fallow land at the onset of the rotation is 20 mnd ha^{-1}, but when the land has been cultivated the year before, only superficial cleaning is required which takes 1 mnd ha^{-1}. By using the same calculation method as for millet (Section 2.5, point 1), the average cleaning time for a normal cowpea crop in the rotation under the semi-intensive technique is set at 5 mnd ha^{-1} and for the intensive technique at 1 mnd ha^{-1}.

2. Transport and application of manure

No organic manure is applied in the semi-intensive technique. For the intensive technique the same method of calculation is applied as for millet (Section 2.5, point 2). The labour requirements are given in Table 6.5, e.g. for soil type C1 in rainfall zone I, 8 mnd ha^{-1} are required.

Table 6.5. Yields of grain and crop residues [kg DM ha^{-1}], requirements of farmyard manure [kg DM ha^{-1}], chemical N, P and K fertilizer [kg ha^{-1}] and ratio of fallow years per year cultivated (RJC) for the various cowpea activities on different soil types. In addition, labour requirements [mnd ha-1] for transport and application of manure (MdO-TEF), for harvesting (MdO-R), for transport (MdO-T), and for threshing and winnowing (MdO-BV), as a function of the maximum quantity of manure required and maximum target yield.

Semi-intensive					
ACTIVITY	i38	i39	i40	i41	i42
Soil	B2	C1	C2	D1	F1
Grain	250	750	450	750	750
Hay	1 050	1 700	1 560	2 270	2 080
Manure	0	0	0	0	0
N	0	0	0	0	0
P	1	6	4	5	5
K	0	0	0	0	0
RJC	3	3	3	3	3
MdO-TEF	0	0	0	0	0
MdO-R	15	31	21.5	31	31
MdO-T	3	6	4.5	7	7
MdO-BV	2	6	3.5	6	6
Intensive					
ACTIVITY	i43	i44	i45		
Soil	B2	C1	F1		
Grain	1 080	1 540	500		
Hay	3 100	2 500	1 750		
Manure	1 450	1 130	1 090		
N	52	43	53		
P	11	19	12		
K	72	56	44		
RJC	.	.	.		
MdO-TEF	11	8	8		
MdO-R	41.5	56	44		
MdO-T	7.5	8	7		
MdO-BV	10	14.5	11		

Source: van Duivenbooden (1991).

3. Basic dressing

For the semi-intensive technique, the labour requirements for basic dressing with a phosphate fertilizer are set at 1 mnd ha^{-1}.

For the intensive technique the labour requirements for applying complete basic dressing, containing nitrogen as a starter, are also set at 1 mnd ha^{-1}.

4. Land preparation

Manual land preparation takes 5 mnd ha^{-1} when done superficially (van Heemst *et al.*, 1981) and 12 mnd ha^{-1} if done more elaborately (PIRT, 1983). In the extensive technique, not included in the LP-model, land preparation is limited, and the earth ridges left following weeding of the preceding crop are used, as for millet (Section 2.5, point 4), and the average labour requirement in the rotation is estimated at 3 mnd ha^{-1}.

For the semi-intensive technique it is estimated that field ridging takes (4 mnd + 2 At) ha^{-1}.

For the intensive technique the labour requirements for land preparation are similar to those for intensive millet cultivation (Section 2.5, point 4), hence (8 mnd + 4 At) ha^{-1} are needed for the first ploughing, to break the soil crust over the entire surface of the field to promote infiltration. Another (4 mnd + 2 At) ha^{-1} are required for ridging, to avoid waterlogging in case of heavy rains. Hence, the total labour requirements for land preparation in the intensive technique are (12 mnd + 6 At) ha^{-1}.

5. Sowing

Cowpea is planted in seed holes, and for both techniques manual handling is assumed, requiring 5 mnd ha^{-1}, similar to that for millet (Section 2.5, point 5).

6. First weeding

Cowpea is very sensitive to competition from weeds until it has covered the soil (Arnon, 1972). For both the intensive and semi-intensive technique the labour requirements for first weeding are set at (10 mnd + 2 At) ha^{-1} (Section 2.5, point 6).

7. Top dressing

No top dressing is applied in either of the two techniques.

8. First spraying of pesticides

Cowpea is highly susceptible to parasites throughout its life cycle. To achieve the target yields, pesticide application is imperative.

The first pesticides are sprayed at the vegetative stage in both techniques, requiring 0.5 mnd ha^{-1} (Section 2.5, point 8).

9. Second weeding

The second weeding, as for millet (Section 2.5, point 9), cannot be done with animal traction to avoid crop damage. In both techniques therefore, it must be done manually, requiring 12 mnd ha^{-1}.

10. Second spraying of pesticides

Pest control is essential during the period of flowering and grain filling. The total labour requirements for the two spraying operations in the semi-intensive technique are 1 mnd ha^{-1}, for the three sprayings in the intensive technique 1.5 mnd ha^{-1}.

11. Harvest

As the cowpea production techniques defined for the LP-model aim at producing grain as well as hay, the selected cultivars must be of the creeping or at least the semi-creeping type, to allow baling to prevent leaf loss during subsequent handling. As creeping cultivars pose problems for mechanized harvesting (Purseglove, 1974), manual harvesting is assumed for both techniques.

Cowpea harvesting consists of two operations: cutting the stems and picking the pods. The pods may be either picked from the plants in the field, after which these are cut at the base, baled and left to dry prior to transport and storage. This method is usually applied for small fields. Alternatively, plants are cut at the base first and collected in heaps where subsequently the pods are picked, after which baling and drying in the field takes place before transport and storage; this is the method usually applied in larger fields.

Calculated times for cowpea harvesting are given in Table 6.5, including both harvesting the hay and picking the pods. For the hay, we have estimated that cutting takes between 5 and 10 mnd ha^{-1}, i.e. on average 7, independent of grain yield. Labour requirements for cutting and transporting a given number of plants do not vary greatly whether the plants are large or small. On the basis of van Heemst *et al.* (1981), we have assumed that pod picking requires 24 mnd per 750 kg of pods (unshelled grains), hence the labour requirements for pod harvesting vary with yield. For instance, for soil type C1 in rainfall zone I, the labour requirements for harvesting cowpea under the semi-intensive technique are 31 mnd ha^{-1} and under the intensive technique 56.

12. Transport

The labour required to transport cowpea products is calculated using the same method as for millet (transport by cart, Section 2.5, point 13), i.e. in dependence of yield. The calculation is based on the following assumptions: In the semi-intensive technique 300 kg of pods or 600 kg of hay can be transported per manday; in the intensive technique these values are 400 kg of pods and 600 kg of hay. Table 6.3 shows the labour requirements for transport as calculated for the various operations. The labour required for storing pods and hay is included in the transport time (de Frahan *et al.*, 1989). This results, e.g. for soil type C1 in rainfall zone I, in labour requirements for transport of 6 mnd ha^{-1} for the semi-intensive technique and 8 mnd ha^{-1} for the intensive technique.

13. Shelling and winnowing

Cowpea must be shelled and winnowed carefully, so as not to damage the peas which would reduce their value and affect their conservation potential (Arnon, 1972). In a normal year, shelling is done after the harvest period; the labour requirements for shelling and winnowing of cowpea are similar to those for threshing and winnowing of flood-retreat sorghum (Section 4.5, point 11), i.e. 75 mnd kg^{-1} of shelled grains. The calculated labour requirements for shelling and winnowing of cowpea are given in Table 6.5 for the various activities. For soil type C1 in rainfall zone I, for instance, the labour requirements for shelling and winnowing in the semi-intensive and intensive technique are 6 and 14.5 mnd ha^{-1}, respectively.

The total labour requirements on soil type C1 in rainfall zone I for the semi-intensive technique are (81.5 mnd + 4 At) ha^{-1} and for the intensive technique (129.5 + 8 At) ha^{-1}, as shown in Table 6.6.

6.6 Monetary inputs

6.6.1 Capital charges

1. Plough

Similarly to that for millet (Subsection 2.6.1, point 1), the annual depreciation rate for ploughs is set at 1 670 and 5 260 FCFA ha^{-1} for the semi-intensive and the intensive production technique, respectively.

2. Small equipment

As for millet (Subsection 2.6.1, point 2), annual depreciation on small equipment is 1 000 FCFA ha^{-1} for the semi-intensive and 1 500 for the intensive technique.

3. Sprayer

As for millet (Subsection 2.6.1, point 3), annual depreciation on the sprayer is 1 200 FCFA ha^{-1} for both techniques.

Total capital charges are 3 870 and 7 960 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive production technique, respectively (Table 6.6).

6.6.2 Operating costs

1. Seed

Thousand grain weight of cowpea is on average 195 g, ranging from 90 to 300 (Purseglove, 1974; RFMC, 1980; Sinha, 1980). According to de Frahan *et al.* (1989) the recommended planting distance for breeding line 'TN 88-63' is 80 * 40 cm, i.e. 31 250 seed holes per hectare with 3 seeds per seed hole (RFMC, 1980). In this study, however, it has been assumed that 5 seeds per seed hole are required, to be on the safe side. The sowing rate for cowpea is therefore set at 35 kg ha^{-1}, or 2 630 FCFA ha^{-1} yr^{-1} for both techniques.

2. Pesticides

More than many other crops, cowpea is susceptible to parasites from sowing to harvest. During the flowering and grain filling phases the attacks are most virulent. Considerable losses may also occur during storage (Arnon, 1972; Purseglove, 1974; Messiaen, 1975; FAO & DANIDA, 1977; Sidibé & Vuong, 1980). It has been found that the losses increase with higher yields. Arnon (1972) draws attention to the fact that the results of many fertilizer experiments on cowpea are not valid because the losses caused by pests cancel out the positive response of the crop to fertilizer. He concluded: 'thus fertilizers can be fully effective only, if diseases and pests are controlled'. Given the considerable yield increases that can be realized, the use of pesticides on cowpea is generally considered profitable. De Frahan *et al.* (1989) report that the cultivar 'TN 88-63' produces 760 kg ha^{-1} of grain with the use of insecticide as against 50 to 100 kg ha^{-1} without. They also give values obtained in Mali from plant-protection experiments: the average increase in yield of cowpea grains was 385%, ranging from 105 to 1 000.

In Mali, Hulet (1983b) observed only a few fungus diseases, apart from *Choanephora spp.* on pods during rainy spells. He recorded a very rapid increase in insect populations in the course of the growing season. Without the use of insecticides, the plant would flower later and have less chances to reach maturity. The insects responsible for serious damage are, in descending order of importance: thrips (*Megalurothrips sjostedti* or *Sericothrips occipitalis*) which destroy the flower-buds; a bee-moth (*Maruca testulalis*) whose larvae damage the young stems, the floral spikes and the young pods, and consumes the flower-buds as well as the flowers; several species of meloidae including *Mylabris bizonata* which eats the flowers; a number of bugs including *Anoplocnemis curvipes*, *Dysdercus superstitiosus*, and *Nezera viridula* which damage the young pods, causing abortion; the cowpea weevil (*Callosobruchus maculatus*) whose larvae infest the grains in the field, causing considerable damage during storage; a number of grasshoppers, present throughout the growing period, as well as various Diptera. Hulet (1983b) also refers to the parasite *Striga gesneroides* which is, however, rare and has apparently little effect. Cowpea is sometimes said to attract chameleons, which is not surprising given its wealth of field insects if untreated. According to Sinha (1980) cowpea tends to have a determinate character under favourable growing conditions and treatment by pesticides, thus synchronizing yield. For the target yields aimed at in our study therefore, the use of pesticides is an absolute necessity.

Seed desinfection costs 500 FCFA ha^{-1} (Subsection 2.6.2, point 2). To protect the crop an investment of 9 000 FCFA ha^{-1} yr^{-1} is required (3 sprayings of 0.5 litres of pesticide at 6 000 FCFA l^{-1}) for the semi-intensive technique and 12 000 FCFA ha^{-1} yr^{-1} (4 sprayings) for the intensive technique. As the costs of protection during storage are not included in this study, the total costs of pesticides are 9 500 FCFA ha^{-1} yr^{-1} for the semi-intensive technique and 12 500 for the intensive technique.

Total monetary inputs are 16 000 and 23 090 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive technique, respectively (Table 6.6).

6.7 Oxen requirements

As a consequence of the use of animal traction in both production techniques, draught oxen are required as input. The requirements are calculated similarly to those in the millet production techniques (Section 2.7). Hence, 0.33 and 0.75 ox ha^{-1} yr^{-1} are required for the semi-intensive and intensive production technique, respectively.

6.8 Input-output table

The inputs and outputs quantified for the two production techniques, are summarized in Table 6.6.

Table 6.6. Input-output table of cowpea production techniques on soil type C1.

CHARACTERISTIC	SEMI-INTENSIVE	INTENSIVE
Animal traction	+	+
Manure	-	+
Chemical fertilizer	+	+
Fallow	+	-
INPUTS [ha^{-1} yr^{-1}]		
FALLOW/MANURE/FERTILIZER		
Ratio fallow years/ year cultivated [-]*	3	-
Manure [kg DM]*	-	1 130
Fertilizer N [kg]*	-	43
Fertilizer P [kg]*	6	19
Fertilizer K [kg]*	-	56
LABOUR[a] [mnd]		
6 Field cleaning	5	1
1 Manure transport & appl.*	-	8
1 Basic dressing	1	1
1 Land preparation	4. + 2 At	12.+ 6 At
1 Seeding	5	5
2 Weeding 1	10. + 2 At	10.+ 2 At
2 Pesticide spraying	0.5	0.5
3 Weeding 2	12	12
3 Pesticide spraying	1	1.5
3 Harvesting*	31	56
4 Transport*	6	8
6 Shelling & winnowing*	6	14.5
Total	81.5 + 4 At	129.5 + 8 At
MONETARY INPUTS [FCFA]		
Capital charges		
Plough	1 670	5 260
Small equipment	1 000	1 500
Sprayer	1 200	1 200
subtotal	3 870	7 960
Operating costs		
Seeds	2 630	2 630
Pesticides	9 500	12 500
subtotal	12 130	15 130
Total	16 000	23 090
OXEN [ox]	0.33	0.75
OUTPUTS [ha^{-1} yr^{-1}][b]		
Grain (shelled) [kg DM]	750	1 540
Stover (with podshells)[c] [kg DM]	1 700	2 500

a) Numbers in front of operations refer to period of the year (Subsection 1.2.1).
b) In a normal year in rainfall zone I.
c) Average N-content is 16.3 and 21.6 g kg^{-1} for the semi-intensive and intensive technique, respectively.
*) Varies as a fuction of activity, see Table 6.5.

7. GROUNDNUT

(P.A. Gosseye)

7.1 Introduction

Groundnut in this study refers to *Arachis hypogaea*. Other vernacular names in English are: peanut and monkeynut, and in French: arachide, cacahuète and pistache de terre (Van Den Abeele & Vandenput, 1956; Arnon, 1972; Purseglove, 1974; Ashley, 1984).

Groundnut is grown in hot climates (25 to 35 °C average daily temperature), in regions varying from semi-arid to humid (400 to 1 200 mm yr^{-1}). The crop can be cultivated on a wide variety of soil types, but prefers well-drained, light to intermediate textured soils. Drought tolerance varies with cultivar, and the effects of water shortage depend on rain, not only the total amount but also its distribution (Mauboussin *et al.*, 1970; RFMC, 1980; Sinha, 1980; Ashley, 1984).

The primary objective of groundnut cultivation is to produce (oil-rich) seeds. Seeds are eaten whole in various forms (as peanuts or in confectionary) or in paste form (peanut butter). Oil is also extracted and the residual cake is used as animal feed. The second objective of groundnut cultivation is hay production as high-quality animal feed. The shells can be used as fuel or as a mulch for crops (Van Den Abeele & Vandenput, 1956; Arnon, 1972; Purseglove, 1974; Ashley, 1984).

The recommended cultivars for the Region, particularly for the southern part, are '55-437' and '47-10' which are both of the 'Spanish' type (*Arachis hypogaea ssp. fastigiata var. vulgaris*). They have an erect growth form, a 90-day growth cycle and are non-dormant. The cultivar '55-437' is considered to be highly resistant to drought and requires a rainfall between 350 and 500 mm yr^{-1}. The cultivar '47-10', which produces groundnut intended for use in confectionary, requires an annual rainfall between 550 and 750 mm (Mauboussin *et al.*, 1970; RFMC, 1980; Ashley, 1984; de Frahan *et al.*, 1989).

Within the Region, groundnut cultivation is associated with that of millet, but it is not considered as a secondary crop. Before describing the various groundnut production techniques used in the LP-model, some points will be briefly discussed.

Groundnut is seldom cultivated in combination with millet, although examples are found within the Region and in other farming areas (Arnon, 1972; Baker, 1978; Reddy & Willey, 1981; Gregory & Reddy, 1982; Nambiar *et al.*, 1983). In addition to monocultures of groundnut, however, sometimes small plots of groundnut are cultivated in association with millet.

The specific characteristics of a crop rotation with millet (or another cereal) are not explicitly taken into account in the present version of the LP-model. For detailed information, reference is made to e.g. Tourte (1963), Jurion & Henry (1967), Jones (1971; 1973; 1976), Jones & Wild (1975) and Piéri (1985).

For the LP-model we have assumed, as for cowpea (Section 6.1), that groundnut is grown as a monoculture. From all possible techniques for producing groundnut, we have selected three on the basis of the four criteria defined earlier (Section 2.1).

Extensive technique

Under the extensive technique, groundnut is cultivated without animal traction, and without application of manure and chemical fertilizer. Sustainability of the technique is guaranteed by fallowing. This technique is widely practiced at present, as other extensive techniques, but as for cowpea, it was excluded from the present study for reasons that were best expressed by Tourte (1963):

'the ultimate goal is not only to preserve the soil but also to increase its productivity. While it is important for farmers to preserve their soil, they are also producers, aiming at increasing their yields,... and improving their techniques, equipment... the farmers owe it to themselves, using the means available, to produce as much as they can. At the same time, it is the task of the government to help them to obtain and add to these means'.

Semi-intensive technique

Under the semi-intensive technique, groundnut is cultivated without the use of manure, with animal traction and chemical fertilizer (phosphorus) application and a very short fallow period.

This production technique, included in the LP-model, corresponds to that promoted by the extension service for groundnut cultivation in Mali (Vallée & Coulibaly, 1978). Like Poulain (1976), however, we recognise that this simple solution may have possible medium-term risks and definite long-term risks with respect to soil fertility. Simple solutions tend to be of a partial, intermediate and temporary nature.

Intensive technique

Under the intensive technique, groundnut is cultivated using animal traction and chemical fertilizer application and without fallowing and manure. As for cowpea, this technique corresponding to the high level fertilizer application in groundnut cultivation promoted by the extension service in Mali (Vallée & Coulibaly, 1978) has been included in the LP-model.

Although groundnuts produced in the Region are mainly used for home consumption, it can be considered also as a cash crop used to capitalise on the fertilizer, that has residual effects on the subsequent food crops (Piéri, 1973). This intensive technique corresponds well with ideas formulated by Piéri (1985):

'Many results ... seem to prove that only intensive cropping systems (involving draught animals, improved varieties, high fertilizer application, rotation) can maintain the long-term mineral balance in the soil'.

The same author goes on to say:

'Just as it would be unthinkable to recommend that cultivated land should be enriched indefinitely, it would be unreasonable to suggest that there is something to be gained by continuously depleting the soil'.

7.2 Environment

Groundnut is considered resistant to drought, whereas actually the slightest lack of water results in yield reductions. The crop is particularly sensitive to drought stress during flowering and grain filling (Arnon, 1972; Ashley, 1984). According to RFMC (1980) flowers formed later than 20 days before the end of the rains do not produce pods. According to Pandey *et al.* (1984), for both groundnut and cowpea, drought stress causes a reduction in the number of pods, the number of grains per pod (the pods tend to contain one grain only if the growing conditions are unfavourable) and a slight reduction in seed weight. In addition, the harvest index decreases linearly with increasing degree of stress.

Groundnut is cultivated in semi-arid to humid regions, i.e. between 400 and 1 200 mm of annual rainfall. The choice of cultivar, however, is determined by rainfall conditions (Mauboussin *et al.*, 1970; RFMC, 1980; Sinha, 1980). According to Van Den Abeele & Vandenput (1956), groundnut requires a rainfall of at least 500 mm yr^{-1}, but it is grown in areas with a rainfall of 250 to 300 mm yr^{-1}. According to Arnon (1972), the minimum required rainfall is around 550 mm yr^{-1}, and according to Purseglove (1974), 500 mm yr^{-1}. Dancette (1970; 1979), reports that short duration groundnut cultivars (90 d) require 420 mm of available water to complete their cycle, hence rainfall has to be higher. According to Ashley (1984), the 'Spanish' types require from 450 to 600 mm yr^{-1}. For pod and seed maturation, however, groundnut also requires a dry period, particularly if the cultivar is non-dormant, as is the case with '55-437'.

Taking into account all these factors it is concluded that for the two selected techniques (both including fertilizer application), the only suitable agro-ecological zones are those of Sourou and Séno Bankass, i.e. rainfall zone I (Table 2.2, page 26). Groundnut could be produced in rainfall zone II and in the southern part of zone III, but yields tend to become increasingly low and erratic, hence these zones have not been included as suitable in this study.

Groundnut will grow on almost any type of soil. Clay soils, however, are less suitable as they are susceptible to waterlogging due to their texture or topographic position. Groundnut generally reacts unfavourably to excess water, hence it should preferably be grown on well-drained, well-aerated sandy loam. Soil properties not only affect the growth of groundnut, but also the establishment of the pegs, which are geocarpic: the pegs have to penetrate the soil, which affects fruit setting, grain filling and the quality of the product, and they also have to be easily harvested at maturity without risks of excessive losses. The pH should be slightly acid (from 6.0 to 6.4) but not less than 5.0 because of the risk of aluminium toxicity (Arnon, 1972; Piéri, 1976; 1986; FAO & DANIDA, 1977; RFMC, 1980; Ashley, 1984).

For the present study, only the sandy loam soil, i.e. soil type C1, is considered suitable (CABO C1 = PIRT DA1, DA2, DA3, DA4, DA5, PS2 and PS3). In Souro that comprises 2 327 km^2 and in Séno Bankass 3 866 km^2.

7.3 Yields

According to Sinha (1980) and Ashley (1984), the wordwide average yield of shelled groudnut varies between 800 and 900 kg ha^{-1}. Ashley (op.cit) also reports that yields of 6 000 kg ha^{-1} have been obtained under optimal experimental conditions.

The target yields in terms of pods (grains + shells), in normal years, are set at 750 kg ha^{-1} (525 + 225) for the semi-intensive and 1 375 (960 + 415) for the intensive production technique. In dry years, the yields are set at 125 (85 + 40; 17% of a normal year) and 250 kg ha^{-1} (175 + 75; 18% of a normal year), respectively.

According to Mauboussin *et al.* (1970), the maximum grain/fruit ratio (ratio of grain to grain + shells) of the variety '55-437' is 0.75. RFMC (1980) reported grain/fruit ratios for groundnut from 0.65 to 0.73. According to Ashley (1984), the average value of the grain/fruit ratio is 0.70, the value applied in this study.

In normal years, the yield of dry groundnut haulms is 920 kg ha^{-1} in the semi-intensive technique. This value has been calculated on the basis of a harvest index of 0.45. For the intensive technique, a harvest index of 0.55 has been applied, leading to a yield of 1 125 kg ha^{-1}. In dry years, the yield of dry haulms is 727 kg ha^{-1} for the semi-intensive technique and 889 kg ha^{-1} for the intensive technique. These values have been derived from those obtained for cowpea haulms in rainfall zone I on soil type C1, assuming that the haulm yield in dry years represents 79% of that in normal years.

7.4 Nutrient requirements

Without going into the details of symbiotic nitrogen fixation of groundnut (Arnon, 1972; Purseglove, 1974; Ashley 1984), we can say that the requirements for nitrogen application are basically identical to those for cowpea (Section 6.1).

Groundnut is considered unpredictable with respect to its response to fertilizer. There is no doubt, however, that large amounts of nutrient elements are required to realize high yields. Lack of response to certain fertilizers could well be due to nutritional imbalances. Another factor that may influence the response of the crop is the way in which the fertilizer is applied.

To produce high yields, groundnut requires large amounts of nitrogen, phosphorus (often in short supply in semi-arid regions), potassium, calcium (particularly in dry climates), sulphur and other minor elements as well as trace-elements. However, groundnut can also perform well on relatively poor soils. It can efficiently extract nutrients, thanks, among other things, to its ability to form a symbiotic relationship with mycorrhizae. Hence, in actual practice groundnut is not only used to produce high yields, but also to utilize soils that are not suitable for other crops. In other words, groundnut can act as soil nutrient-depleting crop. Since almost all products are removed from the field, groundnut is generally considered detrimental to soil fertility.

It is often claimed that for groundnut, the way in which manure is applied plays an important role and nutrient element application should not only cover the requirements of the groudnut crop, but should satisfy the demands of the full rotation. Since the effects of particular rotations are not considered in the LP-model, it is assumed that the required nutrient elements for the whole cycle are added at the start of the rotation before ploughing (Piéri, 1971; 1986; Arnon, 1972; Jenny, 1973; 1974; Purseglove, 1974; Bromfield, 1975; Poulain, 1976; FAO & DANIDA, 1977; Thibout & Kéita, 1978; RFMC, 1980; SAFGRAD, 1981; Bertrand *et al.*, 1982; Ashley, 1984).

On the basis of a literature review (van Duivenbooden, 1991), the minimum concentrations of N, P and K on a dry weight basis in the grain are set at 43.2, 6.0 and 22.2 g kg^{-1}, respectively, in the shells 7.0, 0.4 and 4.0 and in the hay 11.6, 1.0 and 3.4, respectively.

7.5 Crop calendar and labour requirements

The crop calendar of groundnut is very similar to that of millet, in particular for the most suitable cultivar for the Region in rainfall zone I, i.e. the 90 d variety '55-437' (de Frahan *et al.*, 1989). Millet and groundnut crops are therefore in constant competition for the limited resources throughout the growing period.

1. Field cleaning

The labour requirements for field cleaning have been set equal to those for cowpea production techniques (Section 6.5, point 1), i.e. 5 and 1 mnd ha^{-1} for the semi-intensive and intensive production technique, respectively.

2. Seed preparation

Before sowing, the grains have to be removed from the shells. According to Arnon (1972) and RFMC (1980), this process has to be carried out with the utmost care and not earlier than 10 d before sowing, because the oil-rich seeds are very susceptible to pathogens, and the more so if damaged, if even only slightly.

According to van Heemst *et al.* (1981) this operation requires 6 mnd ha^{-1} while RFMC (1980) reports husking requirements of 15 kg mnd^{-1}.

For the present study, we have assumed a seeding rate of 100 kg ha^{-1} (husked grains). Seed preparation therefore requires 6.5 mnd ha^{-1}, assuming that the time needed for cleaning, to remove any bad seeds, is included.

3. Transport and application of manure

No manure is applied, and consequently, the labour requirements for this operation are zero.

4. Basic dressing

For the semi-intensive technique, the labour requirements for basic dressing with a phosphate fertilizer are set at 1 mnd ha^{-1}.

For the intensive technique, the labour requirements for applying complete basic fertilizer are also set at 1 mnd ha^{-1} (Section 2.5, point 3).

5. Land preparation

For groundnut cultivation deep ploughing is very important and generally advantageous (improves the water supply, root growth and the establishment of the pegs). Ridging is generally of little use, unless the soil is very shallow or very heavy. For erect cultivars, such as '55-437', ridging can actually be unfavourable, because it hampers establishment of the pegs in the soil (Arnon, 1972; Purseglove, 1974; Chopart & Nicou, 1976; Vallée & Coulibaly, 1978; RFMC, 1980).

For both techniques, the labour requirements for soil preparation are therefore estimated at (8 mnd + 4 At) ha^{-1}.

6. Sowing

Dense sowing is recommended for groundnut to prevent rosette formation and to synchronize production. The recommended density for early varieties is 40 * 15 cm with one (or two) seeds per seed hole (Van Den Abeele & Vandenput, 1956; Purseglove, 1974; Konaté & Boiré, 1980; RFMC, 1980).

According to van Heemst *et al.* (1981), the labour requirements for groundnut sowing are 11 mnd ha^{-1}, a value that has been used in the LP-model.

7. First weeding

Weeding is essential in groundnut cultivation. The crop is sensitive to competition from weeds and for high yields it is important to improve moisture availability. The first weeding operation should be carried out from the 15th day after sowing onwards (Arnon, 1972; RFMC, 1980). Chemical control has not been considered in this study (Deuse & Hernandez, 1980).

For both production techniques, the labour requirements are set al (10 mnd + 2 At) ha^{-1} (Section 2.5, point 6).

8. Top dressing

Top dressing has not been included in this study, as phosphorus and potassium should always be applied as a basic dressing, combined with nitrogen, the latter acting as a starter.

9. Second weeding

Groundnut has to be weeded twice. In addition to the effects of the first weeding, this second weeding stimulates peg establishment by loosening the soil. The second weeding should be carried out at the beginning of flowering, i.e. between 30 and 40 days after sowing. No weeding should take place after fruit setting has started, to prevent damage to young fruits, which might lead to yield reduction (Van Den Abeele & Vandenput, 1956; RFMC, 1980).

10. Pesticide application

For the semi-intensive production technique, two sprayings are assumed, requiring in total 1.0 mnd ha^{-1}, and for the intensive production technique 3, requiring 1.5 mnd ha^{-1}.

11. Harvest

Groundnut is harvested when two-thirds of the pods are ripe. If harvest takes place too early, the proportion of immature fruits is too high and the remainder is of poor quality which increases strorage losses. If, on the other hand, harvest is too late, a large part of the production will be lost in the field. After uprooting the plants and before picking the pods, the plants have to be dried within a short time, but not too rapidly, preferably in the shade. It is vitally important to prevent rotting. During harvest, not only the quality of the final products (grains and haulms) is determined, but also the risks of an attack by aflatoxin-producing cryptogamia (Van Den Abeele & Vandenput, 1956; Arnon, 1972; Purseglove, 1974; RFMC, 1980). Threshing, to separate the pods, is not considered as that would lead to high losses of the valued by-product, the haulms.

Harvesting groundnut consists of two operations: uprooting the plants and picking the pods. For uprooting, the labour requirements are estimated at 18 mnd ha^{-1} irrespective of yield. For picking the pods, the labour requirements are calculated on the basis of an estimated 24 mnd per 750 kg of pods (van Heemst *et al.*, 1981).

Hence, for the semi-intensive production technique harvest requires 42 mnd ha^{-1} and for the intensive technique, 62 mnd ha^{-1}.

12. Transport

The time required to transport groundnut products is calculated similarly to that for millet (transport in carts, Section 2.5, point 13). The calculation is based on the following assumptions: in the semi-intensive technique, 300 kg of pods or 600 kg of haulms can be transported per man-day; in the intensive technique, these values are 400 kg of pods and 700 kg of haulms. In the semi-intensive technique, therefore, transport requires 2.5 mnd ha^{-1} for the pods and 1.5 mnd ha^{-1} for the haulms, i.e. 4 mnd ha^{-1} in total; in the intensive technique, 3.5 mnd ha^{-1} is required for the pods and 1.5 mnd ha^{-1} for the haulms, i.e. 5 mnd ha^{-1} in total.

Shelling and winnowing are not taken into account in the LP-model.

The total labour requirements for the semi-intensive technique are (100.5 mnd + 6 At) ha^{-1} and for the intensive technique (1118 + 6 At) ha^{-1}, as shown in Table 7.1.

7.6 Monetary inputs

7.6.1 Capital charges

1. Plough

Using the same calculation method as for millet (Subsection 2.6.1, point 1), annual depreciation for ploughs is set at 2 500 FCFA ha^{-1} yr^{-1} for the semi-intensive and 3 500 for the intensive production technique.

2. Small equipment

As for millet (Subsection 2.6.1, point 2), annual depreciation on small equipment is set at 1 000 FCFA ha^{-1} for the semi-intensive and 1 500 for the intensive technique.

3. Sprayer

As for millet (Subsection 2.6.1, point 3) annual depreciation on the sprayer is set at 1 200 FCFA ha^{-1} for both techniques.

Total capital charges are 4 700 and 6 200 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive production technique, respectively (Table 7.1.

7.6.2 Operating costs

1. Seed

The amount of seed required is set at 100 kg ha^{-1} (Section 7.5, point 2), but to be on the safe side, the costs are based on 120 kg ha^{-1}. This represents 170 kg of pods at 75 FCFA kg^{-1}, i.e. 13 000 FCFA ha^{-1} yr^{-1}.

2. Pesticides

Groundnut is susceptible to parasites attacking the seeds stored in the granary. The quality of storage also determines the aflatoxin content (Arnon, 1972; Purseglove, 1974; Diallo & Vuong, 1980; RFMC, 1980; SRCVO; 1980; de Frahan *et al.*, 1989). Moreover, to attain the target yields, the crop has to be protected through the use of pesticides.

The costs for protection of seeds are 500 FCFA ha^{-1} yr^{-1} (Subsection 2.6.2, point 2).

For crop protection during the growing season, 6 000 FCFA ha^{-1} yr^{-1} is required in the semi-intensive technique (2 sprays; Subsection 2.6.2, point 2) and 9 000 in the intensive production technique (3 sprays). The costs for protection during storage have not been included in this study.

Hence, the total costs of pesticides are 6 500 and 9 500 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive production technique, respectively.

Total operating costs are 19 500 and 22 500 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive technique, respectively. (Table 7.1) and total monetary inputs 24 200 and 28 700 FCFA ha^{-1} yr^{-1} for the semi-intensive and the intensive technique, respectively. (Table 7.1)

7.7 Oxen requirements

As a consequence of th use of animal traction in both production techniques, draught oxen are required as input. The requirements are calculated similarly to those for the millet production techniques (Section 2.7). Hence, 0.33 and 0.75 ox ha^{-1} yr^{-1} are required for the semi-intensive and intensive production technique, respectively.

7.8 Input-output table

Inputs and outputs of the defined groundnut production techniques for the LP-model are quantified in Table 7.1.

Table 7.1. Input-output table of groundnut production techniques on soil type C1.

CHARACTERISTIC	SEMI-INTENSIVE	INTENSIVE
Animal traction	+	+
Manure	-	-
Chemical fertilizer	+	+
Fallow	+	-
INPUTS [ha^{-1} yr^{-1}]		
FALLOW/MANURE/FERTILIZER		
Ratio fallow years/ year cultivated [-]	2	-
Manure [kg DM]	-	-
Fertilizer N [kg]	-	37
Fertilizer P [kg]	3	11
Fertilizer K [kg]	-	21
LABOUR[a] [mnd]		
6 Field cleaning	5	1
1 Shelling of seeds	6.5	6.5
1 Basic dressing	1	1
1 Land preparation	8.+ 4 At	8.+ 4 At
1 Seeding	11	11
2 Weeding 1	10.+ 2 At	10.+ 2 At
3 Weeding 2	12	12
3 Pesticide spraying	1	1.5
4 Harvesting	42	62
6 Transport	4	5
Total	100.5 + 6 At	118.+ 6 At
MONETARY INPUTS [FCFA]		
Capital charges		
Plough	2 500	3 500
Small equipment	1 000	1 500
Sprayer	1 200	1 200
subtotal	4 700	6 200
Operating costs		
Seeds	13 000	13 000
Pesticides	6 500	9 500
subtotal	19 500	22 500
Total	24 200	28 700
OXEN [ox]	0.50	0.50
OUTPUTS [ha^{-1} yr^{-1}][b]		
Grain (unshelled) [kg DM]	750	1 375
Stover (without podshells)[c] [kg DM]	920	1 125

a) Numbers in front of operations refer to period of the year (Subsection 1.2.1)

b) In a normal year in rainfall zone I (530 mm).

c) Average N-content is 15.1 and 19.7 g kg^{-1} for the semi-intensive and intensive techniques, respectively.

8. VEGETABLES

(P.A. Gosseye)

8.1 Introduction

The term vegetables refers to all out-of-season crops which *(i)* require additional water, i.e. rely on irrigation in the widest sense of the term, *(ii)* are grown on relatively small areas, *(iii)* receive large amounts of fertilizer (manure), compared to other crops and *(iv)* require a high input of labour. This definition is somewhat wider than that normally applied to vegetables in the strict sense, i.e. the cultivation of vegetables as practised formerly in managed marshlands.

Vegetable cultivation is primarily a commercial activity and only a very small fraction of the crops are used for subsistence needs in the Region. Hence, vegetables are basically cash crops which provide local inhabitants with the means to purchase certain items to improve their everyday life or to ensure survival, to pay taxes and, in some cases even to invest in animals, in anticipation of unfavourable periods or various social events.

Since the products are intended for sale, farmers prefer those crops (fresh or processed, but almost always dried) that can withstand poor transport and storage conditions, such as shallots, cassava, sweet potato or tobacco. For some time now, growers have tended to opt for the so-called 'traditional' vegetable crops, because they satisfy precisely these requirements. Production of perishable vegetables, such as lettuce and tomatoes, is only feasible if there is a market within the immediate vicinity, that is both easily accessible and capable of absorbing these products. The so-called 'modern' crops often tend to be perishable. Hence, the degree to which they can develop depends on the market situation and changes in dietary habits. Finally, 'traditional' crops can all be easily multiplied by producers. With regard to 'modern' crops, farmers generally prefer those for which they can produce seeds themselves. In the Region, vegetable cultivation seems to have developed very slowly until 1970 when it began to catch on. Towards the 1980s, its popularity spread, particularly after 1985 (Annex A4).

In this study, vegetable crops are not individually described, nor via the conventional classification of vegetable crops into leafy vegetables, fruit vegetables and root vegetables. For practical reasons, the various crops are subdivided into two production activities:

- the first activity designated 'shallots';
- the second activity designated 'other vegetables', including all the rest; it can be subdivided into starchy products, miscellaneous vegetables, maize, tobacco and tomatoes, allowing calculation of a weighted aggregate, based on information available.

For each activity, brief explanations have been included on the names of the most common vegetables in the Region (Cérighelli, 1955; Terra, 1973; Messiaen, 1974; 1975; Purseglove, 1974; 1975; RFMC, 1980; De Bon, 1983; 1984; Tindall, 1968; Yamaguchi, 1983; Technisem, 1986; 1987; Van Damme, 1986; Beniest *et al.*, 1987; Dupriez & De Leener, 1987; Rice *et al.*, 1986; Doumbia, 1988).

8.2 Environment

Vegetables are essentially dependent on access to irrigation water. Hence, the choice of cultivated area is determined by the presence of accessible water and not by soil type, exposition, or any other factor. Soil type is not a selection criterion, because in the long term intensive use of organic manure improves the intrinsic qualities of the soil. Manure plays a very important role, not just as a fertilizer (improvement of chemical properties of the soil), but also as a conditioner (improvement of physical properties of the soil), whose effects can be further enhanced by incorporating crop residues at the end of the growing season. The use of manure as a means of correcting the physical properties of the soil leads, after several years of cultivation, to improved horticultural soils which, as mentioned earlier, have been selected mainly because of their proximity to water.

For any given area, the efforts of extraction (depth of the water and pumping facilities) and the amount of water present determine the area of the land that can be cultivated.

Among the various sources of water used are dam reservoirs, natural pools which have in some cases been deepened, with or without improvements to the spillway, man-made pools, draining wells, i.e. deepened areas designed to exploit very shallow water tables (stream bed, subterranean streams, perched water), all types of wells and boreholes, springs including subterranean streams, wadies, temporary streams, rivers and lakes.

Vegetable crops are cultivated in all agro-ecological zones. However, cropping intensity varies considerably from zone to zone and the extent to which the horticultural areas can be expanded depends on a range of factors, including the availability of arable land and water, access to markets, local customs and population density. These conditions are continuously changing.

- In Sourou, vegetable cultivation is beginning to develop along the temporary streams where clay loam soils (F1 = TH3) are exploited.
- In Séno Bankass and Séno Mango, vegetable cultivation is practised along the Plateau, using wadies or their residual subterranean streams. Elsewhere, however, vegetable cultivation is rare due to the deep groundwater. Various soil types are used, but since the relevant area is swamp land, the soil tends to be fairly heavy, sometimes covered with sand.
- At the Plateau, vegetable cultivation is currently the most widespread form of landuse: it seems that vegetable crops have been grown near springs for many years. More recently, however, the large number of artifical structures, particularly dams, starting with the Griaule dam built in 1948, have led to enormous expansion. Cultivated soil types are mainly clay loam (F1 = PL9), often covered by sand and gravelly sandy loam (C2 = TR2). Other types too, however, are cultivated. An important development has been the construction of terraced gardens by manually piling soil (PL9) onto rocky slabs (X = X5) and

along dry stone walls.

- In the Delta Central, vegetable cultivation used to be rare, with the possible exception of the area around Djenné. At present, however, it is becoming more popular, particularly around urban centres. Cultivated soils are mainly heavy loam soils (G = TI4) along river banks.
- In Méma Dioura, Bodara, Hodh and Méma Sourango, vegetable cultivation is virtually non-existent due to the deep groundwater.
- In the Gourma, vegetable cultivation has always been practised in the 'hilly' areas (Dyoundé, etc.) where springs are present, but it is also expanding in the plains. Various soil types are used. In the foothills, the main soil types include clay loam (F1 = PL9) covered with sand, gravelly sandy loam (C2 = TR2) and very sandy, stony alluvial cones. In the plains, they tend to be the heavy soils, sometimes covered with sand, of depressions (pools, temporary streams, perched water tables).
- In the Zone Lacustre, vegetable cultivation has long been practised as a form of flood-retreat cropping on loamy soil (G = TI7). The current drastic changes in flooding pattern, however, tend to hamper its development.

The areas currently cultivated with vegetables have rarely been measured or estimated. The few available data generally refer to administrative units and the way in which they are presented differs between years and also within the year. For the current surface areas, we can refer to the GTZ/SDA measurements (Agricultural Extension Project in the Dogon, pers. comm.) for the Cercle de Bandiagara and the SAC estimates for the Cercle de Douentza (Maïga, 1986) (Annex A4). To our knowledge, there are no estimates, not even theoretical ones, of the areas suitable for horticultural activities. Faced with this lack of information, an estimate (purely theoretical) has been made of the suitable area for vegetables for the various agro-ecological zones. These estimates, illustrated in Table 8.1, are based on our knowledge about easily accessible surface water and availability of labour. Data obtained from the Cercles de Bandiagara and Douentza have also been used (Annex A4.1). In Table 8.1, the soil types are not specified, because water is the selection criterion and the large amounts of organic matter applied may change soil properties.

Table 8.1. Potential area of vegetables (ha) in the eleven agro-ecological zones.

AGRO-ECOLOGICAL ZONE	AREA	AGRO-ECOLOGICAL ZONE	AREA
1. Sourou	100	7. Gourma	100
2. Séno Bankass	100	8. Bodara	0
3. Plateau	1 300	9. Zone Lacustre	600
4. Delta Central	1 100	10. Hodh	0
5. Méma Dioura	0	11. Méma Sourango	0
6. Séno Mango	20	*Total*	3 320

0: area neglectible.

In the LP-model, it is assumed that shallots can account for at most 2/3 of the suitable area, with other vegetable crops accounting for the remainder.

8.3 Shallots

8.3.1 Description

The term 'onion' as used in the Region, actually refers to 'shallots' (*Allium cepa var. aggregatum syn. A. ascalonicum*, i.e. 'dogon onion' or 'djaba missèni'), since 'real' onions (*Allium cepa var. cepa*, i.e. 'large onion' or 'djaba koumbala' or 'toubabou djaba') are seldom grown. For the purpose of this study, the terms 'shallot' and 'onion' have a distinct meaning and are not synonymous. Garlic (*Allium sativum*) which is also grown, but to a much lesser extent, is not separately included and areas cultivated with garlic are included in those allocated to shallot (Table A4.4).

The cropping calendar for shallots always begins after harvest of the wet-season crops, i.e. late October to late December, depending on the particular food crop, which generally is millet, except for the flooded areas with rice. The reasons are twofold: firstly, the areas cultivated with vegetables are occupied by rainfed crops to let the latter benefit from the residual effects of manure, and secondly hardly any labour is available for horticulture during the harvest of food crops. Roughly, one can say that:

- in years of normal rainfall, horticulture tends to be postponed, or limited to a smaller area, and tends to become a means of ensuring better living conditions, or acquiring capital;
- in years of low rainfall, horticultural activities tend to start early, if only because the land and work force are available earlier, and tend to become a means of ensuring subsistence through the sale of products in order to buy cereals.

In addition to these constraints on the use of land and labour, shallot, like many other horticultural crops, is a cold season crop, mainly because of temperature and photoperiod.

Shallots can be planted in two ways, in the form of bulbs or seeds (Annex A4.2), which determines the length of the growing cycle.

If the shallots are grown from bulbs, which is the most common method in the Region, cycle length is generally estimated at between 90 and 100 d. Bakker & Traoré (1990) have calculated, on the basis of 11 observations, that the average cycle length is 108 d. In the LP-model, the value is set at 100 d, based on the assumption that all shallots are grown from bulbs. In theory, if water supply is not limiting and provided the bulbs are planted early, two growing cycles are possible between October and April (210 d). GTZ/SDA (pers. comm.) estimates that in the Cercle de Bandiagara 1.5 cycles are achieved on average.

In this study, it is assumed that one shallot production cycle of 100 d is realised, starting on the day the bulbs are planted.

8.3.2 Yields

The yields of vegetable crops, given below, are expressed in fresh weight (FW) since this is normal practice and since the data reported in the literature are almost always expressed in this way instead of in terms of dry matter (DM), as that depends too much on cultivar and production method. Details on dry matter contents are given, however, for the purpose of this study.

Since only limited data exist on shallots, we have had to rely heavily on data for onions, which closely resemble the shallot. Messiaen (1975b) reported that the yield in terms of onion bulbs of the cultivars 'Violet de Galmi' and 'Blanc de Soumanara', is 20 t ha^{-1} under farmer's conditions, and up to 60 or 80 t ha^{-1} if the crops are well-managed. RFMC (1980) reported onion bulb yields between 20 and 70 t ha^{-1}. In Senegal, according to Beniest *et al.* (1987), onion bulb yields fluctuate between 20 and 30 t ha^{-1}. According to GTZ/SDA (pers. comm.) shallot bulb yields are 25 t ha^{-1} and 50% of the seed-bulbs are lost during storage. At a producer's farm in Boré, Traoré (pers. comm.) obtained a shallot bulb yield of 59 t ha^{-1}, for shallots grown from seed. According to Bakker & Traoré (1990), average shallot bulb yields are 25.7 t ha^{-1} (a very stable figure) and 8.9 t ha^{-1} for the leaves, varying from 7.8 to 10.6 t ha^{-1}.

On the basis of this information, in the LP-model, yields are set at 26 t ha^{-1} for bulbs and 9 t ha^{-1} for leaves, hence in total 35 t ha^{-1}.

The bulbs have an average DM content of 17.2%, varying between 16.8 and 17.6, and the leaves of 11.3, varying from 8.7 to 12.6% (Bakker & Traoré, 1990).

Producer prices for fresh shallots vary considerably. At the Plateau, when stocks were low in 1988, the prices rose from 300 FCFA kg^{-1} in October to 400 in December. In the same agro-ecological zone, when shallots were abundantly available, and prices at their lowest, they varied from 75 FCFA kg^{-1} on 20/02/89 in Bandiagara, to 40 on 26/02/89 in Tégourou and 75 on 27/03/89 in Boré. In February 1990, producers were charging 75 FCFA kg^{-1} in Mopti, compared with just 35 FCFA kg^{-1} in certain markets within the Cercle de Bandiagara.

For dry products, Bakker & Traoré (1990) recorded in Mayarasso, in the course of a single year, for bulbs, price fluctuations between 204 and 510 FCFA kg^{-1}, with a weighted average of 471 (in terms of fresh produce that represents 35 to 88 FCFA kg^{-1}, or 81 on average); prices of dried leaves fluctuated between 42 and 200 FCFA kg^{-1}, the price most commonly paid being 100 FCFA kg^{-1} (in terms of fresh produce that represents 5 to 23 FCFA kg^{-1}, or 11 on average). The quoted values are not true averages but rather the prices most commonly obtained by the producers, who mainly sell dried leaves when prices are lowest and bulbs when prices are at their peak.

For the LP-model, a price of 75 FCFA kg^{-1} for fresh bulbs and 11 FCFA kg^{-1} for fresh leaves is assumed (Table A4.4).

8.4 Other vegetables

8.4.1 Description

Starchy crops, common vegetables, maize, tobacco and tomatoes have been used to establish the relevant parameters for the so-called other vegetables.

Among the starchy crops are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and, less frequently, potato (*Solanum tuberosum*).

The most common vegetables are white garden cabbage (*Brassica oleracea var. capitata*), cucumber (*Cucumis sativus*), gourds (most likely *Cucurbita moschata*), djakattou (*Solanum aethiopicum*, either African or bitter aubergine or 'ngoyo', not to be confused with *Solanum melongena* or 'sweet' aubergine or 'toubabou ngoyo', which is much less common), gumbo (*Hibiscus esculentus* syn. *Abelmoschus esculentus*), lettuce (*Lactuca sativa*, often *var. angustina* or 'Chinese salad'), cowpea (*Vigna unguiculata* syn. *V. sinensis*), peppers (most commonly *Capsicum annuum*, less commonly *C. sinense* and very occasionally *C. frutescens*) and roselle (*Hibiscus sabdarifa*, i.e. Guinea sorrel or bisap). Other vegetables such as amaranth, aubergine, beetroot, carrot, etc. and plants used for seasoning and flavouring such as mint, or believed to possess medicinal properties, such as garden cress, are also cultivated but in small, variable quantities in the various agro-ecological zones.

Maize (*Zea mays*) is grown either at the same time as other vegetable crops (from November to March) or, increasingly, as a third crop (from March to June), when the water supply permits, which is not often the case. Maize, immediately preceding the rainy season crops (from June to October), has not been included in this study. Tobacco (*Nicotiana tabacum*) is grown in the Region for the flowers, leaves and sometimes the stalks that are harvested to be smoked, used as snuff or chewed. Tomatoes (*Lycopersicon esculentum*) are frequently grown, sometimes in considerable quantities.

In addition to the various vegetable crops mentioned above, others are grown which have not been included in the study.

Gourds (*Lagenaria siceraria* syn. *L. leucantha, L. vulgaris*) are often grown in garden plots, but are not used as a vegetable. In addition to the more common forms of use, it is often grown as a so-called 'watering crop', i.e. the gourds produced are used for watering other vegetables. In this study, gourd cultivation in the Gourma, mainly at the foot of the Goundourou, where it is grown as a rainfed crop (Hesse & Thera, 1987), has not been considered.

Fruit trees have not been included in the results of the vegetable crops surveys, but they are often present. Among the various fruit trees encountered, the most common are dwarf banana (*Musa sinensis syn. M. nan*), guava (*Psidium guajava*), lime (*Citrus aurantifolia*) which, contrary to popular belief, bears limes and not lemons (*C. limon*), mango (*Mangifera indica*) and papaya (*Carica papaya*). Date palm (*Phoenix dactilifera*) is found on small plots near Hombori.

The cycle length of other vegetables varies from 50 or 60 d for lettuce to 365 d for cassava (Table A4.7, Annex A4.3). The cycle length for each crop depends on the cultivar (variety) used, growing conditions (water and mineral supply, climate, especially daylength and temperature) and the objectives (needs) of the producer. Within the same plot, for example, the cycle length of the sweet potato may vary from 120 to 180 d. To obtain a weighted average of the length of the growing cycle, use is primarily made of data presented in Table A4.7, taking only the low figures suggested by Beniest *et al.* (1987), in view of the lack of water, and of those in Table A4.4, presenting the fractions of the total surface area occupied by each of the other vegetables.

In this study, a weighted average of the cycle length of 138 d has been used for other vegetables. Since the cropping calendar for other vegetables is very similar to that of shallot, it has been considered identical.

8.4.2 Yields

Yields have been determined on the basis of data from the Region. If information was missing, the lowest values suggested in Table A4.7 have been adopted. Our main source, however, is Beniest *et al.* (1987), which is not always evident in Table A4.7, since that is the result of a synthesis. Fairly low yields have been selected, because neither chemical fertilizer nor pesticides are applied, but only organic manure. Temporary water shortages may occur and in the course of time, growers have selected cultivars not so much for their performance, as for their hardiness. Organic manure alone, which is very important for the physical conditions of the soil, does not necessarily correct chemical imbalances, because it has a fixed composition, that may not cover the specific needs to achieve a balanced supply in each individual case. Yields, therefore, are below potential.

For tobacco, we have disregarded both the figure suggested by GTZ/SDA (pers. comm.) of 500 kg ha^{-1} and that suggested by Bakker & Traoré (1990) of 360 kg ha^{-1}. According to RFMC (1980) tobacco produces between 6 and 12 t FM ha^{-1} with a dry matter content of 20%. According to our observations in special tobacco plots, the crops tend to be heavily manured and carefully tended and the flowers, leaves and sometimes also the stalks, are harvested. For tobacco, therefore, we have assumed a yield of 1 200 kg DM ha^{-1}, i.e. 6 t FM ha^{-1}.

Given the yields of each crop (starchy crops, common vegetables, maize, tobacco and tomatoes, Table A4.4) and their respective surfaces, the average yield of other vegetables is calculated at 16 t FM ha^{-1}.

Producer prices for other vegetables vary considerably, with time of the year and type of crop (Table A4.7). For the LP-model, a weighted average has been applied, i.e. 96 FCFA kg^{-1}.

8.5 Crop calendar and labour requirements

To quantify the working time involved in the two activities, i.e. shallots and other vegetables, a schematic approach is necessary, that avoids in-depth analyses for each individual crop. Here, we give a summary of the various operations for vegetable cultivation included in the model; details on labour requirements can be found in Tables A4.8, A4.9 and A4.10 (Annex A4.4).

Table A4.8 gives the labour requirements for cultivating shallots in Mayarasso, Mali (4th Region, near Baramandougou, close to the 5th Region). Here, shallots are grown from bulbs; the practice of sowing seeds in beds is rarely used. Table A4.9 gives data from a research station in Senegal and indicates the labour times for growing onions from seed-beds, without watering, on sandy soil (Beniest *et al.*, 1987). For the purpose of this study, onion-growing and shallot-growing are treated as identical activities. Table A4.10 provides a weighted average of the two preceding tables.

1. Field cleaning

Before growing vegetable crops during the dry season, one normally has to remove any residue from the wet-season crops which preceded them. For the LP-model, we have assumed that it takes 24 mnd ha^{-1} to clear shallot plots and 16 mnd ha^{-1} to clear plots for other vegetables.

2. Seed-bed

Certain crops are sown first in seed-beds which have to be laid out, sown, weeded, watered and generally maintained. To save on seeds, cut weeding and maintenance time, and facilitate transplanting later on, the seeds should preferably be sown in rows, requiring slightly more sowing time. In the LP-model, the time spent on seed-beds has been set at 0 mnd ha^{-1} for shallot, since the bulbs are planted in situ, and 9 mnd ha^{-1} for other vegetables.

3. Land preparation

Before sowing or transplanting, the plots are worked manually using a hoe, and divided into beds. For shallot, the beds tend to be small in size and surrounded by a small dyke to retain the irrigation water. The dimensions correspond to a watering unit: one gourd per bed. According to our observations, the irrigation infrastructure and footpaths take up approximately 5% of the growing area, not including the water supply installations. Land preparation time for shallot is set at 159 mnd ha^{-1}. For other vegetables, the beds can be arranged in several ways, but in general they tend to be less meticulous than those for shallot and they are generally larger in size (Annex A4.4). In certain places and for certain crops, such as peppers and tomatoes, land preparation is not required. Instead, the growers simply dig small ditches in which they plant. For other vegetables, time for land preparation is set at a weighted average of 24 mnd ha^{-1}, including basic fertiliser application, or spreading of base manure. For the 5th Region, however, one should realise that base manuring is hardly practiced.

4. Enclosures

Vegetable plots are enclosed to protect the crops from animals. The enclosures are made of sorghum or millet stalks or from branches (Annex A4.4). Although enclosures are not always built, we have assumed in this study that this is always the case, requiring 50 mnd ha^{-1}. This value also includes the time required to collect and transport the materials, irrespective of the type of crop grown.

5. Planting

Planting includes both sowing of seeds directly in situ (seeds and any vegetative parts or fragments capable of producing new plants) and the planting or transplanting of seedlings from seed-beds. For shallot and other vegetables, planting time has been set at 54 and 27 mnd ha^{-1}, respectively.

6. Watering

The labour involved in watering plants constitutes a constraint in vegetable cultivation. According to Beniest *et al.* (1987) one has to apply between 6 and 10 mm d^{-1}, i.e. on average 8 mm d^{-1} (= 8 l m^{-2} d^{-1} or 80 m^3 ha^{-1} d^{-1}). Within the Region, pumping, transport and distribution are essentially manual operations. The deeper the water store and/or the slower the flow rate and/or the further away the plots of land, the more this operation tends to restrict the area of cultivated land.

Labour requirements for watering are only reported by Bakker & Traoré (1990): 1 053 mnd ha^{-1}. This value has been used in the LP-model, irrespective of the type of crop grown.

We have only observed one case of mulching with husks of millet (Annex 4.4).

7. Spraying

Spraying with plant-protection agents has been incorporated in the study. The labour requirements are estimated at 1.5 mnd ha^{-1}.

8. Manure and fertilizer application

Manure or fertilizer application during cultivation involves spreading of both organic and chemical fertilizers, either split or all at once. By far the most popular form of fertilizer in the Region at present is mixed animal manure. Chemical fertilizer is hardly ever used.

For the LP-model, labour requirements for this operation, including collecting, transportation and application, are set at 54 mnd ha^{-1} for shallot and 45 mnd ha^{-1} for other vegetables. The calculations used to obtain these values are based on the following labour requirements: 500 kg mnd^{-1} for transporting the manure and 400 kg mnd^{-1} for spreading.

9. Maintenance (weeding)

Maintenance mainly involves weeding (i.e. uprooting undesirable plants and loosening the topsoil), harrowing (second tillage after sowing to loosen and aerate the soil as well as to remove any weeds which may be present) and maintaining the bunds. For some crops such as potatoes, maintenance also involves ridging.

For the LP-model, the labour required for maintenance work is set at 193 mnd ha^{-1} for shallot and 47 for other vegetables.

10. Harvesting and processing

Harvesting methods and the time required vary greatly among crops. Some crops, such as lettuce, carrots or potatoes are harvested in one operation and sold as quickly as possible, because of the perishable nature of the product and poor marketing conditions. Other vegetables such as tomatoes or djakattou, are harvested in stages and then sold. Yet others, such as shallot (leaves followed by bulbs), peppers and tobacco are harvested several times and then transformed, although not always, into dry products; the sale of the produce can then be postponed, since dry products can easily be stored. For details on processing of vegetables, reference is made to Beniest *et al.* (1987).

According to Bakker & Traoré (1990), shallot leaves are harvested, ground and baled before being dried. The bulbs, harvested 8 days later, undergo the same treatment. In the Dogon area, the bulbs are crushed rather than ground and GTZ/SDA is studying ways of improving the production of 'dry onions' to obtain better quality for the domestic markets as well as creating export markets. It is important to establish if the facilities required for better processing should be acquired by individual producers or have small cooperative processing units of the 'Kossam Mopti'-type. The first alternative would allow the producers to remain relatively free from any unwanted social interference. As individuals, however, it would be difficult for producers to stand up to the oligopoly imposed by the traders. The second alternative would make it easier, in theory, to set up producer associations in an attempt to control the prices paid to producers, but at the same time opens the possibilities for extortion and other forms of manipulation.

The labour requirements for harvesting shallot, including processing and transportation, have been set at 375 mnd ha^{-1} for the LP-model.

For other vegetables, only tobacco has to be processed always: each region has its own methods for harvesting and processing and its own commercial channels aiming at a specific region (Annex A4.4). Apart from peppers which can be dried, we assume that other products are sold unprocessed. For the purpose of the model, the time required for all other vegetables, allowing for possible processing and transport operations, has been set at a weighted average of 117 mnd ha^{-1}.

The total labour requirements for shallots grown from bulbs with a fixed cycle length of 100 d are 1 961 mnd ha^{-1} Table 8.2 (page 115). Note that watering accounts for 55% of these requirements. The total labour requirements for alternative methods of producing shallots are given in Annex 4.4.

The total labour requirements for other vegetables amount to 1 387 mnd ha^{-1} (Table 8.2). According to RFMC (1980), vegetable crops require 1 000 mnd ha^{-1} in total, allowing a maximum of 1 500 m^2 per laborer. According to Beniest *et al.* (1987), a full time worker can cultivate between 2 000 and 3 300 m^2, but experience plays an important role and in the peak season casual labour has to be brought in. Bakker & Traoré (1990) report the use of paid casual labour for urgent, peak season work in Mayarasso.

8.6 Monetary inputs

8.6.1 Capital charges

The largest, most onerous investments involving reservoirs, pumping and water supply are normally borne by financial aid packages. Since it is not our intention to carry out an audit, nor to examine the various systems for transferring know-how or technology, we have not compiled any data relating to such investments. It seems, however, that estimates for such costs do not always include those for expertise and administration, and that the participation of the parties concerned is accounted for in terms of opportunity costs.

1. Small equipment

The equipment used for vegetable cultivation in the Region is not very sophisticated:
- Land preparation is carried out using hoes ('daba' and 'falo');
- Second tillage operations are performed using small weeding hoes ('faloni');
- The crops are watered using gourds, except around Mopti where farmers use watering-cans, most of which are produced locally.

In the various regions, manure and products are transported with human labour, using gourds, baskets or sacks. If long distances have to be covered, carts or donkeys are also used. The costs of small equipment have been set at 500 FCFA ha^{-1} yr^{-1}.

2. Sprayer

As for other intensive cultivation activities, biocides are applied using sprayers. We have assumed that one sprayer is required per 2.5 hectare. Using the values indicated in Table A1.1, the costs work out at 2 400 FCFA ha^{-1} yr^{-1}.

8.6.2 Operating costs

1. Seeds

For in-situ planting of shallot bulbs (Annex A4.2 for the sowing of seeds):
- according to Messiaen (1975b), the best method is to plant small shallot bulbs weighing about 4 g each (small bulbs multiply at a lower rate than large bulbs in terms of numbers, but at a higher rate in terms of weight); using this method, one requires 4 t ha^{-1} if planting density is 0.1 * 0.1 m and 2.8 t ha^{-1} for a density of 0.12 * 0.12 m, the densities used by producers in the Region; in addition, the bulbs used weigh 2 g rather than 4, implying 1 to 2 t of bulbs per ha (the Region's producers do not plant whole shallots - clusters of bulbs - but rather each bulb separately and sometimes even fractions of bulbs);

- according to GTZ/SDA, producers in the Plateau region retain approximately 10 t ha^{-1} of their produce as planting material, and loose approximately 50% during storage;
- according to Bakker & Traoré (1990), the Mayarasso producers retain between 0.9 and 1.3 t ha^{-1} of bulbs as planting material, i.e. 1.1 t ha^{-1} on average; between 40 and 60% of these bulbs are lost, with the consequence that producers have to purchase additional bulbs at sowing time. Such purchases account for 70% of the total costs of vegetable cultivation. The Mayarasso producers reserve beds for growing seed-bulbs without harvesting the leaves: these leafy bulbs are stored in the form of ropes, but this is not the case in the Region.

For the model, we have assumed that 2.5 t ha^{-1} of shallot bulbs are required for planting, which in monetary terms represents 187 500 FCFA.

With respect to seeds for other vegetables, we have observed that producers in the Region generally try to be self-sufficient, except if seeds cannot be reproduced locally, such as for carrots or cabbage. Assuming, however, that crops are produced using commercial seeds, we have assumed 38 500 FCFA ha^{-1} for the purchase of seeds (Beniest *et al.*, 1987).

2. Pesticides

Without going into the details of the various diseases that affect vegetables, as described by Bourdouxhe (1983), Collingwood *et al.* (1984) and Beniest *et al.* (1987), we will briefly point out that the most common pests in the Region are:
- at each stage: rodents and grasshoppers;
- at the sowing stage: the agama or grey lizard, seed grasshoppers (*Chrotogonus brevipes*) and rot in the collar region;
- at maturity: caterpillars, Jassidae (*Jacobiasca lybica*), Cucurbitaceae flies (*Dacus spp.*), the red coleopter which attacks melons (*Aulacophora africana*), *Cucurbitaceae coccinella* (*Henosepilachna elaterii*), gall nematodes (*Meloidogyne spp.*), mildew (*Pseudoperonospora cubensis*) and oidium (*Oidium spp.*).

Infestations of other pests, too, occasionally occur. At present, pesticides (insecticides, fungicides, herbicides) are rarely used and whatever small amounts are used originate largely from donations. According to Kamissoko (in charge of PV/Mopti, pers. comm.), producers are very keen to obtain pesticides, but they are currently hardly available through the normal channels. On the few occasions when they do obtain them, they have no knowledge of the products, their use, the associated dangers and their residual effects. Faced with this demand, and to prevent excessive use or misuse of potentially dangerous chemicals, some experts recommend the widespread introduction of 'biological' products, that could be manufactured locally. Such an approach undoubtedly has certain advantages but should not be enforced dogmatically. The aim should be to minimise crop losses from pests in order to obtain a good return on inputs (labour, manure, water), while at the same time ensuring that the consumers, having limited purchasing power, receive good quality at a price they can afford. Finally, one sometimes detects signs of a rather fatalistic or passive attitude on the part of certain producers, not only horticulturists, who seem to live in expectation of some 'miracle solution'. To assign a value to pesticides, which will have to be applied to any crop grown with the aim of potential yield, we have adopted the figure suggested by Beniest *et al.* (1987): 15 000 FCFA ha^{-1}.

8.7 Nutrient requirements

In the Region, vegetable growers make maximum use of any organic manure that can be obtained free of charge, or, more rarely, purchased - so much so, that they will even collect bat droppings. Chemical fertilizer, on the other hand, is rarely if ever used, not because producers don't know of its existence but rather because of the difficulties involved in obtaining it. On the few occasions when chemical fertilizer is used, failure to understand the notion of 'needs' or 'balance' often leads to disappointing results, either at the production or storage stage.

Data on recommended levels of manure can be found in various reports on tropical horticulture (Annex 4.4). Such data are of little use to us, however, because our calculations are based on the amount of minerals present in the plants. Ideally speaking, we should have thoroughly examined all the records concerning every type of tropical horticultural crop, a small sample of which is given in Table A4.7. Given the available time, however, this was not feasible. On the basis of the study carried out by Nijhof (1987), we have calculated the N, P and K requirements for both activities, on the basis of the minimum values for onions and sweet potatoes, since these are currently the most important crops (Table A4.4).

The applied concentrations of N, P and K, on a dry weight basis, of onion bulbs and leaves are 11.0, 2.5 and 13.0 and 14.0, 2.5 and 20.0 g kg^{-1}, respectively. It is assumed (Subsection 8.3.2), that the DM content of bulbs and leaf blades is 17 and 11%, respectively and that the harvest index is 0.82.

The applied concentrations of N, P and K, on a dry weight basis, of tubers and haulms of sweet potatoes are 11.0, 2.0 and 13.0 and 18.0, 2.0 and 20.0 g kg^{-1}, respectively. It is assumed (Subsection 8.3.2), that the DM content of tubers and haulms is 20 and 10%, respectively and that the harvest index is 0.82.

The soils on which vegetable crops are grown cannot truly be compared with the original soil types, since they have undergone intensive treatment with organic manure. It is therefore assumed that 10% of the minerals added is lost and that 30% is incorporated in the soil system, the remaining 60% being taken up by the crops. In addition, it is assumed that all nutrient requirements are met by organic manure. The calculated amounts of organic manure required to satisfy the long-term requirements of both shallots and other vegetables are given in Table 8.2.

8.8 Input-output table

Table 8.2 summarises, in the form of an input-output table, all the data required for a quantitative description of the two vegetable cultivation activities relevant for the LP-model.

Table 8.2. Input-output table of vegetables production techniques.

CHARACTERISTIC	SHALLOT	OTHER VEGETABLES
Animal traction	-	-
Manure	+	+
Chemical fertilizer	-	-
Fallow	-	-
INPUTS [ha^{-1} yr^{-1}]		
FALLOW/MANURE/FERTILIZER		
Ratio fallow years/ year cultivated [-]	-	-
Manure [kg DM]	11 000	10 000
Fertilizer N [kg]	-	-
Fertilizer P [kg]	-	-
Fertilizer K [kg]	-	-
LABOUR[a] [mnd]		
5+6 Cleaning	24	16
5+6 Seed bed	-	9
5+6 Land preparation	158	23
5+6 Manure application	54	45
5+6 Field protection	50	50
5+6 Plantation	54	27
5+6 Irrigation	1 053	1 053
5+6 Pesticides spraying	1.5	1.5
5+6 Maintenance	193	47
5+6 Harvesting & transport	375	117
Total	1 962.5	1 388.5
MONETARY INPUTS [FCFA]		
Capital charges		
Small equipment	500	500
Sprayer	2 400	2 400
Subtotal	2 900	2 900
Operating costs		
Seeds	187 500	38 500
Pesticides	15 000	15 000
Subtotal	202 500	53 500
Total	205 400	56 400
OXEN [ox]	-	-
OUTPUTS [ha^{-1} yr^{-1}]		
Marketable product [kg][c]	35 000	16 000
By-product [kg DM]	-	700[b]

a) Numbers before operations refer to the period of the year (Subsection 1.2.1).
b) Average N% is 18.0 g kg^{-1}.
c) fresh weight (see text for conversion to dry matter).

9. BOURGOU

(N. van Duivenbooden)

9.1 Introduction

Bourgou is the name for the perennial grasses *Echinochloa stagnina* (red bourgou, 'bourdiou' in Tamacheq, water grass) and *Echinochloa longijubatum* (white bourgou, 'aïga' in Tamacheq) originating from the Peul people (Bonis Charancle & Rochette, 1989; Marchand, 1987; Hiernaux *et al.*, 1983). A detailed description of morphology and growth habit is given by François *et al.* (1989) and Hiernaux & Diarra (1986). Bourgou is originally part of the natural vegetation, but since the drought period in the seventies it has been cultivated in the floodplains of the river, in the so-called 'bourgoutières'. Other species often associated with bourgou are *Oryza longistaminata, Vossia cuspidata, Brachiaria mutica, Nymphea lotus* and *Nymphea maculata* (Traoré, 1978).

Bourgou is a multipurpose crop: *(i)* its grains are used to prepare couscous and syrup is extracted from its stems, *(ii)* harvested as fodder crop and sold at the market, *(iii)* used as pasture, *(iv)* protection and feeding fish (e.g. of algae attached to the stems of higher plants), *(v)* protection and feeding birds (to allow hunting), and *(vi)* protection in rice cultivation against waves and rice-eating fish (Bonis Charancle & Rochette, 1989; Stiles, 1989a; Marchand, 1987). Harvest of grains is seldom practiced, only if other crops are failing completely (François *et al.*, 1989). A conflict exists between farmers who want to cultivate bourgou for their animals and those who want to cultivate rice or other crops in the same area of the floodplains (Stiles, 1989a).

The decrease in natural bourgou stands and its cultivation in recent years may be traced back to several causes: e.g. recurrent droughts have negatively affected the regrowth potential of bourgou in the dry season and the extent of the floods with its negative consequences for the surface area of the bourgoutières. Part of the 'traditional' bourgoutières have been incorporated in the development schemes for rice cultivation. In addition, overgrazing in the dry season (both at too high grazing density and grazing at the wrong time) has led to a reduction in the number of plants that were able to grow with the rising water and in reduced vigour (Bonis Charancle & Rochette, 1989). For the Zone Lacustre two periods are reported when grazing is possible without too much damage to the bourgou stand: just after the retreat of the water and just after the start of regrowth between the onset of the rainy season and the beginning of the flood. However, in practice, animals start grazing the bourgoutières before complete retreat of the water, with the consequent lower amount of usable standing biomass. On the other hand, a beneficial effect is trampling of stems into the mud, which favours abundant regrowth (François *et al.*, 1989; Hiernaux & Diarra, 1986). Owners of bourgou receive about 5 000 FCFA for a cattle herd of 50 to 100 head or a small ruminant herd of 100 head (Sangaré, 1989), but no length of grazing period is reported. Diakité & Kéita (1988) report that owners receive on average 20 000 FCFA ha^{-1} for the 3 months period of starvation ('période de soudure').

Shooting from stems buried in the soil is induced by the first rains just before the beginning of the flood and growth of new material keeps pace with the rising water. First harvest takes place after maximum height of the river (Bonis Charancle & Rochette, 1989; Stiles, 1989a), in the Delta in October/November (Report 1, Chapter 5). For continued growth, it is essential that a fraction of the plant remains above the water surface, to maintain its photosynthetic capacity. The length of the period of inundation is from three to six months and the depth of water may reach 5 m (François *et al*.,, 1989; Hiernaux & Diarra, 1986; Hiernaux *et al*., 1983).

Bourgou is normally not available during the rainy season and although its yields may be high, only a limited part can be exploited due to difficult accessibility of the fields and, when accessible, to the relatively low quality (Hiernaux *et al*., 1983; in terms of nitrogen, but not in energy content) and to trampling into the soil (François *et al*., 1989). The effect of mowing on total bourgou production is a function of its intensity; for an optimal biomass production mowing should take place two times a month (Hiernaux & Diarra, 1986).

Two major methods to regenerate bourgou are practiced: seeding and transplanting. Seeding can be practiced either in pockets or broadcast. The moment of seeding can be just after the retreat of the flood or at the start of the rainy season. The first method requires irrigation of seedlings after about 20 days. Furthermore, the germination rate in the field is only half of that under controlled conditions, 44 versus 90%. Sowing at the start of the rainy season has the disadvantage, that the time between seeding and the rise of the flood can be too short, so that the seedlings will be flooded and consequently die (François *et al*., 1989). In addition, bourgou reproduces much better from cuttings than from seed (Moorehead, 1989). Hence, transplanting is increasingly practiced. The seedlings can be either bought from outside the Region, grown in a seed-bed or as cuttings taken from the bourgou of the preceding year (top of stem with one of more nodes. The moment of transplanting is either at the start of the rainy season (with seedlings), at the beginning of the flood (sometimes in the water) or directly after the flood retreat (cuttings). The disadvantage of the second method is that the plants are too small to expect a reasonable yield and the risk of flooding remains. Hence, François *et al*. (1989) consider the first method the best for the northern part of the Region, where the beginning of the flood is in August, using 2 months old seedlings. However, as in the Delta Central the beginning of the flood is in July (Report 1, Chapter 5), transplanting should preferably be in May, but as rainfall in that month is unreliable, some additional watering may be required. The third method is trampling of stems into the mud, as described above.

In this study two bourgou production techniques are defined:

Extensive technique

Under this technique only a small fraction of total biomass production is used as fodder, and soil fertility is maintained by river water and by nutrients originating from the recycling of non-grazed biomass left on the field. This technique is considered part of the natural pasture management in the Region and is treated as such in Chapter 11.

Semi-intensive technique

Under this technique soil fertility is maintained by application of manure and chemical fertilizer. The first harvest of bourgou is assumed to take place in November. It is assumed that at the end of the growing season 20% of the total above-ground dry matter remains at the field, available for grazing by animals. Regeneration is practiced three out of four years by animals, that are allowed to enter the bourgoutière just before the retreat of the flood and the other year by transplanting of seedlings on a chisselled soil after the first rains.

9.2 Environment

Bourgou cultivation is practiced generally in the Delta Central and the Zone Lacustre on loamy sand and clay sand (Bonis Charancle & Rochette, 1989). Although in the Zone Lacustre the soils contain more sand, it is assumed in this study that the extensive bourgou technique is practiced only on the more heavy soil types, similar to those used for outside-polder rice cultivation (Section 3.2). Competition between rice and bourgou occurs (e.g Diakité, 1989b), but only for the soils with high floods (Table 9.1): soil type E1b in rainfall zones II, III & IV and soil type F3b in rainfall zone II. As shown in the same table, bourgou can be cultivated on soil type G as well, but for practical purposes in this study, that soil type is only used for cultivation of flood retreat sorghum (Section 4.2). Regenerated bourgoutières exist in the Region as shown in Table 9.2.

For the semi-intensive technique only soil type F3b is considered suitable and limited to the surface area of the ORM-polders.

9.3 Yields

Dry matter production of bourgou (total above-ground) may vary considerably from year to year (Tables A5.1, A5.2 and A5.3). In addition, Hiernaux *et al.* (1983) reported dry matter yields of 6 000 to 8 000 kg ha^{-1} in an experiment with regular harvests by mowing. But in that experiment, no data were given to relate mowing to the vigour of the bourgou (which proportion of the biomass can actually be exploited without endangering persistence).

Peak standing biomass is generally reached in the third decade of October at the reference point Mopti (Report 1, Chapter 5), but it is earlier in the south of the Region and later in the north, and standing biomass gradually decreases from then onwards. Reported peak dry matter yields range from about 17 000 kg ha^{-1} (Bonis Charancle & Rochette, 1989) via 30 000 to 32 000 kg ha^{-1}, and drops to about 20-25 000 kg ha^{-1} at the moment the animals enter the bourgoutières (François *et al.*, 1989).

Table 9.1. Flooded areas in a normal year [km^2] and the competition between vegetation formations (<->) per soil type in the various ZAE for the various heights (Cotes [m], above the zero value of the limnimetric scale at Mopti). R = rice cultivation, P = inondated pasture other then bourgou = VH et Agb+P+Ac et ESP+VSP et EOR+VOR+O-Op; B = bourgou = VB+B et VB+B+Bp according to PIRT (1983).

SIDES	COMPE-TITION	RAINFALL/AGRO-ECOLOGICAL ZONE						TOTAL
		II PT	II DC	III MD	III GM	IV BD	IV ZL	
TI4 = G								
6.6-6.0	P	.	333	.	.	.	.	333
TI3 = E2b								
6.6-6.3	P	4	1 926	128	.	1	177	2 236
6.3-6.0	P<->R	5	1 926	128	.	1	178	2 238
TI2 = F3b								
6.3-6.0	R<->PI	9	141	.	.	.	.	150
6.0-5.1	R<->PI	29	423	.	.	.	.	452
5.1-4.8	R<->B	9	141	.	.	.	.	150
TI1 = E1b								
6.0-5.1	P<->R	14	1 630	15	20	1	316	1 996
5.1-4.8	B<->R	5	544	5	7	1	106	668
4.8-2.6	B	34	3 930	37	49	3	763	4 816
TI7 = G								
6.0-5.1	P<->R	.	208	.	29	.	228	465
5.1-4.8	B<->R	.	69	.	10	.	75	154
4.8-2.6	B	.	502	0	70	.	549	1 121
Totaux		109	11 773	313	185	7	2 392	14 779

Source: Report 1, Chap. 5.

Table 9.2. Area [ha] of regenerated bourgoutières in various sectors of the Region.

SECTOR	AREA	SECTOR	AREA
Bandiagara	12	Mopti	2 133
Bankass	-	Ténènkou	74
Djenné	71	Youwarou	519
Douentza	300	Niafunké	285
Koro*	17		
Total			3 411

Source: Diakité & Kéita, 1988.
*: valloy of Sourou.

Average daily dry matter production is estimated by the latter authors at 200-250 kg ha^{-1} in the period from the start of regrowth to peak standing biomass. In the second year, the growth rate of bourgou is 100 and 120 kg ha^{-1} d^{-1} between 15-45 and 45-75 days after the start of regrowth, respectively. These values are higher than those reported by Hiernaux & Diarra (1986): maximum growth rates in the order of 40 to 55 kg ha^{-1} d^{-1} for bourgou in February and May, respectively (Central Mali). Seed yield is low according to François *et al.* (1989), but as no data are available, grain production is neglected in this study.

In the light of the experimental data presented, the target yield (total above-ground biomass) is set, admittedly rather arbitrarily, at 15 000 kg ha^{-1}. To account for the lower yield and the reduction in area harvested in a dry year, the reduction factor as applied for the semi-intensive technique 1 polder rice cannot be used, as that refers mainly to the reduction in grain yield (Subsection 3.3.3). Hence, the average of that value and the reduction of bourgou as natural pasture (Chapter 11) is applied, resulting in a target yield of 5 000 kg ha^{-1} in a dry year.

The price of bourgou received by farmers varies in the course of the year between 25 and 100 FCFA per packet, or 17 to 67 FCFA kg^{-1} DM (the highest in the dry season). Diakité & Kéita (1988) and Diakité (1989) report a price ranging from 5 to 50 FCFA kg^{-1}. In small villages the price does not exceed 50 FCFA $packet^{-1}$ (Bonis Charancle & Rochette, 1989; Stiles, 1989a). The price is much lower according to Moorehead (1989), but is reconfirmed by Stiles (1989b). A price of 50 FCFA $packet^{-1}$ was reported at the market in Mopti (January 1990, van Duivenbooden pers. comm.). In this study the price is set at 35 FCFA kg^{-1} of dry matter.

9.4 Nutrient requirements

Average nitrogen content of standing biomass of bourgou is a function of growth stage and varies from 20.8 g kg^{-1} at the start of regrowth, via 8.8 in January to 12.4 at the retreat of the flood in April (Table A5.4). The increase in N-content towards April must be due to regrowth material being mixed with the old material. The variation in nitrogen content within the plant is also considerable, e.g. from 6.2 g kg^{-1} in stems under water to 16.4 g kg^{-1} in stems and leaf blades above water (period of measurement not reported) (François *et al.*, 1989) and from 3.2 g kg^{-1} in stems in December to 25.6 in leaf blades and new material in June/July (Traoré, 1978).

Phosphorus content varies also with time both as a function of growth stage and the composition of the material: from 0.6 g kg^{-1} in stems in June and July to 3.2 in the new material in July (Traoré, 1978).

For potassium less information is available (Table A5.4).

Based on the values given in Table A5.4, minimum values of 6, 1.2 and 14 g kg^{-1} are used for N, P and K content of the exploited above-ground dry matter, respectively.

9.5 Crop calendar and labour requirements

Seeding takes place in April/May and final harvest is in March. The labour requirements for the various operations are treated below.

1. Maintenance of dikes

As for polder rice, no labour requirements of farmers are attributed to this operation.

2. Seed-bed

As for irrigated rice, the labour requirements for seeding, maintenance of the seed-bed and irrigation are set at 6 mnd ha^{-1}. Taken into account that 25% of the fields requires regeneration by transplanting, the labour requirements are 1.5 mnd ha^{-1}.

3. Basic dressing

Just before land preparation an chemical compound fertilizer, comprising nitrogen, phosphorus and potassium is broadcasted in the semi-intensive technique, the labour requirements are 1 mnd ha^{-1}.

4. Transport and application of manure

Manure is assumed to be applied in the semi-intensive technique. As for polder rice, the average distance to be covered is set at 8 km and 70% of the transport is carried out by donkeys and 30% by donkey carts, hence the rate of manure transport is 150 kg mnd^{-1}. Furthermore, it is assumed that about 300 kg ha^{-1} is already available in the field at the moment the animals enter the bourgoutières. Labour requirements for spreading of manure are calculated similar to those for millet, at a rate of 400 kg mnd^{-1}. Hence, total labour requirements for these operations are 27.5 mnd ha^{-1}.

5. Land preparation

Land preparation is principally carried out by oxen traction, before the onset of the rainy season. Similar to the labour requirements for land preparation of polder rice, the labour requirements for chisselling are set at (8 mnd + 4 At) ha^{-1} and taking into account that 25% of the fields requires regeneration by transplanting, the labour requirements are (2 mnd + 1 At) ha^{-1}.

6. Transplanting

Transplanting of bourgou requires 10 mnd ha^{-1} (Bonis Charancle & Rochette, 1989). This is less than for rice (35 mnd ha^{-1}, Subsection 3.4.4), because of a lower planting density. Taking into account that 25% of the fields requires regeneration by transplanting, the labour requirements are 2.5 mnd ha^{-1}.

7. Harvest

Harvest of bourgou is practiced either by wading through the water or by a small boat. The same harvest rate is applied as for irrigated rice (Subsection 3.4.4), but now related to total above-ground dry matter, resulting in a harvest rate of 250 kg mnd^{-1}. As 80% of total dry matter is harvested in the course of the period of flood retreat (the remainder is grazed), the labour requirements for this operation are 48 mnd ha^{-1}.

8. Transport

It is assumed that the average distance to be covered is 8 km and that transport is carried out by donkey chart, at a rate of 400 kg mnd^{-1}. Hence, the labour requirements are 30 mnd ha^{-1}.

The total labour requirements of (112.5 mnd + 1 At) ha^{-1} are distributed over the various periods of the year (Subsection 1.2.1), as given in Table 9.3.

9.6 Monetary inputs

9.6.1 Capital charges

1. Chissel

Considering the length of the period available for land preparation (20 d) and its labour requirements, one chissel is required for each 20 ha. Assuming that the purchase price and life expectancy of a chissel are equal to those of a normal plough (Table A1.1) and taking into account the same factor for accessibility of chissels in the Region, the depreciation rate is 630 FCFA ha^{-1} yr^{-1}.

2. Small equipment

As no data are available on the type of small equipment required, and hence on its purchase price and life expectancy, the depreciation rate for polder rice cultivation is applied: 500 FCFA ha^{-1} yr^{-1}.

3. Dike

As for polder rice (Subsection 3.3.5), the depreciation rate is set at 30 000 FCFA ha^{-1} yr^{-1}.

4. Boat

A small boat is required for harvest and transport of bourgou. The acreage exploited per household is estimated at 4 ha. Assuming one boat per household and given the purchase price of 190 000 FCFA with a life expectancy of 7.5 years (Table A1.1), the depreciation rate is 6 350 FCFA ha^{-1} yr^{-1}.

9.6.2 Operating costs

1. Seed

Density of broadcast seeding is 3 kg ha^{-1} at a price of 150 FCFA kg^{-1} (Diakité & Kéita, 1988). As only 25% of the area is regenerated and assuming that the seed density in the seed-bed is the same, these costs are 110 FCFA ha^{-1} yr^{-1}.

2. Pesticides

Although no data are available on the actual application of pesticides, it is assumed that they are applied to the soil just after seeding. The costs are, as for other semi-intensive techniques, set at 250 FCFA ha^{-1} yr^{-1}.

3. Maintenance of dikes

As for polder rice (Subsection 3.3.5), the annual costs for maintenance of dikes are set at 5 000 FCFA ha^{-1} yr^{-1}.

4. Lickstone

A typical characteristic of bourgou is its high digestibility (= digested dry matter/total dry matter intake). Even at low nitrogen contents (5 g kg^{-1}), digestibility remains at about 65%, a value normally obtained for forage with a N-content of about 15 g kg^{-1} (Breman & de Ridder, 1991) (Figure 9.1). This has consequences for the diet of the animal. With availability of such fodder, the animal needs other fodder to satisfy its protein requirements. In practice, Traoré (1978) has observed that the fraction of bourgou in the diet does not exceed 0.51 (in May, with 0.43 dry bourgou and 0.08 green bourgou from the fields), the remainder being met by relatively protein rich feed.

Thus, to make optimal use of the bourgou (upgrading from point 1 to point 2 in Figure 9.1) and taking into account the average N-content of bourgou (Section 9.4), that requires almost a doubling of the N-content, from 8 to 15 g kg^{-1}. In this study, the nitrogen 'deficiency' is relieved by the use of a lickstone, as also observed for bush hay by Baur *et al.* (1989), which is mainly composed of urea. An alternative N-source could be a block of molasse-urea, as reported by Sansoucy (1986). The required amount of N is then 120 kg ha^{-1}.

As no data on the purchase price are available, it is assumed that the price of N in the lickstone is that of N in the form of urea (Annex 1.2) plus 10% due to additional appetizers and other minerals, i.e. 491 FCFA kg^{-1} of nitrogen. Hence, these operating costs are 58 870 FCFA ha^{-1} yr^{-1}.

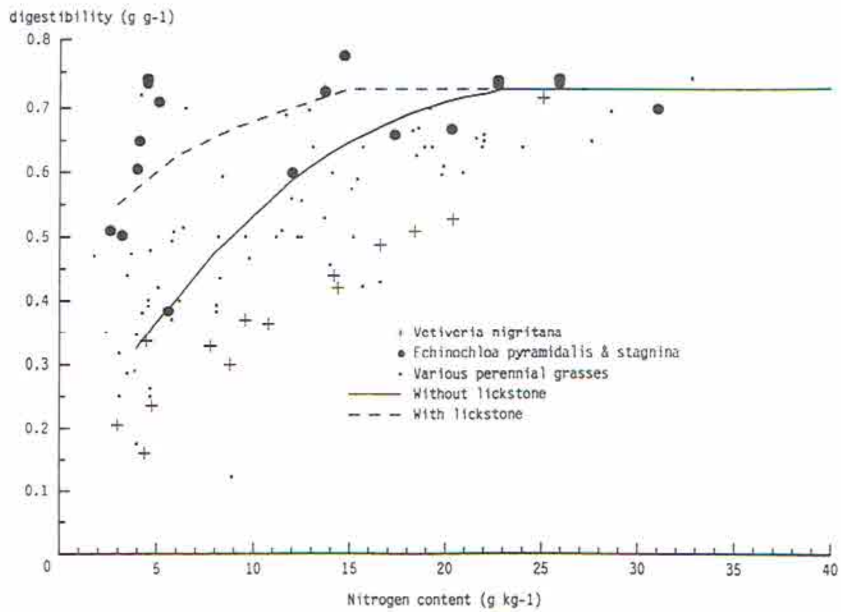


Figure 9.1. In vitro-digestibility of organic material as a function of the nitrogen content of dry matter (Breman & de Ridder, 1991).

The total monetary inputs for the semi-intensive bourgou cultivation are considerable, estimated at 102 000 FCFA ha^{-1} yr^{-1} (Table 9.3).

9.7 Oxen requirements

As a consequence of chissel requirements for land preparation, oxen requirements are two times higher than the chissel requirements, i.e. 0.13 ox ha^{-1}.

9.8 Input-output table

Inputs and outputs of the semi-intensive bourgou production technique for the LP-model are quantified in Table 9.3.

Table 9.3. Input-output table of the semi-intensive bourgou production technique on soil type F3b.

CHARACTERISTIC	SEMI-INTENSIVE
Animal traction	+
Manure	+
Chemical fertilizer	+
Fallow	-
INPUTS [ha^{-1} yr^{-1}]	
FALLOW/MANURE/FERTILIZER	
Ratio fallow years/ year cultivated [-]	-
Manure [kg DM]	3 500
Fertilizer N [kg]	387
Fertilizer P [kg]	65
Fertilizer K [kg]	297
LABOUR[a] [mnd]	
6 Seed-bed	1.5
1 Basic dressing	1
1 Manure transport & application	27.5
1 Land preparation	2. + 1 At
1 Transplanting	2.5
6 Harvesting	48
6 Transport	30
Total	112.5 + 1 At
MONETARY INPUTS [FCFA]	
Capital charges	
Chissel	630
Small equipment	500
Dike	30 000
Boat	6 350
subtotal	37 480
Operating costs	
Seeds	110
Pesticides	250
Dike maintenance	5 000
Lickstone	58 870
subtotal	64 230
Total	101 710
OXEN [ox]	0.13
OUTPUTS [ha^{-1} yr^{-1}][b]	
Stover[c] [kg DM]	15 000

a) Numbers in front of operations refer to period of the year (Subsection 1.2.1)
b) In a normal year in rainfall zone I (530 mm).
c) Average N-content in combination with lickstone is 15 g kg^{-1}.

10. FODDER CROPS

(N. van Duivenbooden)

10.1 Introduction

In addition to natural pastures, concentrates and agricultural by-products, fodder crops can be grown as an additional source of forage for animals to live through the dry season and/or to increase animal production. Such fodder crops need much more care than natural pastures, such as fertilizer application and spraying against pests and diseases to obtain a substantial yield. Hence, because of the investments necessary for establishment, growth conditions should be made as optimum as possible. Fodder crops are cultivated on a small scale, with reported field sizes varying between 0.1 and 0.5 ha in 1984 in Central Mali (Coulibaly, 1984), but no data are available for the 5th Region.

Coulibaly (1984) reports five species proposed to farmers: *Cenchrus ciliaris, Cenchrus setigerus, Dolichos lablab, Macroptillum atropurpureum* and *Stylosanthes hamata*. As pointed out before (Section 6.1), cowpea can also be grown as fodder crop, often used to feed draught oxen (Coulibaly, 1984; Berckmoes & Bengaly, 1989). The cowpea cultivar, treated in Chapter 6, served as a double purpose crop (grains and fodder), but several varieties exist that are cultivated only for forage. In that case, the grain yield, if any, can be considered a by-product. For more details on cowpea, reference is made to Chapter 6. For more details on other forage crop species, reference is made to e.g. Coulibaly (1984), Samaké *et al.* (1986), Bayer (1986) and Skerman *et al.* (1988).

In this chapter an intensive fodder crop is defined based on the use of cowpea. Grains are not harvested separately, but are part of the fodder. The technique applied includes animal traction, fertilizer and manure application and spraying to control pest and diseases.

To avoid confusion with the cowpea defined in Chapter 6, the fodder crop is identified as cowpea-CF.

10.2 Environment

As a consequence of our definition, the environment of fodder crops equals that of the intensive cowpea technique (Section 6.2), that can be practiced on soil types B2, C1 and F1 in rainfall zones III & IV, I to IV and I to III, respectively.

10.3 Yields

Reported yields on a dry matter basis of fodder crops at experimental stations varied between 400 and 4 800 kg ha^{-1}, but between 450 and 950 kg ha^{-1} on farmers fields (Coulibaly, 1984). For both situations, yields varied with species, but no data was given on application of chemical fertilizer. Samaké *et al.* (1986) reported yields of up to 5 000 kg ha^{-1} on fertilized fields at the experimental station.

Total dry matter production of cowpea-CF is calculated on the basis of the reported simulation results on water-limited production (Erenstein, 1990). As the conversion efficiency of assimilated into grain dry matter is lower than that for leaf blades (e.g. Penning de Vries & van Laar, 1982) the target total above-ground matter is set at 80% of the sum of simulated straw production and simulated grain production increased by 15% (Table 10.1). Those values are of the same order of magnitude as 80% of the sum of the yield under non-fertilized conditions and an additional production of 3 000 kg ha^{-1} due to fertilizer application (Penning de Vries, 1982).

The target yields for a dry year are calculated similarly to those for the intensive cowpea technique: 2 300, 2 620 and 1 450 kg ha^{-1} for soil type B2, C1 and F1, respectively.

Although a forage-type cowpea cultivar is used, some grains are normally produced as well. Based on the results of the literature review by van Duivenbooden (1991), the harvest index is set at 0.05. However, these grains remain part of the forage. Moreover, the grain/fruit ratio is set equal to that of the intensive cowpea technique at 0.70.

10.4 Nutrient requirements

As a consequence of taking cowpea as fodder crop, the same minimum nutrient elements contents as for cowpea (Section 6.4) can be applied. On a dry matter basis the N, P and K contents [g kg^{-1}] are 35.0, 3.0 and 12.0 for grains and 11.0, 0.7 and 8.0 for podshells and 13.0, 0.9 and 6.8 for stems and leaves, respectively (van Duivenbooden, 1991).

On the basis of these contents and the method described in Subsection 1.4.1, the requirements for organic manure and chemical fertilizer are calculated for each of the activities (Table 10.1).

10.5 Crop calendar and labour requirements

The growing season of cowpea-CF is more or less the same as for the double purpose cowpea (Section 6.5), but its harvest is earlier. As a consequence of our definition of the cowpea-CF technique, the moments of labour requirements are similar to those of intensive cowpea, except the labour requirements for harvest and shelling. For the other operations the same labour requirements (Section 6.5) are applied or calculated in the same way (labour requirements for transport and application of farmyard manure, harvest and transport of produce).

The total labour requirements are about (60 mnd + 8 At) ha^{-1} yr^{-1}, as presented in Table 10.1. This value exceeds the value reported by Coulibaly (1984) of 43 mnd ha^{-1} yr^{-1}. However, on the basis of the available data no reason for this difference can be derived.

10.6 Monetary inputs

10.6.1 Capital charges

The capital charges of cowpea-CF are identical to those of the grain-cowpea (Subsection 6.6.1), i.e. 7 960 FCFA ha^{-1} yr^{-1}.

10.6.2 Operating costs

The operating costs of cowpea-CF are identical to those of the grain-cowpea (Subsection 6.6.2), i.e. 15 130 FCFA ha^{-1} yr^{-1}.

Hence, the total monetary inputs are 23 090 FCFA ha^{-1} yr^{-1}.

10.7 Oxen requirements

As a consequence of the high plough requirements for land preparation, the oxen requirements are accordingly high, i.e. 0.75 ox ha^{-1}.

10.8 Input-output table

Inputs and outputs of the defined fodder crop technique are quantified in Table 10.1.

Table 10.1. Input-output table of intensive fodder crop techniques on the three soil types.

CHARACTERISTIC	INTENSIVE		
	B2	C1	F1
Animal traction	+	+	+
Manure	+	+	+
Chemical fertilizer	+	+	+
Fallow	-	-	-
INPUTS [ha^{-1} yr^{-1}]			
FALLOW/MANURE/FERTILIZER			
Ratio fallow years/ year cultivated [-]	-	-	-
Manure [kg DM]	1 300	910	680
Fertilizer N [kg]	54	37	43
Fertilizer P [kg]	11	14	9
Fertilizer K [kg]	80	58	44
LABOUR[a] [mnd]			
6 Field cleaning	1	1	1
1 Manure transport & appl.	8	5.5	4
1 Basic dressing	1	1	1
1 Land preparation	12.+ 6 At	12.+ 6 At	12.+ 6 At
1 Seeding	5	5	5
2 Weeding 1	10.+ 2 At	10.+ 2 At	10.+ 2 At
2 Pesticide spraying	0.5	0.5	0.5
3 Weeding 2	12	12	12
3 Pesticide spraying	1.5	1.5	1.5
3 Harvesting	7	7	7
4 Transport	6	5.5	5
Total	64.+ 8 At	61.+ 8 At	59.+ 8 At
MONETARY INPUTS [FCFA]			
Capital charges			
Plough	5 260	5 260	5 260
Small equipment	1 500	1 500	1 500
Sprayer	1 200	1 200	1 200
subtotal	7 960	7 960	7 960
Operating costs			
Seeds	2 630	2 630	2 630
Pesticides	12 500	12 500	12 500
subtotal	15 130	15 130	15 130
Total	23 090	23 090	23 090
OXEN [ox]	0.75	0.75	0.75
OUTPUTS [ha^{-1} yr^{-1}][b]			
Stover (with grains)[c] [kg DM]	4 000[d]	3 900	3 300

a) Numbers before operations refer to period of the year (Subsection 1.2.1).
b) In a normal year in rainfall zone I (530 mm).
c) Average N-content is 26.9 g kg^{-1}.
d) Soil B2 occurs only in rainfall zone III and IV.

11. Pastures

(H. Breman)

In this chapter the quantity and quality of forage produced by natural pastures is evaluated on the basis of the available data. Feed availability from arable crops has been discussed in the preceding chapters. Methodologically, a distinction has been made between the rangelands of the delta zone (Delta Central and Zone Lacustre) that are temporarily flooded and the purely rainfed pastures. For the former, field observations constitute the point of departure for the study; for the latter, the starting point is rainfall and the properties of the various soil types. The rangelands of the Sahel are so dynamic, that it is preferable to base an analysis on the two latter factors rather than on a single evaluation from the past (Wilson *et al.*, 1983; Cissé, 1986; Breman *et al.*, 1984a).

In their 'Manual for evaluation of Sahelian rangelands', Breman and de Ridder (1991) have developed a method for determining the forage situation for both normal and dry years, as a function of rainfall and properties of the various soil types. This method has been applied to the pastures outside the delta zone, without further reference in the text. All the necessary calculations have been carried out for each landscape unit, both for the current situation with respect to the incidence of brush fires and for a situation with effective fire control.

The only quality criterion that has been taken into account is the nitrogen content of the forage, at least for the herb layer. For browse, account has also been taken of palatability. This does not mean that other quality criteria have been neglected: the method is based on empirical relationships between nitrogen content and digestibility and between the nitrogen and phosphorus contents.

11.1 Rainfed pastures: herb layer

11.1.1 Approach

The production of the rangelands and the quality of the forage produced depend on soil properties and on rainfall. Two approaches have been used, using as a criterion the quantity of infiltrated rainwater corrected for percolation losses. If this quantity is below 250 mm yr^{-1}, average annual biomass production is calculated with the following equation:

$$B = 8.77 * (I - D) - 692 \qquad (14)$$

where,

B = average annual total above-ground biomass production of herbaceous forage [kg ha^{-1}]

I = quantity of rainwater infiltrated [mm yr^{-1}]

D = percolation losses [mm yr^{-1}]

For this situation water availability is the dominant constraint on production. If, on the other hand, this quantity exceeds 250 mm, the availability of nutrients, especially nitrogen, is the limiting factor for forage production. For that situation, the following equation is used:

$$N_b = (0.83 * (I - D))/(f - 0.13) \qquad (15)$$

where,

N_b = average annual available quantity of nitrogen for the above-ground biomass [kg ha^{-1}].

f = average fraction of N_b lost per year.

This study is based on the average fertility of the soils of the Region, except in certain special cases (Subsection 11.1.4). The production of biomass is then calculated on the basis of N_b, using its nitrogen content at the end of the growing season, defined as a function of soil type (Subsection 11.1.5).

11.1.2 Availability of water

The availability of water [mm yr^{-1}] in a normal year and in a dry year is determined on the basis of rainfall, run-off as a function of soil type, soil storage capacity and percolation losses. Water is assumed to be lost when it percolates below 2 metres, unless the cover of woody species exceeds 15%. For shallow soils, the effective soil depth is applied, instead of 2 m.

It is assumed that at more than 15% tree cover the water percolating beyond 2 m depth is lost to the herb layer, but that the nitrogen in this water is still available for all vegetation, thanks to the trees (Subsection 11.1.4).

The availability of water calculated in this way differs from that indicated for arable crops (Report 2, Section 2.3). For that situation run-off has not been taken into account, in view of tillage and the type of soils suitable for arable farming.

A summary of the availability of water is presented in Table 11.1, showing that available water is in most cases lower than rainfall: there is a net loss due to surface run-off and percolation. Run-off losses are low on loamy sand soils (soil type B) and very high on loam or clay soils (D, E, F). The availability of water is strongly limited on the very shallow soil types (C2 and F2), where, in addition, percolation losses occur.

On sandy soils (soil type A) there are no run-off nor percolation losses, because on the one hand these soils are deep and on the other hand they occur only in the north of the Region where rainfall is insufficient to cause wetting beyond 2 m.

Soil types E1a and F1 receive run-off water from the surrounding soils: availability of water is higher than annual rainfall.

Table 11.1. Quantity of available water [mm yr^{-1}] per soil type in the 4 rainfall zones [RZ] in a normal and a dry year.

SOIL TYPE	RZ I		RZ II		RZ III		RZ IV	
	Normal	Dry	Normal	Dry	Normal	Dry	Normal	Dry
	530	360	455	300	375	235	255	155
A	.	.	.	.	.	.	255	155
B1,2	420	330	0	0	330	160	245	150
C1	422	315	375	275	320	215	240	145
C2	.	.	155	155	155	155	.	.
D1,2	380	285	340	250	285	210	225	140
E1a	.	.	0	0	470	295	320	195
E2a	.	.	225	150	280	175	0	0
F1	660	450	375	250	225	140	0	0
F2	155	144	227	150	187	117	127	77
F3	0	0	.	.	0	0	320	195

.) impossible value; 0) surface area neglectible.

11.1.3 The factor f

No experimental data are available for the Region on the factor f, the average fraction of nitrogen in the herbaceous biomass lost annually from the soil-plant system. To calculate production, we have therefore selected standard values defined as a function of average rainfall. For the rainfall zones I to IV in Table 11.1, these values are 0.38, 0.36, 0.35 and 0.32, respectively. They have, however, been adjusted to take into account estimated losses due to fire and grazing. It is assumed that the contribution of fire to the losses represented by f, increases from 0 in the North of the Region to 0.13 in the South.

On the basis of animal density and the distribution of the herds during the year, the contribution of grazing losses to the factor f is estimated at 0.075 for soil types A, B, C1 and E, at 0.15 for soil types C2, F and G, at and 0.09 for soil type D in rainfall zone I (RZ I) increasing to 0.15 in RZ IV. The contribution of the other processes is fixed at 0.2, as for the standard values.

These evaluations show that the values for f are a little higher than the standard values for most soil types in the southern half of the Region (around 0.4 in RZ I & II) and a little lower (around 0.3) in the more northern sector of the Region (RZ IV).

11.1.4 Production

Biomass production has been calculated for a year of average rainfall with the equations presented in Subsection 11.1.1 on the basis of the estimated availability of water and on values for f. Equation 14 has been used in approximately 30% of the cases, when availability of water was below 250 mm (Table 11.1). Alternatively, Equation 15 has been applied. In these cases, biomass production was derived from the value of N_b using the average nitrogen content of the biomass, which can graphically be determined from data on rainfall and run-off as described in the Manual.

The nitrogen content is used in the same way to calculate the nitrogen yield if biomass has been calculated with Equation 14. The value of N_b is necessary to calculate the production in a dry year. It may vary considerably as a function of the depth of soil wetting. If this depth is estimated from infiltration during a normal year, and during a dry year, taking into account soil texture and hence its water-holding capacity, N_b for a dry year can be calculated from the related value for a normal year, assuming a proportional relation with depth of wetting. Subsequently, the biomass is again calculated on the basis of the nitrogen content (derived from precipitation during a dry year).

A slightly more complex calculation has been carried out for situations (combinations of soil type and average rainfall) where the cover of woody species exceeds 15%. In such situations we can expect considerable competition with the herb layer for nutrients, light and water. The method described in the Manual leads to a biomass production by the herb layer which for the F1 soil in rainfall zone I (RZ I) represents 57% of the biomass without competition from woody species, against 72% for E1a in RZ I and 90% for F1 in RZ II. The correction for B2 in RZ I is negligible, and elsewhere it does not apply.

It appears that the fertility of certain soil types deviates considerably from the average for which the Equations 14 and 15 are valid, and that for those sistuations a correction of the calculated production levels is necessary. The correction factor is derived from differences in the nitrogen balance that are the result of differences in the availability of phosphorus, which in turn originate from differences in organic matter content. The production calculated for D2 and E2a has, for example, been multiplied by 0.75 (extremely poor soils) and that calculated for F3a by 1.15 (relatively rich soils).

The results of these calculations are presented in Table 11.2 together with one of the most important characteristics, the nitrogen content at the end of the growing season.

A comparison with field surveys conducted in the Region in 1971 (Boudet *et al.*, 1972) provides an indication of the reliability of the calculated values; in 1971 rainfall was approximately 10% below normal. A synthesis of all observations (Breman, 1975) indicates that in that year the production of the herb layer varied from 1 000 kg ha^{-1} in the North (RZ IV) to 2 100 kg ha^{-1} in the South (RZ I); the pastures on shallow soils (C2, E2a and F2) yielded a little less than half of those on sandy soils (A and B) and almost one third of those located on deep alluvial soils (C1, D1 and E1a). The tendencies shown in Table 11.2 are in good agreement with the results of these field observations, but the theoretical approach seems to have a tendency to slightly under-estimate production levels in the South of the Region.

Table 11.2 shows that in a dry year production in the South is on average approximately 75% of that in a normal year, compared with 35% in the North.

Table 11.2. Annual production of herb layer [kg DM ha^{-1}] and nitrogen content of the biomass at the end of the growing season [g kg^{-1}] in a normal year and a dry year and according to sol types and rainfall zones.

TYPE DE SOLS	ZONE PLUVIO	PRODUCTION		TENEUR EN N	
		Normale	Dry	Normale	Dry
A	IV	1 575	845	9.6	14.0
B1	I	1 790	1 395	7.2	8.4
B1.2	III	1 675	1 080	8.6	11.3
B2	IV	1 455	625	10.2	14.9
C1	I	1 855	1 345	7.0	9.0
	II	1 645	1 255	7.9	9.5
	III	1 575	1 050	8.9	11.8
	IV	1 415	580	10.6	15.9
C2	II.III	665	665	13.8	16.2
D1	I	1 485	1 020	7.6	9.9
	II	1 235	860	8.5	10.9
	III	960	710	9.9	12.1
	IV	1 280	535	11.7	17.0
D2	IV	960	400	11.7	17.0
E1a	III	3 255	2 240	6.3	8.4
	IV	2 315	940	8.2	11.5
E2a	II	960	465	10.5	15.3
	III	910	385	10.0	14.5
F1	I	1 600	1 190	5.6	6.5
	II	1 235	760	7.3	9.7
	III	1 280	535	11.6	17.3
F2	I	665	570	9.9	14.4
	II	1 300	625	10.5	15.5
	III	950	335	12.8	19.0
	IV	420	-	18.0	.
F3a	IV	1 715	615	8.1	11.4

-) zero value; .) impossible value.

11.1.5 Availability of forage and quality

The availability of forage has been calculated on the basis of the production as shown in Table 11.2. Two situations have been distinguished: one where the pastures are effectively protected against brush fires, the other based on the current incidence of brush fires. For both situations, corrections are first applied to take into account biomass losses due to grazing and causes other than fire and grazing. For grazing during the rainy season only, the availability of forage is derived by multiplying annual production by 0.5; for continuous grazing or grazing during the dry season only, the conversion factor is 0.35.

The effect of brush fires is estimated on the basis of a linear increase in the losses of biomass of 0% at an annual production lower than or equal to 700 kg ha^{-1} to 60% at a yield of 5 000 kg ha^{-1}. In the long term, at a constant stocking rate, effective fire control will result in a higher N_b value and an increase in production, because the value of f in Equation 15 decreases. In theory, therefore, one could expect a production 1.9 times higher in RZ I, 1.6 times higher in RZ II and 1.3 times higher in RZ III. These values have not been applied in this study, as only the direct effects of fire control have been taken into account.

The estimated forage availability from the herb layer is shown in Tables 11.3a and 11.4a (normal year, with and without brush fire, respectively) and 11.3b and 11.4b (dry year, with and without brush fire, respectively). In all cases three exploitation regimes are considered: grazing during the rainy season, year-round and during the dry season.

A single quality characteristic is given in Tables 11.3 and 11.4: the nitrogen content of the available forage. This value is derived from the nitrogen content of the biomass at the end of the growing season, taking into account the dynamics of nitrogen content during growth, which depends on rainfall and during the dry season. In Breman & de Ridder (1991), three situations are presented for the Region: at an annual rainfall below 300 mm, the nitrogen content decreases from 33 g kg^{-1} in July to 17.5 in October and 10 in June; between 300 and 600 mm yr^{-1} these values are 28, 10 and 7 g kg^{-1}, respectively; for rainfall exceeding 600 mm yr^{-1}, they are 24, 7 and 3.5 g kg^{-1}, respectively. These figures were graphically presented, and from these graphs the dynamics of nitrogen content of the pastures in the Region were derived by interpolation or extrapolation at the end of the growing period (Table 11.2). The average nitrogen contents for the rainy and the dry season were subsequently determined on the basis of these dynamics (Tables 11.3 and 11.4).

Finally, for the dry season, the fraction of forage just constituting a diet with a nitrogen content of 7.5 g kg^{-1} has been determined; on the basis of that average nitrogen content it is also possible to derive the nitrogen content in the remainder of the forage (Tables 11.3 and 11.4). The Manual indicates a nitrogen content of 7.5 g kg^{-1} as a minimum for forage. The remainder of the biomass may be still be consumed, provided that enough agricultural by-products or browse with a sufficiently high nitrogen content are available.

Table 11.3a. Forage availability [D, kg ha^{-1}] and nitrogen content [T, g kg^{-1}], based on the herd layer with year round grazing in a normal year without brush fires.

SOIL TYPE	RAINFALL ZONE	RAINY SEASON		SAISON SECHE					
				good		medium		bad	
		D	T	D	T	D	T	D	T
A	IV	140	19	410	8	-	.	-	.
B1	I	160	16	-	.	200	7.5	270	3
B1,2	III	150	17	-	.	380	7.5	60	4
B2	IV	110	20	380	9	-	.	-	.
C1	I	160	15	-	.	210	7.5	270	3
C1	II	140	16	-	.	280	7.5	150	3
C1	III	140	18	-	.	360	7.5	60	4
C1	IV	110	20	370	9	-	.	-	.
C2	II	60	21	180	10	-	.	-	.
C2	III	60	2	180	11	-	.	-	.
D1	I	130	16	-	.	260	7.5	140	3
D1	II	110	17	-	.	220	7.5	110	3
D1	III	80	19	240	8	-	.	-	.
D1	IV	100	21	340	10	-	.	-	.
D2	III	60	19	190	8	-	.	-	.
D2	IV	80	21	250	10	-	.	-	.
E1a	III	280	15	-	.	470	7.5	640	3
E1a	IV	200	17	-	.	470	7.5	230	3
E2a	II	100	20	320	9	-	.	-	.
E2a	III	80	19	310	8	-	.	-	.
F1[a)]	I	250	15	-	.	430	7.5	560	3
F1[a)]	II	120	16	-	.	210	7.5	280	3
F1[a)]	III	100	21	340	10	-	.	-	.
F2	I	60	19	180	8	-	.	-	.
F2	II	110	20	340	9	-	.	-	.
F2	III	80	22	250	11	-	.	-	.
F2	IV	40	26	110	14	-	.	-	.
F3a	IV	150	17	-	.	400	7.5	210	3

a) TH6 and TH7 (classification of PIRT) excluded in the Delta Central and the Zone Lacustre.

-) zero value; .) impossible value.

Table 11.3b. Forage availability [D, kg ha^{-1}] and nitrogen content [T, g kg^{-1}], based on the herd layer with year round grazing in a dry year without brush fires.

SOIL TYPE	RAINFALL ZONE	RAINY SEASON		SAISON SECHE					
				good		medium		bad	
		D	T	D	T	D	T	D	T
A	IV	70	23	220	11	-	.	-	.
B1	I	120	17	-	.	240	7.5	120	3
B1,2	III	90	21	280	10	-	.	-	.
B2	IV	50	24	160	12	-	.	-	.
C1	I	120	18	-	.	310	7.5	50	4
C1	II	110	19	330	8	-	.	-	.
C1	III	90	21	280	10	-	.	-	.
C1	IV	50	24	150	13	-	.	-	.
C2	II	60	24	180	13	-	.	-	.
C2	III	60	25	180	13	-	.	-	.
D1	I	90	19	270	8	-	.	-	.
D1	II	80	20	230	9	-	.	-	.
D1	III	60	22	190	11	-	.	-	.
D1	IV	50	25	140	13	-	.	-	.
D2	III	50	22	140	11	-	.	-	.
D2	IV	40	25	110	13	-	.	-	.
E1a	III	200	17	-	.	390	7.5	200	3
E1a	IV	80	21	250	10	-	.	-	.
E2a	II	40	24	120	13	-	.	-	.
E2a	III	30	24	100	11	-	.	-	.
F1[a)]	I	180	15	-	.	240	7.5	310	3
F1[a)]	II	70	19	220	8	-	.	-	.
F1[a)]	III	50	25	140	14	-	.	-	.
F2	I	50	24	150	12	-	.	-	.
F2	II	60	24	160	13	-	.	-	.
F2	III	30	26	90	14	-	.	-	.
F2	IV	-	.	-	.	-	.	-	.
F3a	IV	50	21	160	10	-	.	-	.

a) TH6 and TH7(classification of PIRT) excluded in the Delta Central and the Zone Lacustre.

-) zero value; .) impossible value.

Table 11.4a. Forage availability [D, kg ha^{-1}] and nitrogen content [T, g kg^{-1}], based on the herd layer with year round grazing in a normal year with brush fires.

SOIL TYPE	RAINFALL ZONE	RAINY SEASON		SAISON SECHE					
				good		medium		bad	
		D	T	D	T	D	T	D	T
A	IV	140	19	360	8	-	.	-	.
B1	I	160	16	-	.	170	7.5	230	3
B1,2	III	150	17	-	.	330	7.5	50	4
B2	IV	110	20	340	9	-	.	-	.
C1	I	160	15	-	.	180	7.5	230	3
C1	II	140	16	-	.	240	7.5	130	3
C1	III	140	18	-	.	320	7.5	50	4
C1	IV	110	20	330	9	-	.	-	.
C2	II	60	21	180	10	-	.	-	.
C2	III	60	23	180	11	-	.	-	.
D1	I	130	16	-	.	230	7.5	120	3
D1	II	110	17	-	.	200	7.5	100	3
D1	III	80	19	240	8	-	.	-	.
D1	IV	100	21	310	10	-	.	-	.
D2	III	60	19	190	8	-	.	-	.
D2	IV	80	21	240	10	-	.	-	.
E1a	III	280	15	-	.	310	7.5	420	3
E1a	IV	200	17	-	.	360	7.5	180	3
E2a	II	100	20	310	9	-	.	-	.
E2a	III	80	19	310	8	-	.	-	.
F1[a)]	I	250	15	-	.	300	7.5	390	3
F1[a)]	II	120	16	-	.	190	7.5	250	3
F1[a)]	III	100	21	310	10	-	.	-	.
F2	I	60	19	180	8	-	.	-	.
F2	II	110	20	310	9	-	.	-	.
F2	III	80	22	240	11	-	.	-	.
F2	IV	40	26	110	14	-	.	-	.
F3a	IV	150	17	-	.	340	7.5	180	3

a) TH6 and TH7 (classification of PIRT) excluded in the Delta Central and the Zone Lacustre.
-) zero value; .) impossible value.

Table 11.4b. Forage availability [D, kg ha^{-1}] and nitrogen content [T, g kg^{-1}], based on the herd layer with year round grazing in a dry year with brush fires.

SOIL TYPE	RAINFALL ZONE	RAINY SEASON		SAISON SECHE					
				good		medium		bad	
		D	T	D	T	D	T	D	T
A	IV	70	23	220	11	-	.	-	.
B1	I	120	17	-	.	220	7.5	110	3
B1,2	III	90	21	270	10	-	.	-	.
B2	IV	50	24	160	12	-	.	-	.
C1	I	120	18	-	.	280	7.5	40	4
C1	II	110	19	300	8	-	.	-	.
C1	III	90	21	260	10	-	.	-	.
C1	IV	50	24	150	13	-	.	-	.
C2	II	60	24	180	13	-	.	-	.
C2	III	60	25	180	13	-	.	-	.
D1	I	90	19	250	8	-	.	-	.
D1	II	80	20	220	9	-	.	-	.
D1	III	60	22	190	11	-	.	-	.
D1	IV	50	25	140	13	-	.	-	.
D2	III	50	22	140	11	-	.	-	.
D2	IV	40	25	110	13	-	.	-	.
E1a	III	200	17	-	.	300	7.5	160	3
E1a	IV	80	21	240	10	-	.	-	.
E2a	II	40	24	120	13	-	.	-	.
E2a	III	30	24	100	11	-	.	-	.
F1[a)]	I	180	15	-	.	190	7.5	250	3
F1[a)]	II	70	19	220	8	-	.	-	.
F1[a)]	III	50	25	140	14	-	.	-	.
F2	I	50	24	150	12	-	.	-	.
F2	II	60	24	160	13	-	.	-	.
F2	III	30	26	90	14	-	.	-	.
F2	IV	-	.	-	.	-	.	-	.
F3a	IV	50	21	160	10	-	.	-	.

a) TH6 and TH7 (classification of PIRT) excluded in the Delta Central and the Zone Lacustre.
-) zero value; .) impossible value.

11.2 Rainfed pastures: woody species

11.2.1 Approach

The method used to determine the available browse is based on an analysis and synthesis of many publications on trees and shrubs in the Sahelian countries. Where local data are not available, the production is estimated on the basis of tree cover, estimated as a function of the properties of the soil and rainfall on the one hand and the number of leaf layers on the other. This latter characteristic depends on the availability of water, and increases from 2 at an infiltration below 400 mm yr^{-1} to 6 at values over 900 mm yr^{-1}.

The soil types with a shallow groundwater table, close to the delta zone, are assumed to have a cover that deviates from the average, while it is also impossible to derive the number of leaf layers from infiltration only. For evaluation of these soil types, as for those of the delta zone (Section 11.3), the most recent observations have been used.

11.2.2 Woody cover

There are no reliable observations that allow determination of the cover and production of woody species for the Region as a whole. A full evaluation of the pastures of the Region was carried out in 1971 by Boudet *et al.* (1972), but since then, many of the trees and shrubs have died because of the drought (Breman *et al.*, 1984b). Therefore a method was selected that allows estimation of cover and number of leaf layers on the basis of soil type and the availability of water, assuming that human and animal population density are not exceptionally high.

To test the reliability of the method for the Region, the study by Boudet *et al.* (1972) was analyzed with respect to the cover of woody species as a function of rainfall and soil type. A comparison with the theoretically derived cover for the situation before the drought indicates, that for the Region, the cover of trees and shrubs for the soil types outside the delta zone or its immediate sphere of influence does not differ significantly from that for the Sahel in general. For the dunes and sandy zones, for example, the measured cover increases from less than 5% at a rainfall of 200 mm yr^{-1} to around 20% at a rainfall of 600 mm yr^{-1}; theoretically, values from 5 to 18% were derived. For shallow soils, the measured values varied between 0 and 20% at a rainfall of 200-300 mm yr^{-1} and slightly over 20% at a rainfall of 600 mm yr^{-1}. Theoretical estimates ranged from 5 to 15% at a rainfall of 200-300 mm yr^{-1} to 27% at a rainfall of 600 mm yr^{-1}.

Mortality of woody species due to drought was assessed in order to estimate the current cover. For the first half of the seventies, a synthesis based on data from the whole of the Sahel (Breman *et al.*, 1984a) was applied. To estimate the mortality rates in the extremely dry years of 1983 and 1984, use was made of the observed reduction in cover during the period 1979 to 1989 on a north-south transect located just to the west of the Region. In the period 1976 to 1979, the rangelands on this transect were described annually on the basis of 35 permanent quadrats on different soil types between the isohyets of 900 and 200 mm (Penning de Vries & Djitèye, 1982). In 1989 the observations were repeated by L. Diarra (ILCA) and M. Traoré (CNRZ/DRSPR). Comparison of the theoretical cover estimates with observations by ILCA since 1984 in the Gourma (Hiernaux *et al.*, 1990), suggests that the cover is under-estimated for shallow soils and grossly under-estimated for clay depressions. In 1989, observed cover on the sandy and loamy soil types agreed very well with the theoretically derived values. So as not to under-estimate the pasture resources, in this study, for shallow soils the results of measurements from the Gourma were used and for the clay depressions the theoretical estimates for the Seventies. A limited number of observations in the Gourma sugest this approach.

The cover values on which the production of browse is subsequently based, are shown in Table 11.5. For soil types F1 and B2 having a shallow watertable that would therefore not have suffered severely from the drought, the results of observations from the Eighties by Hiernaux (1980) and by the author have been used.

Because of the overriding effect of the shallow groundwater, no distinction between rainfall zones was made, especially since the number of observations was small.

Table 11.5. Total covering of tree and shrubs (horizontal projection) [REC, %] and the number of leaf layers [CF, n] for the various soil types and in the four rainfall zones.

SOIL TYPE	RZ I		RZ II		RZ III		RZ IV	
	REC	CF	REC	CF	REC	CF	REC	CF
A	2	2	2	2	2	2	2	2
B1	2	2	2	2	2	2	2	2
B2	15	4	15	4	15	4	15	4
C1	1	2	1	2	-	.	-	.
C2	-	.	3	2	2	2	2	2
D1	1	2	1	2	-	.	-	.
D2	1	2	1	2	-	.	-	.
E1a	30	4	17	3	6	2	4	2
E2a	1	2	1	2	-	.	-	.
F1	30	4	17	3	6	2	4	2
F1*	.	.	10	3	.	.	10	3
F2	-	.	3	2	2	2	2	2

*) Delta Central and Zone Lacustre.
-) valeur nulle; .) valeur impossible.

11.2.3 Production, availability and quality

To calculate production based on cover, the number of leaf layers was determined on the basis of the availability of water in a normal year as indicated in Subsection 11.2.1 (Table 11.1). These values have been adapted, however, for soil types with a shallow water table, based on production measurements by Hiernaux (1980).

The average specific leaf weight is 120 g m^{-2}, hence a theoretical single layer of leaves on 1 hectare would weigh 1 200 kg (dry matter). It is therefore possible to calculate annual leaf production for a cover consisting of several leaf layers (Table 11.5). For estimating production in a dry year it has been assumed, on the basis of observations by Bille *et al.* (1974), that the production of woody species in the Sahel is proportional to rainfall.

If we multiply leaf production by a factor of 1.5, total production of foliage, twigs and fruits is obtained. Average availability during the dry season is estimated at 30% of that total production.

Not all available forage is also accessible. In the Sahel zone, 35% of the browse is on average below two metres, but total exploitation of all accessible forage is not desirable from the point of view of sustainability: a maximum of 15% of the total production of browse in a normal year is regarded exploitable without permanent damage to trees and shrubs.

The quantity of useful browse, derived in this way, is indicated in Table 11.6, which presents the situation during the dry season.

The situation for the year as a whole can be derived from the above information. The nitrogen content of browse is set at 14 g kg^{-1} for the dry season. Differences between soil types and rainfall zones have been neglected. However, selection has been taken into account, the starting point being an average nitrogen content of 20 g kg^{-1} for the consumed species. Given the quality of the branches and fruits and their contribution to total browse, this figure has been multiplied by a factor of 0.7.

Table 11.6. Browse availability [kg ha^{-1}] in the dry season per soil type and rainfall zone.

SOIL TYPE	NORMAL YEAR				DRY YEAR			
	I	II	III	IV	I	II	III	IV
A, B1	8	8	8	8	5	5	5	5
C1, D1, D2, E2a	4	4	-	-	3	3	-	-
E1a	.	35	23	14	.	20	14	9
C2, F2	12	12	8	8	8	8	5	5
F1[a]	230	100	20	15	230	100	20	15
B2, G	.	80	80	80	.	80	80	80
F3a	50	.	50	50	50	.	50	50

a) TH6 and TH7 (classification of PIRT) excluded in the Delta Central and the Zone Lacustre.

-) zero value; .) impossible value.

11.3 Rangelands of the delta zone

11.3.1 Approach

The production and quality of rangelands in the delta zone within the Delta Central and the Zone Lacustre has been described on the basis of field observations by ILCA and others (Hiernaux, 1980; Hiernaux & Diarra, 1986), supplemented by those from Boudet *et al.* (1972) and Traoré (1978). These observations refer to the Seventies when the vegetation was more or less intact and dominated by perennial grasses. At that time, however, there were already fallow lands that had lost their original vegetation and its associated production and were dominated by *Oryza longistaminata*. That has been taken into account in this study.

To be able to utilize the data recorded by others, first a comparative study has been carried out to examine common aspects of different soil types. Hiernaux (1980) gives a detailed description of the relations between his soil types and those of Boudet *et al.* (1972). The soil types used here (Report 1, Chapter 3), have been compared only to those of Hiernaux: E1b consists of B(+Bp), VB, O(+Op) and VOR, i.e. the deeper areas of the delta zone; E2b consists of EOR, VSP, ESP and VH, i.e. the shallow areas of the delta zone; F3b is fallowed rice land, derived from the preceding soil types; its production is considered equal to that of O. F1 is a heterogeneous group of soil types (AC, Agb, Ag, TT, TA, TD, TC and TS) whose common characteristic is that they are not flooded. They could have been analyzed earlier in Sections 11.1 and 11.2, but their location within the delta zone in the middle of the flooded areas makes them so special, that it was felt that field observations were much more reliable than the preceding theoretical approach. Especially since the perennial grass *Andropogon Gayanus* dominates on 80% of the surface area, while the theory that has been applied is based only on observations from annual grasses.

To estimate forage availability, the information given by Hiernaux (1980) has been used, however in combination wth own criteria. Two arguments justify this approach:(*i*) Hiernaux included a species-specific quality criterion, while in the linear programming model the required quality varies as a function of the production target; (*ii*) unnecessary differences between the approach used for rangelands of the Delta Central and the Zone Lacustre and the rest of the Region are avoided.

The forage situation (quantity and quality) is defined for the dry season only, since only during that period the delta zone is accessible to the animals. For soil type F1 only, the possibility of grazing during the rainy season has been considered. Contrary to Hiernaux (1980), no special estimate has been made of pasture availability at the start of the dry season (initial grazing). That would suggest unwarranted accuracy of the figures and is hardly justified in view of the lack of detail in the description of the animal production systems.

11.3.2 Herb layer

Average production reported by Hiernaux (1980) has been assumed to refer to that for a normal year in terms of flooding; the minimum production as that for a dry year. Rainfall is considered for soil type F1 only. Table 11.7 gives a summary of the production level for both the main growth period and the regrowth. In addition to the difference between normal and dry years, allowance has been made for the difference between 'with or without' brush fire. For estimating losses due to brush fires, the values indicated by Hiernaux (1980) have been used. The indirect effects of the absence of brush fires, i.e. increased production, have not been taken into account.

Table 11.7. *Biomass production [t ha^{-1}] of the herb layer of the pastures in the delta zone, specified per growing period in a normal and a dry year.*

SOIL TYPE	NORMAL YEAR		DRY YEAR	
	main	regrowth	main	regrowth
E1b	10.9	2.0	7.5	1.3
E2b	6.8	0.6	4.2	0.3
F3b	8.0	0.8	5.0	0.4
F1	5.0	0.5	3.2	0.1

Absence of brush fires does not necessarily imply an improvement in the forage situation. In that situation, there will be no regrowth that can easily be selected and available forage of reasonable quality will fall to one quarter as a result (Breman *et al.*, 1978). From the viewpoint of animal husbandry therefore, absence of brush fire is not an advantage, unless availability of regrowth is assured in some other way or if the feed supply can be supplemented with high-quality concentrates. The first alternative has been selected, i.e. availability of regrowth is assured by mowing, conserving and storing the biomass produced during the main growing season. For that material, 40% losses have been taken into account. For bourgou (soil type B), the losses have been estimated at 50% given the length of the period of flooding.

As successive harvests and export of biomass cause rapid exhaustion of the soil, the sustainability of this production system is only guaranteed if the exported nutrients are restituted in the form of fertilizer.

Without mowing, and even in the present situation of frequent brush fires, the nutrient losses are much lower. When estimating the availability of forage in the case of brush fires, it has been assumed that production is sustainable if one quarter or less of the production during the main growing season is consumed annually by the herds (Breman & de Ridder, 1991). For situations where Hiernaux (1980) indicated an even lower availability, that value has been selected to estimate forage availability from total production. This only refers to the 'true' bourgou pastures for which Hiernaux gives a value of 0.16.

Production from the main growth period (Table 11.7) is multiplied by 0.25 (or 0.16) before deducing losses by brush fires, as observed by Hiernaux. The correction factors used are 0.35, 0.5, 0.5 and 0.65 for soil types E1b, E2b, F3b and F1, respectively. The availability of forage calculated in this way is given in Table

11.8. Availability from regrowth is calculated as a function of the production during the main growth period using factors derived by Hiernaux (1980) that vary between 0.6 and 0.7.

Table 11.8 also gives the nitrogen content of the available forage. These are average values for the dry season; for soil type F1 a value for the rainy season has also been given, considering its accessibility.

Tableau 11.8. Forage availability [D, kg ha^{-1}] and nitrogen content [T, g kg^{-1}] in the Delta Central and the Zone Lacustre in a normal and a dry year, with and without brush fires.

SOIL TYPE	DRY SEASON					
	good		medium		bad	
	D	T	D	T	D	T
E1b						
normal year, with fire	2 960	12	-	.	-	.
normal year, no fire	8 040	8	-	.	-	.
dry year, with fire	1 960	11	-	.	-	.
dry year, no fire	5 140	8	-	.	-	.
E2b[a]						
normal year, with fire	-	.	1 080	7.5	190	4
normal year, no fire	-	.	2 840	7.5	1 670	3
dry year, with fire	-	.	570	7.5	140	4
dry year, no fire	-	.	1 680	7.5	1 030	3
F1[b) c)]						
normal year, with fire	-	.	900	7.5	200	4
normal year, no fire	-	.	1 940	7.5	1 290	3
dry year, with fire	-	.	450	7.5	240	3
dry year, no fire	-	.	1 070	7.5	880	3
F3b						
normal year, with fire	1 710	11	-	.	-	.
normal year, no fire	-	.	7 110	7.0	-	.
dry year, with fire	980	10	-	.	-	.
dry year, no fire	-	.	3 350	7.0	-	.

a) Including TI4 (classification of PIRT), fraction of G.
b) TH6 and TH7 (classification of PIRT) in the Delta Central and the Zone Lacustre.
c) forage availability of herb layer in rainy period: 20 kg ha^{-1} with N-content of 17 g kg^{-1} (in a normal year) and of 20 g kg^{-1} (in a dry year). Browse: 50 kg ha^{-1} (normal year) or 30 kg ha^{-1} (dry year) and N-content of 20 g kg^{-1}.
-) zero value; .) impossible value.

The data have been derived from observations by Hiernaux & Diarra (1986) and Traoré (1978). It has been assumed that for the flooded soils, the differences between normal and dry years are negligible; variations in species composition and soil type are of greater importance (compare soil types E1b and F3b on the one hand, and soil types E2b and F1 on the other; deep and shallow or non-flooded areas, respectively).

11.3.3 Browse

In the delta zone substantial woody cover is present only on soil type F1. Measurements by Hiernaux (1980) of leaf production have been taken as the point of departure: his values have been multiplied by 1.5 to arrive at total browse production.

For dry years, estimates have not been based on a proportionality with rainfall as in Subsection 11.2.3, because of the influence of flooding and the groundwater table. Instead, a proportional relationship was established with the production of the perennial grass dominating on this soil, *Andropogon Gayanus*. In dry years the production of *Andropogon* is 3800 kg ha^{-1}, compared with 6000 kg ha^{-1} in normal years.

The availability of browse, shown in Table 11.8, has been derived from annual production according to the method given in Subsection 11.2.3, as has the quality.

11.4 Degradation and current forage situation

11.4.1 Over-estimation of forage availability

Availability of forage derived as described in the preceding sections, is an over-estimate compared to the current situation. For the Delta Central and the Zone Lacustre the reason is that the observations from the second half of the Seventies have been used as the basis for calculations, whereas since then mortality has decimated the population of perennial grasses, with catastrophic consequences for production (Hiernaux 1983; Hiernaux & Diarra, 1984; Diarra & Hiernaux, 1986). For the pastures outside the delta zone, equations have been used that yield accurate results if the vegetation is more or less intact (Penning de Vries & Djitèye, 1982; p. 275-283; 368-375). Even before the drought of the Seventies, some vegetation units already showed symptoms of overgrazing in the Gourma region (Boudet *et al.*, 1971). For the western part of the Region severe degradation of rangelands was reported during the Seventies, in particular on soils susceptible to crust formation (Penning de Vries & Djitèye, 1982; p. 384-386; Haywood, 1981).

Unfortunately, no systematic evaluation exists of the extent of degradation of the rangelands in the Region. An attempt has already been made (Subsection 11.2.2) to evaluate the present situation of woody species on the basis of a limited number of observations from areas in the vicinity of the Region. A similar attempt for the herb layer is made below.

The data presented so far are, however, valuable. On the one hand, it is unlikely that the low-lying areas in the delta zone and the pastures on the sandy soils outside the delta are seriously affected. On the other hand, the availability of forage as presented, refers to the situation that could be achieved by rangeland regeneration. With the LP-model it is therefore possible to evaluate the economic feasibility of such a regeneration. This refers only to the herb layer; as said before, the availability of browse is linked to the present cover by trees and shrubs. Given the cover of woody species prior to the drought, it has been estimated that the production potential of soil types E1a and F1 is not much higher than today (without irrigation and fertilizer). For soil types A and B1 it has been estimated that in a normal year the availability of browse in the north (RZ IV) could reach a value 15 kg ha^{-1} higher and in the south (RZ I) 40; for soil types C1, C2, D1, D2, E2a and F2 these figures are 45 and 110 kg ha^{-1}, respectively.

11.4.2 Current availability of forage

Rainfed pastures

Especially on susceptible soils, degradation due to over-grazing and drought, is to be expected under the current conditions. The method used to estimate the production of the herb layer, yielded for 1984 a figure twice that observed for similar, but degraded, pastures (Breman & Traoré, 1987). Both, to the east and to the west of the Region, pastures on a transect have been described during a number of years which allows determination of the extent of over-estimation of production for the whole of the Region (Penning de Vries & Djitèye, 1982; Hiernaux *et al.*, 1990). On the basis of this information it has been estimated that the current dry matter production on soil types C2, D2 and F2 in the four rainfall zones (I to IV) is on average 1 250, 500, 150 and 50 kg ha^{-1}, respectively. Soil type D1 is also seriously affected, but soil type C1 less seriously. As no quantitative information was available, soil type D1 was assigned the same value for current production as the other three soil types referred to above (under-estimate) and to regard soil type C1 as non-degraded (over-estimate).

The risk of brush fire is negligible on the degraded soil types given their annual production. The difference in production between dry and normal years is limited. In 1988 and 1989, at a rainfall that was 70 to 75% of normal, the average production over the transect in the Gourma (rainfall 200 to 500 mm) was only 7% higher than in 1987, when rainfall was only 40% of normal (Hiernaux *et al.*, 1988; 1989; 1990). A more accurate estimate is not possible considering the accuracy of the basic data. Therefore, a single average situation has been defined for the degraded pastures outside the delta zone, with or without brush fire and for normal and dry years.

The availability of forage is derived from the production as described in Subsection 11.1.5. Nitrogen content is estimated on the basis of 25 observations on degraded sites over the north-south transect to the west of the Region (Penning de Vries & Djitèye, 1982). The results are given in Table 11.8.

The degree of degradation of the pastures in the Delta Central and Zone Lacustre has been estimated on the basis of observations by Hiernaux & Diarra (1986). Based on their production measurements and their observations on the disappearance of populations of perennial grasses, it has been estimated that the current forage availability on soil type E1b is 15% below the estimate given in Table 11.8, on soil type E2b 65% and on soil type F1 80%.

In this case, variations in quality have been neglected; for those pasture areas that are still intact, the production conditions have not changed very much.

11.4.3 Carrying capacity of pastures and herd size

If the carrying capacity (i.e. the maximum possible number of animals) would be assessed on the basis of forage availability, taking into account the degradation of pastures, the value could differ substantially from the present herd size in the Region. Increase in herd size, commensurate with that in human population, has resulted in severe over-exploitation of the Region's rangelands (Breman & Taoré, 1987): in calculating the carrying capacity of pastures, the criteria of sustainability have largely been ignored. In this study, two of these criteria have been used in estimating forage availability: only 15% of the annual browse production in an average year is considered exploitable; apart from the losses due to grazing, brush fires, etc., only 50% of the annual production of perennial grasses can in principle be exploited.

If these correction factors are not taken into account, the calculated forage availability would come close to the current situation. If the carrying capacity is estimated on the basis of the situation corresponding to a dry year, the value will generally be lower than the current herd size; if based on the situation in a normal year, the value will be higher. Reasons are the high mortality rate of livestock during years of extreme drought and the rather slow rate of regeneration of herds, especially when cattle are the dominating species.

The forage situation that closest resembles the reality of the Eighties, taking into account brush fires, can be calculated from the data presented by:
- multiplying the values for production of the herb layer of the delta zone by 2, except for soil type F1 for which a factor of 1.8 must be applied;
- multiplying the availability of browse by 2.3 for normal years and 1.5 for dry years.

PART II. LIVESTOCK PRODUCTION

12. FEED AND ANIMAL PRODUCTION

(N. van Duivenbooden)

12.1 Livestock systems in the region

12.1.1 General description

The livestock systems practised in the Sahel appear to be highly diverse, comprising among others (FAO, 1977; Wilson *et al.*, 1983; Wilson, 1986):
- systems characterized by a high degree of mobility of the animals, a wide range of animal species, a wide range of objectives in terms of production and a wide range of activities covering both farming and non-farming activities;
- systems characterized by a sedentary lifestyle, specialising in different species and products and a tendency to concentrate on one particular activity;
- intermediate systems with a combination of these characteristics.

However, efficient they may have operated in the past, at present pastoral systems are deteriorating under the combined effect of intermittent drought and demographic pressure. More and more, animal husbandry is practised not so much by experienced, traditional pastoral herdsmen but by farmers and investors. As a consequence, pastoral societies gradually erode and large parts of the population find themselves in impoverished conditions. There is an increasing tendency towards a more sedentary way of life and the focus of animal husbandry has shifted southwards (Breman & Traoré, 1986a, 1986b; 1987).

At present, the key production parameters of livestock in the Sahel are governed by feeding conditions (Breman *et al.*, 1990). The level of animal production is very low, and virtually all the energy intake is used to ensure survival of the individual animal and the population as a whole. Under such circumstances, even slight differences in the quality of the available forage can lead to significant differences in productivity levels. Regional or local differences in the quality of the natural vegetation, or more in general, in the quality of the available feed are therefore decisive for the prospects of animal husbandry.

One of the aims of Part II of this report is to provide a quantitative analysis of the level of animal production, especially meat and milk production on the basis of feed availability. The analysis is based on the method developed in the Manual for Evaluation Sahelian Rangelands (Breman & de Ridder, 1991).

12.1.2 Description of production techniques

In the Region (Fifth region and Cercle de Niafunké) cattle, sheep, goats, camels, donkeys, horses, pigs, poultry and wild game are present, in number and economic value ranging from minor importance to very important. In this study, only the major production systems have been included and the degree of differentiation depends on the relative importance of the animal species. Twenty two production techniques are distinguished, based on four criteria: *(i)* animal species (cattle, sheep, goats, donkeys, and camels), *(ii)* main production objective (meat and/or milk or traction/transport), *(iii)* mobility of animals (migrant, semi-mobile or sedentary) and *(iv)* animal target production level (low, intermediate and semi-intensive).

The species included in this study are cattle including oxen (Chapter 13), sheep and goats (Chapter 14), donkeys and camels (Chapter 15) (Table 12.1). Pigs and poultry (e.g. chickens, ducks) are excluded, as the production systems at present are very extensive, i.e. almost without external inputs (e.g. absence of veterinary care leading to high mortality rates in chickens) and the outputs being mainly consumed by the farmer or sold at the market within the region (Kuit *et al.*, 1986; Wilson *et al.*, 1987; Sangaré, 1989) and more intensive production techniques are not considered feasible, as the regional grain production is considered insufficient. Moreover, data on investments for pig stalls, ckicken laying batteries, feed mills, and on labour requirements for the various relevant operations are scarce. In addition, the viability of these production techniques depends to a large extent on a strong demand for their products in the immediate vicinity (market), which is more likely to develop in the surroundings of Bamako, than in the Fifth region. As horses are considered a minor activity and data on wild game are lacking, these two species have not been included either.

With regard to mobility, the following definitions are applied:

- **Sedentary** (sed.)
  The animals stay all year within a 6 km radius of a permanent water point.
- **Semi-mobile** (s-m)
  During the hot season (February-June) the animals exploit the pastures between 6 and 15 km from a permanent water point. Overnight they stay in temporary camps; they return at least once every three days to the permanent water point to be watered.
- **Migrant** (mig.)
  During the rainy season (July-October) the animals leave the arable farming area to graze the so-called wet season pastures, i.e. pastures outside a 15 km radius from a permanent water point. During the dry season they stay within that distance.

Regardless of their mobility, all animals exploit crop residues left in the field after harvest during the cold season (November-January). These fields are within a 6 km radius of a permanent water point.

All livestock activities are expressed per Tropical Livestock Unit [TLU], equivalent to an animal of 250 kg liveweight. Hence, in the calculations, the parameters are defined as functions of liveweight. Generally, an average animal can be converted to TLU by the following conversion factors: 1 cow: 0.7 TLU; 1 donkey: 0.5 TLU; 1 sheep/goat: 0.1 TLU; 1 camel: 1.2 TLU (Le Houérou & Hoste, 1977).

Table 12.1. Defined livestock activities in the LP-model.

ACTIVITY CODE	SPECIES	MAIN PRODUCT	MOBILITY	PRODUCTION LEVEL
B1	cattle	traction	sedentary	low
B2	cattle	meat	semi-mobile	low
B3	cattle	meat	semi-mobile	intermediate
B4	cattle	meat	migrant	low
B5	cattle	meat	migrant	intermediate
B7	cattle	milk	sedentary	intermediate
B8	cattle	milk	sedentary	intermediate
B9	cattle	milk	migrant	intermediate
B10	cattle	milk	migrant	intermediate
B11	cattle	milk	sedentary	semi-intensive
B12	cattle	milk	sedentary	semi-intensive
B13	sheep	meat	sedentary & semi-mobile	low
B14	sheep	meat	sedentary & semi-mobile	intermediate
B15	sheep	meat	migrant	low
B16	sheep	meat	migrant	intermediate
B17	sheep	meat	sedentary	semi-intensive
B18	goats	meat & milk	sedentary & semi-mobile	low
B19	goats	meat & milk	sedentary & semi-mobile	intermediate
B20	goats	meat & milk	migrant	low
B21	goats	meat & milk	migrant	intermediate
B22	donkeys	transport	sedentary	intermediate
B23	camels	transport	migrant	low
B6	vacant			

12.2 Feed

12.2.1 Availability of feed

The starting point of the analysis is the inventory of available feed resources. They comprise natural pastures (Chapter 11), crop residues, fodder crops (Table 12.2) and products from agro-industry (e.g. low-quality flour and cotton-seed cake).

Table 12.2. Availability of stover, straw or hay for animal consumption as fraction of their total production for the various crops.

FORAGE	CONSUMABLE	ACCESSIBLE	AVAILABLE	SOURCE
Millet	0.75	0.90	0.68	chapter 2
Rice	0.90	0.70	0.63	chapter 3
Sorghum	0.45	0.50	0.23	chapter 4
Fonio	1.00	0.90	0.90	chapter 5
Cowpea	0.90	0.30	0.27	chapter 6
Groundnut	0.85	0.30	0.26	chapter 7
Shallot	0	0	0	chapter 8
Other vegetables	1.00	0.80	0.80	chapter 8
Bourgou	1.00	0.80	0.80	chapter 9
Fodder crops	0.90	0.90	0.81	chapter 10

12.2.2 Quality of feed

In addition to our quantitative assessment of the available forage, we have also estimated the quality in terms of nutritional value for the animals. The following approach is based on a single key parameter: the nitrogen content in the dry matter [g kg^{-1}]. Four quality classes have been distinguished:

- bad quality $N < 7.5$ (average N-content 3 g kg^{-1})
- medium quality N 7.5 - 10.0 (average N-content 8 g kg^{-1})
- good quality N 10.0 - 17.5 (average N-content 12 g kg^{-1})
- excellent quality $N > 17.5$ (average N-content 20 g kg^{-1})

This emphasis on nitrogen content does not mean that digestibility, the second quality parameter has been neglected. In the Manual, digestibility is derived from the nitrogen content. The average relation between nitrogen content and digestibility on which this is based, is such that digestibility tends to be underestimated for bourgou, and overestimated for leguminous plants and browse (Breman & de Ridder, 1991).

This description of the quality of the fodder on the basis of nitrogen content and average digestibility allows a reasonable estimate of the level of animal production, because the energy value and/or the protein content are the major limiting factors. Locally, mineral content (e.g. P) or vitamins may, however be more constraining.

In the LP-model, the diets used in the various animal husbandry activities have been composed on the basis of one or more feed sources of different quality, in such a way that on the one hand, the average qualities required for the various activities and their defined levels of production are attained and, on the other hand, maximum use is made of the available fodder (Table 12.3). The source of fodder (natural pasture, arable crops) in all 4 categories is irrelevant in this context, with one exception, 'browse', which is treated separately and is considered as a source of fodder for goats and camels only. Goats can spend 87% of their time searching for browse (Wilson, 1983). Although cattle and sheep may also feed on browse towards the end of the dry season, if there is not enough herbaceous fodder, in the current version of the LP-model that has not been taken into account. The average nitrogen content of browse is estimated at 14 g kg^{-1} in the dry season.

Table 12.3. Composition of livestock forage diets [% of dry matter intake] and average N-content of that diet [g kg^{-1} DM].

	WET SEASON	DRY SEASON		ALL YEAR
		Cattle/sheep	Goats/camels	
Diet I				
Quality class 1	0	33	44	
Quality class 2	0	67	41	
Quality class 3	50	0	0	
Quality class 4	50	0	0	
Browse	-	-	15	
Average N-content	16.0	6.7	6.7	9.0
Diet II				
Quality class 1	0	22		
Quality class 2	0	50		
Quality class 3	50	28		
Quality class 4	50	0		
Browse	-	-		
Average N-content	16.0	8.0		10.0
Diet III				
Quality class 1	0	13		
Quality class 2	0	50		
Quality class 3	30	37		
Quality class 4	70	0		
Browse	-	-		
Average N-content	17.6	8.8	8.8	11.0
Diet IV				
Quality class 1	0	13	13	
Quality class 2	0	50	50	
Quality class 3	50	14	14	
Quality class 4 (incl. concentrates)	50	23	23	
Browse	-	-	-	
Average N-content	16.0	10.7	10.7	12.0

Sources: Breman & de Ridder (1991); Veeneklaas, pers. comm.

12.2.3 Quantity of feed intake

The next step is to estimate the amount of dry matter of a given diet consumed daily per animal. That determines the amount of energy (digestible dry matter, DDM) available for maintenance and production. The method to derive feed intake by Sahelian cattle as a function of the desired production levels, is treated in detail by Breman & de Ridder (1991). Intake is expressed as a percentage of the metabolic weight ($W^{0.75}$). The feed requirements of an animal of a certain age and size can thus be used to derive those requirements for different age groups of both sexes, taking into account the specific needs of pregnant or lactating females.

12.3 Production level

The quality of the fodder on offer not only determines the quality ingested but also the production level of individual animals. Breman & de Ridder (1991) also treat the influence of the diet on the fertility of cattle, i.e. age at first calving and calving frequency. The most important production parameters of a given herd are thus related to fodder availability, because even average mortality seems to be linked to the feed situation.

On the basis of information on quantity and quality of the available fodder, we have calculated the productivity of the herds, using a simple demographic model. This is important because the total production of a population, has to be derived from the characteristics of individual animals. From an economic point of view, the herd is the most commonly used unit in extensive animal husbandry systems. The main requirement is that the herd should be sufficiently productive to provide a reasonable income to the owner and his family. Four feeding levels have been distinguished, characterized by different qualities and quantitaties of required forage:

- The lowest level guarantees the survival of the animal population and opens prospects for meat and manure production; milk production is still so low that it has to be completely reserved for calves. This situation designated level I is the minimum level at which a herd can continue to function. Since the heifers begin reproduction fairly late on and the birth rates are low, the population is barely able to sustain itself. All heifers reaching breeding age are needed for replacement of adult cows that have either died or culled at the age of eleven; increasing herd size through natural reproduction is therefore impossible. The average N-content of diet I to guarantee this production level is 9 g kg^{-1} and the corresponding digestibility 52%.
- Level II, refers to a situation where the feed situation is slightly better. Here, conditions are such that more than one third of the total milk production can be used for human consumption without seriously jeopardising the calves' chances of survival. The average N-content of diet II to guarantee this production level is 10 g kg^{-1} and the corresponding digestibility 54%.
- Levels III and IV represent a further improvement in the productivity parameters through the effect of better dietary conditions. For level III and IV, average N-content of the diet to guarantee this production level is 11 and 12 g kg^{-1} and the corresponding digestibility 56 and 59%, respectively.

The production level of the animals has been calculated for all four production situations, based on the following assumptions:

- Herd size is considered constant; any growth potential is added to production.
- Animals may die or be sold. Adult cows are sold at the age of eleven. The age at which heifers, not required for replacement, are sold is considered variable. The same applies to the selling age of male animals.
- Production consists of animals sold and the amount of milk exceeding 500 litres, required per calf.

The various animal husbandry systems currently practised in Mali are somewhere within this range of production levels. In the Soudanese region, sedentary systems operate between level I and level II. More to the north, the prospects are in principle more promising: here, most of the systems operate around level II, and sometimes even at level III, except if the animal population is too high. Nomadic systems that alternately use natural pastures in the North during the rainy season and pastures in the Niger Delta or similar flood plains in the dry season, can attain at least level II and even level III, unless over-grazing prevents profiting of the potential benefits of good dry season grazing land. The destruction of the pastures dominated by perennial grasses in the delta area is probably the main reason for the decrease in productivity of these systems. Level IV is only attained in research stations, or occasionally on dairy farms, thanks to the use of large amounts of agricultural by-products.

The production of the livestock systems dealt with in the following chapters are characterized by one of the four levels defined, and their fodder requirements are fixed automatically. Production has been expressed per TLU per year.

A TLU is a hypothetical animal, and it should be realized that production and intake expressed per TLU may differ between animal species. For example, 1 TLU of cattle produces 75 kg of meat annually and 1 TLU of sheep 97 kg. Hence, in this study we have distinguished TLU of cattle, TLU of sheep, etc.

13. CATTLE

(N. van Duivenbooden)

13.1 Introduction

The predominant breed of cattle in the region is the Soudanese Fulani, but Azawak occur as well (Wilson, 1986). According to Coulomb *et al.* (1981) occurring breeds are the West African Shorthorn (Taurus), the Touareg Zebu and the Soudan Peul Zebu. The latter can be subdivided into four types: Zébu Peul de Seno, Zébu Peul de Macina, Zébu Peul de Bourgou and Zébu Peul de Haire (RIM, 1987).

In this study eleven cattle activities are defined, based on the following three criteria: *(i)* main production objective, *(ii)* mobility of animals and *(iii)* animal target production level:

B1	traction	sedentary	intermediate production level
B2	meat	semi-mobile	low production level
B3	meat	semi-mobile	intermediate production level
B4	meat	migrant	low production level
B5	meat	migrant	intermediate production level
B7	milk	sedentary	intermediate production level
B8	milk	sedentary	intermediate production level
B9	milk	migrant	intermediate production level
B10	milk	migrant	intermediate production level
B11	milk	sedentary	semi-intensive with concentrates
B12	milk	sedentary	semi-intensive without concentrates

The main characteristics of cattle have been reviewed in detail by Ketelaars in the manual for evaluation of Sahelian pastures (Breman & de Ridder, 1991). On that basis, in this chapter various cattle parameters, as far as possible specific for the Region and relevant to the LP-model are discussed. Milk and meat production activities are treated in Section 13.2 and the oxen activity in Section 13.3.

13.2 Cattle for milk and meat

13.2.1 Herd structure

The herd structure (age and sex distribution) is function of the main production objective of the herd (e.g. live calves, meat, milk) and of course fecundity, death rates and offtake rate. Hence, the structure may vary from year to year (e.g. Wilson, 1986; Daudel, 1988). Breeding is generally not controlled, and its seasonality is a result of natural environmental conditions acting through fluctuations in feed supply (Wilson, 1986).

As pointed out in Subsection 1.3.2 and Section 12.4, the herd structure is assumed to be such, that the herd size remains constant in the long run. The struc-

Table 13.1. Productivity of cattle in Sahelian countries as a function of feed quality (I-IV), with emphasis on either meat (a) or milk (b) production.

	Feed quality level						
	I	II		III		IV	
		a	b	a	b	a	b
Composition of forage:							
N-content [g kg^{-1}]	9	10	10	11	11	12	12
digestibility [%]	52	54	54	56	56	59	59
Herd structure [%]:							
male	33	43	18	44	22	44	22
female	67	57	82	56	78	56	78
Weights [kg]							
at birth (m/f)	20	20	20	20	20	20	20
yearling (m/f)	100	100	100	100	100	100	100
2 years (m/f)	125	150	150	175	175	200	200
adult	200	250	250	300	300	300	300
Average weight [kg animal^{-1}]	150	173	162	183	173	196	177
Weight [TLU]	0.6	0.69	0.65	0.73	0.69	0.78	0.71
Metabolic weight [kg]	42.9	47.7	45.4	49.8	47.7	52.4	48.5
First calving age [yr]	5.5	3.5	3.5	2.5	2.5	2.5	2.5
Fertility rate [%]	50	71	71	86	86	86	86
Mortality [%]							
< 1 yr	20	20	20	20	20	20	20
1-2 yr	5	5	5	5	5	5	5
> 2 yr	2	2	2	2	2	2	2
Age at the time of selling:							
male [yr]	5	5	1	4	1	4	1
female [yr]	5	3	1	2	1	2	1
Offtake of total [%]	11	15	27	19	33	19	33
Distribution at selling [%]:							
male	54	51	53	51	52	51	52
heifer	0	26	26	33	33	33	33
adult cow of 11 yr	46	23	21	16	15	16	15
Production [kg animal^{-1}]:							
liveweight	22	39	35	52	43	59	43
milk	-	64	107	160	260	229	368
Feed intake:							
[% of weight]	2.2	2.2	2.3	2.3	2.4	2.2	2.4
Relative energy price [%]	100	108	108	115	115	123	123

Source: Breman & de Ridder, 1991.

ture of the herd thus varies as function of the production level and the corresponding diet, as a consequence of the relationship between feed quality and fertility, death rates, etc. (Table 13.1).

13.2.2 Productivity parameters

The productivity parameters as given in Table 13.1 show the importance of the quality of feed (Breman & de Ridder, 1991) and are in the same range as data reported by Coulomb *et al.* (1981), Daudel (1988), Diakité & Kéita (1988) and Wilson (1986). Hence, these values are applied in this study.

13.2.3 Weights and growth rates

Weights of animals vary in the course of the year and from year to year, mainly as a function of quality and quantity of available forage (Breman & de Ridder, 1991; Diakité & Kéita, 1988; Wilson, 1986).

The average weights applied in this study are given in Table 13.1.

13.2.4 Diseases and mortality rates

The most important diseases occurring in the region are rinderpest, contagious bovine pleuropneumonia (CBPP) and Black-quarter. Some cattle may have had pasteurellosis (Haemorrhagic septicaemia) and/or tuberculosis (Daudel, 1988; RIM, 1987). More details on disease incidence are given by e.g. Hall (1985).

Data on mortality rates of cattle in the region are scarce. Wilson (1986) observed an abortion rate of about 3% in Central Mali. For calves up to one year of age the mortality rate is about 30%, but may decrease to 15%, if the herd is fed continuously on improved pastures for 15 years, whereas the mortality rate of animals between 1 and 3 years of age may decrease under the same conditions from 8 to 3% and from animals over 4 years of age from 3 to 2% (Diakité & Kéita, 1988). Observed mortality rate of cattle over 4 years of age is about 5% (Wilson, 1986).

In this study the data derived by Breman & de Ridder (1991) have been used (Table 13.1), that are not significantly different from those quoted above.

13.2.5 Outputs

As pointed out in Chapter 12, the production level is assessed first, and subsequently the quality of the required diet (I-IV) is derived.

13.2.5.1 Milk

The competition for milk between young calves and human consumption is evident. Young animals are prevented from suckling when milk from their dams is required for human consumption (Wilson, 1986). Milking for human consumption starts from 10 days after calving (Daudel, 1988), but for milking the calf must be present.

Milk production for the various production techniques is calculated on the basis of the data presented in Table 13.1 and is given in Table 13.4.

Milk can be traded locally, exchanged against cereals, transformed into butter-oil or sold elsewhere. The price obtained varies accordingly, as a function of the time of the year and subject to the law of demand and supply. In the surroundings of Mopti the milk price varies from 75 to 150 FCFA kg^{-1} in the period of sufficient supply, but from 200 to 300 FCFA kg^{-1} in the period of scarcity, even up to 500 FCFA kg^{-1} in extreme cases. In areas with a high milk production and a low demand, milk is almost available for free at a price between 10 and 50 FCFA kg^{-1} (Diakité & Kéita, 1988; Daudel, 1988). According to Sangaré (1989) the price of milk is 250 FCFA kg^{-1}, and according to Cissé (pers. comm.) 180 FCFA kg^{-1}.

In this study the price of milk at Mopti is set at 180 FCFA kg^{-1}.

13.2.5.2 Meat

Meat production for the various production techniques as calculated on the basis of the data from Table 13.1 is given in Table 13.4.

The price of meat is a function of the time of the year, with a high level at the end of the dry season (May-July) and a low level at the return of the animals from the wet season pastures (October-December, Diakité & Kéita, 1988). In addition, the sales price varies with age and sex of the animal (Table 13.2). Unfortunately, no weights of those animals are reported, so that the price per kg can not be assessed. Reported meat prices in the Region are between 250 and 320 FCFA kg^{-1} (Sangaré, 1989; Cissé, pers. comm.).

In this study the price is set at 320 FCFA per kg liveweight.

Table 13.2. Prices of cattle at market.

OX	YOUNG BULL	HEIFER	COW	AVERAGE[a]	SOURCE
100 000	75 000	85 000	50 000	77 500	1
100 000					2
75 000[b]					3
				62 500	4
85 400	54 470	45 580	38 150		5[c]
		60 000			used

Sources: 1 = Diakité, 1989a; 2= PIRT, 1983; 3 = INRZFH & ORSTOM, 1988; 4 = Sangaré, 1989; 5 = Diakité & Kéita, 1988.

a) indicates a non-specified animal.

b) 4 years of age.

c) in 1987.

13.2.5.3 Manure

Manure is an important by-product of animal activities, because of its use as fertilizer in arable farming and as fuel. Hence, calculation of manure availability is of major importance. The manure requirements for fuel are set in the LP-model at 0.5 kg DM $person^{-1}$ d^{-1} and the availability of manure is estimated on the basis of the following considerations:

- During the rainy season (July-September), sedentary cattle stay on average 12 hours per day in a corral, where 80% of the manure can be recovered. For the remainder of the day when the animals are grazing, their manure is lost for arable farming. Semi-mobile cattle spend 6 hours a day in the corral. Migrant cattle are during the rainy season too far away for their manure to be used in crop cultivation.
- During the cold season (October-January) all cattle, sedentary, semi-mobile and migrant, spend most of their time in the field: 65% of their manure is effective on those fields.
- During the hot season (February-June), finally, sedentary cattle are again on average 12 hours a day in a corral (80% manure recovery), while during grazing of the pastures around the villages no manure is recovered. It is assumed that migrant and semi-mobile cattle spend 6 hours per day in the corral as they are grazing pastures further away from the village. Manure recovery is consequently half of that of the sedentary animals.

Summarizing, 46% of the manure produced by sedentary cattle can in principle be utilized in crop cultivation, compared to 31% of that of semi-mobile and 24% of that of migrant cattle. Manure availability per TLU for the various production techniques is included in Table 13.4.

13.2.6 Inputs

13.2.6.1 Feed requirements

Feed requirements of cattle at the various production levels are calculated on the basis of their liveweight, as indicated in Table 13.1. For the semi-intensive milk activity B11, 15% of the feed requirements are assumed to be met by concentrates. The feed requirements as used in the LP-model are included in the input-output table (Table 13.4).

13.2.6.2 Labour requirements

Labour requirements are specified separately for two periods: the rainy season from July to October (90 days, periods 1 to 3, Subsection 1.2.1) and the remainder of the year (275 days, periods 4 to 6).

1. Herding

According to Sangaré (1989), cattle herds are herded all year round, up to 15-16 hours per day. One herdsman is required for a herd of about 35 TLU, equivalent to 0.03 mnd TLU^{-1} d^{-1}. Daudel (1988) reports a labour requirement of one herdsman for 15 to 20 lactating cows, equivalent to 0.06 mnd TLU^{-1} d^{-1}.

For the LP-model, labour requirements for herding are set at 0.03 mnd TLU^{-1} d^{-1}, hence, 3 (=90*0.03) and 8 (=275*0.03) mnd TLU^{-1} for the rainy (July-September) and the dry season, respectively.

2. Milking

Milking is carried out twice a day in the rainy season and once in the dry season, requiring one hour each time for a herd of 35 TLU (Sangaré, 1989), equivalent to 0.007 and 0.004 mnd TLU^{-1} d^{-1}, for the rainy and dry season, respectively, if all cows are milked. According to Daudel (1988) milking requires 3 to 5 minutes per cow, set at 0.012 mnd TLU^{-1} d^{-1} (one milking per day).

It is assumed in the LP-model that the labour requirements for this operation are 0.012 mnd TLU^{-1} d^{-1} when milk is a by-product, 0.024 mnd TLU^{-1} d^{-1} if milk is the main product and 0.036 mnd TLU^{-1} d^{-1} for the semi-intensive milk production. The length of the period that milking can be practised is set at 200 and 240 d for the meat- and dairy-cattle, respectively. Subsequently, the fraction of lactating cows should be taken into account in calculating the total labour requirements. Table 13.1 gives information on the fraction of cows in the herd, but not on the proportion of lactating cows. Hence, it is assumed that 75% of cows are lactating, i.e. 42% of the herd for meat-cows and 59% of a dairy herd (note that cows on diet I are assumed not to produce milk for human consumption). The total labour requirements for milking for the two periods are included in Table 13.4.

Note that transport of milk to the factory is not included in these requirements.

3. Watering

Watering of animals is normally practised between noon and 14.00 h (Sangaré, 1989) and is included in the regular tasks of herdsmen (Daudel, 1988). Hence, no separate labour requirements are defined for this operation.

4. Vaccination

Vaccination is carried out in the period from December to March (Daudel, 1988), generally by ODEM (Diakité & Kéita, 1988; RIM, 1987). No data are available on the time spent by owners or herdsmen on this operation. Hence, it is assumed that these labour requirements are included in the regular tasks of the herdsmen.

5. Feeding

Labour for feeding is required for those production techniques, in which cattle are kept in a corral (semi-intensive milk production). However, no data are available on these requirements. Hence, it is assumed that forage collection, veterinary care and watering combined requires the same labour as herding (0.03 mnd TLU^{-1} d^{-1}), i.e. 3 and 8 mnd TLU^{-1} for the rainy and the dry season, respectively.

13.2.6.3 Monetary inputs

Capital charges are zero, except for the semi-intensive milk production techniques. Note that capital charges for small equipment (calebasses, etc.) are neglected, due to lack of data and the difficulty in attributing them to a specific livestock unit.

For the semi-intensive techniques capital charges are included for improved corrals and equipment:

1 Improved corral

Reported construction costs of a building with a capacity of 2 400 head of cattle in 1978 were about 160 million FCFA, equivalent to 66 700 FCFA head^{-1}. However, these costs are considered very high (Delgado, 1980). Wennink (1988) reported investment costs of round corrals (consisting of wooden poles and fence of wire-netting of 1.5 m height and three rows of barbed wire) with a capacity of 10 and 80 head ranging from 79 000 to 215 000 FCFA, respectively. As profit increases with number of animals (e.g. Delgado, 1980), the capacity of 80 head is applied in this study. Taking into account a life expectancy of 10 years, the depreciation rate is 21 500 FCFA yr^{-1}, equivalent to about 270 FCFA head^{-1} yr^{-1} or 400 FCFA TLU^{-1} yr^{-1}.

2 Equipment

Reported purchase costs of milking equipment in 1978 were about 73 million FCFA (Delgado, 1980), but no specifications are given. A life expectancy of 5 years was reported for the equipment for 2 400 head of cattle. This would imply a depreciation rate of about 8 700 FCFA TLU^{-1} yr^{-1}. This value seems rather high, but no other data are available to confirm our doubt. In this study, depreciation costs of this equipment are estimated at 3 000 FCFA TLU^{-1} yr^{-1}.

Operating costs comprise the following six items:

1 Vaccination

Vaccins against the common diseases are available in the Region at ODEM, but not all animals are vaccinated at present (Table 13.3). The costs per vaccination are given in Table 13.3. Price of doses against gastro-intestinal et hepatic parasites is 150 FCFA, but also against these diseases not all animals are vaccinated (45%, Sangaré, 1989). According to Baur *et al.* (1989), routine vaccinations are carried out against rinderpest and contagious bovine pleuropneumonia, anthelmintic treatments and prophylactic treatments against trypanosomiasis. However, the number of vaccinations per year is not reported.

In this study the vaccination costs against hemoparasites are estimated at 20 FCFA per dose. It is assumed that the animals are vaccinated once per year. The total monetary inputs for vaccinations, thus amount to 260 FCFA head^{-1} yr^{-1}. However, in the light of the assumed mortality rates and actual practice, it is assumed that only 75% of the total population is vaccinated. Application of the general conversion factor of 0.7 head TLU^{-1} (each head must be vaccinated, there is thus no relation to weight), this implies operating costs of 280 FCFA TLU^{-1} yr^{-1}.

2 Supplements

For exploitation of bourgoutières (Chapter 9), herdsmen have to pay to owners

Table 13.3. Information on the actual state of vaccination against common diseases of cattle and price of vaccination per dose.

DISEASE	% VACCINATED	PRICE/VACCINATION		
		SOURCE 1	SOURCE 2	USED
Rinder pest	68	13	20	20
Bovine peripneumonia	47	18	20	20
Black-quarter	15	13	20	20
Pasteurellosis	8	15		15
Charbon bactéridien	2	15		15
Hemoparasites	45	?		20
Gastro-intestinal and hepatic parasites	?	150		150
Total				260

Sources: 1= Sangaré, 1989; 2= Daudel, 1988.

5 000 FCFA for a herd of 50 to 100 head (Sangaré, 1989). It is repeated, that fodder crops do not have a price in the LP-model, because they do not cross the boundaries of the subregion. Hence, these costs are not included.

Other supplemental feed (e.g. concentrates) are priced separately in the LP-model. The reported price of concentrates ranges from 12.5 FCFA kg^{-1} (Sangaré, 1989) to 25 (Daudel, 1988), and from 25 FCFA kg^{-1} in the rainy season to 60 at the end of the dry season. A limited inquiry in Mopti in January 1990 showed prices at the market of 71 FCFA kg^{-1} (sac of 0.7 kg) and 38 FCFA kg^{-1} for a sac of 50 kg. The latter value is used, which taking into account a dry matter content of 86% equals 44 FCFA kg^{-1} DM.

3 Salt

Salt is important for maintaining body condition of the animal. The minimum salt requirements are about 1/7 of those for camels (Wilson, 1984; Paragraph 15.2.9.2), i.e. 5.6 kg TLU^{-1} yr^{-1}.

Given a purchase price of 4 500 FCFA for a block of 5 kg (Cissé, pers. comm.), the costs are 5 100 FCFA TLU^{-1} yr^{-1}.

4 Maintenance of improved corral

According to Wennink (1988), maintenance costs (e.g. for oil to preserve the wood) of a corral for 80 head are about 23 000 FCFA yr^{-1}, equivalent to about 400 FCFA TLU^{-1} yr^{-1}.

5 Drinking water

Costs associated with the supply of drinking water include the depreciation and maintenance of wells, with or without storage tanks, which can be substantial: they have been estimated at 15 to 35% of the gross revenue of livestock systems, depending on herd management (sedentary or migrant), animal productivity and type of well (Breman *et al.*, 1987). For a new well the costs are estimated at 2 500 to 3 000 FCFA TLU^{-1} yr^{-1}. These values, however, refer to a situation where new wells are drilled, to open previously unexploited pastures. In the actual situation in the region, existing wells are used, and, moreover, most of the animals exploit during the dry season the natural surface water of the river, the lakes and the remaining pools. Drinking water is not paid in terms of money, but Wilson (1986) reports that e.g. Moors pay for access to a well in the form of manure.

In the present version of the LP-model no costs for drinking water are included.

6 Taxes

Taxes and levies (e.g. on marketing, customs, OMBEVI, veterinary costs, etc.; Diakité, 1989b) are not included in this study. Prices, as given are without taxes.

The total monetary inputs are given in Table 13.4.

13.3 Oxen

13.3.1 Introduction

According to Baur *et al.* (1989), at least one ox is kept per household, but hiring of oxen also occurs (Wilson, 1986).

Oxen are mainly fed roughages, but in the dry season additional forages may be offered, to maintain their condition, so that after the first rains they are able to work. Observed supplemental feed comprised rice bran, millet bran and millet grains (Kolff & Wilson, 1985). In addition, some household or other type of salt may be provided in the dry season (Wilson, 1986).

In this study, oxen are not treated as a complete herd, but as individuals. This implies that to satisfy the demand for oxen in the Region, the number of oxen should not exceed 40% of the total number of cattle in the Region, as calculated in the LP-model. Hence, oxen are supposed to be bought at the market and their active life is set at 10 years. To keep the animals in working condition, the feed requirements in terms of energy should be met, but in addition, the quality in terms of nitrogen content should be sufficient. Therefore, it is assumed that the animals are kept on diet II (Section 12.3).

13.3.2 Herd structure and productivity

As a consequence of our definition, no herd is defined. The animals dying from diseases or other causes are replaced by buying new animals at the market, in the LP-model represented by purchase from other cattle production techniques.

13.3.3 Weight and growth rates

Weight of Malian draught oxen may range from 350 to 450 kg (Wilson, 1984), but much lower values are also reported, from 325 to 360 kg, the latter in case of good forage supply (Diakité & Kéita, 1988).

In this study the weight is set at 325 kg, equivalent to 1.3 TLU.

13.3.4 Diseases and mortality

Oxen are susceptible to the same diseases discussed in Subsection 13.2.4. In this study the average mortality rate is set at 4% yr^{-1}, on the basis of the data presented in Table 13.1.

13.3.5 Outputs

Draught power is the main product of oxen, mainly used for land preparation and weeding and for transport (4-wheel carts). For details on the draught power delivered, reference is made to e.g. FAO (1972) and Munzinger (1982). In this study, the availability of draught power is expressed in terms of animals per TLU, i.e. 0.77 ox TLU^{-1} (=1/1.3).

Meat originating from oxen is not considered explicitly in the LP-model, because it is already taken into account as meat from other cattle production techniques (note that oxen are bought as 'meat').

Manure availability is estimated on the basis of the data presented in Paragraph 13.2.5.3 at 60% of the total production, i.e. 580 kg DM TLU^{-1} yr^{-1}.

13.3.6 Inputs

13.3.6.1 Feed requirements

In analogy with the data in Table 13.1, the feed requirements are based on the intake requirements for Diet II, i.e. 2.2% of the liveweight per day. For the average weight of 325 kg, that implies an intake of 2 010 kg DM TLU^{-1} yr^{-1}.

13.3.6.2 Labour requirements

Labour is required for the following two operations:

- Herding
  Draught oxen are herded with the bulk of the village cattle on fields close to the homestead in the early dry season. Later on, when the main herd leaves for the annual short transhumance, they are allowed to graze freely, but are kept at night in the compound (Wilson, 1986).
  It is assumed in this study, that the average labour requirements for herding in the rainy season are 0.02 mnd TLU^{-1} d^{-1} and in the dry season 0.022. Hence, 2 and 6 mnd TLU^{-1} for the rainy and the dry season, respectively.
- Training
  As a consequence of purchasing young bulls, training is required (e.g. Mungroop, 1989) before they can be used as draught oxen. It is assumed that for

Table 13.4. Input-output table of defined cattle production techniques.

CHARACTERISTIC	B1	B2	B3	B4	B5	B7	B8	B9	B10	B11	B12
Production target											
meat	–	+	+	+	+	–	–	–	–	–	–
milk	–	–	–	–	–	+	+	+	+	+	+
transport/traction	+	–	–	–	–	–	–	–	–	–	–
Production level											
low	+	+	+	–	–	–	–	–	–	–	–
intermediate	–	–	+	–	+	+	+	+	+	–	–
semi-intensive	–	–	–	–	–	–	–	–	–	+	+
Mobility											
sedentary	+	–	–	–	–	+	+	–	–	+	+
semi-mobile	–	+	+	–	–	–	–	–	–	–	–
migrant	–	–	–	+	+	–	–	+	+	–	–
INPUTS [TLU^{-1} yr^{-1}]											
FEED [kg DM]											
Diet I	–	2 000	–	2 010	–	–	–	–	–	–	–
Diet II	2 010	–	2 000	–	–	2 090	–	2 090	–	–	–
Diet III	–	–	–	–	2 100	–	2 200	–	2 200	–	–
Diet IV	–	–	–	–	–	–	–	–	–	1 850	2 180
Concentrates	–	–	–	–	–	–	–	–	–	330	–
Browse	–	–	–	–	–	–	–	–	–	–	–
LABOUR[a] [mnd]											
1-3 Herding	2	3	3	3	3	3	3	3	3	–	–
1-3 Milking	–	–	0.5	–	0.5	1.5	1.5	1.5	1.5	2	2
1-3 Feeding	–	–	–	–	–	–	–	–	–	3	3
4-6 Herding	6	8	8	8	8	8	8	8	8	–	–
4-6 Milking	–	–	1	–	1	2	2	2	2	3	3
4-6 Feeding	–	–	–	–	–	–	–	–	–	8	8
4-6 Training	8.5	–	–	–	–	–	–	–	–	–	–
Total	16.5	11	12.5	11	12.5	14.5	14.5	14.5	14.5	16	16

.../...

a) Numbers in front of operations refer to period of the year. Labour refer to the sum during these periods.

Table 13.4. Continued.

CHARACTERISTIC	B1	B2	B3	B4	B5	B7	B8	B9	B10	B11	B12
MONETARY INPUTS [FCFA]											
Capital charges											
Corral	1 120	–	–	–	–	–	–	–	–	400	400
Equipment	–	–	–	–	–	–	–	–	–	3 000	3 000
Oxen	6 000	–	–	–	–	–	–	–	–	–	–
subtotal	7 120	–	–	–	–	–	–	–	–	3 400	3 400
Operating costs											
Vaccinations	280	280	280	280	280	280	280	280	280	280	280
Salt	5 100	5 100	5 100	5 100	5 100	5 100	5 100	5 100	5 100	5 100	5 100
Corral	400	–	–	–	–	–	–	–	–	400	400
subtotal	5 780	5 380	5 380	5 380	5 380	5 380	5 380	5 380	5 380	5 780	5 780
Total costs	12 900	5 380	5 380	5 380	5 380	5 380	5 380	5 380	5 380	9 180	9 180
OUTPUTS [TLU^{-1} yr^{-1}]											
Meat [kg liveweight]	0	37	57	37	71	54	62	54	62	61	61
Milk for human consumption [kg]	–	–	93	–	219	165	377	165	377	518	518
Available manure [kg DM]	580	299	287	232	222	462	445	241	232	716	716
Number of animals [ox]	0.77	–	–	–	–	–	–	–	–	–	–

training 2 man are occupied during two months in the dry (off-peak) season with one oxen-team and taking into account the annual purchase of 0.1 young bull, labour requirements for training are 8.5 mnd TLU.

13.3.6.3 Monetary inputs

Capital charges comprise the following two items:

- Oxen
  Considering the purchase price of a young bull (Table 13.2) and the average life expectancy of 10 years, the charges are 6 000 FCFA TLU^{-1} yr^{-1}.
- Improved corral
  Construction costs of an improved corral for oxen vary with size, from 29 000 to 37 000 FCFA for 2 and 6 oxen, respectively. The difference is mainly due to the use of wood only in the first and of wood and wire netted Ursus in the latter case (Wennink, 1988).
  It is assumed that farmers keep 2 oxen in an improved corral, hence, the construction costs are 29 000 FCFA. Taking into account a life expectancy of 10 years, the depreciation rate is 1 120 FCFA TLU^{-1} yr^{-1}.

Operating costs comprise the following five items:

1 Supplements
  No supplementary feed (imported from outside the region) is included, hence these costs are zero.
2 Salt
  The requirements are assumed identical to those for the other cattle production techniques, i.e. 5 100 FCFA TLU^{-1} yr^{-1}.
3 Vaccination
  According to Berckmoes & Bengaly (1989), routine vaccinations are against rinderpest and peripneumonia.
  The vaccination requirements are assumed identical to those for the other cattle production techniques, i.e. 5 400 FCFA TLU^{-1} yr^{-1}.
4 Maintenance of corral
  Maintenance costs of a corral are set equal to those for the other cattle production techniques, i.e. at 400 FCFA TLU^{-1} yr^{-1}.
5 Drinking water
  As for the other cattle production techniques no operating costs are attached to drinking water.

The total monetary inputs are given in Table 13.4.

13.4 Input-output table

The inputs and outputs of the various cattle production techniques are quantified in Table 13.4.

14. SHEEP & GOATS

(N. van Duivenbooden)

14.1 Introduction

In this chapter information on sheep and goats relevant to the LP-model is discussed. The approach followed is in principle similar to that for cattle, but for small ruminants not sufficient detailed information on the relationship feed quality - productivity under tropical conditions is available. Therefore, the results of a study of sheep and goats in a millet- and a rice-agropastoral system (Wilson, 1986) have been used for assessment of that relationship. The millet-agropastoral system was identified as level I, the rice-agropastoral system as level III. In this study sheep in these systems are referred to as 'millet-sheep' and 'rice-sheep', respectively.

Derivation of the relevant parameters is discussed in Sections 14.2 and 14.3 for sheep and goats, respectively and these are used in a simple model. This so-called 'SR-model' calculates meat production and feed requirements of an average animal in the herd, under the condition that herd size remains constant in the long run (Annex 6). Inputs for sheep and goat production techniques, comprising feed requirements, labour requirements and monetary inputs, are treated in Section 14.4. The inputs and outputs are finally summarized in the input-output table (Section 14.5). All technical coefficients are again expressed per Tropical Livestock Unit.

14.2 Sheep

14.2.1 General description

The predominant breed of sheep in the region is the haired West African long-legged sheep or Sahel sheep, with three distinct types:
- The Toronké type, owned by Fulani, who migrate seasonally over most of the region, and by most of the agropastoral sedentary farmers of the region;
- The long-haired Black Maure ('Maure', Moor, Black Arab or Nar) found in the west of the region, towards the Mauretanian border;
- The white, pied or fawn Tuareg type, kept mainly by nomadic or semi-nomadic Tuaregs, especially in the Gourma and Seno Mango; two subtypes are distinguished on the basis of shape and hair:
  + the big-sized Targui with a height of 0.7-0.8 m, a weight of 40 to 50 kg, and white wool marked to a greater or lesser extent with reddish brown spots.
  + the small-sized Targui, with a height of 0.5-0.6 m, weighing about 20 to 30 kg. The wool is greyish and longer than that of the big-sized sheep. These sheep occur principally in the Gourma above 15° N (Currey *et al.*, 1980; Gatenby, 1986; Wilson, 1986).

In addition, one of the few true wool breeds of Africa is found along the border of the river Niger in the Region. The owners of this Macina breed are almost all agropastoral Fulani who also cultivate rice (Charrey *et al.*, 1980; Coulomb *et al.*, 1981; Wilson, 1986). For a detailed description of the breed, reference is made to e.g. Charray *et al.* (1980). As wool is used for home processing and for trade at the local markets within the Region, this animal production technique is not defined as a separate activity.

In this study, focus is on the first three animal types. As the the small-sized Tuareg sheep only occur to a limited extent, that type is not treated. The main production objective is meat for all sheep production techniques. Five activities are defined for the present version of the LP-model on the basis of two criteria, mobility and production level:

B13	sedentary & semi-mobile	low production level
B14	sedentary & semi-mobile	intermediate production level
B15	migrant	low production level
B16	migrant	intermediate production level
B17	sedentary	semi-intensive production level.

The first four activities are more or less identical to the actual agropastoral and transhumant production techniques. The semi-intensive mutton production technique refers to the so-called 'mouton de case', discussed in more detail in the following paragraph.

14.2.1.1 Mouton de case

Sheep fattening by smallholders is generally known as the mouton de case production technique and can be defined as one in which mainly rams, but sometimes also goats (RIM, 1987) are tethered or confined near the house and are fed feed of good quality (e.g. groundnut, cowpea or sweet potato hay or bourgou), grains and concentrates. Rice and millet bran and millet grains may also be fed. The animals are sometimes allowed to graze freely during day-time. One of the principal reasons for this fattening system is to have sheep for slaughter (or for sale) at the annual Feast of the Sacrifice ('Tabaski'). In addition, some sheep (females) are kept for breeding purposes. The period of confinement was about 4 to 6 months for about 35% of the animals, but differences were observed (Kolff & Wilson, 1985).

The type most often used is the Maure or the Tuareg (Charray *et al.*, 1980). The fraction of female sheep in this production system varies from 15 to 25%. In a detailed study Kolff & Wilson (1985) observed that of the rams, 62% were aged under 15 months, 28% were 15-21 months, 8% were 21-27 months and 2% were 27-33 months. Hence, 'on average' between 1 and 1.5 year of age.

Although in actual practice various management systems are applied, in this study the mouton de case production technique had to be simplified. Based on the description given above and the distinction of year classes for the other types of sheep, the mouton de case production technique is defined as follows:

- No herd is defined, but a fraction of the total number is female sheep. Consequently, milk is produced as a by-product. Lambs are assumed to be sold as well at the end of the period of confinement;

- The ratio of female to male sheep older than one year of age is 0.20:0.80
- Sheep of 1 year of age are bought at yearling weight as for sedentary, semi-mobile or migrant sheep.
- The period of confinement lasts 8 months, with the growth rate as discussed in Subsection 14.2.5;
- Grazing is omitted, hence all feed (of good quality, diet IV) has to be supplied;

14.2.2 Herd structure

The herd structure (age and sex distribution) is function of the main production objective of the herd (e.g. hoggets, mutton, milk) and of course of fecundity, death rates and the offtake rate. Breeding is generally not controlled, and its seasonality is a result of natural environmental conditions acting through fluctuations in feed supply. Some breeding control is practised, however, by certain ethnic groups by the 'kunan' method, a cord which prevents intromission (Wilson, 1986).

Reported values of herd structure are given in Table 14.1. On the basis of these values, and taking into account that herd size should remain constant, the herd structure in the SR-model is defined for the two production levels (Table 14.2).

Table 14.1. Composition of sheep herd [% of the total number].

FEMALE			MALE				SOURCE
TOTAL	BREEDING	LAMBS	TOTAL	BREEDING	CASTRATES	LAMBS	
75	65	25	25	6	5	14	Kolff, 1983
75	56	25	25	•	11	•	Wilson, 1983
75	56-70	13	25	18	7	0	Wilson, 1986
75	•	•	25	•	•	•	Gatenby, 1986
70	44	26	30	7	12	11	RIM, 1987
70	•	•	30	•	•	•	Peacock quoted by RIM, 1987
68	•	•	32	•	•	•	OMBEVI quoted by Sangaré, 1989

•) missing value.

14.2.3 Productivity parameters

First lambing is on average after about 1.3 years (480 d), but for millet-sheep significantly later than for rice-sheep, 497 versus 431 days (Wilson, 1986).

Litter size (lambs ewe^{-1} yr^{-1}) varies with lambing time, from 1.01 in September to 1.14 in April and is on average 1.04-1.05 without a significant difference between the rice-sheep and millet-sheep (Kolff, 1983; Lambourne, 1985; Wilson, 1983; 1986). These data are in close agreement with values of 1.07 and 1.01-1.07

Table 14.2. Parameters of sheep as function of feeding level as used in this study.

	FEEDING LEVEL		
	I	III	IV[a]
Forage composition:			
N-content [g kg^{-1}]	9	11	12
Digestibility [%]	52	56	59
Daily feed intake as % of weight	2.6	2.6	2.5
Herd structure [%]:			
male	16	16	82[b]
female	84	84	18[b]
Weights [kg]			
Female			
at birth	2.6	2.7	2.7
at weaning	13	18	16.5
at 0.75 year			33.5
yearling	24	29	-
at 1.75 year			35
at 2 years	27	32	-
3 years	29	34	-
Male			
at birth	2.7	2.8	2.8
at weaning	15	20	18.5
at 0.75 year			35.5
yearling	29	34	-
at 1.75 year			40
at 2 years	38	43	-
3 years	40	45	-
average per animal	25.8	30.8	32.3
average per TLU	0.10	0.12	0.13
Age at first lambing [yr]	1.4	1.2	1.2
Fecundity[c]	121	134	100[d]
Mortality [%]			
pre-weaning	30	22	22
post-weaning	5	5	10.7
1-2 yr	12	12	5
> 2 yr	12	12	-
Production per animal:			
Offtake [kg kg^{-1}]	0.38	0.48	0.36
Total milk [kg]	19	25	8
Milk for human consumption [kg]	0	7.5	2.5

a) only for mouton de case production technique.
b) proportion of individuals, see definition.
c) Fecundity = fertility * prolificacy [lambs born alive per ewe available for mating].
d) only for the 8 months period.

in Tchad for Fulani and Maure sheep, respectively (Dumas quoted by Gatenby, 1986).

Parturition interval (period between two droppings) is less than a year (254-290 d, Wilson, 1983; 1986), with 259 and 260 d for the rice- and millet-sheep, respectively. This is somewhat shorter than the period of 301 d observed in Niger (Haumesser & Gerbaldi, quoted by Wilson, 1986).

Consequently, the annual reproduction rate (number of lambs per ewe per year) ranges from 1.37 (Kolff, 1983) via 1.5 (Wilson, 1983; Lambourne, 1985) to 1.6 (Wilson, 1986).

Reliable data on conception rate (ratio of ewes lambing to ewes joined) are scarce. Kolff (1983) reported an estimated value of 0.89. This seems relatively low, compared to the reported abortion rate of about 0.04-0.05 (Kolff, 1983; Wilson, 1986).

On the basis of the data given above, no distinction can be made between migrant, sedentary or semi-mobile sheep production techniques. In the SR-model, litter size and conception rate are set at 1.04 and 0.92 for both the low and the intermediate production level. Average number of lambings per year is set at 1.26 and 1.40, for the low and the intermediate production level, respectively. The latter value is also applied for the mouton de case production technique, but is modified proportionally to the length of the period of confinement.

14.2.4 Weights and growth rates

For assessement of the rate of meat production, data on weights in the course of the animal's life are required or, if they are not available, observed daily growth rates may give solace. As such data for sheep in the Region are scarce, data from another part of Mali are presented below.

Average birth weight of lambs is about 2.6 kg with little difference between female and male lambs at 2.6 and 2.7 kg, respectively (Wilson, 1986). Weaning weight is a function of the age at weaning, generally 150 days, but about 120 for Macina sheep. Average weights are 15.1 and 17.1 kg for female and male lambs, and 14 and 18 kg for the millet-sheep and the rice-sheep, respectively. Much higher weights are reported for surviving Macina lambs in the Delta Central, that approach almost yearling weight (24.7 kg). Female and male yearling weight is about 24.6 and 29.8 kg, respectively (Wilson, 1986). Final body weights were achieved at about 4 years of age. Reported mature weight is about 32-37 kg, and specified for the various types: 30-45, 40-60, 34-45 and 30-50 for Maure, Tuareg, Macina and Toronké, respectively (Charray *et al.*, 1980; Devendra & McLeroy, 1982; Wilson, 1983; 1986). Weights as a function of age are shown in Figure 14.1. Mature ram weight is about 42 kg, i.e. about 9-12 kg higher than for ewes; for Maure and the large Tuareg rams about 45-50 kg (Devendra & McLeroy, 1982).

Figure 14.1 is used as the basis for the assessment of average weights of sheep in the course of time, required for the SR-model. It is assumed that ram weight is 40 and 45 kg for the low and intermediate production level, respectively. The difference between ram and ewe weight is 2, 5, 11 and 11 kg at weaning, 1, 2, and 3-5 years of age, respectively (Table 14.2).

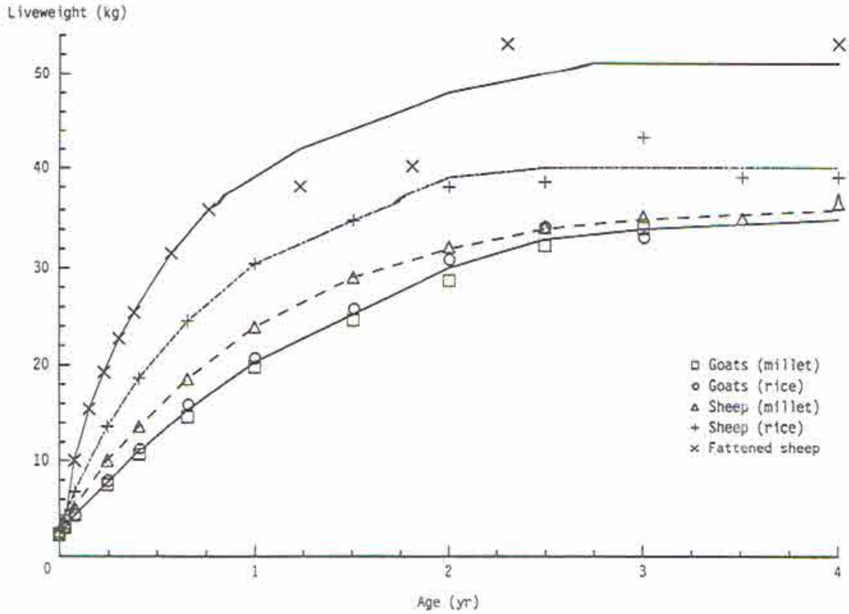


Figure 14.1. Average weights in the course of time of sheep and goats fed in a millet- or rice-based agropastoral system (Wilson, 1986) and of mouton de case (Kolff & Wilson, 1985).

Average growth rates from birth to weaning, from weaning to one year of age and from one year to 3 years of age are calculated at 90, 67, and 33 g d^{-1}, respectively (Wilson, 1983; 1986). A general value of growth rate for lambs between 0 and 8 months of age is between 50 and 100 g d^{-1} (Wilson, quoted by Gatenby, 1983).

The average growth rate of mouton de case sheep from birth until 9 months of age is about 120 g d^{-1} (Kolff & Wilson, 1985). This rate is not extremely high, compared with the rate reported by Brinckman (quoted by Gatenby, 1983) of a non-specified sheep in Africa of up to 250 g d^{-1}. The average growth rate (Figure 14.1) of mouton de case sheep from weaning (5 months) to one year of age and from one year to two years of age is much lower, at 61 and 25 g d^{-1}, respectively. If sheep are fattened from the age of 1 year onwards, their growth rate is expected to be between these values. It is assumed that a growth rate of 45 g d^{-1} can be applied for male yearlings, and one of 37 g d^{-1} for females, due to increased feed requirements for gestation and milk production. Considering the period of confinement, selling weight of fattened ewes and rams is 35 and 40 kg, respectively.

14.2.5 Diseases and mortality

Mortality can be the result of various causes, such as *(i)* accidents, wild animals (up to 10% of the total death), snake bite, drowning, crushing, etc., *(ii)* pathological causes (e.g. pasteurellosis, *Haemorrhagic septicaemia* and small ruminant pest) and *(iii)* malnutrition (Coulomb *et al.*, 1981; Gatenby, 1983; RIM, 1987; Wilson, 1986).

To quantify death, the life cycle of the animal has been schematically divided in four periods: *a)* before lambing (abortion), *b)* between lambing and weaning, *c)* between weaning and one year of age and *d)* older than 1 year. The death rate during the first phase has already been discussed in relation to lambing rate (Subsection 14.2.3). The other death rates are discussed below.

1 Pre-weaning mortality

Reported pre-weaning mortality rates range from 23 to 39% as a function of parity, feeding level, season of birth and environmental conditions. The average rate is 32 and 24% for millet-sheep and rice-sheep, respectively, without a significant difference between male and female lambs (Wilson, 1986).

In this study, herding is assumed to be practised and consequently, losses due to wild animals are assumed to be eliminated. The pre-weaning mortality rate for both sexes is set in the SR-model at 30 and 22% for the low and intermediate production level, respectively. As in the mouton de case production technique lambing is allowed, this mortality rate is set for the time being at 0.22%.

2 Post-weaning mortality

Reported post-weaning mortality rate is about 5% (Wilson, 1986), which is used in the SR-model. For the mouton de case the value is reduced in proportion to the length of the time the lambs are tethered, i.e. 3 months compared to 7 normally, hence, 2%.

3 Death rate after 1 year of age

According to Coulomb *et al.* (1981), the death rates for 1-2 year old and over 2 year old sheep are 10-25% and 4-17%, respectively. Wilson (1986) reported a death rate of 12% for this age class.

The value of 12% is applied in the SR-model for both the low and intermediate production level of transhumant sheep. It is assumed that due to improved feeding conditions, this death rate is much lower for the mouton de case production technique, and it is set at 3% in the SR-model.

14.2.6 Outputs

14.2.6.1 Mutton

Sheep are sold alive and slaughtered afterwards. 'Mutton' is used here as an overall term for the sum of real meat and carcass, and is expressed in kg liveweight. Determinant factors for real meat production are culling rate (or offtake rate, the proportion of the total number that is taken out of the herd annually), the weight of the culled animals and the dressing percentage (ratio of meat weight to liveweight). Detailed data on these factors are scarce, but are given below as illustration of their variability as function of type, sex, environmental condition, etc.

Culling rates vary as a function of environmental conditions, production objective of the herd, age of animal, etc. Reported values range from 1 to 30% for different categories (Delgado, 1980; Wilson, 1986), but it should be realized that these rates do not refer to a constant herd size.

Average weight at offtake was 26.8 kg (Wilson, 1986), but can be as high as 80 kg for feedlot fattened Maure sheep (Charray *et al.*, 1980).

Dressing percentage varies according to breed: 0.40 (Macina), 0.40-0.45 (Maure), 0.46 (Tuareg) and 0.48-0.50 (Toronké) (Charray *et al.*, 1980).

Meat production values, based on results of the SR-model (Annex 6, Tables A6.1 and A6.2 for sheep in general and mouton de case, respectively) are included in Table 14.2 ('offtake', expressed as kg liveweight per kg average animal) and as kg per TLU in the input-output table (Table 14.5).

The sale price depends on the weight of the animal, but on colour, horn size and shape as well, and increases exponentially above a weight of 50 kg (Kolff & Wilson, 1985). The price is generally high in the period of the Tabaski festival, but low when the animals return from their annual transhumance (October-December; Diakité & Kéita, 1988). A head price of 12 000 to 15 000 FCFA in 1987 is reported (Diakité & Kéita, 1988; Diakité, 1989), but no weight is given. In the LP-model the sale price is set at 340 FCFA kg^{-1} liveweight (S. Cissé, pers. comm.) for all sheep production techniques.

14.2.6.2 Milk

During the rainy season, milk is mainly used for home-consumption, but in the dry season 90% is sold (Sangaré, 1989). Accurate data on milk production of sheep are scarce. Wilson (1986) reported a total yield of 50 kg per lactation period for Macina sheep, but the fraction consumed by lambs is not given. The same holds for the value of 50 kg reported by Lambourne (1985) and for the following data of Charray *et al.* (1980):

Macina sheep:	0.25-0.40 kg d^{-1};
Sahel sheep:	0.20-0.40 kg d^{-1};
Maure type:	0.20-0.40 kg d^{-1};
Tuareg type:	0.20-0.40 kg d^{-1} in dry season;
Tuareg type:	0.40-0.60 kg d^{-1} in rainy season.

Sangaré (1989) reported a value of 30 kg per lactating small ruminant available for human consumption.

In this study, total milk production is set, admittedly arbitrarily, at 30, 40 and 50 kg per lactating ewe for ewes fed on diet I, III and IV, respectively. Availability for human consumption is set at 0, 30 and 30%, respectively, as per definition milk availability of sheep fed on diet I is zero (Section 12.3). Taking into account the fraction of ewes lambing, milk production and availability for the various production techniques are calculated, as given in Table 14.5.

14.2.6.3 Wool and hair

Shearing of Macina sheep is done with a double-bladed knife, and individual sheep are generally shorn twice a year (Devendra & McLeroy, 1982; Sangaré, 1989), but that may increase to as many as four times a year (Wilson, 1986). Average production is from 0.6-0.7 kg yr^{-1} (Charray *et al.*, 1980) up to 1.0-1.5 kg yr^{-1} (Devendra & McLeroy, 1982). Hair is produced by Maure sheep, but no quantitative data on production are available.

Wool production is neglected in the present study, as the wool is mainly used by owners or herdsmen and not traded outside the Region.

14.2.6.4 Manure

Manure production is important as input in various crop activities. Calculation of availability of manure for arable farming and as fuel source is based on the following considerations.

Sheep normally do not graze at night and hence, both sedentary and semi-mobile animals spend 12 hours a day in the corral, where 80% of the manure can be recovered. Manure recovery during grazing is negligible. Migrant sheep spend four months per year outside the arable farming area, manure not being available for cropping activities. Hence, the recovery of manure of sheep is 46% in sedentary and semi-mobile production techniques and 33% in migrant production techniques.

The values of manure availability for the various production techniques are included in Table 14.5.

14.3 Goats

14.3.1 General description

According to Wilson (1986) goats belong to the West African Sahel type, but no distinct breeds can be distinguished. Charray *et al.* (1980) distinguished two types: Maure and Tuareg. Goats are a double purpose animal, i.e. for meat and milk (Devendra & Burns, 1983). For a detailed description of the appearance of the animals, reference is made to e.g. Charray *et al.* (1980).

Four activities are defined for the present version of the LP-model on the basis of two criteria, mobility and production level:

B18	sedentary & semi-mobile	low production level
B19	sedentary & semi-mobile	intermediate production level
B20	migrant	low production level
B21	migrant	intermediate production level

The main production objective is meat and milk for all goat production techniques.

14.3.2 Herd structure

The herd structure (age and sex distribution) is regulated by the same mechanisms as for sheep (Subsection 14.2.2). Reported values of herd structure are given in Table 14.3. On the basis of these values, and taking into account that herd size should remain constant, the herd structure in the SR-model is defined for the two production levels (Table 14.4).

Table 14.3. Composition of goat herd [% of the total number].

FEMALE			MALE				SOURCE
TOTAL	BREEDING	KIDS	TOTAL	BREEDING	CASTRATES	KIDS	
70	51	19	30	3	15	12	Kolff, 1983
71	40	12	29	7	12	10	RIM, 1987
76	62	14	24	7	5	12	Wilson, 1986
79	•	•	21	•	•	•	Peacock quoted by RIM, 1987

•) missing value.

14.3.3 Productivity parameters

First kidding is on average after about 1.3 years (485 d), but in another herd it was 486 and 508 days for millet- and rice-goats, respectively (Wilson, 1986).

Litter size (kids doe^{-1} yr^{-1}) varies with time of kidding, from 1.14 in August/September to 1.31 in March (Wilson, 1986). Reported average values range from 1.15 (Kolff, 1983) to 1.19-1.23 (Wilson, 1983; 1986; Lambourne, 1985), without significant difference between millet- and rice-goats (1.15-1.17; Wilson, 1986).

Parturition interval is less than a year, ranging from 271 to 298 d (Wilson, 1983; 1986), without significant differences between millet- and rice-goats (298 d; Wilson, 1986).

Consequently, the annual reproduction rate ranges from 1.51-1.53 (Kolff, 1983; Wilson, 1986) to 1.65 (Wilson, 1983; Lambourne, 1985).

Data on conception rate (the ratio of does kidding to does joined) are scarce. Kolff (1983) reported an estimated value of 0.92, which seems relatively high, compared to an abortion rate of about 0.13 (Wilson, 1986), but relatively low compared to an abortion rate of 0.05 (Kolff, 1983).

In the light of the data given above, no distinction can be made between migrant and sedentary & semi-mobile goat production techniques. In the SR-model, litter size, average number of kiddings per year and conception rate are set at 1.15, 1.22 and 0.85 for both production levels.

Table 14.4. Parameters of goats as function of feeding level as used in this study.

	FEEDING LEVEL	
	I	III
Forage composition:		
N-content [g kg^{-1}]	9	11
Digestibility [%]	52	56
Daily feed intake as % of weight	2.6	2.7
Herd structure [%]:		
male	35	18
female	65	82
Weights [kg]		
Female		
at birth	1.8	2.0
at weaning	10	10
yearling	21	21
at 2 years	26	26
3 years	30	30
Male		
at birth	2.0	2.2
at weaning	11	11
yearling	23	23
at 2 years	34	34
3 years	40	40
average per animal	25.2	24.5
average per TLU	0.10	0.10
Age of first kidding [yr]	1.4	1.3
Fecundity [kids/doe]	119	119
Mortality [%]		
pre-weaning (f)	31	24
pre-weaning (m)	35	27
post-weaning	5	5
1-2 years	12	12
> 2 years	12	12
Production per animal:		
Offtake [kg kg^{-1}]	0.27	0.38
Total milk [kg]	34	61
Milk for human consumption [kg]	0	18

14.3.4 Weights and growth rates

Average birth weight of kids is about 1.8 kg, but in another herd weight of female kids and male kids was higher, at 2.1 and 2.3 kg, respectively. Weaning weight is a function of the age at weaning, generally 150 days with a weight of 10.4 and 11.4 kg for female and male kids. Much higher weights were reported for surviving kids in the Delta Central, that approached almost yearling weight (18.2 kg). Female and male yearling weight is about 19.1 and 21.3 kg, respectively (Wilson, 1986). Final body weights were achieved at about 4 years of age. Reported mature doe weight is about 27 to 35 kg; 32 (Wilson, 1983; 1986) and more specific: 26-40 for Maure goats (Charray *et al.*, 1980). Weights as a function of age are shown in Figure 14.1. Mature buck weight is about 40 kg, about 13 kg higher than a mature doe (Wilson, 1986).

Figure 14.1 is used as the basis for assessment of the average weights of goats in the course of time, showing no significant difference between the millet- and rice-goats. It is assumed for the SR-model that buck weight is 40 kg for both the intermediate and low production levels. The difference between buck and doe is assumed to be 1, 2, 8 and 10 kg at weaning, 1, 2 and 3-5 years of age, respectively (Table 14.4).

14.3.5 Diseases and mortality

The causes of death of goats are the same as those for sheep (Subsection 14.2.4). The distinguished periods of death are between kidding and weaning, between weaning and one year and older than 1 year of age.

1 Pre-weaning mortality
Reported pre-weaning mortality rates range from 19 to 52%, as function of the same parameters as sheep (i.e. accidents, pathological causes and malnutrition), the average mortality rate of male kids being significantly higher than that of females, 37 versus 33%. The average mortality rate was 39 and 31% for the millet- and rice-goats, respectively (Wilson, 1983; 1986).
As herding is assumed to be practised, the pre-weaning mortality rate of female kids is, similarly to that of sheep, reduced by eliminating losses due to predation (17%) and are set at 31 and 24% for the low and intermediate production level, respectively. For male kids these values are set at 35 and 27%, respectively.

2 Post-weaning mortality
Reported post-weaning mortality rate applied in the SR-model is 5% (Wilson, 1986).

3 Death rate after 1 year of age
Reported mortality rate applied in the SR-model is 12% (Wilson, 1986).

14.3.6 Outputs

14.3.6.1 Meat

Goats are sold alive and slaughtered afterwards. Three types of goat meat are marketed: from kids (8-12 weeks old), from young goats (1-2 years old) and from old goats (2-6 years old) (Devendra & Burns, 1983). 'Meat' is used here as a general term for the sum of real meat and carcass, and is expressed in kg liveweight. Determinant factors for real meat production are culling rate, the weight of the culled animals and the dressing percentage. Detailed data on these factors are scarce, but are given below as illustration of their variability as function of type, sex, environmental condition, etc.

Culling rates vary as a function of environmental conditions, production objective of the herd, age of animal, etc. Reported values range from 2 to 35% for different categories (Delgado, 1980; Wilson, 1986), but it should be realized that these rates do not refer to a constant herd size.

Reported average weight at offtake was 20.7 kg (Wilson, 1986).

Meat production values, based on results of the SR-model (Annex 6, Table A6.1) are included in Table 14.4 ('offtake', expressed as kg liveweight per kg average animal) and as kg per TLU in the input-output table (Table 14.5).

The sale price depends on the weight of the animal, but on colour, horn size and shape as well. A head price of 7 500 to 8 000 FCFA was reported for 1987 (Diakité & Kéita, 1988; Diakité, 1989), but unfortunately no weights were given. In the LP-model the price is set identical to that for mutton, i.e. 340 FCFA kg^{-1} liveweight.

14.3.6.2 Milk

Daily milk production varies with type: 0.8-1.1 and 0.6-0.8 kg d^{-1} for Maure and Tuareg, respectively. Peak daily milk production of Maure goats can be as high as 1.5 kg d^{-1}, as observed in Mauritania, with a lactation period of about 6 months (Charray *et al.*, 1980). A milk production of 75 kg in a 145 d lactation period is reported by Coulomb *et al.* (1981).

In this study, total milk production is set, admittedly arbitarily, at 70 and 100 kg for goats fed on diet I and III, respectively. As for sheep, availability for human consumption is set at 0 and 30%.

14.3.6.3 Hair

No relevant information is available on hair production. If any shearing is carried out, production would be used by herdsmen or their family. Hence, hair production is not included in the present study.

14.3.6.4 Manure

Manure production and availability is calculated similar to that for sheep (Paragraph 14.2.6.4). The values of manure availability for the various production techniques are included in Table 14.5.

14.4 Inputs

14.4.1 Feed requirements

In analogy with the assessment of feed requirements for cattle, the energy requirements for animals on diet I are those for maintenance plus 10%. Maintenance requirements of small ruminants are 27 g digestible dry matter (DDM) $W^{-0.75}$ d^{-1} (Zemmelink, 1980; Tolkamp and Ketelaars, pers. comm.), i.e. considerably lower than for cattle (36 g DDM $W^{-0.75}$ d^{-1}; e.g. Breman & de Ridder, 1991). As for cattle, the increase in maintenance requirements is set at 30 and 35% for small ruminants on diets III and IV, respectively. Expressed in terms of intake: 30, 34 and 35 g DDM $W^{-0.75}$ d^{-1} for small ruminants fed on diets I, III and IV, respectively. The feed requirements calculated with the SR-model (Annex 6) are included in Table 14.5.

14.4.2 Labour requirements

1. Herding

According to Sangaré (1989) sheep are herded 10 hours per day, irrespective of the season, with one herdsman per 50 to 100 heads. Watering is considered one of the regular tasks of herdsmen. Among pastoral Tuareg the daily period of herding is about 16 hours (Gatenby, 1986). Children herding a small herd can often be observed in the neighbourhood of villages (RIM, 1987).

As mentioned before (Subsections 14.2.5 and 14.3.5), herding is important for survival of young animals in the herd. From the data given above, labour requirements for herding are approximated at 0.14 mnd TLU^{-1} d^{-1}, equivalent to 13 and 39 mnd TLU^{-1} for the rainy season and remainder of the year, respectively.

2. Milking

Labour requirements for milking of small ruminants are estimated at 3 minutes per head (Sangaré, 1989), equivalent to 0.06 mnd TLU^{-1} per operation.

In this study, it is assumed that sheep on diets III and IV are milked once daily, and goats on diet III twice. The length of the milking period is set at 110 days for all relevant production techniques. Taking into account the fraction of sheep on diets III and IV and that of goats on diet III that give birth, total labour requirements for milking are 4, 1 and 8 mnd TLU^{-1} for these production techniques, respectively. In addition, it is assumed that the labour requirements are divided among the two periods of the year proportional to their lengths.

3. Shearing

Labour requirements for shearing of sheep are estimated at 0.5 hour for two men for an adult sheep and 0.25 for young ones (ratio adult to young in the herd = 0.6:0.4, Sangaré, 1989), hence on average 0.8 h $head^{-1}$, equivalent to 1 mnd TLU^{-1}, which is applied in this study. No data are available for goats, but the labour requirements are neglected in this study.

4. Watering

Drinking water requirements of the animals depend on dry matter content of the feed, productivity level and ambient temperature. Charray *et al.* (1980) reported for a ewe of 30 kg water requirements of 1.5-2.5, 2.5-3.5 and 3.5-5 l d^{-1} during maintenance, gestation and lactation, respectively. Coulomb *et al.* (1981) reported water requirements of 2, 3 and 5 l d^{-1} during the rainy season, the cold season and the hot season, respectively. Additional details are provided by King (1983). However, in the present study no explicit requirements are included in the model, while watering is considered part of the regular herding task.

5. Feeding

As a consequence of the definition, labour is required for feeding of the mouton de case production technique. If any labour is required for the other production techniques, it is assumed to be negligible.

Labour requirements for feeding the mouton de case are estimated at 50% of those for herding, i.e. 0.08 mnd TLU^{-1} d^{-1}. Total labour requirements for this operation are therefore 20 mnd TLU^{-1} (=8/12 * 365 * 0.08). The Tabaski festival takes place on a shifting date, so that the labour requirements are distributed proportional to the length of the two distinguished periods.

14.4.3 Monetary inputs

14.4.3.1 Capital charges

No capital charges are included for small ruminant production techniques. The shed of the mouton de case is considered part of the homestead.

Table 14.5. Input-output table for sheep and goat production techniques.

CHARACTERISTIC	SHEEP					GOATS			
	B13	B14	B15	B16	B17	B18	B19	B20	B21
Production target									
meat	+	+	+	+	+	+	+	+	+
milk	+	+	+	+	+	+	+	+	+
transport/traction	-	-	-	-	-	-	-	-	-
Production level									
low	+	-	+	-	-	+	-	+	-
intermediate	-	+	-	+	-	-	+	-	+
semi-intensive	-	-	-	-	+	-	-	-	-
Mobility									
sedentary	+	+	-	-	+	+	+	-	-
semi-mobile	+	+	-	-	-	+	+	-	-
migrant	-	-	+	+	-	-	-	+	+
INPUTS [TLU^{-1} yr^{-1}]									
FEED [kg DM]									
Diet I	2 340	-	2 340	-	-	2 000	-	2 000	-
Diet II	-	-	-	-	-	-	-	-	-
Diet III	-	2 350	-	2 350	-	-	1 740	-	1 740
Diet IV/Conc.	-	-	-	-	1 510	-	-	-	-
Browse	-	-	-	-	-	350	800	350	800
LABOUR[a)] [mnd]									
1-3 Herding	13	13	13	13	-	13	13	13	13
1-3 Milking	-	1	-	1	-	-	1	-	1
1-3 Feeding	-	-	-	-	5	-	-	-	-
1-3 Shearing	-	-	-	-	-	-	-	-	-
4-6 Herding	39	39	39	39	-	39	39	39	39
4-6 Milking	-	3	-	3	1	-	3	-	3
4-6 Feeding	-	-	-	-	15	-	-	-	-

a) Numbers in front of operations refer to period of the year (Subsection 1.2.1). Labour requirements refer to the sum of periods.

.../...

Table 14.5. Continued.

CHARACTERISTIC	SHEEP					GOATS			
	B13	B14	B15	B16	B17	B18	B19	B20	B21
4-6 Shearing	1	1	1	1	–	–	–	–	–
Total	53	57	53	57	21	52	56	52	56
MONETARY INPUTS [FCFA]									
Capital charges	–	–	–	–	–	–	–	–	–
Operating costs									
Vaccinations	1 500	1 500	1 500	1 500	750	1 500	1 500	1 500	1 500
Salt	5 100	5 100	5 100	5 100	3 400	5 100	5 100	5 100	5 100
Total	6 600	6 600	6 600	6 600	4 150	6 600	6 600	6 600	6 600
OUTPUTS [TLU^{-1} yr^{-1}]									
Meat									
[kg liveweight]	97	121	97	121	89	68	96	68	96
Total milk [kg]	190	208	190	208	62	340	610	340	610
Milk for human									
consumption [kg]	0	62	0	62	19	0	180	0	180
Available manure									
[kg DM]	517	476	371	341	500	519	514	372	369
No. of animals	–	–	–	–	–	–	–	–	–

14.4.3.2 Operating costs

Operating costs comprise the following five items:

1. Vaccinations

Small ruminant are sometimes (about 3%) vaccinated against pasteurellosis at a price of 15 FCFA per vaccination (Sangaré, 1989). In addition, vaccination of 95% of the total number against gastro-intestinal and hepatic parasites is practised, at a price of 150 FCFA per treatment. Sangaré (1989) reports that actual expenses are only 8 to 20 FCFA TLU^{-1} yr^{-1}.

As insufficient data are available, the vaccination costs are estimated at 150 FCFA $head^{-1}$ yr^{-1}, equivalent to 1 500 FCFA TLU^{-1} yr^{-1} on the basis of the information for cattle (Paragraph 13.2.6.3). For the mouton de case production technique 50% of that value is used.

2. Supplements

Herdsmen pay owners of bourgoutières, 5 000 FCFA for exploitation by a herd of 50 to 100 head (no species specification; Sangaré, 1989), but as for cattle activities, these cost are not included in the model. The price of other supplementary feed (e.g. concentrates) is defined separately in the LP-model.

3. Salt bricks

According to Kolff & Wilson (1985) salt is generally offered to the animals. Application of the values reported by Wilson (1984), results in annual salt requirements of 5.6 kg TLU^{-1}, equivalent to 5 100 FCFA TLU^{-1} yr^{-1}. For the mouton de case production technique 8/12 of that value is used, i.e. 3 400 FCFA TLU^{-1} yr^{-1}.

4. Drinking water

As for cattle activities, no costs are attached to this input.

5. Taxes

As for cattle activities, no taxes are included in the LP-model.

14.5 Input-output table

Inputs and outputs of the various small ruminant production techniques for the LP-model are quantified in Table 14.5.

15. DONKEYS & CAMELS

(N. van Duivenbooden)

In this chapter animal species used for transport and traction, other than oxen, are treated. A constraint for a reliable quantitative description has been the lack of data, especially specific for the Region. Consequently, a model similar to the SR-model could not be constructed, and hence the data presented in this chapter should be considered as preliminary.

15.1 Donkeys

15.1.1 General description

Donkeys are mainly kept for local transport, of for instance marketable products or persons (e.g. Diakité, 1989b). Various types of donkeys occur in the Region of which two are relevant: Sahel and Gourma donkeys (Coulomb *et al.*, 1981).

As the actual number of donkeys in the Region is difficult to assess (RIM, 1987), a minimum of 1 donkey per 20 inhabitants is arbitrarily defined as a lower limit in the LP-model.

15.1.2 Herd structure

For donkeys, the concept of a herd is hardly applicable in practice, as farmers keep one or a few donkeys, but never herds like for ruminants. Therefore, data on herd structure of donkeys are hardly available. As a theoretical model, however, a herd structure is useful, it being assumed that its size is constant and that animals lost are bought on the market.

15.1.3 Productivity parameters

No data on the productivity of donkeys in the Region are available. As a constant herd size is assumed, it implies that the number of donkey foals is sufficient to cover the losses due to diseases and other causes.

15.1.4 Weights and growth rates

The liveweight of donkeys varies considerably, being in Mali about 110 to 130 kg (Wilson, 1984). In this study the average donkey weight is set at 125 kg, equal to 0.5 TLU.

15.1.5 Diseases and mortality

As no data are available, the average mortality rate is estimated at 10%, on the basis of the data for cattle and small ruminants.

15.1.6 Outputs

15.1.6.1 Draught power

Donkeys play an important role in transport of agricultural products, manure and fire-wood. According to RIM (1987), they are also used for land preparation, but availability of light ploughs restricts the utilisation of donkeys for this purpose. In addition, the fact that donkeys can plough only for about 3-3.5 hours a day, instead of 5-6 hours as oxen (FAO, 1972), limits their use in Burkina Faso (Kolff, 1985). As reported earlier in this study, donkeys are not assumed to be used for land preparation.

Draught power is defined as the number of donkeys per TLU, i.e. 2 TLU^{-1}.

15.1.6.2 Manure

For donkeys, as for sedentary cattle, sheep and goats, a relatively high recovery of manure (46%) can be attained.

15.1.7 Inputs

15.1.7.1 Feed requirements

According to the University Federation for Animal Welfare (quoted by Fielding, 1987), the donkey is a less selective feeder than either the mule or the horse, being able to thrive on the poorest quality feed, provided enough is available. However, at the end of the dry period feed of better quality is offered, to improve animal condition before the start of the cropping season. Kolff (1985) reported a considerable decrease in bodyweight of donkeys in Burkina Faso if no supplements were available. Hence, in this study it is assumed that feed of diet II (Section 12.4) is offered.

Annual feed requirements, in terms of energy, for maintenance are about 550 Scandinavian Feed Units (FAO, 1972; Munzinger, 1982), equivalent to 6 900 MJ metabolizable energy (ME) or equivalent to 28 g DDM $W^{-0.75}$ d^{-1}. Feed requirements for traction (ploughs and carts) are calculated at 1 800 MJ ME yr^{-1} (van Duivenbooden, 1987). Feed requirements for 'other' purposes are estimated at 10% of those for maintenance. Hence, the total feed requirements of donkeys are approximated at 9 400 MJ ME yr^{-1} (= 1.1 * 6 900 + 1 800).

Taking into account a digestibility of 0.54, an energy content of 17.6 MJ per kg digested material and a factor of 0.8 for the conversion of digestible energy into metabolizable energy (Breman & de Ridder, 1991), this implies an intake of about 1 000 kg DM $head^{-1}$ yr^{-1}, equivalent to 2 000 kg DM TLU^{-1}.

15.1.7.2 Labour requirements

Labour requirements are calculated for the LP-model for three main operations.

1. Herding

During the dry season donkeys are often left unguarded, alone or in small groups, during day-time and guarded or at the homestead at night. Their forelegs are tied during day-time, to prevent them from escaping (RIM, 1987). In the rainy season, they are herded. Average herd size is estimated at 30 head per herdsman.

Hence, total labour requirements for herding are then 0.08 mnd TLU^{-1} d^{-1}, in total for the rainy season 7 mnd TLU^{-1}.

2. Veterinary care

Data on time spent for veterinary care are not available. In this study it is assumed that it is included in herding.

3. Watering

Watering during the rainy season is is assumed to be included in the herding activity. The labour requirements during the dry season are estimated at 25% of those for herding in the rainy season, i.e. 0.02 mnd TLU^{-1} d^{-1}, in total for the dry season 6 mnd TLU^{-1}.

15.1.7.3 Monetary inputs

Capital charges are zero, as buildings or other investments are considered unnecessary.

Operating costs comprise salt and vaccinations. As for the other animal species, no costs are attached to drinking water. Salt is important to maintain body condition of donkeys, and the requirements are estimated at 5.6 kg TLU^{-1} (Wilson, 1984), equivalent to 5 100 FCFA TLU^{-1} yr^{-1}. No information is available on vaccination, but the requirements are set, admittedly arbitrarily, at 200 FCFA TLU^{-1} yr^{-1}.

15.2 Camels

15.2.1 General description

Camels, or more accurately dromedaries (*Camelus dromedarius*), having one hump, occur almost exclusively in the pure pastoral systems in the arid zones of central Mali (north of the Region and Gourma), although some are found in the agropastoral systems (Wilson, 1986). Breeds in the Region include the Adra n Iforas, the Azwad, the Aïr and the Hodh (Wilson, 1984). Principal owners are the Touareg (Tamasheq, Iklan) (Wilson, 1984; RIM, 1987). Camels are used up to an age of 25 years (Nicolaisen, quoted by Dahl & Hjort, 1976).

The main objectives for raising camels are their use as pack-animal for salt transport, for traction, for pulling buckets from deep wells, and milk and meat production (RIM, 1987; Diakité, 1989b), whereas their manure is used as fuel. Moreover, they are used in search of good pasture, ahead of the cattle herd (RIM, 1987).

Browse is, in addition to other rangeland vegetation, an important source of feed (Wilson, 1983; Yagil, 1985; Stiles, 1987).

15.2.2 Herd structure

Reported data show that female camels comprise up to 78% of the total number, of which 57% were breeding. Mature males comprise only 2% (Swift, quoted by Wilson, 1984). A stable herd structure would imply 72% females and 48% breeding females of the total number (Wilson, 1984).

15.2.3 Productivity parameters

Age of first parturition is about 5 years with 1.0 foal per birth (Wilson, 1984). The ratio of camel foal to total female camels breeding ranges from 0.38 to 0.5 (Coulomb *et al.*, 1981). The weighted average parturition interval for the Adra n Iforas breed is 21 months, thus about two years (Swift, quoted by Wilson, 1984). No data are available on conception rate. It is assumed in this study that on average 50% of the total number is giving birth per year.

15.2.4 Weights and growth rates

Birth weight is about 26 kg and mature weights of 350 kg and 450-550 kg are obtained at about 6 years of age for female and at 8 years for male camels (Wilson, 1984). Average liveweight of a camel in this study is set at 300 kg, equivalent to 1.2 TLU, in agreement with the average weight reported by Wilson (1984).

15.2.5 Diseases and mortality

The most important disease is trypanosomiasis (local names: 'touhaga' or 'n'diomdé'), but others like camel pox, rabies, skin necrosis, blackquarter and brucellosis occur as well. For more details, reference is made to Wilson (1984). Calf mortality is high (Dahl & Hjort, 1976), up to about 50% according to Wilson (1984). Death rate after the age of one year is about 5% (Wilson, 1984).

15.2.6 Outputs

15.2.6.1 Meat

Meat is mainly consumed on special occasions and as supplementary food in the dry season when milk production is low (Dahl & Hjort, 1976), but in the northern part of the Region camel meat may comprise up to 60% of the total meat consumption (Diakité, 1989b). Reported offtake rate is about 30% (Wilson, 1983) and dressing percentage ranges from 50 to 60% (Yagil, 1985; 1986).

The offtake rate of 30% is applied in this study, i.e. 75 kg TLU^{-1} yr^{-1}.

15.2.6.2 Milk

Daily milk production varies considerably depending on breed and forage supply, ranging from 3 to 11 kg d^{-1}. Total milk production ranges from 800 to 3 600 kg (Williamson & Payne, 1978; Sohail, 1983; Knoes *et al.*, 1986; Yagil, 1985; 1986; Stiles, 1987). Capot-Rey (quoted by Dahl & Hjort, 1976) reported for Saharan camels a daily milk yield for human consumption of 1.9 to 4 kg.

As specific data on camels in Mali are not available, the total annual milk production is estimated at 2 000 kg per lactating camel when fed diet II and milk production for human consumption at 30% of the total. Taking into account that 40% is lactating, milk production for human consumption is 240 kg TLU^{-1} yr^{-1}.

15.2.6.3 Hair

Hair production ranges from 1.0-1.4 (Wilson, 1984) to 1.5-2.0 kg $head^{-1}$ yr^{-1} (Sohail, 1983), but this production is neglected in the LP-model.

15.2.6.4 Manure

Manure of camels is generally not used in arable farming, but as fuel. The manure recovery of camels is set as for migrant cattle at 24%, i.e. 318 kg TLU^{-1} yr^{-1}.

15.2.6.5 Draught power

Camels play an important role as transport animals and for land preparation in some cases. In this study, camels are not assumed to be used for the latter operation.

Draught power is defined as the number of camels per TLW, i.e. 1.2 TLU^{-1}.

15.2.7 Inputs

15.2.7.1 Feed requirements

Feed requirements for maintenance are estimated at 36 MJ ME d^{-1} for a camel of 300 kg (equivalent to 35 g DDM $W^{-0.75}$ d^{-1}), and those for milk and work at 5 MJ ME kg^{-1} and 8 MJ ME h^{-1}, respectively (Wilson, 1984). Following the method applied by Wilson (1984), and assuming that 50% of the camels work on average 250 days per year (8 h d^{-1}) and 50% produce 2 000 kg of milk annually, the total energy requirements may be approximated at 26 140 MJ ME TLU^{-1} yr^{-1} (365 * 36 + (0.5 * 2 000 * 8) + (0.5 * 2 000 * 5)).

In this study it is assumed that 15% of these requirements are met by browse, and the remainder by diet II (digestibility of 54%). This implies a required total feed intake of 3 455 kg DM $head^{-1}$ yr^{-1}, subdivided into 535 and 2 920 kg of browse and forage of diet II, equivalent to 445 and 2 435 kg DM TLU^{-1} yr^{-1}, respectively.

Note that the sum of lactating and working camels is not necessarily 100%, as lactating females can also be used for transport. Furthermore, digestibility of feed for camels is assumed to be equal to that for cattle, as data on the relation of digestibility and intake of feed are conflicting (e.g. Richard, 1989a; 1989b). In addition, digestibility of browse is set equal to that of diet I.

15.2.7.2 Labour requirements

1. Herding

As camels are mainly used for transport, herding is not considered.

2. Veterinary care

In this study time requirements are considered negligible.

3. Watering

It is assumed that watering during the rainy season is included in the regular working day. For the dry season the labour requirements are estimated, as for donkeys, at 6 mnd TLU^{-1}.

4. Milking

As no data on labour requirements are available for this operating, they are set arbitrarily similar to those for cattle, i.e. 0.024 mnd TLU^{-1} d^{-1}. The length of the milking period is estimated at 1 year, hence annual labour requirements are in total 9 mnd TLU^{-1}.

5. Shearing

Labour requirements for shearing of camels are estimated analogously to those for sheep at 1 mnd TLU^{-1}.

15.2.7.3 Monetary inputs

Capital charges are zero, as for donkeys, as buildings or other investments are not considered necessary.

Operating costs comprise salt and vaccinations. As for the other animal species, no costs are attached to drinking water.

- Salt is important to maintain body condition of the camel and the requirements are 6-8 times higher than for other livestock species. Reported intake was 0.12 kg $animal^{-1}$ d^{-1} if fed *ad libitum* (Wilson, 1984), but values of 0.14 kg d^{-1} are also reported (Yagil, 1985). Hence, annual salt requirements are set at the average of the two, i.e 40 kg TLU^{-1}, equivalent to 36 000 FCFA TLU^{-1} yr^{-1}.
- Vaccins against camel trypanosomiasis are generally available in Mali, but their availability in the Region is not reported. With respect to other vaccins, information is also lacking. The costs of vaccinations are set, admittedly arbitrarily, at 250 FCFA TLU^{-1} yr^{-1}.

15.3 Input-output table

The input and output parameters for donkey and camel activities are quantified in Table 15.1.

It should be realized that for these two species, the input and output coeffients are less reliable than for the preceding species, due to lack of relevant data and the absence of a demographic model. Hence, the results should be considered as preliminary indications.

Table 15.1. Input-output table of donkey and camel production techniques.

CHARACTERISTIC	DONKEY	CAMEL
Production target		
meat	-	+
milk	-	+
transport/traction	+	+
Production level		
low	+	+
intermediate	-	-
high	-	-
Mobility		
sedentary	+	-
semi-mobile	-	-
migrant	-	+
INPUTS [TLU^{-1} yr^{-1}]		
FEED [kg DM]		
Diet I	-	-
Diet II	2 000	2 435
Concentrates	-	-
Browse	-	445
LABOUR[a)] [mnd]		
1-3 Herding	7	-
1-3 Watering	-	-
1-3 Milking	-	2
4-6 Herding	-	-
4-6 Watering	6	6
4-6 Milking	-	7
4-6 Shearing	-	1
Total	13	16
MONETARY INPUTS [FCFA]		
Capital charges	-	-
Operating costs		
Vaccinations	200	250
Salt	5 100	36 000
Total	5 300	36 250
OUTPUTS [TLU^{-1} yr^{-1}]		
Meat [kg liveweight]	-	75
Total milk [kg]	-	1 000
Milk for human consumption [kg]	-	240
Available manure [kg DM]	614	320
Number of animals	2.0	0.83

a) Numbers in front of operations refer to period of the year (Subsection 1.3.1). Labour requirements refer to the sum of periods.

PART III. FISH PRODUCTION

16. FISHERIES

(P.A. Gosseye & F.R. Veeneklaas)

16.1 Introduction

Products from fishing activities account for 3% of Mali's Gross National Product. In terms of export, it ranks fourth, after cotton, groundnut and animal husbandry products.

From an economic point of view, products derived from fishing rank number one in the Region. According to DRPS (1984), they account for 46.8% of the regional gross domestic product, compared to 28.5% for products derived from animal husbandry and 21.7% for arable crops. In total, therefore, these three agricultural activities make up 97% of the regional gross domestic product.

The present study does not aim at an exhaustive analysis of the past, present and future of what is currently a highly unstable and rapidly changing sector. Rather, we will attempt to summarize all the various fishing activities in input and output coefficients, that can be applied in the LP-model, based on the most recent data. The latter, however, must be quantified or at least quantifiable, and internally consistent. In addition, the data must be described in terms commensurate with the definition of the Region's resources as used for vegetable and animal production (Parts I & II of the present report).

The inputs for fishing activities are the environment, labour, equipment and wood for smoking. The output is the catch, expressed in fish fresh weight.

The fishing activities selected for this study are defined on the basis of three types of fishing households, each characterized by a certain amount of available equipment and a certain level of production, i.e.:

- **Main Migrant Fishermen** (MMF) practicing fishing as their main activity and lead, as a household, a migratory life.
- **Main Sedentary Fishermen** (MSF) practicing fishing as their main activity and partly sedentarized. Certain members of the household, however, may temporarily migrate.
- **Secondary Sedentary Fishermen** (SSF) practicing fishing as a secondary (or tertiary) activity and partly sedentarized. Certain members of these households, however, temporarily migrate. This category includes part-time sedentary fishermen and individuals who fish on an occasional basis.

16.2 Environment

Before describing the environment in which fishing is practised, it should be pointed out that our study exclusively focuses on the delta zone, i.e. mainly the agro-ecological zones Delta Central and Zone Lacustre, hence fishing outside this area (e.g. in the reservoirs of the Plateau), has been excluded. We are aware that the development of fishing farms and/or the introduction of fish into various surface waters increases the competition for water, which is in short supply. Among the main competitors for water are humans, their animals, crops and, in some cases too, their fish farms, irrespective of the degree of technical sophistication of the latter. An additional complication is the attitude of health departments, that are constantly trying to eradicate all sources of bilharziosis.

We have deliberately avoided a detailed description of the various delta habitats required for the fish to complete their life cycle. Firstly, little is yet known about these habitats, and secondly, it is impossible to quantify them in any detail. Finally, it is impossible to establish relations between these different habitats and the various types of fish produced. Despite recent efforts in this field, this type of information is difficult to incorporate into the LP-model. For a qualitative description of fish habitats and fishing environments in the Region, the reader is refered to, among others, INRZFH/ORSTOM (1988) and Dansoko & Kassibo (1989a; 1989b).

Table 16.1 shows the total surface area within the Region flooded by the Niger and the Bani under a normal flood level (660 cm) or a low one (510 cm). This table based on Chapters 3 and 5 of Report 1, describes the various edaphic environments and the relationship between flood level and flooded area within the Region, respectively. For the purposes of this study, we have considered only soil types TI4, TI3, TI2, TI1 and TI7, i.e. soil types flooded by rivers; soil type TI5 has not been taken into account. Soil type X6 is also included, i.e. areas with permanent surface water (Hiernaux, 1982; PIRT 1983; 1989; Hiernaux & Diarra, 1986).

In summary, under normal flood levels:

- Soil type TI4 comprises riverbank formations (areas with *Vetiveria spp.*), covered by a layer of water between 0 and 60 cm deep.
- Soil type TI3 comprises high laying formations (with vegetations of *Andropogon spp., Panicum spp. Eragrostis spp.* and *Vetiveria spp.*) covered by a layer of water between 0 and 60 cm deep.
- Soil type TI2 comprises rice-growing areas (ORM polders and areas outside the polders) covered by a layer of water between 30 and 180 cm deep.
- Soil type TI1 comprises medium to low formations (with vegetations of *Eragrostis spp., Vetiveria spp., Oryza spp.* and *Echinochloe spp.*), covered by a layer of water between 60 and 150 cm deep or more.
- Soil type TI7 comprises water channels and lake beds liable that may dry up; they have no vegetation now, but they may temporarely have had earlier; they are included in TI1 with respect to water depth (Report 1, Chapter 5), but this results in overestimation of the surface area of soil type TI7 when flood levels are low.
- Soil type X6 comprises all areas permanently covered with free water having very little vegetation.

We have deliberately disregarded the possible influence of the rice-growing areas of TI2 on the amount of fish produced. We have assumed that these improved areas have the same productivity as the other habitats.

It is estimated that in years of normal flooding (660 cm), 10 048 km^2 of the delta zone is flooded, i.e. 56% of the total surface area of 28 625 km^2, including the rainfed regions. The Delta Central and Zone Lacustre comprise 92% of the total surface area of the delta zone and 96% of the area that can potentially be flooded.

Table 16.1. Maximum surface areas [km^2] liable to be flooded in the event of normal flooding (660 cm) and in the event of low flooding (510 cm), according to the taxonomic units of PIRT (T1 and X6) and according to the agro-ecological zones

AGRO-EC. \CABO ZONE \PIRT	E2b TI3	G TI4	F3b TI2	E1b TI1	G TI7	Y X6	TOTAL
Year of normal flood							
Plateau	9	-	47	53	-	-	109
Delta Central	3 852	333	705	6 104	779	820	12 593
Méma Dioura	256	-	-	57	-	-	313
Gourma	-	-	-	76	109	-	185
Bodara	2	-	-	5	-	-	7
Zone Lacustre	355	-	-	1 185	852	449	2 841
Total	4 474	333	752	7 480	1 740	1 269	16 048
Year of low flood							
Plateau	-	-	9	39	-	-	48
Delta Central	-	-	141	4 474	571	820	6 006
Méma Dioura	-	-	-	-	-	-	-
Gourma	-	-	-	-	-	-	-
Bodara	-	-	-	-	-	-	-
Zone Lacustre	-	-	-	869	624	449	1 942
Total	-	-	150	5 382	1 195	1 269	7 996
Low flood as percentage of normal flood							
Plateau	-	.	19	74	.	.	44
Delta Central	-	-	20	73	73	100	48
Méma Dioura	-	.	.	-	.	.	-
Gourma	.	.	.	-	-	.	-
Bodara	-	.	.	-	.	.	-
Zone Lacustre	-	.	.	73	73	100	68
Total	-	-	20	72	69	100	50

The delta zone covers a total area (floodable and emerged land) of 28 625 km^2, 539 km^2 of which is located on the PT, 16 079 km^2 on the CD, 1 190 km^2 on MD, 217 km^2 on GM, 243 km^2 on BD and 10 357 km^2 on LZ.
-: nil value; .: impossible value.
Source: Report 1, Chapters 3 and 5.

The maximum flooded area in the Delta Central is estimated at 12 593 km^2, i.e. 78% of the total area of 16 079 km^2 and that in the Zone Lacustre at 2 841 km^2, i.e. 27% of its total area of 10 357 km^2.

In years of low flooding (510 cm), 7 996 km^2 of the delta zone is flooded, i.e. only 50% of the maximum flooded area and a mere 28% of its total surface area. In the Delta Central, 6 006 km^2 is flooded, i.e. 27% of its total area, in the Zone Lacustre, 1 942 km^2 or 19%.

In years of high floods (701 cm), 19 105 km^2 of the delta zone is flooded, i.e. 67% of its total surface area.

16.3 Total catch of fresh fish

The comprehensive lists of the fish population by Dansoko & Kassibo (1989b) indicate that it consists of 138 species, distributed among 58 genuses, representing 26 families. Only 38 species, however, belonging to 20 genuses, are of economic importance. Dansoko & Kassibo (op. cit.) also give information on the temporal distribution of the species caught and unloaded in Mopti. Unfortunately, however, all of this information is difficult to incorporate in the fishing activities defined for the LP-model (Section 16.1).

For estimating actual and potential fresh fish production in the delta zone, various data sources were used, quoted by Dansoko & Kassibo (1989b). Daget reports that, in a good year, potential fish production in the delta zone is 120 000 t yr^{-1} for a surface area of 30 000 km^2, i.e. 40 kg ha^{-1}. Welcome concludes that fresh fish production can be estimated by:

$$C = 3.83 * A \qquad (16)$$

where,
C = The amount of fresh fish caught [t]
A = The surface area within which fish is caught [km^2]

This equation implies that the yield is 38.3 kg ha^{-1}. Danville & Janet indicate that the potential yield is 160 000 t yr^{-1}, with possibilities for an increase. Other authors, not quoted here, have estimated that in periods of low floods, the flooded area is between 17 000 and 22 000 km^2 with yields of 40 kg ha^{-1}, i.e. production fluctuating between 68 000 and 90 000 t yr^{-1}. Maharaux has divided the Bani and Niger rivers into 27 sectors, each with its own production potential. The average, not weighted for the length of these sectors, is between 250 and 300 kg ha^{-1}. However, in judging these results it should be realized that both these rivers, just as improved fish ponds, are highly concentrated sources of fish. In reality, fish production included (temporarily) a much larger area.

It is not relevant, however, to follow here the discussion on the possibilities for increasing production through the use of increasingly controlled production methods.

Information is available on the controlled sale of smoked and dried fish at Mopti (Table A8.1). In addition, an equation is available, the so-called 'Opération Pêche de Mopti formula' (OPM formula), that can be used to estimate the total amount of fresh fish caught in the delta zone on the basis of the observations in Mopti. A detailed explanation is given in Appendix A8.1. In simplified form it reads:

$$R = 5.15424 * A + 43\,174\,476 \qquad (17)$$

where,
R = Estimated total fish production in the delta zone [kg fresh weight]
A = Smoked and dried fish production, marketed at Mopti [kg].

The OPM equation contains four sets of constants, as shown in Appendix A8.1:

1. The population

It is assumed that, the number of fishermen is 80 000. The total rural population of the Region is 1 200 000 individuals. Because of lack of information on population development between 1966 and 1988, we have retained these constants.

2. Consumption

Consumption of smoked and dried fish is assumed to be 20 g per fisherman per day and 15 g per rural inhabitant. Fresh fish consumption is set at 150 g per working fisherman, 50 g per non-working fisherman and 39 g per rural inhabitant. Because of lack of information on population development, and since for the purposes of the LP-model we have used different notions of 'active' and 'inactive' and 'self-sufficient', we have retained these constants.

3. Processing factor

It is assumed that 3 kg of fresh fish is required per kg of smoked fish and 4 kg of fresh fish per kg of dried fish. These constants have been retained.

4. Smoked fish/dried fish ratio

It is assumed that 75% of all processed fish (A) is smoked while the remainder is dried. Since accurate data are available on the ratio of dried and smoked fish (SF/DF: Table A8.1), the basic OPM equation can be modified as follows:

$$R' = SF\% \, (4.75776 * A + 21\,168\,000) + DF\% \, (6.34368 * A + 28\,224\,000) + 20\,242\,476 \qquad (18)$$

where,

R' = Estimated total fresh fish production in the delta zone [kg]
A = Smoked and dried fish marketed at Mopti [kg]
SF% = Percentage of A consisting of smoked fish [%]
DF% = Percentage of A consisting of dried fish [%]

On the basis of the modified OPM equation, therefore, we have estimated the total amount of fresh fish caught as indicated in Table A8.1.

On the basis of the relation between the maximum decadal flood level at Mopti and the flooded surface area in the delta zone (Chapter 5, Report 1), the amount of fresh fish caught (R') can be correlated to the area flooded (S) and thus the amount of fresh fish caught per unit area in the delta zone (R'/S), can be derived as shown in Table A8.1.

The various factors described in detail in Table A8.1 are summarised for a number of periods in Table 16.2.

Table 16.2. Average values of quantities of smoked and dried fish sold and inspected in Mopti [A in t], the percentage of smoked and dried fish (SF/DF), estimates for the total amount of fresh fish caught [R' in t], maximum decadal flood levels in Mopti [X in cm], estimated values for flooded areas [S in km2] and fresh fish yields [R'/S in kg ha^{-1} of floodable area]. Values for 7 periods between 1966 and 1988.

Périodes	A	PF/PS	R'	X	S	R'/S
1966 - 68	10 106	•	103 146	685	17 798	56
1969 - 73	8 605	53/47	92 059	625	13 692	67
1974 - 78	6 566	60/40	79 622	623	13 192	61
1979 - 83	5 782	68/32	74 178	581	10 926	69
1984 - 88	2 420	72/28	55 955	517	8 258	70
1969 - 88	5 843	63/37	75 454	587	11 517	67
1966 - 88	6 466	•	79 066	599	12 336	65

•) missing value.
Source: Table A8.1.

The table shows that from 1969 to 1988, total sales of smoked and dried fish (A) decreased from 8 600 t yr^{-1} to 2 400, i.e. from 92 000 t yr^{-1} to 56 000 in terms of the total amount of fresh fish caught (R'). This drop in catch in the delta zone can be attributed to the lower flood levels; at Mopti, for example, the maximum decadal average fell from 625 to 517 cm. More accurately, the drop in catch is due to the reduction in the level and duration of the floods, with the associated reduction in flooded area. The latter was estimated to have decreased from 13 700 to 8 300 km^2. Fish production is basically determined by the area of land flooded, the water level within these areas and the duration of flooding. In combination, these three factors determine the possibilities for reproduction and growth. The latter depends on food availability within a given area. More accurately, the determinant factor is the available volume, which is influenced both by the surface area and the depth of water. Growth of the fish is not only affected by the type of food available but also by the volume in which, i.e. surface area times depth. The number of individuals and the liveweight per unit volume, are also important.

Table 16.2 also shows that reductions in the amount of fish caught are accompanied by changes in the ratio of smoked fish to dried fish (SF/DF). In terms of total sales of processed fish (A), the ratio SF/DF increased from approximately 50/50 in the period 1969 to 1973 to approximately 70/30 in the period from 1984 to 1988. This is largely due to the fact that large fish is mainly dried and small fish smoked, irrespective of the most suitable form of processing for the various species. It is likely that the combination of lower water levels and shorter flooding periods and hence a reduction in the flooded area results in smaller fish on average. This theory was confirmed by INRZFH/ORSTOM (1988) who showed that fishermen are using increasingly fine-meshed nets, thus becoming increasingly less selective as to the size of fish caught. In addition, Dansoko & Kassibo (1989b) point to the growing practice of the burning technique, applied for very small fry, and producing a very low-quality product.

The drop in total catch seems to have been accompanied by a slight increase in yield per unit area, which has risen from 67 kg ha^{-1} of flooded area to 70 (Table 16.2). In other words, fishermen are trying to compensate the reduction in available area by increasing the pressure per unit area. Hence, they become less selective with respect to the size of the catch and the type of fish caught. According to INRZFH/ORSTOM (1988), fishermen are increasingly turning to 'catch-all' implements such as the xubiseu (fish net), even though this is discouraged for both social and sociological reasons. On reading Dansoko & Kassibo (1989b), it is paradoxical to note that the B fishing permit is valid for fishermen using gill nets, trawl lines and cast-nets whereas that permit is banned throughout the Region.

The increase in exploitation pressure is also due to more intensive fishing activities. Fishing grounds are constantly decreasing in size, while the number of fishermen increases. There is a tendency for large families to break up, causing smaller families to scatter, in an attempt to make better use of all fishing opportunities; if they do not break up, they tend to manage their human resources more effectively. There is a growing tendency to use privately owned fishing implements, both old and new. All together, these changes result in a more intensive exploitation of the fishing grounds, including areas less suitable for the use of collectively owned and/or 'traditional' equipment.

Finally, there is every likelihood that the increasing exploitation pressure is increasingly affecting fish born in the same year.

16.4 Fish catch and flood levels

For describing arable farming and livestock, two types of rainfall years were distinguished: normal and dry years (Report 1, Chapter 4). With regard to floods, also two patterns were defined (Report 1, Chapter 5), i.e. normal floods (660 cm as the maximum decadal flood level at Mopti) and low floods (510 cm). It is logical therefore, to follow the same approach and link fish production to the two types of floods.

In Table A8.1 the estimated fish production in terms of fresh weight (R'), obtained from the modified OPM equation is given and maximum decadal flood levels at Mopti (X). One can therefore establish the following correlation:

$$Yc = -82\,919\,424 + 67\,703 * X1 + 125\,326 * X2 + 74\,325 * X3 \qquad (19)$$

where,

Yc = Estimated total catch [kg fresh weight].

X1 = Maximum decadal flood level at Mopti for the year in which the fish was caught [cm].

X2 = Maximum decadal flood level at Mopti for the year preceding that in which the fish was caught [cm].

X3 = Maximum decadal flood level at Mopti for the year two years previous to that in which the fish was caught [cm].

All coefficients are significantly different from zero at a level of significance of 1%. The results of this multiple linear regression are shown in Figure 16.1, where R' = f(Yc).

Note the substantial effect of the flood level in the year preceding that of the catch. This effect is also clearly demonstrated when linear or, even better, exponential correlations, of the type Y = f(X), are established between total catch and flood levels, thus confirming the old adagium: 'Favourable floods this year mean good fishing next year'.

The effect of flooding level in three successive years can be explained by the fact that the total catch depends on reproduction and growth in the year that the fish is caught, and is therefore linked to the depth and duration of the floods, as well as the surface area flooded. It also depends, however, on the level of reproduction and growth in the preceding year, which affects the quantity and quality of the residual fish for catch, as well as for breeding purposes. This residual effect is still noticeable after four years (Dansoko, pers. comm.). Another point of interest is that fish production also depends on the residual water level, when the water is at its lowest. This water serves as a refuge for the fish. The more residual water is available, the greater the chance of survival. It also affects the exploitation pressure at low water levels. Basically, the lower the water level, the smaller the available surface area, and hence the volume for fishing.

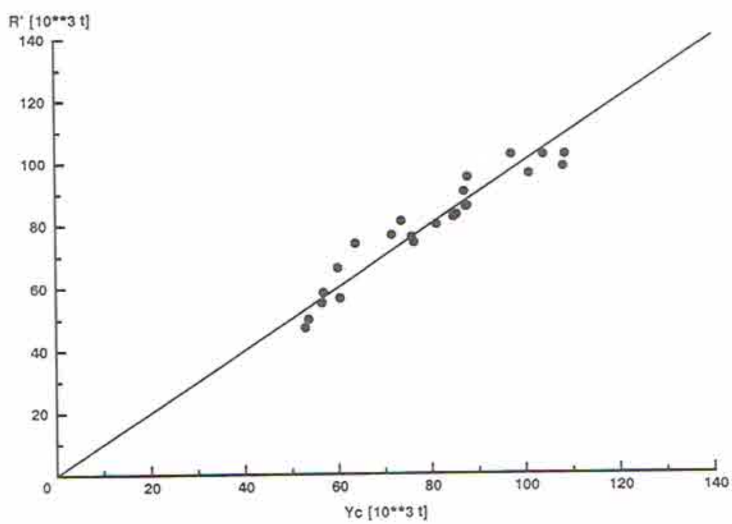


Figure 16.1. Total catch in terms of fresh fish estimated according to the modified OPM equation (R') as a function of the total catch in fresh weight estimated according to the maximum decadal flood levels at Mopti (Yc).

The flood levels, used to establish the correlation with total catch, integrate the effects of level and duration of flooding, as well as the surface area flooded. No attempt was made to correlate fish production to measured values of level and duration of the floods, nor to the surface area flooded, since that is an estimated value calculated on the basis of the flood level.

The next step is to determine the total catch during the two types of floods. The LP-model is not dynamic, hence the calculated regression cannot be used as such.

On the basis of empirical data, it was established that the flood levels are not distributed at random, but are grouped in series. Between 1959 and 1988, the six lowest flood levels were recorded in 1972, 1982, 1983, 1984, 1986 and 1987. We have assumed therefore, that a normal flood represents a series of normal floods and a low flood a series of low floods. For the purposes of this study that implies that, in applying the regression, it is assumed that X1 = X2 = X3 = 660 cm for a year with a normal flood and that X1 = X2 = X3 = 510 cm for a year with a low flood.

By applying the regression equation, we have calculated that in a year with a normal flood, the total catch is 93 534 t yr^{-1} for a maximum flooded area of 16 048 km^2, i.e. 58 kg ha^{-1}. In a year with a low flood, the total catch is 53 431 t yr^{-1} for 7 996 km^2, i.e. 67 kg ha^{-1}.

16.5 Fishing calendar and labour requirements

For the purpose of this study, the basic unit for defining labour is the household. The definitions used are given in Appendix A8.2.

Lae (1988) estimated that 289 801 individuals are involved in fishing, constituting 28 136 households, comprising 5409 migrant households and 22 727 sedentary households. According to Lae (op. cit.), the composition of the households varies with the degree of mobility. Of the migrant households 52% comprises less than 7 individuals, 42% between 7 and 15 and 6% more than 15. Of the sedentary households 36% comprises less than 7 individuals, 52% between 7 and 15 and 12% more than 15. According to Lae (op. cit) and Dansoko and Kassibo (1989a), the average household (migrant and sedentary combined) is made up of 10.3 individuals, the average migrant household of 9.2 and the average sedentary household of 10.6 .

On the basis of this and other information, Table A8.2 was compiled, containing details on the number of households and individuals per activity. In compiling the table, various ethnic groups have been taken into account, i.e. Bozo (14 470 households), Sorko (5 139 households), Somono (2 588 households), Rimbaïbé (3 307 households) and others (2 632 households). The term 'Bozo' as used here, refers to Kélinga, Sorogo and Tié. The term 'others' refers among others to Bambara, Marka, Peul, and Sonraï.

Herry (1988) has classified the fishing population on the basis of age and gender, for each of the two types of mobility distinguished, which allowed compilation of Tables A8.3 and A8.4. These data indicate that there are 5 409 MMF households (main migrant fishermen), 17 068 MSF households (main sedentary fishermen) and 5 659 SSF households (secondary sedentary fishermen). The number of individuals involved in fishing activities comprises 61% of the population of the Delta Central and the Zone Lacustre, which number 476 346 inhabitants in total. Fishing represents a total of 133 308 man-years (Table 16.3; Report 1, Chapter 7).

Table 16.3. Population involvement and labour supply [1000 man-year] in the three fishery activities.

ACTIVITY TYPE	NUMBER OF HOUSEHOLDS ENGAGED IN FISHERIES	AVERAGE HOUSEHOLD SIZE [person]	PERSONS [x1000]	LABOUR SUPPLY[a]	TIME SPENT FISHING [%]	LABOUR SUPPLY
Main Migrant	5 409	9.20	49.8	22.9	85.5	19.6
Main Sedentary	17 068	10.56	180.3	82.9	74.5	61.8
Secondary Sedentary	5 659	10.56	59.8	27.5	37.5	10.3
Total	28 136	10.30	289.8	133.3	-	91.7

a) number of persons * 0.46

Even those, whose main occupation is fishing are not fully occupied in this activity, i.e. not all their working time is spent fishing or processing fish. It is assumed that all three groups are also involved in arable farming.

On the basis of the information from INRZFH/ORSTOM (1988) and Dansoko & Kassibo (1989b), it appears that 25% of the MMF households grow crops as a secondary activity. For this particular group, ethnic diversity has not been taken into account, for two reasons: Bozo make up 86% of the group and the households are basically very similar in terms of size, type of fishing equipment used and way of life. In the MSF group, 70% of the Bozo, 97% of the Sorko and 80% of the Somono households grow crops, but only as a secondary activity. In the SSF group, 99% of the Rimbaïbé households grow crops as their main activity, while all the other households grow crops and practice fishing only as a tertiary activity.

Taking into account the available information, it has been estimated, for the purpose of this study, that MMF spend 85.5% of their working time fishing, MSF 74.5% and SSF 37.5%. Hence, total labour involved in fishing represents 91 648 man-years (Table 16.3), which represents 40% of the available work force in the Delta Central and the Zone Lacustre.

For the purpose of the LP-model, it has been assumed that MMF and MSF households fish all year round, without variation in the intensity of their fishing activities. On the other hand, it has been assumed that SSF only fish during period 6, i.e. after the harvest of millet and before the first rains.

16.6 Equipment

The various implements used in fishing are described in Appendix A8.2. A detailed estimate of the number of the various items is given in Table A8.5 and is summarised in Table 16.4.

Table 16.4. Number of items of fishing gears for the three fishing activities.

GEARS	MAIN MIGRANT	MAIN SEDENTARY	SECONDARY SEDENTARY
Seine	649	1 372	96
Xubiseu	595	2 984	0
Gill net PM	1 839	6 416	915
Gill net MM	3 462	10 907	896
Gill net GM	1 839	3 993	113
Cast-net	1 785	8 606	301
Ganga	1 028	4 015	312
Swanya	1 244	3 610	123
2-handed net	920	4 726	4 027
Trawl line	3 408	10 821	740
Harpoon	1 460	6 396	529
Diéné	8 650	21 350	870
Durankoro	34 080	11 445	4 370
Papolo	17 310	65 370	2 010
Dugout canoe	4 219	11 689	774
Shallop	865	1 710	117
Pole	16 117	41 907	2 790
Paddle	12 657	35 067	4 494
Engine	865	1 710	117

PM: close-meshed, MM: medium-meshed, GM: wide-meshed.
Source: Table A8.5.

As for labour, the basic unit is the household (Table A8.2). In the survey carried out in the framework of the Fishery Research Project in the Delta Central of the Niger, the actual number of items per household is not specified, but only whether it is present or not. The total number, therefore, has most certainly been underestimated.

To obtain as accurate an estimate as possible, the highest values recorded using the various calculation methods have been used. Moreover, we have incorporated additional information. Baumann (1988) claims that it is very rare for households to own more than one seine, gill net or cast-net; we have also added the xubiseu (fish net used in the Region) to the list. For these items, therefore, the results of the survey have been used directly. The same author claims that it is not unusual for fishermen to own several dozen of bow nets, particularly the diéné, per household. For bow nets (local names diéné, dourankoro, papolo), therefore, we have multiplied the figures recorded by a factor of 10. For other items (ganga, swanya, two-handed net, trawl line, harpoon), we have the figures from the survey. Estimates of the number of canoes and shallops are based on data of Baumann (1988) and Lae (1988). No information is available on the number of motorised vessels, but it has been assumed that a shallop is a motorised canoe (Baumann, 1988). Dansoko & Kassibo (1989b) estimate that there are 3 poles and 3 paddles per canoe and 4 poles per shallop.

According to Baumann (1988), present practice is to replace equipment rather than expand. According to Lae (1988), collectively owned 'traditional' implements are replaced by privately owned equipment, either 'traditional' or relatively modern such as the xubiseu. Furthermore, there is a tendency for fishing techniques to become increasingly uniform. Nevertheless, ethnic differences in life style and fishing techniques still exist.

Quantitative information on the yields of the various implements [kg of fish per day and per person] is only fragmentary (Dansoko & Kassibo, 1989a).

The data on the equipment used in the three activities (Table 16.4) is not directly applicable in the LP-model. Firstly, the equipment is highly diverse (19 different items) and secondly, not each of these items can be directly linked to production. The equipment therefore has to be schematized into one or more items that can be easily linked to labour, and a monetary value has to be assigned to the equipment. In the LP-model, the equipment is defined in monetary terms rather than in physical units.

The costs of the fishing implements, their life expectancy and hence the depreciation and maintenance costs, are based on the information in Tables A8.7 to A8.9, giving detailed information compiled from the relevant literature. Table 16.5 summarizes the values adopted for the LP-model.

Table 16.5. Unit costs [FCFA], average life expectancy [in years], annual depreciation [FCFA] and maintenance costs [FCFA] for the various types of fishing gears.

GEARS	COUTS	DURATION	DEPRECIATION	MAINTENANCE
Seine	800 000	3.2	250 000	35 000
Xubiseu	55 000	2.5	22 000	5 000
Gill net PM	42 500	1.5	28 333	5 000
Gill net MM	40 000	1.5	26 667	5 000
Gill net GM	50 000	1.5	33 333	5 000
Cast-net	16 500	2.5	6 600	1 000
Ganga	18 500	2.5	7 400	750
Swanya	6 250	2.5	2 500	500
2-handed net	4 000	2.5	1 600	500
Trawl line	7 500	1.0	7 500	0
Harpoon	1 500	3.0	500	0
Diéné	25 000	1.0	25 000	0
Durankoro	1 125	1.0	1 125	0
Papolo	1 125	1.0	1 125	0
Dugout canoe	187 500	7.5	25 000	15 000
Shallop	262 500	7.5	35 000	40 000
Pole	1 000	0.2	5 000	0
Paddle	1 750	1.0	1 750	0
Engine	500 000	10.0	50 000	70 000

PM: close-meshed, MM: medium-meshed, GM: wide-meshed.
Source: Annex A8.3.

This information permits calculation (Table A8.6), of the total value of the capital investments, annual depreciation and maintenance costs per household for each of the three activities. The operating costs of the engines (fuel and lubricant) are estimated at 300 000 FCFA per engine per year. The various components of the annual capital charges for the equipment, per fishing activity and per household, are given in Table 16.6.

Taking into account the number of households as given in Table A8.2, the total capital investment [FCFA] in fishing equipment amounts to 2.7, 6.9 and 0.5 billion, respectively for MMF, MSF and SSF, i.e. 10.0 billion FCFA in total. The associated depreciation costs are set at 987, 2 646 and 174 million, respectively, i.e. 3 808 million in total. Capital also includes maintenance costs of 223, 549 and 40 million respectively, i.e. 812 million in total. Finally, it includes fuel costs of 260, 513 and 35 million, respectively, i.e. 808 million in total. Total annual capital charges are therefore 5 428 million, consisting of 1 470 million for MMF activities, 3 708 million for MSF activities and 250 million for SSF activities.

Table 16.6. Value of capital [thousand FCFA per household], monetary inputs for the three fisheries activities [thousand FCFA per household per year].

	ACTIVITY		
	MAIN MIGRANT	MAIN SEDENTARY	SECONDARY SEDENTARY
Value capital	501	402	82
Monetary inputs			
Depreciation	182	155	31
Maintenance	41	32	7
Fuel for motor boats	48	30	6
Total	272	217	44

16.7 Fishing activities and catch

Catch per activity is not known. To distribute the total catch among the three activities distinguished, the economic theorem has been applied that the rate of return on capital for different activities tends to converge. In other words, it has been assumed that production for each activity is proportional to its annual capital charges.

This assumption enables compilation of Table 16.7 distributing total catch among the three activities. In a year with a normal flood, MMF, accounting for 19% of the households, catch 27% of the total quantity of fish caught; MSF, who account for 61% of households, 68%, and SSF, constituting 20% of the households 5%. In years of low floods, total catch is lower, but the distribution among the three groups remains the same, since production is proportional to annual capital charges.

Table 16.7 also gives productivity levels for each activity per household [t/household] and per man-year actually devoted to fishing [t/myr]. That shows that

Table 16.7. Monetary inputs [million FCFA], total fish catch [ton] and productivity in the three fishing activities.

ACTIVITY TYPE	MONETARY INPUT	TOTAL CATCH		PRODUCTIVITY [t/househ.]		PRODUCTIVITY [t/man-yr]	
		NORMAL	DRY	NORMAL	DRY	NORMAL	DRY
Main Migrant	1 470	25 333	14 471	4.68	2.68	1.29	0.74
Main Sedentary	3 708	63 899	36 502	3.74	2.14	1.03	0.59
Secondary Sedentary	250	4 302	2 458	0.76	0.43	0.42	0.24
Total	5 428	93 534	53 431	3.32	1.90	1.02	0.58

MMF is the most productive, followed by MSF and SSF. In calculating these productivity levels, it was assumed that the entire work force defined above (Section 16.5) is actually involved in fishing.

Part of the catch is consumed by the household and therefore has to be substracted from the total catch to arrive at the amount of marketable fish.

According to Dansoko & Kassibo (1989b), 10% of the total catch is consumed by the fishing households, which means that in a year with a normal flood 9 353 ton is not marketed. This represents 332 kg per household per year, or 36 kg per individual for the MMF group and 31 for the MSF and SSF groups. Assuming constant values, implies that the lower the fishing intensity per household, the higher the proportion of the catch used for home consumption. In a year with a normal flood, MMF households use 1 798 t for home consumption, i.e. 7% of their total catch; MSF households 5 674 t, i.e. 9% and SSF households 1 881 t, i.e. 44%.

It has been assumed that in years with a low flood, home consumption is identical. In that situation, home consumption therefore represents 18% of the total catch, or 12% for MMF households, 16% for MSF and 77% for SSF.

Information on the prices paid to producers is scarce. Dansoko & Kassibo (1989b) quote a price of 250 FCFA kg^{-1} for fresh fish, 750 for smoked fish and 1 200 for dried fish. In the LP-model, we have assumed a price of 275 FCFA kg^{-1} of fresh fish.

Monetary values of marketed fish are given in Table 16.8 per year and per household. Taking into account the number of households given in Table A8.2, the gross value of the catch in FCFA (excluding home consumption) in a year with a normal flood amounts to 6.5 billion for MMF, 16.0 for MSF and 0.7 for SSF, i.e. 23.1 billion in total. In years with a low flood, the figures are 3.5, 8.5 and 0.2 billion, respectively, i.e. 12.1 billion in total.

Most of the catch is actually sold in processed form. Part of the product marketed in Mopti is transported internally mainly to Bamako, Sikasso, Kayes, Ségou, Koutiala and Bougouni. The remainder is exported, mainly to Ghana, Ivory Coast and Burkina Faso. The partitioning between internal consumption and export for

Table 16.8. Financial balance of fishery activities (thousand FCFA per household).

	ACTIVITY		
	MAIN MIGRANT	MAIN SEDENTARY	SECONDARY SEDENTARY
Normal flood			
Total catch (fresh)	1 288	1 030	209
Marketable product (fresh)	1197	938	118
Monetary inputs[a]	272	217	44
Firewood	77	62	13
Gross revenue	847	659	61
Low flood			
Total catch (fresh)	736	588	119
Marketable product (fresh)	644	497	28
Monetary inputs[a]	272	217	44
Firewood	44	35	7
Gross revenue	328	244	-23

[a]) firewood excluded.

various periods was (Dansoko & Kassibo, 1989b) from 1966 to 1970: 43 and 57%, from 1971 to 1975: 66 and 34% and from 1976 to 1980: 74 and 26%, respectively.

16.8 Wood for smoking

Since fresh fish is basically a perishable product, it is normally processed for conservation before marketing. The main processing methods are, in order of importance, smoking, drying and burning. In addition, seasonal activities take place such as the manufacture of tinéni oil (*Alestes leucisus*) and the processing of threadfin (*Lates niloticus*). In this study, it has been assumed that drying does not require the use of inputs, since the fish is dried in the sun (Dansoko & Kassibo, 1989b). Burning, which is carried out using straw, results in a low-quality product and has not been incorporated in this study. Sale of fresh fish has also been neglected.

Smoking, on the other hand, requires large amounts of wood. According to Dansoko & Kassibo (1989b), 2.95 kg of fresh fish and 5.8 kg of wood are required for the production of 1 kg of smoked fish. According to the same authors, however, 20% of the fish is smoked using cow-dung, giving a lower quality product. According to the OPM formula (Eqn. 15), 75% of all fish is marketed in smoked form. According to Tables 16.2 and A8.1, this percentage is not constant in time. In the LP-model, the value calculated between 1979 and 1988 has been used, i.e. 70%

of all marketed fish is in smoked form. Assuming that it takes 3 kg of fresh fish to produce 1 kg of smoked fish and 4 kg to produce 1 kg of dried fish, 64% of the marketed catch is converted into smoked fish. In this study, however, a value of 70%, has been used, slightly increasing the input of wood, to take into account the various other inputs such as, knives, smoke house grills, etc.

We know that home consumption also includes processed fish, but not the proportions represented by the various processing methods. We have therefore assumed, that they are identical to those for the products sold.

According to Dansoko & Kassibo (1989b), wood is valued at 15 FCFA kg^{-1}, whereas cow-dung for smoking has no monetary value.

To calculate the wood input, therefore, it has been assumed that 70% of all fresh fish caught is smoked, that 20% is smoked using cow-dung, that 2.95 kg of fresh fish and 5.8 kg of wood are required per kg of smoked fish, that wood costs 15 FCFA kg^{-1} and that cow-dung is free.

The monetary values for wood are given in Table 16.8, per household and per year.

Taking into account the number of households given in Table A8.2, total wood requirement for smoking fish is 103 t, i.e. 1 545 million FCFA in a year with a normal flood. For the MMF, MSF and SSF households, these numbers are 27 892 kg, i.e. 418 million, 70 354 kg, i.e. 1 055 million and 4 736 kg, i.e. 71 million, respectively. In years with a low flood, the total comes to 58 829 kg of wood, i.e. 882 million FCFA, and for the three activities, 15 933 kg, i.e. 239 million, 40 190 kg, i.e. 603 million and 2 706 kg, i.e. 41 million, respectively.

16.9 Gross revenue

Total catch in terms of fresh fish, marketable catch expressed in terms of fresh fish, capital charges (depreciation, maintenance costs, fuel for the engines) and smoking costs have been used to estimate gross income generated by the three fishing activities (Table 16.8). The figures are given per household and per year.

Taking into account the number of households as given in Table A8.2, fishing thus generates a gross income of 16.2 billion FCFA in a year with a normal flood, distributed as follows: 4.6 billion for MMF, 11.2 for MSF and 0.3 for SSF. In years with a low flood, gross income generated is 5.8 billion, with 1.8 billion for MMF, 4.2 for MSF and a loss of 0.1 for SSF households, respectively.

16.10 Input-output table

Table 16.9 shows the various inputs and outputs used in the LP-model.

Table 16.9. *Inputs and outputs of fishery activities.*

	ACTIVITY		
	MAIN MIGRANT	MAIN SEDENTARY	SECONDARY SEDENTARY
INPUTS [household^{-1} yr^{-1}]			
Labour [man-year]	3.62	3.62	1.81[a)]
Monetary inputs [1000 FCFA]			
- Depreciation equipment	182	155	31
- Maintenance equipment	41	32	7
- Fuel for motor-boats	48	30	6
- Firewood (normal/dry year)	77/44	62/35	13/7
Total (normal/dry year)	348/315	279/252	57/51
OUTPUTS [household^{-1} yr^{-1}]			
Fish [ton][b]			
- Normal year	4.68	3.74	0.76
- Dry year	2.68	2.14	0.43

a) employed only during labour period 6: 'rest of the year', see under crop cultivation.
b) smoked and drought fish, but expressed as fresh fish.

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ANNEXES

a2

ANNEX 1. COSTS OF VARIOUS INPUTS

This annex belongs almost to each of the chapters 2 to 11.

A1.1 Equipment

Purchase prices of large and small equipment are given in Tables A1.1 and A1.2, respectively. Accurate depreciation rates of small equipment for the various production techniques are impossible to derive due to lack of detailed information.

Table A1.1. Purchase price of large equipment [FCFA], price and life expectancy as used in the LP-model.

EQUIPMENT	PUR. PRICE	SOURCE	PRICE USED	LIFE EXP.
Plough				
millet, extensive techniques				
Millet plough	40 000	1		
	50 000	3		
	25-35 000	9		
Local made	12-15 000	9		
1 wheel plough	40 000	7		
2 wheels plough	65 000	7		
Bourguignon plough	28 130	5		
donkey plough	15 000	7		
Bajac plough	32 000	4	50 000	5
rice & intensive millet techniques				
Rice plough	65 000	1		
rice plough	63 000	4		
rice plough in Segou	40 000	2		
rice plough in Mopti	85 000	2		
rice plough at ORM	67 000	2		
B2 plough	67 000	2	70 000	5
Harrow	20 000	2	20 000	5
Sowing machine	31 000	4	40 000[a)]	5
Chains	3 000	1	3 000	5
Donkey chart	75 000	1	80 000	10
Oxen chart				
(4 wheels)	68 000	4	70 000	10
Sprayer	19 100	4		
	30 000	6	30 000	5
Pirocque	187 500	8	190 000	7.5

Sources: 1: van Duivenbooden, pers. comm. from various shops in Mopti, 2: ORM, pers. comm.; 3: INRZFH & ORSTOM, 1988; 4: PIRT, 1983; 5: OMM, 1988; 6: Traoré of Bureau d'Assistance Technique, pers. comm.; 7: de Frahan & Diarra, 1987; 8: Gosseye, pers. comm.; 9: RIM, 1987.

a) increase to account for quality difference

Table A1.2. Small basic equipment of farmers, purchase price [FCFA] and life expectancy.

EQUIPMENT	PUR. PRICE	LIFE EXP.
Hoe ('Dabah')	1500	4
Hoe ('Faloh')	750	4
Axe	750	10
Sickle	500	1
Millet knife	100	3
Knife	150	3

Source: van Duivenbooden, pers. comm. from various shops in Mopti.

A1.2 Inorganic fertilizer

The purchase price of inorganic (chemical) fertilizer, applied in the LP-model, is based on a non-subsidised market policy, as subsidised prices vary from place to place. For example urea costs 145 FCFA kg^{-1} at CMDT, but 149 FCFA kg^{-1} at ODIPAC (in May 1990, van der Heijden, pers. comm.). By definition of non-subsidised prices an option is kept open to calculate the effect of subsidies on the use of fertilizers. In this study, prices are defined on the basis of N, P and K, and not for compound fertilizers.

The purchase price of non-subsidised urea (46% N) is 205 FCFA kg^{-1} (Samou, ORM, pers. comm.), equivalent to about 450 FCFA kg^{-1} of N. Comparison of fertilizer prices, both for Europe and West Africa (e.g. Gosseye, 1981; Gosseye & le Houérou, 1979; Gosseye *et al.*, 1979) indicates that the price ratio of N and K is around 1. Hence, the purchase price of K-fertilizer is set equal to that for nitrogen.

Phosphorus is generally applied to the field as a compound fertilizer, in combination with N, K, Ca, S, etc. Based on the prices of urea and the prevailing simple superphosphate, the price ratio of P to N is about 1:2.8. Hence, for phosphorus in the LP-model a price of 1 250 FCFA kg^{-1} is applied.

ANNEX 2. RICE

This annex belongs to Chapter 3.

A2.1 Yield and surface complements

Table A2.1. Dry matter yield of floating rice O. glaberrima [kg ha^{-1}].

VARIETY	YIELD	RANGE	NO.	REMARKS	REFERENCE
Dembu	2 400	700-4 400	19		Schreurs, 1989
Jinga	2 400	2 300-2 400	5		Schreurs, 1989
Kossa	1 200		1		Schreurs, 1989
Mogo	1 250		1	1968	Bidaux, 1971
	3 220		1	1967	Bidaux, 1971
	3 000	1 250-4 420	3	1966	Bidaux, 1971
	3 000		1	1965	Bono & Marc.'66
?	1 195		5	farmers best plots	ADRAO, 1985
?	495		1		ADRAO, 1985
	2 210	WEIGHTED AVERAGE (n = 37)			

Table A2.2. Zone of ORM polders in the fifth region after PAPE and area of individual polders that can be cultivated [ha], CP = pasture, PPIV = small village irrigation scheme.

ZONE	POLDER	AREA CULT.	AREA OF PPIV	NET AREA
Mopti North	Diambacourou	1 005	0	1 005
	Ouro - Mema	3 350	0	3 350
	Tiroguel	845	20	825
	Karbaye	(710) CP	0	CP
	Mopti N. Tongorogo	3 765	41	3 724
	Mopti N. Sévaré	1 985	0	1 985
subtotal		10 950	61	10 889
Mopti South	Mopti South - Tibo	1 956	0	1 956
	Mopti South Périmpé	2 100	0	2 100
	Souroufoulaye	2 240	0	2 240
	Souroufoulate Diaby	CP (900)	0	CP
	Torokoro - Kouna	1 620	20	1 603
	Saré Mala	2 460	47	2 414
	Ibetemi	CP (300)	0	CP
subtotal		10 376	67	10 309
Sofara	Sofara	675	0	675
	Sarantomo-syn	2 315	0	2 315
	Bougoula	2 470	0	2 470
subtotal		5 460	0	5 460
Diaka	Ténenkou	4 600	0	4 600
	Dia	1 770	0	1 770
subtotal		6 370	0	6 370
TOTAL		33 156	128	33 128

Source: ORM, 1979; Report 1, Chapter 5.

Table A2.3. Ratio of sown and available area for rice cultivation [%], ratio of harvested and sown area [%] and yield of harvested polder rice [kg ha^{-1}] in the period 1972-1988 CL. = Classification: D = dry and N = normal year.

YEAR	CL.	SOWN/AVAILABLE		HARVESTED/SOWN		YIELD	
		DRY	NORMAL	DRY	NORMAL	DRY	NORMAL
1972/73	D	55.3		33.2		899	
1973/74	N		48.4		45.4		931
1974/75	N		50.1		86.3		1618
1975/76	N		58.1		79.0		1452
1976/77	N		66.0		81.6		1818
1977/78	N		68.0		71.1		1243
1978/79	N		65.0		75.4		1146
1979/80	N		56.4		76.6		1080
1980/81	N		47.6		81.8		1080
1981/82	N		62.0		71.0		1048
1982/83	D	63.2		10.3		729	
1983/84	D	70.2		13.1		1500	
1984/85	D	67.4		0.0		0	
1985/86	N		66.7		73.7		1424
1986/87	D	58.7		35.9		742	
1987/88	D	57.0		5.6		718	
1988/89	N		50.8		77.1		1285
AVERAGE		62.0	58.1	16.4	74.5	765	1284

Source: Report 1, Chapter 5.

Table A2.4. Dry matter yield of polder rice on experimental and farmers sites [kg ha^{-1}] HWL = deep water level; MWL = medium water level; LWL = shallow water level: NF = no fertilizer; WF = with fertilizer.

Variety	ADRAO			FARMER/others			
	mean	range	No	mean	range	No	REMARK
Khao Gaew				1884	542-4000	26	
Khao Gaew	3084	1620-4269	47				HWL-WF
Khao Gaew	2307	1288-3129	6				HWL-NF
Khao Gaew	2146	1080-3638	49				HWL-?
Khao Gaew	2693	1544-3250	11				MWL-WF
Khao Gaew	1954	1613-2294	2				MWL-NF
Khao Gaew	2949	2032-3948	5				MWL-?
Khao Gaew	1942		1				LWL-?
Khao Gaew	2208	864-3361	36				? -WF
Khao Gaew	1290	736-1708	5				? -NF
Khao Gaew	2433	1159-4500	36				? ?
	2463	WEIGHTED AVERAGE (N= 198)					
FRRS-43-3				2323	1812-3334	5	
FRRS-43-3	3186	2835-3281	4				HWL-WF
FRRS-43-3	2673		1				HWL-NF
FRRS-43-3	3000	2348-4054	4				HWL-?
FRRS-43-3	3540	3397-3616	3				MWL-WF
FRRS-43-3	2808		1				MWL-NF
	3142	WEIGHTED AVERAGE (N= 13)					
D52-37				2439	440-3800	6	
D52-37	2438	2098-2777	2				MWL-WF
D52-37	5327		1				MWL-?
D52-37	3233	2301-4059	3				LWL-WF
D52-37	5071		1				LWL-?
D52-37	4250	2500-4500	2				? -?
	3719	WEIGHTED AVERAGE (N = 9)					

.../...

Table A2.4. Continued.

Variety	ADRAO			FARMER/others			
	mean	range	No	mean	range	No	REMARK
DM16				2544	630-4147	78	
DM16	2764	1409-3580	9				HWL-WF
DM16	1977		1				HWL-NF
DM16	3355	1415-4465	13				HWL-?
DM16	3178	2325-3870	9				MWL-WF
DM16	2883		1				MWL-NF
DM16	2972	2097-3685	7				MWL-?
DM16	3825	3756-3894	2				LWL-WF
DM16	2414	1315-3755	10				LWL-?
	2972	WEIGHTED AVERAGE (N = 10)					
BH2				2110	512-3854	41	
BH2	1667	1198-2208	8				HWL-WF
BH2	1077		1				HWL-NF
BH2	2842	2180-3503	2				HWL-?
BH2	2696	1697-3487	20				MWL-WF
BH2	2561	1900-3221	2				MWL-NF
BH2	2944	1708-3736	3				MWL-?
BH2	3369	2476-3954	3				LWL-WF
BH2	3029	2158-3865	7				LWL-?
BH2	2027	1061-5000	11				? -?
	2484	WEIGHTED AVERAGE (N = 57)					

Sources: ADRAO (1986; 1985; 1982; 1980); Koli *et al.* (1983); Bidaux (1971) & Gosseye (1982) quoted by van Duivenbooden (1990b).

Table A2.5. Total area [ha] of irrigation schemes in the fifth region[a] (values between brackets not used).

NAME	REMARK	TOTAL AREA[b]
DELTA CENTRAL		
Dagawomina	in ORM polder	20
Déra		2
Kaléssourou		5
Kanio		25.(20, 13)
Komio		40.(30, 25)
Konna		7
Kouakourou		28
Kouna	in ORM polder	20.(17)
Médine	in ORM polder	21
Néma	in ORM polder	27
Ouro-Modi		15
Saba 1		17
Saba 2		18
Sahona		13
Saré-Mala		20.(19)
Séné		?
Ténenkou		?
Tongorongo	in ORM polder	20
Toguéré		7
Wagnoka		18
	subtotal	323
ZONE LACUSTRE		
Ambiri		40
Deyboita		11
Owa		20
Sah		20
Seybi		20
	subtotal	111
TOTAL		434

Sources: Dansoko & Kassibo (1989); GR Mopti (1988); ORM (pers. comm.).
a) Areas planned by FED not included.
b) Area cultivated = 0.9 times total area.

Table A2.6. Dry matter yields of irrigated rice in farmers fields [kg ha^{-1}].

VARIETY	MEAN	RANGE	No	REMARK	REFERENCES
unspecified	4936	3648-5766	6	dry season	ORM, 1988a
unspecified	450*		1	dry season	de Jong & Harts-Broekhuis, 1989
unspecified	5060		1	dry season	ORM, 1989g
unspecified	4081		1	dry season	ORM, 1989g
unspecified	1522	1433-1610	2	dry season	ORM, 1989f
unspecified	5579		1	dry season	ORM, 1989e
unspecified	6090		1	dry season	ORM, 1989d
unspecified	6172		1	dry season	ORM, 1989c
unspecified	4991		1	dry season	ORM, 1989b
	4617	WEIGHTED AVERAGE (n = 14)			
unspecified	3456		1	first season 1986	ORM, 1989f
unspecified	4161	1662-6800	11	rainy season	ORM, 1989a
unspecified	4200	3624-4760	10	rainy season	ORM, 1988b
IR 1529	3440	2667-4110	4	first season	ESPR, 1988c
unspecified	4733	3000-5700	3	rainy season	de Jong & Harts-Broekhuis, 1989
	4100	WEIGHTED AVERAGE (n = 29)			
	4275	WEIGHTED AVERAGE (n = 43)			

*) not taken into account for calculation of weighted average.

ANNEXE 3. NIEBE

A3.1 Cultures en couloir

La culture en couloir est un système agro-sylvo-pastoral c'est-à-dire que c'est un système qui cherche a intégrer la culture, l'élevage et la sylviculture. Les buts de la culture en couloir sont:

1. lutter contre la dégradation des sols (érosion physique et chimique) sous l'influence des cultures itinérantes et donc fixer les cultures selon un système soutenable (durable);
2. fournir du fourrage de qualité en saison sèche;
3. fournir du bois.

Ces buts sont atteints par l'introduction de légumineuses ligneuses en rangées dans les champs. Lors des saisons de croissance des cultures, ces ligneux sont régulièrement émondés et les branches feuillées sont étalées sur le sol (paillage ou mulching). En fin de saison de croissance des cultures, ces ligneux ne sont plus émondés et les branches feuillues sont laissées sur les arbres et servent de fourrage lors de la saison sèche. Les branches sèchées sur le sol servent comme bois de chauffe.

La restauration de la fertilité des sols se ferait:

1. par la fixation de l'azote par la légumineuse;
2. par le transport des éléments minéraux via le mulching qui agit directement en libérant des éléments minéraux en surface du sol où se trouve la majorité des racines des céréales et indirectement par son apport de matière organique qui améliore les propriétés chimiques et physiques;
3. par l'amélioration du bilan hydrique via le mulching qui agit directement en diminuant l'évaporation du sol et qui agit indirectement par sa matière organique qui améliore les propriétés physiques, et donc hydriques du sol; de plus, si ces légumineuses ligneuses sont pâturées directement, il y a apport supplémentaire de fumier qui agit par ses propriétés chimiques et physiques.

Le but de restauration de la fertilité des sols nécessite:

1. de trouver un ou des cultivars (variétés) d'espèces de légumineuse ligneuse qui soient adaptés à la zone agro-écologique où ils seront introduits et qui soient adaptés au sol où ils seront implantés;
2. que ces ligneux adaptés soient d'implantation facile: si possible par semis directement en place et si possible ne pas nécessiter des innoculations de rhizobium, ce qui est actuellement une technique peu accessible aux paysans;
3. que ces ligneux doivent être de croissance rapide et supporter l'émondage lors des cultures, le rythme d'émondage étant à préciser;
4. de résoudre le problème de géométrie spatiale de l'ensemble qui minimiserait la compétition intraspécifique entre le ligneux et la culture (céréale); autrement dit, il faut mettre au point le mode d'implantation et le mode de conduite du système.

Ce premier but amène cependant des remarques:

1. par l'apport d'azote suite à la fixation, il pourrait y avoir, la ou les premières années, un effect de pseudofumure; c'est-à-dire que l'apport d'azote permet de mieux exploiter les autres minéraux mais accélère leur consommation et donc l'épuisement des sols; pour que le système soit réellement durable, il faut veiller à ce que l'apport d'azote par la fixation soit équilibré par l'apport externe des autres éléments minéraux; il semble admis que lors de l'installation d'un tel système une fumure ternaire soit nécessaire, surtout sur les sols naturellement carencés;
2. l'apport de fumier supplémentaire, qui se ferait par les animaux venant brouter le fourrage vert sur pied en saison sèche, participe au transfert de fertilité;
3. lorsqu'un système est mis au point pour une zone agro-écologique donnée et un type de sol donné, il y a, à long terme, des modifications de ces sols quant à leurs propriétés physiques et chimiques; il se peut que les légumineuses ligneuses ayant permis la mise en route du système ne soient plus valables sur les sols de meilleure qualité qu'elles ont permis de "construire"; il se peut aussi que ces légumineuses ligneuses restent valables mais que leur mode de conduite doive être modifié.

Le but de fournir du fourrage nécessite: *(i)* de trouver une espèce appétée qui soit verte en saison sèche, de préference en fin de saison sèche, moins pour améliorer la quantité de fourrage que pour améliorer surtout la qualité du fourrage disponible (en terme de taux de N) et *(ii)* cette espèce doit supporter le broutage, s'il y a pâturage sur pied, ou l'émondage, s'il y a affouragement.

Le but de fournir du bois ne semble pas une priorité et il servirait plus à fournir du petit bois (piquet, bois de chauffe). Cependant cet objectif est parfois vital dans les zones très intensément cultivées où il n'existe plus, ou quasi plus, de réserves de bois exploitable, car les réserves de bois des "vergers" (karité, acacia, etc.) sont immobilisées étant donné que ces essences ont pour objectifs de fournir des fruits, des feuilles, etc. et non pas du bois.

En ce qui concerne la mise au point de ces systèmes et de la preuve de leur efficacité:

1. pour la zone humide (Ibandan, Nigéria), ce système agro-sylvo-pastoral est mis au point en association avec le maïs et son efficacité est prouvée;
2. pour la zone sub-humide (de 800 à 1 000 mm), ce système agro-sylvo-pastoral est en cours de mise au point et donc son efficacité sur la maïs, le sorgho et le mil n'est pas encore prouvée;
3. pour la zone sub-aride (450 mm), qui nous intéresse, ce système est au tout début de mise au point (criblage des variétés d'espèces adaptées) et donc son efficacité sur le mil n'est pas encore prouvée; en effet, à Niono, sur sol allant du sable au sable limoneux aride ("terre à mil"), le CIPEA retiendrait actuellement, suite à ses essais:

a. 11 cultivars (variétés) de *Gliricidia sepium* provenant des zones sèches du Mexique;

b. *Leucaena leucocephala* cv. "Cuningham"; cette espèce présente la particularité d'être assez spécifique quant au rhizobium et d'être très sensible aux termites;

c. le *Prospis (juliflora?)* n'est pas retenu;

d. les espèces locales ne sont pas retenues vu leur croissance trop lente et leur production trop faible; pour la zone sub-aride, il semble déjà certain que la mise au point de la géométrie de plantation devra concilier: *(i)* une compétition, intraspécifique au ligneux, accentuée par la faible disponibilité en eau, surtout en saison sèche; *(ii)* une compétition, interspécifique entre le mil et le ligneux, accentuée par la faible disponibilité en eau de cette zone et par la forte compétitivité du mil, qui à un système racinaire puissant et profond.

ANNEXE 4. CULTURE MARAICHERE

A4.1 Superficies actuelles sous horticulture

Le Cercle de Bandiagara est entièrement compris dans le Plateau dont il ne représente qu'une partie. Le tableau A4.1 nous donne les surfaces emblavées à un moment de la contre-saison 1986-87 ainsi que les contributions des différentes cultures: en moyenne 65% sont sous échalote et 35% sont sous d'autres cultures, dont 15% en légumes et 15% en tomate. Notons pour Goundaka, l'importance des autres cultures soit 85% dont 64% en tomate du fait de la présence proche et accessible du marché qu'est la ville de Mopti. Les cultures horticoles du Cercle de Bandiagara exploitent 148 points d'eau dont 60 barrages.

Tableau A4.1. Pour les Arrondissements du Cercle de Bandiagara, nombre de barrages (Bar) et d'autres points d'eau (PtE) exploités par la culture maraîchère, superficies [ha]. De ces superficies pourcentage occupé par les échalotes (EC%) et les autres cultures (AC%) qui comprennent les féculents (FC%), les légumes (LG%), le tabac (TA%) et la tomates (TO%). Contre-saison 1986-1987.

Arron	Bar	PtE	ha	EC%	AC%	FC%	LG%	TA%	TO%
Bgara	14	13	180	70	30	3	15	2	10
Dourou	12	11	153	80	20	2	8	8	2
Gdaka	-	5	67	15	85	5	15	1	64
Kani-G	9	8	95	85	15	-	9	2	4
Kendié	5	12	95	66	34	12	17	2	3
Ningari	4	7	19	50	50	-	30	-	20
Ouo	-	-	-	-	-	-	-	-	-
Sangha	16	32	116	89	11	2	5	2	2
Total	60	88	724	65	35	3	15	2	15

Source: GTZ/SDA (com. pers.).
-) valeur nulle.

Le tableau A4.2 nous donne, entre autre, les superficies et le nombre d'exploitants en 1987-88. Nous voyons au tableau A4.3 que seulement 0.09% de la superficie du Cercle de Bandiagara est sous maraîchage et que cela ne concerne que 9.2% de la population. Autrement dit, chaque habitant exploiterait théoriquement 45 m^2 en moyenne et chaque exploitant cultiverait 484 m^2 en moyenne. Mais ce tableau nous montre aussi la disparité entre les Arrondissements de ce Cercle. La disponibilité en terre arable et en eau ainsi que l'accès au marché influencent l'éventuelle augmentation des superficies horticoles en même temps que l'augmentation de la densité de population.

Tableau A4.2. Pour les Arrondissements du Cercle de Bandiagara, superficies[a] [km²], population[b] (Pop), superficies maraîchères[c] [ha] et nombre d'exploitants maraîchers[c] (Exp). Contre-saison 1987-1988.

Arrondis.	km²	Pop	ha	Exp
Bandiagara	1 650	30 980	300	4 678
Dourou	720	17 370	99	2 101
Goundaka	542	16 880	83	646
Kani-Gogouna	720	16 620	89	1 490
Kendié	700	25 170	163	3 241
Ningari	787	29 840	17	402
Ouo	2 400	25 990	-	-
Sangha	700	20 020	65	4 294
Total	8 219	182 870	816	6 852

[a]) DNI (1987). [b]) DNSI (1987). [c]) GTZ/SDA (com. pers.).
-) valeur nulle.

Tableau A4.3. Pour les Arrondissements du Cercle de Bandiagara, densité de population [habitants km^{-2}], superficies maraîchères par exploitant [m^2/exp] ainsi que par habitant [m^2/pop], pourcentage du territoire concerné (%ter) et pourcentage de la population concernée (%pop). Contre-saison 1987-1988.

Arrondis	DENSITE	m²/exp	m²/pop	%ter	%pop
Bandiagara	18.8	641	97	0.18	15.1
Dourou	24.1	469	57	0.14	12.1
Goundaka	31.1	1 287	49	0.15	3.8
Kani-Gogouna	23.1	600	54	0.12	9.0
Kendié	36.0	504	65	0.23	12.9
Ningari	37.9	426	6	0.02	1.3
Ouo	10.8	-	-	0.00	0.0
Sangha	28.6	151	32	0.09	21.4
Total	20.5	484	45	0.10	9.2

Source: GTZ/SDA (com. pers.).
-) valeur nulle.

Le tableau A4.4 nous donne, à un autre moment de la contre-saison 1986-87, diverses informations: les 919 ha d'horticulture sont à 70% sous échalote et à 30% sous autres cultures à raison de 18% pour les féculents, 4% pour les légumes, 5% pour le tabac et 3% pour la tomate. Nous retiendrons cette répartition des superficies de 70% pour l'activité "échalote" et de 30% pour l'activité "autres cultures".

Tableau A4.4. Pour le Cercle de Bandiagara, superficies allouées aux différentes cultures maraîchères [ha], pourcentage qu'elles représentent [%], rendements [t ha^{-1} de MV] et prix [FCFA kg^{-1}]. Contre-saison 1986-1987.

Cultures	ha[b]	%[b]	t ha^{-1}	FCFA kg^{-1}
ECHALOTES				
Bulbes	645.9	70.3	25.7[c]	75[b]
Feuilles	645.9	70.3	8.9[c]	11[c]
Echalotes	645.9[a]	70.3[a]	34.6	59
AUTRES				
patate douce	148.0	16.1	20.0[b]	75[b]
pomme de terre	16.5	1.8	20.0[e]	75[d]
Féculents	164.5	17.9	20.0	75
betterave	0	0	15.0[e]	100[d]
callebasse	0.2	0	20.0[e]	25[d]
carotte	0.5	0	15.0[e]	100[d]
chou	3.1	0.3	25.0[e]	100[d]
djakattou	15.2	1.7	5.0[b]	75[b]
laitue	0.8	0.1	15.0[e]	100[d]
melon	0	0	10.0[e]	100[d]
pastèque	0	0	20.0[e]	100[d]
piment	13.8	1.5	12.3[g]	89[g]
Légumes	33.6	3.7	10.4	88
Maïs	0.1	0	0.4[d]	55[f]
Tabac	47.1	5.1	6.0[i]	427[h]
Tomate	27.4	3.0	15.0[b]	40[b]
Autres	72.8	29.7	15.9	96

a) comprend 2.9 ha d'ail soit 0.3% de la superficie.
b) selon GTZ/SDA-Bandiagara.
c) selon Bakker & Traoré (1990).
d) valeur estimée.
e) selon Beniest *et al.* (1987) et RFMC (1980): valeurs les plus faibles des fourchettes.
f) prix plancher céréales.
g) selon GTZ/SDA: piment 4 t ha^{-1} de MS à 275 FCFA kg^{-1} or piment frais de 25 à 40% de MS soit 32.5% de MS selon RFMC (1980).
h) selon GTZ/SDA: tabac à 2 137 FCFA kg^{-1} de MS or tabac frais à 20% de MS selon RFMC (1980).
i) selon GTZ/SDA: tabac 0.5 t ha^{-1} de MS mais prenons valeur de RFMC (1980) de 6 t ha^{-1} de MV.
0: moins de 0.05 ha ou de 0.05%.

Le Cercle de Douentza est composé d'un patchwork de zones agro-écologiques: le coin nord-est du Séno Bankass, les extrémités nord-est du Plateau, presque tout le Séno Mango sauf son coin sud-ouest, le Gourma à l'exclusion de la frange ouest, quasi tout le Bodara sauf l'extrêmité de la pointe ouest et la bordure est de la Zone Lacustre.

Tableau A4.5. *Pour les Arrondissements du Cercles de Douentza, superficies consacrées aux cultures maraîchères [ha] et pour ces superficies, pourcentage que représentent l'échalote (EC%], les féculents (FC%), les légumes (LG%), le maïs (MA%), le tabac (TA%) et la tomate (TO%). Contre-saison 1984-1985.*

Arron	ha	EC%	AC%	FC%	LG%	MA%	TA	TO%
Boni	0.04	21	79	-	52	-	-	27
Boré	17.26	62	38	1	15	0	20	2
Douentza	109.14	40	60	16	5	5	3	31
Hombori	0.94	14	86	42	32	-	-	12
Mondoro	0.04	7	93	23	38	8	9	15
N'Gouma	7.56	12	88	42	23	13	9	1
Total	134.98	41	59	15	9	4	5	26

Source: Maïga (1986).
-) valeur nulle. 0) valeur négligeable.

Le tableau A4.5 nous donne les superficies horticoles du Cercle de Douentza lors de la contre-saison 1984-85, soit 135 ha. Il est à noter la disparité entre les Arrondissements quant aux surfaces et aux spéculations. Ceci est dû entre autre au fait que ce Cercle a vécu trois vagues d'installation maraîchère. Selon nos observations et Hesse & Thera (1987), nous pouvons décrire ces trois vagues comme pré-coloniale, coloniale et post-coloniale.

1. Pré-coloniale: exploitation des sources aux pieds des massifs rocheux grâce à tout un système de gestion de l'eau d'irrigation par gravité plus ou moins réussi selon le périmètre mais en perpétuelle évolution. Selon les informations recueillies à Kikara, ce système était déjà en place lors de l'installation des Sonraïs au Dyoundé. Les cultures y sont surtout l'échalote, l'ail, le tabac, le manioc, la patate et la courge. Ces cultures "traditionnelles", bien que toutes exotiques, ont leurs semences productibles par les cultivateurs, ont subi une sélection locale, ont leurs techniques de production et de conservation bien dominées dans le contexte actuel. De plus, leurs circuits de commercialisation sont bien établis entre des marchés, souvent spécifiques, et les producteurs qui seraient des "professionnels" veillant à ne pas saturer leur marché et ayant, dans certaines limites, une capacité d'adaptation aux évolutions du contexte de production, c'est-à-dire qu'ils ne sont pas cristallisés. A ce type d'exploitation, s'ajoute les cultures maraîchères de décrue, surtout de manioc et de patate, dans l'Arrondissement de N'Gouma mais vu l'état actuel des crues, ce type de production est profondément perturbé.
2. Coloniale: mise en exploitation de céanes à Boré "plaine" et aux alentours de Hombori vers 1940-50; étant donné la disponibilité en eau plus faible et le travail d'exhaure de l'eau, ces cultures sont réalisées sur des surfaces plus petites qu'au point précédent mais finalement tendent à y ressembler très fort.
3. Post-coloniale: accélération du processus d'introduction de nouvelles cultures vers les années 1970. Dans un souci de sécurisation alimentaire, forte

installation de périmètres potagers "modernes" à partir de 1984-85, suite à des initiatives du bas, ou des interventions du haut, ou à des conciliations de gens essayant de satisfaire les uns sans heurter les autres. Ces nouvelles productions, parfois très appréciées comme la pomme de terre, sont soumises à un approvisionnement en semences totalement aléatoire, ne sont pas toujours bien dominées quant à leurs techniques de production et sature rapidement un marché actuellement petit. Ce nouveau secteur, dans le Cercle de Douentza, est très désorganisé (producteurs atomisés) ainsi que dans tous les autres Cercles de la Région ce qui n'empêche pas l'émergence de nouveaux "professionnels" organisés comme les producteurs de laitues de Nantaka.

Au tableau A4.6, nous voyons que le Cercle de Douentza n'a que 0.007% de son territoire sous maraîchage soit 14 fois moins que le Cercle de Bandiagara, autrement dit 9 m^2 par habitant soit 5 fois moins que pour le Cercle de Bandiagara. La disparité entre les Arrondissements du Cercle de Douentza montre cependant une tendance à l'augmentation des superficies horticoles avec l'augmentation de la densité de la population.

Nous ne disposons pas d'informations pour les autres Cercles de la Région si ce n'est pour celui de Niafunké qui aurait eu sous horticulture 1 268 ha en 1985, 680 ha en 1986, 520 ha en 1987 et 130 ha en 1988.

Tableau A4.6. Pour les Arrondissements du Cercle de Douentza, superficies[a] [km^2], population[b], densité de population [habitant km^{-2}], superficies maraîchères[c] [ha], pourcentage du territoire concerné (%ter) et superficies maraîchères par habitant [m^2/pop].

Arrondissement	km^2	Population	Densité	ha	%ter	m^2/pop
Boni	4 592	15 867	3.5	0.04	0	0
Boré	2 378	16 474	6.9	17.26	0.01	10
Douentza	880	54 926	62.4	109.14	0.12	20
Hombori	2 203	17 583	8.0	0.94	0	1
Mondoro	5 598	16 140	2.9	0.04	0	0
N'Gouma	3 252	29 618	9.1	7.56	0	3
Total	18 903	150 608	8.0	134.98	0.01	9

a) DNI, 1987. b) DNSI, 1987. c) Maïga, 1986.
0) valeur négligeable.

A4.2 Semis d'échalote

Il existe 2 méthodes de semis de l'échalote: soit par semis de bulbes, soit par semis de graines. La technique par semis de bulbes, retenue pour le modèle-PL, à des avantages et des inconvénients. Les avantages sont:

- souplesse dans les dates de semis qui peuvent être étalées de octobre à fin décembre;

- occupation du terrain de 90 à 110 d et besoin d'eau seulement durant cette période;
- possibilité de réaliser 2 cycles.

Les inconvénients sont:
- prélèvement sur la production des semences ou achat au prix fort;
- conservation de bulbes-semences avec des pertes énormes.

La technique de production d'échalote en utilisant le semis de graines en pépinière, non retenue pour le modèle-PL, est parfois utilisée et est par exemple la technique préférée des producteur de Boré "plaine". Elle a des avantages et des inconvénients. Les avantages sont:
- toute la production de bulbes est commercialisable;
- il ne faut pas conserver des bulbes-semences pour la campagne suivante avec des taux de pertes de l'ordre de 50%, ni acheter des bulbes au moment où ils sont le plus cher.

Les inconvénients sont:
- elle oblige le cultivateur à semer en pépinières au plus tard fin octobre ou début novembre;
- elle demande 160 d de croissance (de 40 à 60 d de pépinière et environs 120 d en planche pour les échalotes locales de jour court), donc un seul cycle est permis et il faut de l'eau durant ces 160 d.

En ce qui concerne les distances de plantation de l'échalote, les distances habituellement utilisées par les producteurs de la Région sont de 0.10 * 0.10 ou de 0.12 * 0.12 m (obs. pers.). Les distances recommandées sont de 0.12 * 0.12 ou de 0.20 * 0.08 ou de 0.20 * 0.10 m (Messiaen, 1975b).

En cas de semis de graines d'échalote, méthode non retenue pour le modèle-PL, il faut, selon Messiaen (1975b), de 2 à 5 g de graines par m^2 de pépinière et comme 1 g de graines d'oignon contient 250 graines, il faut de 2 à 4 kg ha^{-1} de graines d'oignon selon la densité de plantation finale, sans tenir compte des pertes à la conservation, aux semis et au repiquage. Soit le producteur achète des graines et les graines d'oignons valent à Bamako 20 100 FCFA kg^{-1}, soit il réserve une partie de ses planches à la production de graines; les planches grainières peuvent produire 2 t ha^{-1} de graines mais les rendements en bulbes sont réduits à un maximum de 2 t ha^{-1}, bulbes de mauvaise qualité et conservation. Selon Beniest *et al.* (1987), il faut 3.5 kg ha^{-1} de graines d'oignon.

A4.3 Données phytotechniques.

Le tableau A4.7 montre les données de base concernant les cycles des cultures horticoles ainsi que les rendements normalement atteignables si toutes les conditions de croissance sont réunies.

Tableau A4.7. Pour les principales cultures maraîchères rencontrées dans la Région, durée d'occupation de la pépinière [PEP en d] et du terrain [TER en d], fumure organique préconisée [FUO en t ha^{-1}] (fumure organique du type 1.20-0.32-1.28 + 1.24 CaO + 0.61 MgO) et minérale [FUM en t ha^{-1}]; (fumure minérale toujours à fractionné; sur base d'un engrais du type 10-10-20) ainsi que rendement en matière verte ou fraîche [t ha^{-1}]. Les formules des fumures sont en $N-P_2O_5-K_2O$.

CULTURES	PEP	TER	FUO	FUM	t ha^{-1}
Amarante	15-20	30	20	-	13-38[a]
Amarante	15-20	•	20	•	25-50[b]
Aubergine	30-50	150-240	20-30	0.75	25-40
Betterave	-	•	•	•	10-25
Carotte	-	100-120	10-20	0.80	10-40
chou	15-35	80-100	20-30	0.70	10-40
Chou de Chine	25-35	55- 85	15-20	0.70	10-40
Concombre	-	85-120	30-40	1.00	10-80
Courge	-	•	•	•	10-20
Courgette	-	70- 90	15-25	1.10	20-40
Echalote	40-60	100-170	10-20	1.00	20-70[c]
Echalote	-	90-100	10-20	1.00	20-30[d]
Djakattou	30-40	130-200	10-20	1.00	8-20
Gombo	-	90-160	10-20	0.60	4-29
Haricot gousse	-	75- 85	10-15	0.50	3-14
Haricot sec	-	75- 85	10-15	0.50	1-03
Laitue	20-30	60-105	15-25	1.00	8-25
Manioc	-	240-365	1-10	0.60	2-20
Melon	-	100-140	30-40	1.00	10-20
Niébé	-	•	•	•	0- 2
Oignon	40-60	100-170	10-20	1.00	20-70[c]
Pastèque	-	100-150	20-30	0.50	20-45
Patate douce	-	100-120	1-15	0.90	3-50[e]
Patate douce	-	100-120	1-15	0.90	15[f]
Piment	45-60	90-240	15-20	0.70	1-15[g]
Pomme de terre	-	75-100	15-20	0.75	5-40
Poivron	30-45	120-180	15-25	1.30	10-30
Radis chinois	-	35- 50	15-25	0.70	15-25
Roselle	-	120-180	10-20	0.90	10-20[f]
Roselle	-	120-180	10-20	0.90	3- 4[h]
Tabac	50-90	50-100	40	•	6-12[f]
Tomate	25-40	110-150	20-30	1.20	5-50

Sources: Grubben, 1975; RFMC, 1980; Beniest *et al.*, 1987.

a) feuilles fraîches en 1 récolte à 15% de MS.
b) en 2 à 4 récoltes par coupes successives contenant de 50 à 75% de feuilles fraîches.
c) par semis de graines.
d) par semis de bulbilles.
e) tubercules.
f) feuilles fraîches.
g) jusqu'à 8 mois d'occupation du terrain pour les potentiellement vivaces.
h) calices frais soit 0.5-0.6 t ha^{-1}.
-) valeur nulle. •) valeur manquante.

A4.4 Compléments sur les opérations et les temps de travaux

Le tableau A4.8, établis selon Bakker & Traoré (1990), donne les temps des travaux de la culture de l'échalote à Mayarasso, au Mali (4e Région, vers Baramandougou, en frontière avec la 5e). Cette culture se fait par plantation de bulbes et ne passe pas par le semis de graines en pépinières, technique peu utilisée dans la Région.

Tableau A4.8. Temps de travail [dth ha^{-1}], selon les divers travaux de la culture de l'échalote à Mayarasso (vers Baramandougou en 4e Région faisant frontière avec la 5e) et pourcentage moyen que représentent ces divers travaux. SA: sols argileux, SS: sols sableux, SM: moyenne de SA et SS.

Travail	SA	SS	SM	%
Nettoyage du sol	34	18	24	1
Labourage	191	135	159	8
Clôturage	66	39	50	3
Plantage	67	43	54	3
Arrosage	942	1 135	1 053	55
Fumage	21	15	17	1
Désherbage	175	206	193	10
Récolte[a]	375	375	375	19
Total	1 871	1 966	1 925	100

Source: Bakker & Traoré (1990).
a) incluant la transformation des produits frais (bulbes et feuilles) en produits secs.

Sur sols lourds, le nettoyage, le labourage, le clôturage, le plantage et le fumage prennent 379 dth ha^{-1} tandis que sur sols légers, ces opérations prennent 250 dth ha^{-1} soit une diminution de 34%. Par contre sur sols lourds, l'arrosage et le désherbage prennent 1 117 dth ha^{-1} contre 1 341 sur sols légers soit une augmentation de 20%. Le temps total de travail investi est presque le même quel que soit le sol mais la répartition interne est différente. L'arrosage prend en moyenne 55% du temps total de travail investi dans la culture de l'échalote, soit 50% sur sols lourds et 58% sur sols légers. Donc, le premier facteur limitant est l'arrosage. Il est suivi par la récolte-transformation qui prend 19% du travail total.

N'ayant pas la décomposition entre la récolte stricte et la transformation, nous ne pouvons pas les distinguer mais comme souvent les produits de cette activité quittent les frontières de l'activité sous forme transformée, cela ne fausse pas les données totales.

Le tableau A4.9 nous donne les temps des travaux, sans l'arrosage, obtenus au Sénégal en station expérimentale pour l'oignon avec semis de graines en pépinières (Beniest *et al.*, 1987). Nous assimilons, pour cette étude, la culture de l'oignon à celle de l'échalote.

Tableau A4.9. Temps de travail [dth ha^{-1}] pour divers travaux maraîchers et selon 5 cultures (OIG = oignons, PDT = pomme de terre, CHO = chou, TOM= tomate, TAB= tabac).

Travail	OIG	PDT	CHO	TOM	TAB
Nettoyage	21	13	20	19	•
Pépinière	98	-	15	24	30
Labourage et fumage	18	23	19	21	30
Plantage	87	23	29	21	45
Fumage	8	15	8	9	•
Désherbage	57	21	28	21	60
Buttage	-	21	-	-	-
Pulvérisation	6	6	12	10	•
Récolte[a]	41	84	17	73	65
Total[b]	336	207	147	198	230

Sources: RFMC (1980); Beniest *et al.* (1987).

a) récolte n'incluant pas les transformations post-récoltes faites à et par l'unité de production; si transformations du tabac incluses, ajouter 265 dth ha^{-1} soit un total pour le tabac de 495 dth ha^{-1}.

b) total n'incluant pas l'arrosage.

-) valeur nulle. •) valeur manquante.

Entre les tableaux A4.9 et A4.8, des différences sont remarquées pour le labourage (18 dth ha^{-1} contre 159), le plantage (87 dth ha^{-1} contre 54), le fumage (8 dth ha^{-1} contre 17) et le désherbage (57 dth ha^{-1} contre 193).

- Pour le labourage, les différences proviennent peut-être du fait qu'au Sénégal, les labours sont exécutés sur des sols très légers avec des outils plus performants (bêche, râteau, etc.) et que les planches sont plus classiques (environ 1.2 m de large sur X m de long), tandis qu'à Mayarasso, les outils sont la houe pour retourner -après arrosage si les sols sont trop durs-, émotter et égaliser des sols, qui mêmes légers, sont des sables limoneux à la limite des limons sableux. De plus, la confection des petites planches demande du travail. Mais ces planches très petites, mesurant 0.55 * 0.55 m (Bakker & Traoré, 1990) ou 0.5 * 0.5 m (ob. pers.), sont souvent une nécessité pour assurer une répartition homogène de l'eau d'arrosage sur des planches horizontales construites sur des reliefs irréguliers et en pente sans devoir passer par un aménagement foncier. De plus, elles correspondent à une unité d'arrosage: un arrosoir-calebasse correspond à une planche.
- Pour le plantage, la différence est due au fait que mettre en terre des bulbes est plus rapide que de déterrer des plantules, les démarier soigneusement et les repiquer proprement à distance.
- Pour le fumage, la différence provient peut-être du fait qu'au Mali, selon nos observations, il n'y a pas application de fumure de fond tant organique que minérale mais que tout au long du cycle, il y a épandage très fractionné de fumure organique du type poudrette de parc.
- Pour le désherbage, la différence provient peut-être du fait que les cultures d'échalote, ainsi que toutes les cultures maraîchères que nous avons observées au

Mali, reçoivent tout au long du cycle des façons culturales de surface: nombreux sarclages en début de cycle pour éradiquer les adventices suivi de très nombreux binages pour incorporer les fumures organiques très fractionnées, faciliter la pénétration de l'eau et limiter les pertes par évaporation.

Tableau A4.10. Temps de travaux [dth ha^{-1}] pour les 2 activités de culture maraîchère en comparison avec celles de 4 autres cultures (EC: échalote, AC: autres cultures subdivisées en FC: féculents, LG: légumes, TA: tabac et TO: tomate).

Travail	FC	LG	TA	TO	AC[e]	EC
Nettoyage	13	20	24	19	16	24
Pépinière	-	15	30	24	9	-[c]
Labourage	23	19	30	21	24	159
Clôturage[a]	50	50	50	50	50	50
Plantage	23	29	45	21	27	54[c]
Arrosage	1 053	1 053	1 053	1 053	1 053	1 053
Fumage	15	8	17	9	14	17
Entretiens[b]	48	40	60	31	47	193
Récolte	84	17	330	73	117	375[d]
Total	1 309	1 251	1 639	1 301	1 358	1 925

Sources: RFMC, 1980); Beniest *et al.*, 1987; Bakker & Traoré, 1990.
a) clôturage pas toujours réalisé mais considéré comme tel.
b) entretiens: désherbage, buttage s'il a lieu, etc.
c) si au lieu de plantation de bulbes il y a semis de graines en pépinière, il faut alors ajouter 98 dth ha^{-1} de pépinière (confection, semis, arrosage, entretiens) et 33 dth ha^{-1} au plantage (repicage) soit un total de 2 056 dth ha^{-1} pour un cycle de croissance.
d) comprenant les traitements post-récolte ou séchage: sans les traitements, la récolte est de 41 dth ha^{-1} soit un total de 1 591 dth ha^{-1}.
e) moyenne pondérée en considérant que les autres cultures sont constituées, quant à leurs surfaces, de 60.3% de féculents, de 12.3% de légumes, de 17.3% de tabac et de 10.0% de tomate.

La colonne échalote (EC) du tableau A4.10 est la combinaison des tableaux A4.8 (SM) et A4.9 (OIG). Nous rappelons qu'en réalité, il y a quatre méthodes d'obtention de l'échalote (tableau A4.10):

- plantation de bulbes en place et transformation: 1 925 dth ha^{-1}, valeur retenue pour le modèle-PL;
- plantation de bulbes en place et non transformation: 1 591 dth ha^{-1};
- semis de graines en pépinières et transformation: 2 023 dth ha^{-1};
- semis de graines en pépinières et non transformation: 1 689 dth ha^{-1}. L'idéal aurait été de pondérer les temps des travaux de l'échalote sur la base des proportions exactes des quatre façons d'obtention mais étant donné que nous ne connaissons pas ces proportions, seule la première méthode est considérée.

Le tableau A4.9 nous donne les temps des travaux pour un féculent, un légume, la tomate (Beniest *et al.*, 1987) et le tabac (RFMC, 1980). Nous pouvons voir que chaque production a ses spécificités. Ces données nous servent de base à l'établissement du tableau A4.10 où, lorsque des valeurs nous manquent, comme celles de l'arrosage, nous prenons celles de Bakker & Traoré (1990). Les temps des travaux de l'activité "autres cultures" du tableau A4.10 sont les moyennes pondérées par les surfaces respectives des féculents, des légumes, du tabac et de la tomate. Les labours sont conservés à 24 dth ha^{-1} vu que les autres cultures comprennent la tomate et le piment qui souvent ne sont pas plantés sur des terres labourées mais dans de petites fosses servant à l'arrosage et que, suite à une impression générale de nos observations dans la Région, les autres cultures sont le plus souvent établies sur des planches plus grandes que celles couramment utilisées pour l'échalote.

Ne pouvant réaliser une étude exhaustive et détaillées de toutes les spéculations maraîchères, nous admettons, que pour le modèle-PL, les autres cultures nécessitent en moyenne 1 358 dth ha^{-1}.

Le clôturage par des haies fabriquées avec des branches de ligneux contribue au déboisement, vu la durée de vie très courte de ce type de clôture. Malgré les interventions des Eaux et Forêts, peu de haies vives permanentes sont implantées. Mais ceci entre dans le contexte général d'une apparente inertie du monde rural au reboisement due, entre autre, au fait que tout arbre planté serait perçu comme appartenant au Code Forestier et non plus au planteur.

En ce qui concerne l'arrosage, de toutes nos observations dans la Région, nous n'avons vu qu'une seule fois l'usage du paillage (Tabaco), avec des balles de mil. La pratique du paillage, bien que connue de certains maraîchers (Sévaré), n'est pas appréciée. L'apport de mauvaises herbes est la raison invoquée. Cependant, notre expérience montre que beaucoup d'eau et du temps d'arrosage sont économisés par cette pratique. Mais la matière du paillage n'est pas toujours facile à se procurer (rareté, éloignement, compétition avec d'autres usages). Il y a aussi effectivement apport de graines d'adventices avec parfois envahissement par des plantules, par exemple si la balle de mil "non prégermée" est utilisée. Parfois, il y a de forts ravages dûs à des attaques des collets. Cependant, nous pensons que cette pratique n'est pas utilisée par méconnaissance. Il ne s'agit pas de simplement mettre un paillis mais il faut aussi changer le mode d'apport du fumier, non plus en fractionné tout au long du cycle mais en fond avant le paillage; il faut contrôler l'état hydrique du sol avant d'arroser et beaucoup d'échecs dus "au paillage" sont en fait dus à un excès d'eau; le désherbage ne se fait plus par sarclage mais par arrachage ou remuage manuel du paillage; finalement, certaines plantes nécessitent un dégagement des collets. En résumé, la notion d'économie de l'eau, et du travail, ne serait pas toujours perçue et cette technique demande l'abandon de certaines habitudes et pratiques, mises au point sans paillage, au profit de nouvelles, à mettre au point avec paillage.

En ce qui concerne le système d'approvisionnement en eau, il est à noter que le système de céanes non aménagées tend à transformer lentement les périmètres potagers en un assemblage de bosses et de fosses peu propices aux cultures. L'exploitation des sources dans les cônes de déjections nécessite un minimum d'aménagement de la canalisation de l'eau. Cette mesure doit être accompagnée de lutte anti-érosive. En effet, si la canalisation de l'eau est trop simpliste, comme de simples surcreusements de rigoles non protégées et mal conçues, elle peut être la cause d'érosions en ravines lors des pluies, ainsi que visible à Tabako.

Par contre, des aménagements biens conçus, comme à Ibissa où même les diguettes sont valorisées par la culture du cresson alénois, tendent à permettre une exploitation maximale de l'eau disponible, ainsi que des surfaces, tout en garantissant la protection de l'aménagement.

Il est à constater cependant, que tous les périmètres d'exploitation des sources nécessitent un aménagement et/ou reboisement des bassins versants afin de régulariser, lors des pluies, les débits des oueds et donc diminuer leur force destructive. Ces aménagements permettraient également d'assurer une meilleure alimentation des inféroflux qui suivent ces cours d'eau temporaires et donc des sources, base du système.

En ce qui concerne le fumage, le tableau A4.7 nous donne également les fumures organiques et minérales préconisées pour les cultures les plus souvent rencontrées dans la Région. Ces fumures sont basées sur du fumier dosant ($N-P_2O_5-K_2O$) 1.20-0.32-1.28 + 1.24 CaO + 0.61 MgO et un engrais minéral ($N-P_2O_5-K_2O$) du type 10-10-20 (Beniest *et al.*, 1987). En moyenne, toutes cultures confondues, il faudrait de 15 à 23 t ha^{-1} de fumier et 800 kg ha^{-1} d'engrais minéral 10-10-20. Ces auteurs préconisent pour l'oignon une fumure de 14.5 t ha^{-1} de fumier et 450 kg ha^{-1} d'engrais minéral.

En réalité, chaque culture a ses exigences spécifiques qui ne sont vraiment applicables que si chaque culture est pratiquée en monoculture intensive sur de grandes étendues et si ces fumures spécifiques sont accessibles aux producteurs sur le marché. Comme souvent dans la Région, les cultures horticoles sont des mosaïques de productions, tant sur le terrain que dans le temps, et que les producteurs doivent travailler avec ce qu'ils peuvent trouver sur le marché, ils ne peuvent donc pas appliquer les fumures minérales indicatives passe-partout qui sont recommandées ci-dessous.

Messiaen (1974) recommande 3 t ha^{-1} d'engrais minéral ($N-P_2O_5-K_2O$) du type: 16- 8- 8 pour les légumes feuilles, 12-12-12 pour les légumes fruits et 4-12-20 pour les légumes racines. Les deux premières fumures sont à fractionner, pour l'azote, si le cycle de la culture dépasse 50 d.

Rice *et al.* (1987) recommande, en t ha^{-1}, l'application de ($N-P_2O_5-K_2O$): 2.2-2.2-2.2 pour les légumes feuilles, 1.1-1.1-1.7 pour les légumes fruits, 1.7-1.1-2.8 pour les légumes racines et 0.6-0.8-0.6 pour les légumineuses; l'azote est à fractionner en deux ou trois applications.

Beniest *et al.* (1987), au Sénégal, utilisent pour leurs calculs de rentabilité la dose de 14.5 t ha^{-1} de fumier à 3 500 FCFA t^{-1}. Actuellement dans la Région, l'usage des engrais minéraux est proche de 0 kg ha^{-1}. Nous insistons sur le fait que le non usage des engrais minéraux n'est pas dû à un refus, mais à une difficulté d'approvisionnement.

En ce qui concerne la récolte-transformation du tabac, il semblerait que chaque périmètre a ses habitudes de récolte-transformation et a son circuit de commercialisation s'adressant à une région précise.

A Ibissa, les inflorescences sont récoltées plusieurs fois, séchées et pilées pour faire de la poudre à chiquer. Puis toute la plante est récoltée et divisée en:

1. première qualité: feuilles, sauf celles du bas, avec pétioles et noeuds qui sont soigneusement ordonnées en petits tas et séchées sur lit de son de mil; cette qualité est destinée à être fumée, prisée ou chiquée;
2. deuxième qualité: fleurs séchées en vrac sur le sol et destinées à faire de la poudre à chiquer;
3. troisième qualité: entre-noeuds refendus en long, séchés sur le sol et destinés à faire de la poudre à chiquer;
4. quatrième qualité: feuilles du bas et bourgeons feuillés, séchés sur le sol et destinés à faire de la poudre à chiquer.

A Kara, les inflorescences sont récoltées en 3 passages, sont écrasées avec des pierres pour les rendre méconnaissables et sont séchées sur le sol. Lorsque les feuilles commencent à jaunir, elles sont récoltées et séchées sur le sol. Finalement, lorsque les bourgeons se sont développés, toutes les plantes sont récoltées, séchées sur le sol puis battues pour séparer les feuilles de repousses des tiges. Les fleurs, feuilles et repousses sont mélangées, bien que parfois les repousses soient gardées à part pour faire du tabac à priser et que les feuilles soient séparées pour faire du tabac à fumer ou à chiquer. Les tiges ne sont pas utilisées et sont jetées ou brûlées pour la fabrication de "potasse".

ANNEX 5. BOURGOU

A5.1 Yields and nutrient elements contents

This annex belongs to Chapter 9 and presents values of plant biomass production (Tables A5.1 - A5.3) as well as data on nutrient element contents (Table A5.4).

Table A5.1. Biomass production [kg DM ha^{-1}] of bourgou in the course of the years after transplanting.

YEARS AFTER TRANSPLANTING						
1	2	3	4	5	UNKNOWN	SOURCE
5 000	10 000	12 500	15 000	30 000	30 000	François *et al.*, 1989[a]
8 760[b]	-	-	-	-	-	François *et al.*, 1989
5 910[c]	-	-	-	-	-	François *et al.*, 1989
2 700[d]	-	-	-	-	-	François *et al.*, 1989
1 270[e]	-	-	-	-	-	François *et al.*, 1989
1 500	10 000	15 000	15 000	15 000	-	Bonis Charancle & Rochette, 1989
-	-	-	-		17-30 000	Stiles, 1989a
-	-	-	-	-	17 000[f]	Traoré, 1978
-	-	-	-	-	7 000[g]	Traoré, 1978
4 190	10 000	13 750	15 000	22 500	20 000	Average

a) density 1.0 * 0.7 m, transplanting in rainy season.
b) density 0.5 * 0.5 m, transplanting with rise of flood.
c) density 1.0 * 1.0 m, transplanting with rise of flood.
d) density 1.5 * 1.5 m, transplanting with rise of flood.
e) density 2.0 * 2.0 m, transplanting with rise of flood.
f) in 1976, Delta.
g) in 1977, Delta.

Table A5.2. Standing dry matter [kg ha^{-1}] and number of observations for three categories[a] of bourgou stands.

PLACE	MONTH	YEAR	LOW	NO	MEDIUM	NO	HIGH	NO	SOURCE
Banadje	2	1986	3410	3	7260	6	9650	3	Hiernaux, 1986
Banguita	2	1986	920	3	3380	6	6080	3	Hiernaux, 1986
Banadje	11	1985	2280	1	5310	1	12280	1	Hiernaux, 1985
Kakagnan[b]	11	1985	1320	3	2140	6	2950	3	Hiernaux, 1985

a) definition unknown.
b) production above water.

Table A5.3. Measured total standing dry matter and average [kg ha^{-1}] in the course of the year of bourgou in an area protected against animals in Central Mali.

MONTH	1979-80	1980-81	1981-82	1982-83	1983-84	AVERAGE
July	-	3 210	-	24 600	-	13 900
August	-	6 140	6 340	-	-	6 200
September	-	-	13 680	9 580	-	11 000
October	-	-	9 780	19 160	-	14 500
November	-	11 040	22 040	19 360	15 680	17 000
December	-	-	21 970	-	-	22 000
January	-	21 830	17 830	-	-	20 000
February	-	25 400	21 540	-	-	23 500
March	-	29 320	18 130	-	27 140	25 000
April	-	20 900	22 190	-	-	21 500
May	9590	21 760	27 110	-	-	19 500
June	8430	24 110	21 830	-	-	18 100

Source: Hiernaux & Diarra, 1986.

Table A5.4. Mineral content on dry matter basis [g kg^{-1}] of bourgou during three periods of the year.

PERIOD	N	P	K	Ca	Mg	Na	Mn	Source
REGROWTH	20.8							1
	25.6	3.2						2
MAXIMUM INUNDATION	8.8	1.8	14.4	2.9	1.7	0.6	0.1	1
	12.8							2
	11.8							3
	6.3	1.0		1.1				3[c]
	16.6							3[c]
DRY	12.4	1.7	25.3	3.8	3.3	0.6	0.7	1
	4.8	0.6						2[a]
	4.5	0.8						3[a]
	4.8	1.1						2[b]
	4.0	0.6						3[b]

Sources: 1 = François *et al.*, 1989; 2 = Traoré, 1978; 3: Hiernaux & Diarra, 1986.

a) stems only.

b) hay.

c) stems under water.

ANNEX 6. SMALL RUMINANTS

A6.1 Listings of SR-models

The listings of the SR-models used are presented in Tables A6.1 and A6.2 for sheep and goats and mouton the case activities, respectively.

The listings read as follows: The first column gives the number of the line, the second the characteristic, the third the value of that characteristic as given in the main text (Chapter 14) or as calculated by the formula presented in the last column.

Table A6.1. Listing of the SR-model for calculation of herd composition, meat production and feed intake of sheep and goats. Values for low meat production level of sheep (B13).

No	CHARACTERISTICS (D)	VALUE	FORMULA
2	animal	sheep	
3	mobility	all	
4	productivity	low	
5			
6	Herd		
7	female lamb 0-1	22	
8	ewes 1-2	19.3	
9	ewes 2-3	16.6	
10	ewes 3-4	14.1	
11	ewes 4-5	12.4	=D10*(1-D35)
12	male lamb 0-1	8.5	
13	ram 1-2	4	
14	ram 2-3	1.2	
15	ram 3-4	1	
16	ram 4-5	0.9	=D15*(1-D35)
17	total	100.0	=SUM(D7:D16)
18	total breeding	62	=SUM(D8:D11)
19	total ram	16	=SUM(D12:D16)
20			
21	PRODUCTIVITY		
22	Prolificacy	1.04	
23	lambings per year	1.26	
24	conception rate	0.92	
25			
26	Fraction female lambs	0.5	
27	Total females net breeding	55	=(D8*(1-D34)+(D9+D10+D11)*(1-D35))
28	Female lambs born	33	=D27*D22*D23*D24*D26

.../...

Table A6.1 Continued.

No	CHARACTERISTICS (D)	VALUE	FORMULA
29	Male lambs born	33	=D27*D22*D23*D24*(1-D26)
30			
31	Pre-weaning mortal. (f)	0.3	
32	Pre-weaning mortal. (m)	0.3	
33	Post-weaning mortality	0.05	
34	mortality age 1-2	0.12	
35	mortality age >2	0.12	
36			
37	Culling rates to maintain herd structure		
38	female yearlings	0.01	=D28*(1-D31)*(1-D33)-D7
39	ewe 2	0.06	=D7*(1-D34)-D8
40	ewe 3	0.38	=D8*(1-D35)-D9
41	ewe 4	0.51	=D9*(1-D35)-D10
42	ewe 5	10.92	=(D10*(1-D35))-D11+(D11*(1-D35))
43	male yearling	13.51	=D29*(1-D32)*(1-D33)-D12
44	ram 2	3.48	=D12*(1-D34)-D13
45	ram3	2.32	=D13*(1-D35)-D14
46	ram 4	0.06	=D14*(1-D35)-D15
47	ram 5	0.77	=(D15*(1-D35))-D16+(D16*(1-D35))
48	total	32.0	=SUM(D38:D47)
49			
50	Weights		
51	Female weaning	13	
52	ewe 1	23.8	
53	ewe 2	27.8	
54	ewe 3	28	
55	ewe 4	28	
56	ewe 5	28	
57	Male weaning	15	
58	ram 1	28.8	
59	ram2	37.8	
60	ram 3	40	
61	ram 4	40	
62	ram 5	40	
63			
64	culling weight	9.95	=(D38*D52+D39*D53+D40*D54+D41*D55+D42*D56+D43*D58+D44*D59+D45*D60+D46*D61+D47*D62)/100

.../...

Table A6.1 Continued.

No	CHARACTERISTICS (D)	VALUE	FORMULA
65	average weight	25.8	=(D7*(D51+D52)/2+D8*(D52+D53)/2+D9*(D53+D54)/2+D10*(D54+D55)/2+D11*(D55+D56)/2+D12*(D57+D58)/2+D13*(D58+D59)/2+D14*(D59+D60)/2+D15*(D60+D61)/2+D16*(D61+D62)/2)/100
66	av. weight/250	0.103	=D65/250
67	Production/UBT	97	=D64/D66
68	Prod as % of av. weight	39	=D64/D65*100
69			
70	ddm intake d-1/ $W^{0.75}$	30	
71	intake (kg av. head-1 yr-1)	125.2	=D70*($D65^{0.75}$)*365/1000
72	% Browse	0	
73	Digestibility diet	0.52	
74	Digestibility Browse	0.52	
75	DM-intake diet av. head-1	241	=D71*(100-D72)/(100*D73)
76	DM intake Browse av head-1	0	=D71*(D72/100)/D74
77			
78	DM Intake diet UBT-1	2337	=D75/D66
79	DM Intake Browse UBT-1	0	=D76/D66
80	DM intake UBT-1	2337	=D78+D79

Table A6.2. Listing of the SR-model for calculation of herd composition, meat production and feed intake of the mouton de case activity.

NO	CHARACTERISTICS (C)	VALUE	FORMULA
1			
2	animal	sheep	
3	mobility	mouton de case	
4	productivity	high	
5			
6	HERD		
7	female lamb 0- 8 months	3.9	=C34
8	ewes 1-1.67	15.4	
9	ewes >1.67	0	
10	male lamb 0-0.67	3.9	=C37
11	ram 1-1.67	76.9	
12	ram >1.67	0	
13	total	100.0	=SUM(C7:C12)
14	total breeding	15	=SUM(C8:C9)
15	total ram	81	=SUM(C10:C12)
16			
17	PRODUCTIVITY		
18	Prolificacy	1.04	
19	lambings per year	1.05	
20	conception rate	0.92	
21			
22	Fraction female lambs	0.5	
23	Total net breeding	15	=(C8*(1-C30)+(C9)*(1-C31))
24	Female lambs born	5	=C23*C18*C19*C20*C22*0.75
25	Male lambs born	5	=C23*C18*C19*C20*(1-C22)*0.75
26			
27	Pre-weaning mortality (f)	0.22	
28	Pre-weaning mortality (m)	0.22	
29	Post-weaning mortality	0.01	
30	mortality age 1-2	0.033	
31	mortality age >2	0.033	
32			
33	Culling rates		
34	female lambs of 8 months of age	3.87	=C24*(1-C27)*(1-C29)
35	yearlings	-15.4	=-C8

.../...

Table A6.2. Continued.

NO	CHARACTERISTICS (C)	VALUE	FORMULA
36	ewes of 1.67 year age	14.89	=C8*(1-C30)
37	male lambs of 8 months of age	3.87	=C25*(1-C28)*(1-C29)
38	yearlings	-76.9	=-C11
39	rams of 1.67 year of age	74.36	=C11*(1-C31)-C12
40	total	4.7	=SUM(C34:C39)
41			
42	Weights		
43	Female birth weight	2.7	
44	ewe 0.67 year	33.5	
45	ewe 1 year (bought)	24	
46	ewe 1.67 year (sold)	35	
47	Male birth weight	2.8	
48	ram 0.67 year	35.5	
49	ram 1 year (bought)	29	
50	ram 1.67 year (sold)	40	
51			
52	net culling weight	11.63	=(C34*C44+C35*C45+ C36*C46+C37*C48+ C38*C49+C39*C50) /100
53	average weight	32.5	=(C7*(C43+C44)/2+ C8*(C45+C46)/2+ C9*C46+C10*(C47+ C48)/2+C11*(C49+ C50)/2+C12*C50) /100
54	av. weight/250	0.13	=C53/250
55	Production/UBT	89	=C52/C54
56	Prod as % of av. weight	36	=C52/C53*100
57			
58	ddm intake d-1/ $W^{0.75}$	35	
59	intake (kg av. head-1 yr-1)	116	=C58*(C53$^{0.75}$)*365 /1000*8/12
60	% Browse	0	
61	Digestibility diet	0.59	
62	Digestibility Browse	0.52	
63	DM-intake diet av. head-1	197	=C59*(100-C60)/(100* C61)
64	DM intake Browse av head-1	0	=C59*(C60/100)/C62
65			
66	DM Intake diet UBT-1	1511	=C63/C54
67	DM Intake Browse UBT-1	0	=C64/C54
68	DM intake UBT-1	1511	=C66+C67

ANNEX 7. INITIAL TECHNICAL COEFFICIENTS OF LIVESTOCK ACTIVITIES

(F.R. Veeneklaas)

A7.1 Introduction

As for crops, target production levels are defined. The production values were assessed for cattle based on Breman & de Ridder (1991) (including a demographic model) and a quick literature review for the other animal species. However, a more detailed study on production of the various animal species (Chapters 12-15), at a later stage showed that the original values for all animal species except cattle, needed adaptations.

Considering de time limitations, however, it was decided to run the LP-model with the alternative data set as a variant to the original one (Report 4, Subsection 6.4.4).

Here the "original set" of technical coefficients is presented, along with the "alternative set" to enable the reader to see where we have changed what.

A7.2. Outputs

The original technical coefficients defining the outputs are summarized in Table A7.1, and those derived from Chapters 13 to 15 in Table A7.2. For the calculation method of manure availability, reference is made to the various chapters (13-15), but in the original data set, manure recovery for the camel production technique has been set at 0%.

Table A7.1. Original technical coefficients of outputs of livestock activities [kg liveweight, kg milk, number of animals or kg dry matter of manure, per TLU per year].

ACT. CODE	MAIN PRODUCT	MOBILITY	DIET[a]	MEAT	MILK	ANIMALS	MANURE[b]
Cattle							
B1.	Oxen	sedentary	I	22	0	0.55	442
B2.	Meat	semi-mobile	I	37	0	-	298
B3.	Meat	semi-mobile	II	56	92	-	285
B4.	Meat	migrant	I	37	0	-	230
B5.	Meat	migrant	III	71	219	-	222
B7.	Milk	sedentary	II	54	165	-	444
B8.	Milk	sedentary	III	62	376	-	445
B9.	Milk	migrant	II	54	165	-	232
B10.	Milk	migrant	III	62	376	-	232
B11.	Milk	sedentary	IV+c	61	520	-	415
B12.	Milk	sedentary	IV	61	520	-	415
Sheep							
B13.	Meat	sed. & s-m	I	70	-	-	718
B14.	Meat	sed. & s-m	III	100	50	-	688
B15.	Meat	migrant	I	70	-	-	515
B16.	Meat	migrant	III	100	50	-	494
B17.	Meat	sedentary	IV				
Goats							
B18.	Meat	sed. & s-m	I+b	40	100	-	718
B19.	Meat	sed. & s-m	III+b	75	200	-	688
B20.	Meat	migrant	I+b	40	100	-	515
B21.	Meat	migrant	III+b	75	200	-	494
Other							
B18.	Donkeys	sedentary	II	-	-	2.00	466
B19.	Camels	migrant	I+b	-	-	0.83	-

a) see Table 3.9; +b: browse is included; +c: concentrates are included.
b) available for arable farming.
Sources: Breman & de Ridder (1991); Veeneklaas, pers. comm.

Table A7.2. Technical coefficients of outputs of livestock activities [kg liveweight, kg milk or number of animals per TLU per year]

ACT. CODE	MAIN PRODUCT	MOBILITY	DIET[a]	MEAT	MILK	ANIMALS	MANURE[b]
Cattle							
B1.	Oxen	sedentary	I	0	0	0.77	580
B2.	Meat	semi-mobile	I	37	0	-	299
B3.	Meat	semi-mobile	II	57	93	-	287
B4.	Meat	migrant	I	37	0	-	232
B5.	Meat	migrant	III	71	219	-	222
B7.	Milk	sedentary	II	54	165	-	462
B8.	Milk	sedentary	III	62	377	-	445
B9.	Milk	migrant	II	54	165	-	241
B10.	Milk	migrant	III	62	377	-	232
B11.	Milk	sedentary	IV+c	61	518	-	716
B12.	Milk	sedentary	IV	61	518	-	716
Sheep							
B13.	Meat	sed. & s-m	I	97	-	-	517
B14.	Meat	sed. & s-m	III	121	62	-	476
B15.	Meat	migrant	I	97	-	-	371
B16.	Meat	migrant	III	121	62	-	341
B17.	Meat	sedendary	IV+c	89	19		500
Goats							
B18.	Meat	sed. & s-m	I+b	68	0	-	519
B19.	Meat	sed. & s-m	III+b	96	180	-	514
B20.	Meat	migrant	I+b	68	0	-	372
B21.	Meat	migrant	III+b	96	180	-	369
Other							
B18.	Donkeys	sedentary	II	-	-	2.00	614
B19.	Camels	migrant	II+b	75	240	0.83	318

a) see Table 3.7; +b: browse included; +c: concentrates included.
b) kg dry matter TLU^{-1} available for arable farming.
Source: Chapters 12-15.

A7.3 Inputs

A7.3.1 Feed requirements

Feed requirements for all animals were calculated on the basis of their metabolic weight and the associated feed requirements, given in Table 13.1.

A7.3.2 Labour requirements

Labour requirements are specified for each animal species separately based on the following operations: herding (including watering and veterinary care) and milking.

Cattle

The required labour input for herding is calculated on the basis of an average herd size, assumed to be for cattle between 70 and 100 TLU, requiring two herdsmen. Maximum labour requirements for herding would then be 1/35 man per TLU per day. During the dry season this input is taken as standard, including the requirements for veterinary care, watering, etc. However, more selective grazing (in search for better pastures), requires somewhat more time in the dry season. Moreover, the livestock activities with higher productivity per animal require more veterinary care, which implies more labour. The additional labour requirements are for the more productive activities estimated at 20% it would be better to give some argument for the 20 %.

Milk production is highest just after calving, normally in June-July, the onset of the rainy season. Hence, time spent milking will be highest during the rainy season. The labour requirements for this operation are estimated at 20 to 40% of those for herding, depending on milk production.

Summarizing, labour requirements for cattle activities vary from 1/35 to 1.6/35 man per TLU per day.

The supervision of oxen is, during part of the year, included in crop cultivation activities, hence the labour requirements in the wet season can be as low as 0.8/35.

In the semi-intensive milk production technique, labour requirements exceed those of migrant and semi-mobile catlle, due to greater care for feeding, herding and veterinary care. Total labour requirements are estimated at 2.0/35 man-day per day during the rainy season when milk production is highest and 1.8/35 man-day per day during the remainder of the year.

Small ruminants

Average herd size for small ruminants is about 70 head, equivalent to 7 TLU, that can be managed by one herdsman. Applying the same considerations as for cattle, the labour requirements range from 1/7 to 1.6/7 man per day per TLU.

Donkeys

Donkeys must be herded during the crop growing season to prevent crop damage. Average herd size is estimated at 30 head or 15 TLU with one herdsman. Hence, labour input is 1/15 man-day per day during the rainy season.

Camels

For camel husbandry no labour requirements have been specified.

A7.3.3 Monetary inputs

The monetary inputs comprise almost exclusively veterinary care and possibly concentrates. The annual veterinary costs per TLU are estimated at 2 300 and 3 500 FCFA for the low and high level production techniques, respectively. The reported price of concentrates is 37 FCFA per kg, equivalent to 44 FCFA per kg dry matter.

To attain production levels as specified for the semi-intensive cattle activity, high quality forage only is not sufficient. Additional investments in herd management are needed, not only in terms of veterinary care but also in stables or other structures. Moreover, transport costs for milk must be taken into account. Reliable data on these expenses are lacking; in the present version of the model an overall monetary input of 20 000 FCFA TLU^{-1} yr^{-1} has been assumed for the semi-intensive milk production activity.

The inputs used in the original data set are summarized in Table A7.3, and those derived from Chapters 13 to 15 in Table A7.4.

Table A7.3. Original technical coefficients of inputs in livestock activities [TLU^{-1} yr^{-1}]; intake of quality diet comprising forage, browse and concentrates [kg DM]; total labour in the wet and dry season [man-day] and money [1000 FCFA].

		INTAKE				LABOUR		
PRODUCT	MOBILITY	DIET	FORAGE	BROWSE	CONC.	WET	DRY	MONEY
Cattle								
B1. Oxen	sedentary	I	2 000	-	-	2	8	2.3
B2. Meat	semi-mobile	I	2 000	-	-	3	8	2.3
B3. Meat	semi-mobile	II	2 000	-	-	3	9	3.5
B4. Meat	migrant	I	2 000	-	-	3	8	2.3
B5. Meat	migrant	III	2 100	-	-	3	9	3.5
B7. Milk	sedentary	II	2 100	-	-	3	9	2.3
B8. Milk	sedentary	III	2 200	-	-	4	10	3.5
B9. Milk	migrant	II	2 100	-	-	3	9	2.3
B10. Milk	migrant	III	2 200	-	-	4	10	3.5
B11. Milk	sedentary	IV	1 820	-	380	5	14	22.0
B12. Milk	sedentary	IV	2 200	-	-	5	14	22.0
Sheep								
B13. Meat	sedentary & semi-mobile	I	3 250	-	-	13	39	2.3
B14. Meat	sedentary & semi-mobile	III	3 400	-	-	15	47	3.5
B15. Meat	migrant	I	3 250	-	-	13	39	2.3
B16. Meat	migrant	III	3 400	-	-	15	47	3.5
B17. Meat	sedentary	IV	2 300	-	1 100	15	47	5.0
Goats								
B18. Meat	sedentary & semi-mobile	I	2 880	370	-	15	39	0.3
B19. Meat	sedentary & semi-mobile	III	2 630	770	-	21	47	1.5
B20. Meat	migrant	I	2 880	370	-	15	39	0.3
B21. Meat	migrant	III	2 630	770	-	21	47	1.5
Donkeys								
B22. Transport	sedentary	II	2 200	-	-	6	-	0.3
Camels								
B23. Transport	migrant	I	1 550	200	-	-	-	0.3

Source: Veeneklaas, pers. comm.

Table A7.4. Technical coefficients of inputs in livestock activities [TLU^{-1} yr^{-1}]; intake of quality diet comprising forage, browse and concentrates [kg DM]; total labour in the wet and dry season [mnd] and money [1 000 FCFA].

PRODUCT	MOBILITY	INTAKE				LABOUR		
		DIET	FORAGE	BROWSE	CONC.	WET	DRY	MONEY
Cattle								
B1. Oxen	sedentary	II	2 010	-	-	2	15	12.9
B2. Meat	semi-mobile	I	2 000	-	-	3	8	5.4
B3. Meat	semi-mobile	II	2 000	-	-	3	10	5.4
B4. Meat	migrant	I	2 010	-	-	3	8	5.4
B5. Meat	migrant	III	2 100	-	-	3	10	5.4
B7. Milk	sedentary	II	2 090	-	-	4	12	5.4
B8. Milk	sedentary	III	2 200	-	-	4	12	5.4
B9. Milk	migrant	II	2 090	-	-	4	12	5.4
B10. Milk	migrant	III	2 200	-	-	4	12	5.4
B11. Milk	sedentary	IV	1 850	-	330	4	13	9.2
B12. Milk	sedentary	IV	2 180	-	-	4	13	9.2
Sheep								
B13. Meat	sedentary & semi-mobile	I	2 340	-	-	13	40	6.6
B14. Meat	sedentary & semi-mobile	III	2 350	-	-	14	43	6.6
B15. Meat	migrant	I	2 340	-	-	13	40	6.6
B16. Meat	migrant	III	2 350	-	-	14	43	6.6
B17. Meat	sedentary	IV	-	-	1 510	5	16	4.2
Goats								
B18. Meat	sedentary & semi-mobile	I	2 000	350	-	13	39	6.6
B19. Meat	sedentary & semi-mobile	III	1 740	800	-	14	42	6.6
B20. Meat	migrant	I	2 000	350	-	13	39	6.6
B21. Meat	migrant	III	1 740	800	-	14	42	6.6
Donkeys								
B22. Transport	sedentary	II	2 000	-	-	7	6	5.3
Camels								
B23. Transport	migrant	II	2 440	440	-	2	14	36.3

Source: Chapters 12-15.

ANNEX 8. FISHING

A8.1 OPM (Opérating Pêche Mopti) formula

The above formula, known as the OPM formula, enables one to estimate the total amount of fresh fish caught in the delta zone. The formula is in fact a series of calculations, details of which are given below, which can be reduced to a single formula, given in section 16.3. The various calculations have been taken from Dansoko & Kassibo (1989b):

A = production of smoked and dried fish, sold and inspected in Mopti [kg].
B = 20% of A = production of smoked and dried fish, sold and inspected throughout the rest of the zone [kg].
C = 10% of (A + B) = production of smoked and dried fish, sold but not inspected in Mopti [kg].
D = 20% of C = production of smoked and dried fish, sold but not inspected throughout the rest of the zone [kg].
E = A + B + C + D = production of smoked and dried fish, sold in the zone [kg].
F = 3% of E = losses at the packaging stage [kg].
G = 15% of E = losses at the storage stage [kg].
H = 576 000 kg = amount consumed by the fishermen themselves: 20 g per individual per day * 80 000 individuals * 360 days.
I = 6 480 000 kg = consumption by the rural population of the 5th Region: 15 g per individual per day * 1,200,000 individuals * 360 days.
J = E + F + G + H + I = 1.58592 * A + 7 056 000 kg = total processed production [kg].
K = 2.25 J = smoked fish converted into fresh fish: 75% of the total processed produce is smoked fish and it takes 3 kg of fresh fish to produce 1 kg of smoked fish.
L = 1.00 J = dried fish converted into fresh fish: 25% of the total processed produce is dried fish and it takes 4 g of fresh fish to produce 1 kg of dried fish.
M = K + L = 3.25 J = 5.15424 * A + 22 932 000 kg
N = 2 922 048 kg = amount of fresh fish consumed by working fishermen: 150 g per person per day * 54 112 working fishermen * 360 days.
O = 472 428 kg = amount of fresh fish consumed by non-working fishermen: 50 g per individual per day * 26 246 non-working fishermen * 360 days.
P = 16 848 000 kg = amount of fresh fish consumed by the rural inhabitants of the 5th Region: 39 kg per individual per day * 1 200 000 individuals * 360 days.
Q = 20 242 476 kg = N + O + P = total consumption of fresh fish.
R = 5.15424 * A + 43 174 476 kg = M + Q = total catch in terms of fresh fish in the delta zone.

A8.2 Glossary

The following brief glossary uses the definitions given by INRZFH/ORSTOM (1988).

A8.2.1 Basic measuring units.

Household: Social group characterised by a communal dwelling and the communal preparation of meals: one or more women cook for the whole group. The latter generally consists of one married man, his wife (or wives), his children and dependents, if any, married or not. This household corresponds to the "home".

Several households may exist within a single plot of land.
A sedentary or permanent household is a household which inhabits a permanent plot of land.

A migrant or temporary household is one which inhabits a temporary plot of land.

Plot: A group of constructions intended for various purposes, en-bloc or separate, sometimes surrounded by an enclosure. A plot may consist of as little as one construction.

Permanent plot: plot which is ordinarily occupied, even if it is abandoned for part of the year.

Temporary plot: a plot which is occupied for a given fishing campaign or part of a fishing campaign.

Fishing household: Any household which owns fishing gears and which fishes on a regular basis, even on a very small scale, is regarded as a fishing household.

A8.2.2 Fishing gears

Seine: Large net with large floats and ballast and often too, a bag. It spans the river with one end attached to the bank. Two teams drag it in, with one team pulling the balk and the other the lower rope, so as to trap the fish in the bag. At least ten people are needed in order to operate the net, which can only be used at low water level.

Xubiseu: Type of small seine, without the floats and heavily weighted, which has come into being over the past ten years. It is short (between 7 and 9 m), does not dam the river and can be handled by one or two fishermen. It moves very slowly, in such a way as to trap the fish which one then "covers" by pulling the upper section towards the bank, thereby "smothering" the fish. Like the seine, the xubiseu is only used when the water level is low.

Gill nets: Very general term which indicates that the net consists of mesh, in which the fish become entrapped. The nets are fitted with floats, ballast and have different types of mesh depending on the type of fish to be caught. Unlike seines, the gill net is a passive piece of equipment. A broad distinction is made between fixed nets and drift-nets.

Fixed nets: Fixed nets are spread at the end of the day, between pegs. They are hauled in in the morning. Fixed nets are used in the plains when the water level is high, and in the rivers when the water drops, until it reaches its lowest level.

Drift-nets: A net which is left to drift, either between two dugout canoes or between one canoe and a large float. Drift-nets are used at the start of the floods, particularly at high water level. They are chiefly used by the Somono and the Bozo who inhabit the banks of the river.

Cast-nets: A circular net, weighted with lead, with a central mooring rope. Cast by the fisherman, it spreads over the surface of the water. As it sinks to the bottom, it traps the fish like a bell. The fisherman then raises the net using the mooring rope.

Ganga: The ganga is a triangular net comprising a bag which is held open by two wooden poles shaped either in the form of a V or Y. The bag may be closed, pierced or fitted with a tank. The size of the mesh varies greatly. Gangas can be operated on foot or using dugout canoes, and are used in many different ways. The term ganga is normally only used to refer to triangular nets which are used once the floods begin to subside, from October to December, mainly for catching tinéni in specially adapted dams located in the flood plains. All other triangular nets are referred to as "swanyas".

Swanya: See ganga.

Two-handed net: Bag net with Y-shaped wooden frame. The fisherman holds one in each hand and catches the fish by bringing the two openings together. Nets of this type were formerly used for fishing in dams at the start of the cycle, but nowadays they are mainly used when the water is at its lowest, in pools or in the mean-water bed of streams, mostly by farmers.

Trawl line: Lines with multiple fishhooks. Each trawl line is mounted on a snood measuring between five and ten centimetres. The lines are attached to pegs, supported by floats and weighted with lead. They are spread between two areas of water. The fish are caught as they pass the non-baited hooks. Bait is sometimes used, however, mainly at the start of the floods. Trawl lines are used all year round, until the water drops to a very low level.

Diéné: A very large bow net which can measure up to three metres in length and up to two metres in diameter. The frame is made up of wooden hoops. The lining, which was formerly made from palmyra branches, has now been replaced in most instances by a net. The fish enter via the openings in the bottom and middle. The nets are arranged in the form of a dam, secured with pegs and joined together using grass and branches. The V-shaped dams can number up to a hundred or so bow nets. Diénés are used when the water level drops, mainly between November and January. They are also sometimes used when the water is at its lowest.

Durankoro: Small, baited bow net in the form of a flattened cone, with a wooden frame covered with net. Its lower diameter is approximately 50 cm, and the height is roughly the same. Durankoros are used almost all year round (except when the water level is at its highest) in the plains, along rivers, in the form of a dam in river branches at low water level. The durankoro has only emerged over the past ten years and is used mainly by women.

Papolo: A bow net roughly in the shape of a cylinder. It can measure up to 60 cm in diameter and up to 3 metres in length. Smaller versions can also be found however. The papolo is used when the water begins to rise, mainly in backwaters.

Dugout: A long, narrow, flat-bottomed craft which is propelled using a paddle or pole and sometimes a sail. For the purposes of our study, we will assume that it does not have an engine and has a capacity of between 0.5 and 2 t.

Shallop: Flat-bottomed craft. For the purposes of our study, we will assume that it has an engine and a capacity of between 2 and 4 t.

A8.3 Tables

Table A8.1. Quantities of smoked and dried fish sold and inspected in Mopti [t], the ratio of smoked fish to dried fish, as a percentage of these totals, estimators for the total amount of fresh fish caught [t], maximum decadal flood levels in Mopti [cm], estimators for the flooded areas [km^2] and yields in terms of fresh fish [kg ha^{-1}] The figures are based on measurements taken over a period of 23 years.

YR	SMOKED & DRIED	SMOKED/ DRIED	TOTAL FRESH	LEVEL	AREA	YIELD
64	•	•	•	716	nc	•
65	•	•	•	683	nc	•
66	11 578 000	53/47	108 442 179	684	17 838	61
67	9 524 000	53/47	97 138 724	719	20 447	48
68	10 745 000	53/47	103 858 061	651	15 108	69
69	11 243 549	47/53	108 094 889	683	17 763	61
70	10 357 090	57/43	100 784 077	664	16 346	62
71	7 840 097	54/46	87 677 069	648	14 880	59
72	7 751 676	52/48	87 578 868	563	9 673	91
73	5 830 837	57/43	76 162 593	567	9 799	78
74	3 574 349	59/41	63 633 470	650	15 032	42
75	7 634 925	50/50	87 317 807	662	16 197	54
76	8 054 850	64/36	86 872 444	620	12 522	69
77	7 705 000	66/34	84 622 691	566	9 768	87
78	5 859 435	61/39	75 664 219	619	12 441	61
79	7 157 681	70/30	80 987 257	638	14 122	57
80	7 784 976	65/35	85 240 346	591	10 559	81
81	5 600 084	66/34	73 473 009	626	13 007	56
82	5 235 650	67/33	71 389 018	548	9 198	78
83	3 132 824	71/29	59 802 779	502	7 743	77
84	1 994 652	74/26	53 557 585	434	5 822	92
85	1 894 389	76/24	52 838 008	569	9 863	54
86	3 318 427	75/25	60 278 445	532	8 692	69
87	2 431 169	66/34	56 687 352	479	7 020	81
88	2 462 157	70/30	56 413 063	570	9 894	57

•) missing value. nc) estimator not calculated.
Sources: colums 1 & 2: Dansoko & Kassibo (1989) and the archives of OPM (Dansoko, com. pers.); column 4: Direction Régionale de l'Hydraulique de Mopti.

Table A8.2. Number of households and number of individuals according to the various ethnic groups involved in fishing and according to the three separate fishing activities.

ACTIVITY/ETHNIC ORIGIN	HOUSEHOLD	INDIVIDUALS
Bozo	4 652	42 796
Sorko	207	1 904
Somono	270	2 484
others	280	2 576
Main Migrant Fishermen	5 409	49 760
Bozo	9 818	103 697
Sorko	4 932	52 091
Somono	2 318	24 483
Main Sedentary Fishermen	17 068	180 271
Rimaïbé	3 307	34 928
others	2 352	24 842
Secondaires Sedentary Fishermen	5 659	59 770
Total	28 136	289 801

Source: Baumann, 1988; Herry, 1988; Lae, 1988; Morand, 1988; Dansoko & Kassibo, 1989.

Table A8.3. Distribution [%] according to gender (female: F, male: M) and age group. The figures are given for each of the three categories of fishermen.

Age	MAIN MIGRANT		MAIN SEDENTARY		SECONDARY SED.	
	M	F	M	F	M	F
0- 4	9.04	9.04	11.02	8.01	7.76	8.01
5- 9	8.17	8.06	7.66	6.78	7.66	6.78
10-14	5.17	4.26	4.96	5.53	4.96	5.53
15-19	4.41	4.07	4.43	4.67	4.43	4.67
20-24	3.85	3.77	3.49	3.60	3.49	3.60
25-29	3.50	5.54	3.62	4.02	3.62	4.02
30-34	3.10	4.26	2.98	3.63	2.98	3.63
35-39	3.16	2.24	2.74	3.58	2.74	3.58
40-44	1.95	1.82	2.50	2.57	2.50	2.57
45-49	1.96	1.34	2.05	1.78	2.05	1.78
50-54	2.34	1.34	1.96	1.92	1.96	1.92
55-59	0.95	0.78	1.46	1.08	1.46	1.08
60-69	1.63	0.73	2.83	2.02	2.83	2.02
70-79	0.50	0.23	1.08	0.59	1.08	0.59
>80	0.63	0.18	0.46	0.24	0.46	0.24
Total	50.36	49.64	50.23	49.77	50.23	49.77
		100.00		100.00		100.00

Source: Herry, 1988.

Table A8.4. Distribution [number of individuals] according to gender (female: F; male: M) and age group. The figures are given for each of the three categories of fishermen.

Age	MAIN MIGRANT		MAIN SEDENTARY		SECONDARY SED.	
	M	F	M	F	M	F
0- 4	4 498	5 484	14 440	13 989	4 788	4 638
5- 9	4 065	4 011	13 809	12 222	4 578	4 052
10-14	2 573	2 120	8 941	9 969	2 965	3 305
15-19	2 194	2 025	7 986	8 419	2 648	2 791
20-24	1 916	1 876	6 291	6 490	2 086	2 152
25-29	1 742	2 757	6 526	7 247	2 164	2 403
30-34	1 543	2 120	5 372	6 544	1 781	2 170
35-39	1 572	1 115	4 939	6 454	1 638	2 140
40-44	970	906	4 507	4 633	1 494	1 536
45-49	975	667	3 696	3 209	1 225	1 064
50-54	1 164	667	3 533	3 461	1 171	1 148
55-59	473	388	2 632	1 947	873	646
60-69	811	363	5 102	3 641	1 691	1 207
70-79	249	114	1 947	1 064	646	353
>80	313	90	829	433	275	143
Total	25 059	24 701	90 550	89 721	30 022	29 748
		49 760		180 271		59 770

Sources: Tables A8.1 and A8.2.

Table A8.5. Number of items of fishing gears according to the three fishing activities (MMF: main migrant fishermen; MSF: main sedentary fishermen; SSF: secondary sedentary fishermen) and their constituent ethnic groups.

Gears	MMF				MSF			SSF
		Boz	Sor	Som	Tot	Rim	Aut	Tot
Seine	649	589	296	487	1372	20	76	96
Xubiseu	595	1866	937	181	2984	0	0	0
Gill net PM	1839	3731	1874	811	6416	562	353	915
Gill net MM	3462	6087	3058	1762	10907	496	400	896
Gill net GM	1839	1964	986	1043	3993	66	47	113
Cast-net	1785	5204	2614	788	8606	66	235	301
Ganga	1028	2651	1332	32	4015	265	47	312
Swanya	1244	2356	1184	70	3610	99	24	123
2-handed net	920	2945	1480	301	4726	2381	1646	4027
Trawl line	3408	6971	3502	348	10821	364	376	740
Harpoon	1460	4026	2022	348	6396	364	165	529
Diéné	8650	13745	6905	700	21350	630	240	870
Durankoro	34080	70690	35510	8250	114450	2250	2120	4370
Papolo	17310	40257	20223	4890	65370	830	1180	2010
Dugout canoe	4219	6833	3433	1423	11689	478	296	774
Shallop	865	1021	513	176	1710	84	33	117
Pole	16117	24583	12351	4973	41907	1770	1020	2790
Paddle	12657	20499	10299	4269	35067	1434	3060	4494
Engine	865	1021	513	176	1710	84	33	117

PM: close-meshed, MM: medium-meshed, GM: wide-meshed.

Sources: Baumann, 1988; Fay, 1988; Kassibo, 1988; Lae, 1988; Morand, 1988; Dansoko & Kassibo, 1989.

Table A8.6. Monetary values per household involved in fishing [10^3 FCFA] of the total investment in the total fishing gears owned (UC), annual depreciation (DP) and maintenance costs (MC). The figures for the various types of fishing gears are given on the basis of the three categories of fishermen (MMF: main migrant fishermen; MSF: main sedentary fishermen; SSF: secondary seden. fishermen).

	MMF			MSF			SSF		
	CU	AM	FE	CU	AM	FE	CU	AM	FE
Sen	95988	29996	4199	64307	20096	2813	13571	4241	594
Xub	6050	2420	550	9616	3846	874	0	0	0
GnP	14450	9633	1700	15976	10651	1880	6872	4581	808
GnM	25602	17068	3200	25561	17041	3195	6333	4222	792
GnG	16999	11333	1700	11697	7798	1170	998	666	100
Epe	5445	2178	330	8320	3328	504	878	351	53
Gan	3516	1406	143	4352	1741	176	1020	408	41
Swa	1437	575	115	1322	529	106	136	54	11
2Hn	680	272	85	1108	443	138	2846	1139	356
Pal	4725	4725	0	4755	4755	0	981	981	0
Har	405	135	0	562	187	0	140	47	0
Dié	39980	39980	0	31272	31272	0	3843	3843	0
Dur	7088	7088	0	7544	7544	0	869	869	0
Pap	3600	3600	0	4309	4309	0	400	400	0
Pir	146249	19500	11700	128409	17121	10273	25645	3419	2052
Pin	41979	5597	6397	26299	3507	4007	5427	724	827
Per	2980	14898	0	2455	12276	0	493	2465	0
Pag	4095	4095	0	3595	3595	0	1390	1390	0
Eng	79959	7996	11194	50094	5009	7013	10338	1034	1447
Tot	501228	182497	41313	401553	155048	32150	82180	30833	7081

Sources: Tables A8.5 and 16.5.

*Table A8.7. Minimum, maximum and average purchase price of fishing gears and the values used in the LP-model are marked by an asterisk * [FCFA].*

GEARS	MINIMUM	MAXIMUM	AVERAGE	COMMENTS
Seine	650 000	800 000	725 000	
	575 000	750 000	662 500	
	500 000	1 000 000	750 000	
	650 000	1 000 000	825 000	
	575 000	1 075 000	825 000	
	500 000	1 075 000	787 500	
	800 000		800 000*	
Xubiseu	50 000	60 000	55 000*	
Gill net	25 000	60 000	42 500	
	42 500		42 500*	in the case of close-meshed
	40 000		42 500*	in the case of medium-meshed
	50 000		50 000*	in the case of wide-meshed
	35 000			
Cast-net	15 000	37 000	26 000	
	15 000	18 000	16 500*	
	11 000			
Ganga	15 000	22 000	18 500*	
Swanya	5 000	7500	6 250*	
	3 750	5 000	4 375	
2-handed net	3 000	5 000	4 000*	
	1 750			
Trawl line	7 000	8 000	7 500*	
	23 000			
Harpoon	1 500		1 500*	
Diéné	25 000		25 000*	
	20 000			
Durankoro	750	1 500	1 125*	
	500	1 500	1 000	
Papolo	1 125		1 125*	
Pirogue	125 000			[0.5 t]
	125 000	150 000		[1.0 t]
	150 000	250 000		[2.0 t]
	175 000	350 000		[3.0 t]
	300 000			[4.0 t]

.../...

Table A8.7. Continued.

ENGIN	MINIMUM	MAXIMUM	MOYEN	REMARQUES
Pirogue	350 000	400 000		[5.0 t]
	750 000	1 000 000		[7.0 t]
	125 000	250 000	187 500*	from 0.5 to 2 t, no engine
Shallop	150 000	375 000	262 500*	from 2 to 4 t, with engine. Any shallops over 4 t are classed as transport vessels and not fishing boats
Pole	750	1 250	1 000*	
Paddle	1 500	2 000	1 750*	
Engine	500 000		500 000*	

Sources: Baumann, 1988; Dansoko & Kassibo, 1989.

Table A8.8. Life expectancy of the fishing gears [in years]. The figures marked with an asterisk (*) are those used in the LP-model.

GEARS	MINIMUM	MAXIMUM	AVERAGE	COMMENTS
Seine				
	3	4	3.5	
	2	4	3.0	
	2	3		
	2	4	3.2*	
	3	5		
Xubiseu				
	1			no maintenance
	2	3	2.5*	
Filet maillant				
	1			with maintenance
	1	2	1.5*	
	1	3	2.0	
Cast-net				
	2	3	2.5*	
Ganga				
	2	3	2.5*	
Swanya				
	2	3	2.5*	
	2		2.0	

.../...

Table A8.8. Continued.

ENGIN	MINIMUM	MAXIMUM	MOYENNE	REMARQUES
2-handed net	2	3	2.5*	
	3		3.0	
Trawl line	1		1.0*	
Harpoon	3		3.0*	
Diéné	1		1.0*	
Durankoro	2	3	2.5	
	1		1.0*	
Papolo	1		1.0*	
Pirogue	5	7		[0.5 t]
	5			[0.5 t]
	10			[1.0 t]
	10			[2.0 t]
	10			[3.0 t]
	10	15		[4.0 t]
	10	15		[5.0 t]
	10			[7.0 t]
Pirogue:				
	5	10	7.5*	from 0.5 to 2 t no engine
Shallop:				
	5	10	7.5*	from 2 to 4 t with engine
Pole				
	1[a]	2[a]	0.2*	
Paddle				
	1		1.0*	
Engine				
	10		10.0*	

Sources: Baumann, 1988; Dansoko & Kassibo, 1989.
[a]) in months

Table A8.9. Annual cost of maintaining the fishing gears [FCFA]. The figures marked with an asterisk (*) are those used in the LP-model.

GEAR	MINIMUM	MAXIMUM	AVERAGE	COMMENTS
Seine	25 000	40 000	35 000*	
Xubiseu	5 000		5 000*	
Filet maillant	5 000		5 000*	
Cast-net	1 000		1 000*	
Ganga	750		750*	
Swanya	500		500*	
2-handed net	500		500*	acc. swanya
Trawl line	0		0*	
Harpoon	0		0*	
Diéné	0		0*	
Durankoro	0		0*	
Papolo	0		0*	
Pirogue	15 000			[0.5 t]
	40 000			[3.0 t]
	70 000			[7.0 t]
Pirogue	15 000		15 000*	0.5 - 2 t no engine
Shallop	40 000		40 000*	2 - 4 t, with engine
Pole	0		0*	
Paddle	0		0*	
Engine	70 000		70 000*	

Sources: Baumann, 1988; Dansoko & Kassibo, 1989.

ANNEX 9. LIST OF ACRONYMS AND ABBREVIATIONS

ADRAO = Association pour le Développement de la Riziculture en Afrique de l'Ouest (synonym WARDA = West Africa Rice Development Association)
AEZ = agro-ecological zone
At = working day of oxen-team
CABO = Centre for Agrobiological Research
CIPEA = ILCA
CRD = Comité Régional de Développement
CMDT = Compagnie Malienne pour le Développement des Fibres Textiles
d = day
DM = dry matter
DAE = days after emergence
DANIDA = Danish International Development Agency
DRA = Direction Régionale de l'Agriculture (Mopti)
DRSPR = Division de Recherches sur les Systèmes de Production Rurale, IER
ESPR = Equipe chargée de l'Etude sur les Systèmes de Productions Rurales en 5ème Région et Cercle de Niafunké
FAO = Food and Agricultural Organisation of the United Nations
h = hour
ha = hectare
HI = harvest index
IER = Institut d'Economie Rurale
ILCA = International Livestock Centre for Africa
mnd = man-day in adult-equivalent
myr = man-year
ODEM = Opération de Développement de l'Elevage de la région de Mopti
OMBEVI = Office Malien du Bétail et de la Viande
ORM = Opération Mil Mopti
ORM = Opération Riz Mopti
ox = oxen
PIRT = Projet Inventaire des Ressources Terrestres - Mali
PPIV = small village irrigation scheme
RFMC = République Francaise, Ministère de la Coopération
RIM = Resource Inventory and Management Ltd.
RZ = rainfall zone (I-IV)
SRCVO = Section des Recherches sur les Cultures Vivrières et Oléagineuses, IER
t = metric ton or tonne (1000 kg)
TAC = Technical Advisory Comittee to the Consultative Group of International Agricultural Research
WIP = Wirtschaft und Infrastructur GMBH & Co. Planungs
yr = year