Crop Residue Management in relation to Sustainable Land Use

A case study in Burkina Faso

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Moumini Savadogo

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Propositions

1. When cereal stovers are fed alone, allowing selective intake is a prerequisite for animal production or even for body maintenance of animals. *This thesis*

2. The availability of labour is the major household-related limiting factor for management of crop residues in integrated crop-livestock farming perspective. *This thesis*

3. Optimum management of crop residues in an integrated system of crop production and stall feeding of sheep may help to reduce the decline in soil productivity, but external inputs are necessary to trigger sustainable crop-livestock production in Sub-Saharan Africa. *This thesis*

4. The prospects for sustainable crop-livestock production in Sub-Saharan Africa are strongly related to the price of external inputs, availability of working capital and off-farm employment opportunities. *This thesis*

5. The relevant research question with regard to low quality crop residues is not how we can get animals to produce on rations based on these feed resources, but to what extent, how, where and when such materials could be used in the overall production system. *Zemmelink, G., 1995. A Research Approach to livestock Production from a Systems Perspective, a farewell symposium to professor Dick Zwart, page 46; Udo, H. and Cornelissen, T. 1998. Outlook on Agriculture 27, page 240.*

6. Improved crop-livestock interactions remain one of the most environmentally friendly avenues for the intensification of agriculture in semi-arid and sub-humid Africa.

7. Sustainable rural development requires effective integration of expert knowledge and indigenous technical knowledge, through participatory research and extension.

8. Science consists not in the accumulation of knowledge, but in the creation of fresh modes of perception. *Bohm, D., 1993. Last words of a quantum heretic, interview with John Morgan. New Scientist 137, p. 42.*

9. True greatness, true leadership is achieved in selfless service to others. *Engstrom, W.T.,1976. The making of a Christian Leader, Pyrenee Books, Michigan, p. 39)*

10. Nothing determines the confidence people have in you more than your character.

M. Savadogo

Crop Residue Management in relation to Sustainable Land Use: A case study in Burkina Faso. 25 January 2000, Wageningen

To

- My uncle Christophe P. Ouédraogo and his family

- My wife Halizèta Ouangré

Blessed be the name of our Lord Jesus Christ, the strongest tower, the Eternal Horeb.

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Contents

List of tables

List of figures

Chapter 1
Introduction

1.1 Land use in Burkina Faso

Burkina Faso (Upper Volta before August 1984) is a West African country of 274 000 km^2 located between 9° 20' and 15° 05' northern latitude, and 2° 20' eastern and 5 ° 30' western longitude with a population of 10 900 000 persons. The population is mainly rural (83 %) with 81 % illiteracy and 240 US$ gross national product per capita (Table 1.1).

Table 1.1. Main socio-economic characteristics of Burkina Faso

Characteristic	Unit	Value
Population	Millions	10.9
Population annual growth	%	2.8
Urban population	% of total	17
Life expectancy at birth	y	46
Infant mortality	per 1 000 live births	97
Child malnutrition	% of children under 5	33
Illiteracy	% of population age >15	81
Gross primary school enrollment	% of school age population	38
Gross national product per capita	US $	240
Agriculture	% of GDP[¶]	32

[¶] GDP = Gross Domestic Product; **Source:** World Bank web site, 1998.

Population increases by 2.8 % annually, which is among the highest in the world. Agriculture accounts for 32 % of the gross domestic product. Annual rainfall varies from 200 in the North to 1100 mm in the South (Fig. 1.1), concentrated in 3-5 months of the year. Food security is low, due to the low and variable yields of staple crops (Fig. 1.2). Utilisation of inorganic fertilisers is also low, about 7 kg per ha per year (Hien *et al.*, 1994), because of their high cost compared to farmers' income. The quantities imported are, however, increasing (Fig. 1.3) because of government schemes aiming at increasing cotton production, despite devaluation of the currency of FCFA in 1994, which doubled the prices (Fig. 1.4).

The major traditional types of land use are pastoralism (transhumance) and arable cropping. Pastoralism is a production system in which people depend largely (>50 %) on livestock for their livelihood. In the transhumance system, herders move with all or part of the herd more than a day march away from the homestead, during restricted periods of the year. Arable cropping, which is mainly a subsistence activity, involves cultivation of maize, millet, sorghum and cowpea as staples, with groundnut and cotton as main cash crops. Different communities practise these land use types as specialised activities; their relative importance in different regions is associated with the rainfall gradient. In the rainy season (June-October), livestock graze commonly in sylvo-pastoral areas, i.e. areas carrying the natural vegetation, a mixture of annual herbs and woody shrubs and trees (Kessler and Wiersum, 1992). The arable land comprises areas that have been cleared for growing crops, have been left fallow, or have been abandoned because of severe soil degradation. In the dry season (November-May) livestock graze cropland as well as sylvo-pastoral areas. Due to population increase, more land is required to grow crops.

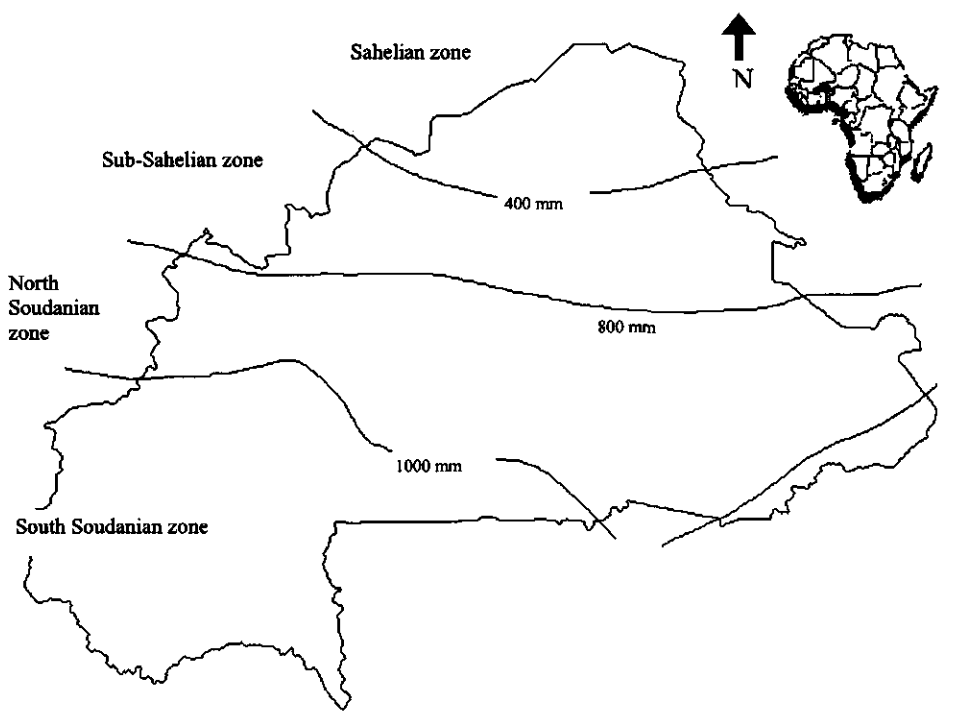

Figure 1.1. Agro-ecological zones of Burkina Faso

As a result, grazing areas decrease and pastoralists attempt to increase food security by adding production of subsistence crops to animal husbandry, because due to reduced size and declining productivity, herds do not provide enough food and cash for the households. Shifting cultivation in which a cultivation phase on land, cleared by slashing and burning, alternates with a fallow period, was an efficient and reliable system when population density was still low. But the rapid increase in human and livestock population has resulted in rapid degradation of land due to overgrazing and shorter periods of fallowing (Zoungrana, 1991). To mitigate the risks of crop failure, arable farmers started to keep livestock. Animals are integrated in the system for maintenance of soil fertility, for diversification and reduction of risk (variability of crops yields due to erratic rainfall), and for draught power. Most of the soils are loamy with high susceptibility to crusting and usually of low fertility, or sandy with low organic matter content, usually less than 0.5 % with a high annual rate (2-3 %) of mineralisation (Pieri, 1989; Janssen, 1993; Hien *et al.*, 1994). Water and wind erosion associated with short but intensive rainstorms at the onset of the rainy season, combined with low vegetation cover of the soil, are the main causes for physical land degradation.

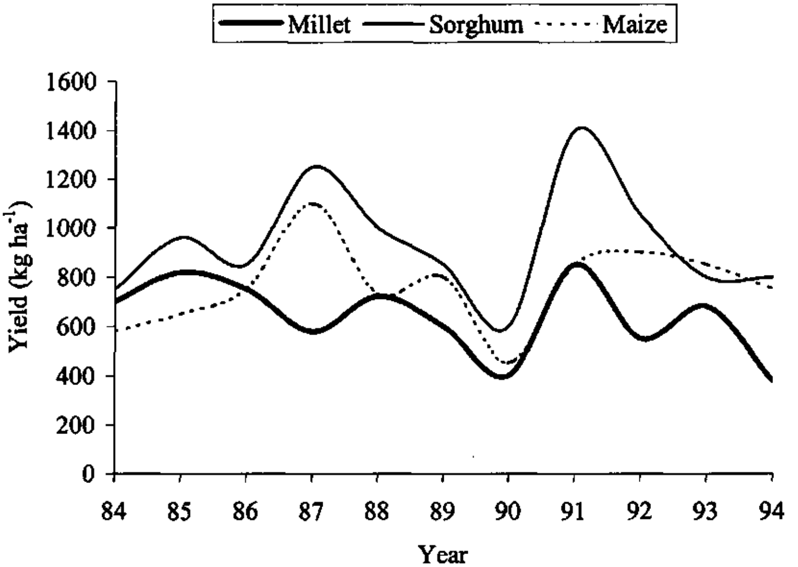

Figure 1.2. Average yields of millet, sorghum and maize in Burkina Faso from 1984 to 1994 (MARA, 1995)

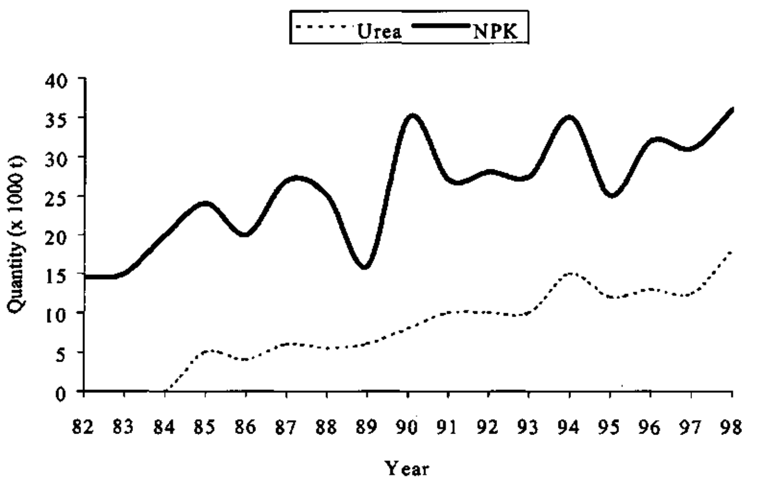

Figure 1.3. Quantities of NPK and urea imported in Burkina Faso from 1982 to 1998 (source: Unité de Gestion de la Fertilité des Sols).

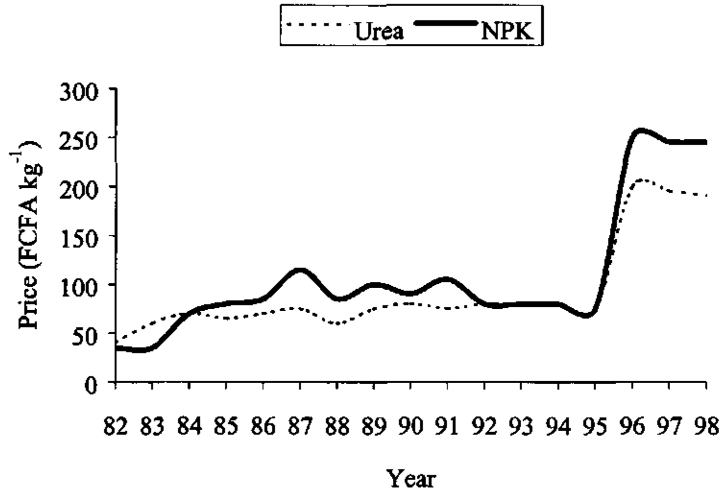

Figure 1.4. NPK and urea prices (official prices) from 1982 to 1998 in Burkina Faso (source: Unité de Gestion de la Fertilité des Sols). 100 FCFA = 1 FF (after devaluation in 1994).

The proportion of rainwater that does not infiltrate into the soil, but runs off, can be as high as 60 % (Stroosnijder, 1996). Important progress has been made in the development of water and soil conservation measures, such as the construction of physical barriers of stones or woody materials (Hien, 1995; de Graaff, 1996) and biological techniques such as stimulating the activity of termites and mulching (Slingerland, 1996; Mando, 1997). These measures may improve infiltration of water into the soil. However, the low fertility of the soil limits the efficient use of this water for intensification of crop and livestock production.

1.2 Sustainable crop-livestock production

FAO (De Grandi, 1996) defines sustainability in agriculture as: "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure attainment and continued satisfaction of human needs for present and future generations. Sustainable development conserves water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially accepted". Many other definitions have been given (Reenberg and Rasmussen, 1992; Kruseman *et al.*, 1996), but all agree on the requirement of increased system output, while preserving the quality of the natural resource base. A necessary condition for sustainable crop-livestock systems in semi-arid West Africa is obviously efficient nutrient cycling in the overall system (van Keulen and Breman, 1990; Reijntjes *et al.*, 1992; Breman, 1995a), because the most important constraint in this region is the low level of nutrient availability. This is closely associated with the dynamics of organic matter in the soil. Integrated management of organic matter and nutrient resources, i.e. synergy between arable farming and animal husbandry that allows efficient nutrient cycling, has been identified as an important basis for sustainable agricultural production in this region (Beets, 1990; Woomer and Swift, 1994; Breman, op. cit.). Livestock provides food (meat, milk), manure, draught power, cash and security, and crops provide food for humans as well as feed (crop residues) for livestock. Crop residues play a key role in the system. They may either be left on the field to be grazed, worked in or burnt, or collected for stall-feeding of animals. In both cases, they serve as a source of nutrients (when decomposed) and/or as a source of (stable) soil organic matter (when resisting decomposition), either directly or in the form of animal manure. Various studies carried out in the Sahel have shown a significant improvement in soil structure and crop yields in systems where crop residues are used for ruminant feeding and the manure is returned to the soil (Bationo and Mokwunye, 1991; Somda, 1994). According to their estimates, the application of manure or compost increases cereal yields significantly. The design of management schemes of crop residues aimed at optimal use of resources requires insight in the organic matter and nutrient flows in the overall system.

Crop residues as ruminant feed

Feed shortage (qualitatively and quantitatively) is a major constraint for livestock production in the dry season (6-7 months). Rangelands are often overgrazed; the carrying capacity in the North Soudanian zone is estimated at 33 tropical livestock units (TLU) per km^2 while the current stocking rate is 37 TLU km^{-2} (Sahelconsult, 1991). In the dry season, carrying capacity decreases by 20-50 %. Few alternative feeds are available at this time of the year. The possibility to use industrial by-products has been advised to farmers, but their relevance is limited due to their low availability and high costs (Compaoré, 1991). Moreover, there is strong competition between ruminants and other animals (poultry, pigs) for industrial by-products. Crop residues remain the main feed source in the dry season, providing 45-100 % of the diets for ruminants (Leloup, 1994; Kiéma, 1994; Elskamp, 1995). The utilisation of crop residues by animals is governed by their nutritive value, animal eating behaviour and feeding methods. Crop residues are generally characterised by high fibre and low nitrogen contents, resulting in low intake and low digestibility (Schiere, 1995). Various methods have been developed to increase utilisation of crop residues. They include physical treatment (grinding, chopping, soaking, boiling), chemical treatment (with urea, NaOH, etc.), biological treatment, supplementation and excess feeding to stimulate selective consumption of the more nutritious parts (Table 1.2). The suitability of each of these methods for animal production depends on the availability of crop residues and alternative feeds, availability of labour, availability and cost of water and chemicals, storage possibilities, etc. In Burkina Faso, chemical treatment is still in the experimentation stage, while chopping of cereal stover is only practised on a limited scale. Most of the farmers store residues for animal feeding in the dry season without further treatment. The feeding value of crop residues depends on many factors, such as species, growing site, growing conditions, leaf to stem ratio, etc. As ruminants are capable of selective consumption, they may ingest a diet of adequate nutritional value by ingesting only the more nutritious components of the available forage (Zemmelink, 1980; Wahed *et al.*, 1990; Fernàndez-Rivera *et al.*, 1994; Subba Rao *et al.*, 1994a;

Table 1.2. Technologies available to improve the utilisation of crop residues in ruminant feeding, the potential constraints to their use and expected impacts (Williams *et al., 1997*).

Technology	Potential constraints			Expected impact
	Labour	Capital	Other	
Crop management				
Fertiliser application	xx	xxx	Availability	Higher yield and quality
Planting density	x		More nutrients needed	Higher yield
Timely harvesting	xx			Lower losses, higher quality
Selective harvesting	xxx			Improved availability, quality
Plant breeding		x	Potential trade-offs	Improved yield, quality
Physical treatment (chopping, grinding, etc.)	xxx	xxx	Uncertainty of animal response	Higher intake, slight decrease in digestibility, less waste
Chemical treatment	xxx	xxx	Uncertainty of animal response, safety concerns, environmental	Increased digestibility, higher intake
Biological treatment	xxx	xxx	Variability in animal response, high technical skills needed	Increased digestibility
Supplementation	x	xxx	Availability, variability in animal response	Increased digestibility, intake, nutrient supply
Residue management				
Excess feeding	xx		Residue availability	Greater selectivity (quality)
Selective grazing	xx		Higher management skills needed	Greater selectivity (quality)
Livestock selection (species and breeds)		xx	Multiplication of superior animals	Animals better adapted to low-quality feeds

Osafo *et al.*, 1997). The intake of crop residues can further be improved by supplementation (Kaasschieter *et al.*, 1994; Kaasschieter and Coulibaly, 1995). It is necessary to describe the relationship between amounts offered, intake and digestibility to determine optimum feeding strategies, in relation to farmer's objectives, using cereal stover alone or in combination with residues of legume crops.

Crop residues as soil amendment

Crop residues contribute to soil fertility either directly (mulch) or in the form of ash (if burnt), animal manure and/or compost. Farmers may leave the residues in the field or collect them for stall feeding, fuel, fences, doormats, etc. (Camara, 1996; Williams *et al.*, 1997). When left in the field, animals usually eat them in-situ and faeces and refusals serve as a source of soil organic matter. In some cases, contracts are drawn up between farmers and herders, allowing herders with their animals to settle during the dry season on farmers' fields. Animals graze the crop residues and the manure is returned to the land. This method of manuring is, however, becoming less frequent because farmers tend to use crop residues for their own animals (stall-feeding). In crop-livestock systems, a large proportion of the crop residues passes first through the animal before (part of) it becomes available as manure. The role of crop residues as soil amendment depends thus on the management of faeces, urine and/or refusals returned to cropland.

1.3 Aim of the study

This study focuses on the role of crop residues in mixed crop-livestock systems in the dry season. The livestock component selected consists of sheep. Small ruminants have in general a high capacity for selective consumption; they are more productive per unit of investment due to their early sexual maturity, short duration of the reproduction cycle and young age at slaughter. They have smaller carcasses than other livestock (cattle, donkey, camel) and marketing is easier, because a slaughtered animal can be consumed in a short period of time (Boutonnet, 1995). Since the droughts of seventies, when livestock numbers fell by 50 - 80 %, there has been a shift from cattle herds to small ruminants, especially in sedentary mixed farming (FAO, 1991). Burkina Faso is the third country in semi-arid Africa in terms of concentration of small ruminants (1.28 animals per capita) after Mauritania (4.60) and Mali (1.76) (Ademosum, 1993). There are more goats than sheep (ratio 56:44). Farmers take advantage of the foraging behaviour of goats (browsing) by letting them roam freely in the dry season (Kiéma, op.cit.; Elskamp, op. cit.). For stall feeding, sheep are considered more suitable. Sheep are also more important on the export market (Fig. 1.5). Sheep for export are generally strategically fattened (during the dry season only), using residues of cereal and leguminous crops and industrial by-products. In addition, sheep are preferred for most ceremonies due to the influence of Islam (Savadogo, 1991), hence demand in the country itself is also increasing. Because sheep have a strong flocking instinct, they can be herded by children and older members of the family, so that labour can be used more efficiently.

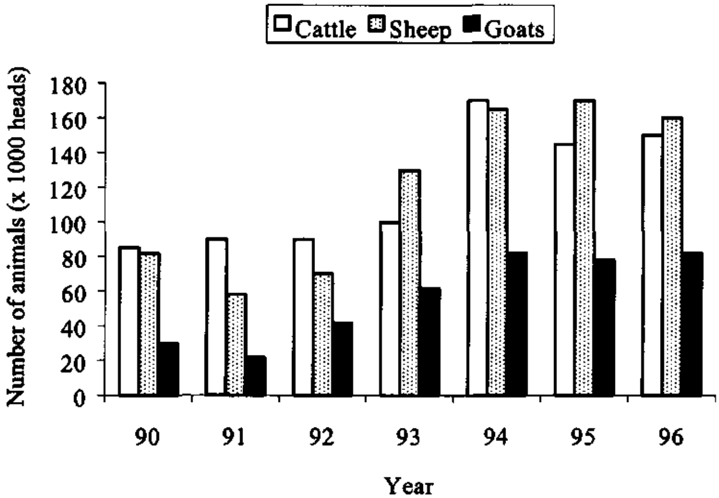

Figure 1.5. Export of live animals from Burkina Faso from 1990 to 1996 (source: Direction des Statistiques Agro-Pastorales).

Crop residues are of strategic importance in mixed farming systems, as the key point of interaction between crops, livestock and soil components (Schetty *et al.*, 1995; Meerman *et al.*, 1996; Latham, 1997). Their increasing role in animal feeding and maintaining soil fertility is widely recognised. Optimum management of crop residues, that minimises losses of nutrients and organic matter in the overall system, is important for sustainable crop-livestock production (Powell and Williams, 1995; Renard, 1997). However, utilisation of crop residues faces constraints, such as their low nutritive value, poor storage and conservation techniques, limited availability of labour needed for more effective use (collection, transport, storage and processing), etc. An integrated analysis of these aspects is required for identification of suitable management schemes. Special attention is paid to excess feeding in this study. This practice allows selection of the more nutritious fractions in the feed, that support higher animal production levels, but is associated with high rates of refusals. Effective return of refusals, in combination with animal excrements (faeces and urine) to crop land may contribute to minimise nutrient losses in the system, while the sale of animals may generate cash for the purchase of agricultural inputs, and thus contribute to the intensification of crop production. A clearer understanding of the socio-economic and technical aspects of these processes is required for sustainable crop-livestock production.

The overall objective of this study was to evaluate the role of crop residues in crop-livestock systems in Burkina Faso, considering their role as animal feed, and as a source of organic matter and nutrients for maintaining soil fertility. The specific objectives were:

- To establish response curves describing the effect of (varying degrees of) selective consumption of crop residues (as single feeds and in various combinations) on animal production;

- To evaluate the effect of alternative systems of feeding crop residues on labour requirements and household income from animal production;
- To evaluate the effect of alternative systems of feeding residues on crop productivity, and on organic matter, nitrogen and phosphorus balances at the farm level;
- To determine the trade-offs among various objectives associated with different alternative uses of crop residues.

1.4 Outline of the thesis

Following this general introduction, the potential contribution of crop residues to ruminant livestock feeding in Burkina Faso is described for 4 agro-ecological zones (Chapter 2). Chapters 3 and 4 describe the results of experiments in which we measured the effect of selective consumption on intake and digestibility of crop residues as single feed and in various combinations. These results are used to determine optimum combinations (least-cost) of cereal stover and supplement for a given production level. Chapter 5 deals with availability of crop residues and factors influencing their allocation at farm level. The results of Chapter 4 are used to quantify part of the technical coefficients, that are used in a Multiple Goal Linear Programming model to determine the trade-offs among agro-technical, economic and environmental objectives for alternative uses of crop residues at farm level (Chapters 6 and 7). Chapter 8 summarises the main findings and conclusions.

Chapter 2
Contribution of crop residues to ruminant feeding in different agro-ecological zones

2.1 Introduction

Sub-Saharan livestock production is increasingly constrained by feed shortage, both quantitatively and qualitatively. Natural forage is not sufficient to satisfy animal requirements in the dry season when the quantity decreases by 25-50 % of peak biomass and N content falls well below 1 % (Penning de Vries and Djitèye, 1982; Breman and de Ridder, 1991; Leloup, 1994; Ayantunde, 1998). In addition, industrial by-products are not available, or so expensive that farmers cannot afford them (Dembélé, 1995; Kaboré, 1996). Hence, crop residues play an increasingly important role in ruminant feeding. The human population of Sub-Saharan Africa increased by 77 % in the last 30 years, crop areas followed the same trend (+120%) (Sansoucy, 1992; UNDP, 1997). In this region, animal feed in the dry season already consists mainly of crop residues (Kiéma, 1994; Leloup, op.cit.). Although this is increasingly the case in all Sahelian countries, reliance on crop residues to sustain animal production faces problems, because of the limited availability and low nutritive value. Nevertheless, many studies have shown scope for improvement of ruminant livestock production in systems based on crop residues, when appropriate feeding strategies are applied (Jabbar, 1993; Smith, 1993; Van Bruchem and Zemmelink, 1994; Kyomo, 1997; Breman and Sissoko, 1998).

Of the three major feed resources, i.e. natural or cultivated forage, industrial by-products and crop residues, only the latter is sure to increase in total production. Improving knowledge of their potential contribution to livestock feeding may therefore help in estimating the carrying capacity of different agro-ecological zones, and to examine the effect of possible changes in feeding systems on the productivity of livestock. The specific objective of this chapter was to quantify the potential contribution of crop residues to ruminant livestock feeding in the different agro-ecological zones of Burkina Faso, taking into account the combined effects of their quantities and nutritive value (digestibility and N content).

2.2 Methods

Study area

This study covers four (4) agro-ecological zones: Sahelian, Sub-Sahelian, North Soudanian and South Soudanian. The Sahelian zone, located in the north of the country, is characterised by annual rainfall ranging from 200 to 400 mm, during 2-3 months; the Sub-Sahelian zone receives 400-800 mm rain in about 4-5 months, the North and South Soudanian zones 800-1000 mm and more than 1000 mm respectively, in about 6 months (Fig. 2.1).

Estimation of crop residue availability

Estimates of the quantities of crop residues were based on crop areas and grain yields derived from the national agro-pastoral statistics (MARA, 1996). The ratios straw/grain were set to 3 for sorghum and millet, 2 for maize, 1.5 for cowpea and groundnut, 1.25 for rice, and 1 for bambara groundnut (Zongo, 1997). The number of livestock was estimated on the basis of the national livestock census data of 1989 updated by an annual rate of increase of 2 % for cattle, donkeys and horses, and 3% for small ruminants (MAE, 1990). Herd size was expressed in tropical livestock units (TLU), a hypothetical animal of 250 kg (Breman and de Ridder, op. cit.). The conversion factors used are 0.8 for cattle, 0.12 for sheep and goats, 0.6 for donkeys, and 1 for horses (MAE, op.cit.). Nutritive values of plant materials were taken from various relevant publications (Rivière, 1978; Kaasschieter *et al.*, 1994, 1998; Kaasschieter and Coulibaly, 1995; Ouédraogo, 1990; Camara, 1996; Kaboré, 1996; De Leeuw, 1997).

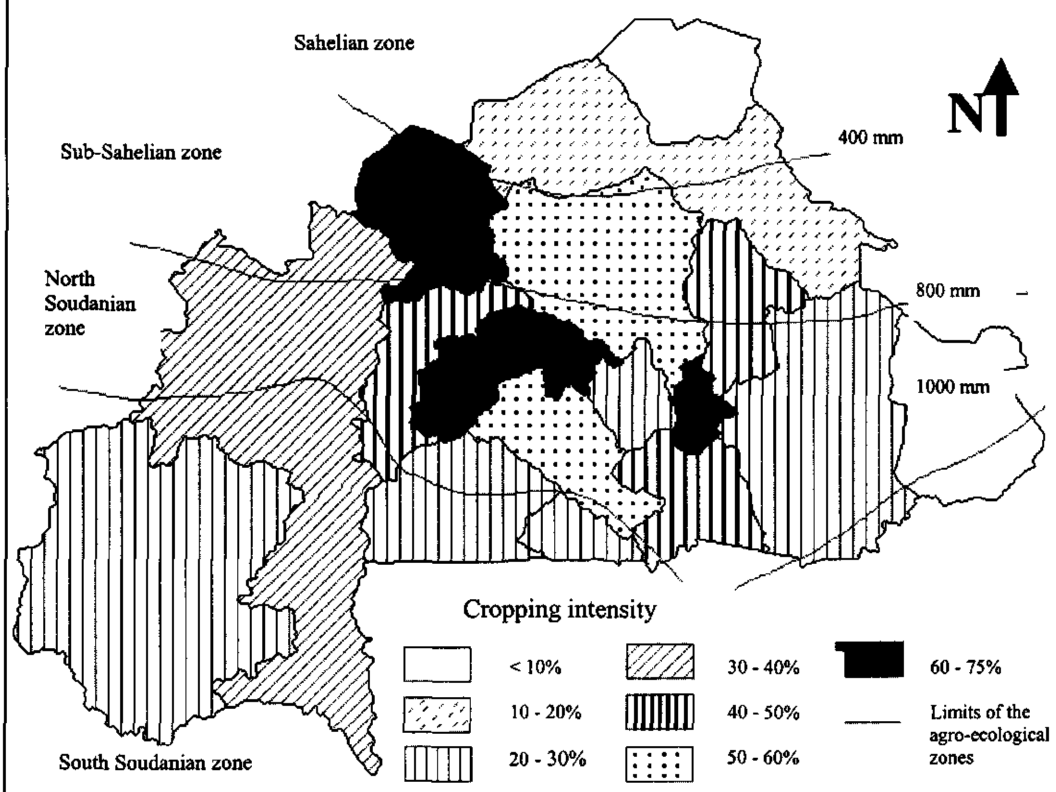

Figure 2.1 Agro-ecological zones and cropping intensity in Burkina Faso (Source: MET, 1991)

Calculation procedure

All calculations were performed with the Java program developed at the Department of Animal Science, Animal Production Systems Group of Wageningen Agricultural University (Brouwer, 1991; Zemmelink *et al.*, 1992; Ifar, 1996). This program estimates the number of animals that can be fed and their production on the basis of availability of a mixture of feeds of different quality. It takes into account that intake of feed by animals depends on the quality (digestibility and N content) of the ration. This allows estimating the effect of selective utilisation of feeds on animal production and hence to estimate optimum degrees of selection to attain maximum production or maximum number of animals that can be maintained during a given period of time.

Intake of organic matter (IOM in g $kg^{-0.75}$ d^{-1}) is estimated on the basis of the quality of each feed, as described by Ketelaars and Tolkamp (1991) for sheep:

$$IOM = -42.78 + 2.3039*OMD - 0.0175*OMD^2 - 1.8872*N^2 + 0.2242*OMD*N$$

($n = 831$; $rsd = 8.9$; $r^2 = 0.65$),

in which OMD (%) is organic matter digestibility and N (%) is nitrogen content in the organic matter. Intake of digestible organic matter is converted to intake of metabolizable energy (ME), assuming that 1 g of digestible organic matter is equivalent to 15.8 kJ ME (NRC, 1988). Values for ME required for maintenance (ME_m) and for growth proposed by Kaasschieter *et al.* (1998) for Sahelian cattle breeds were used: 0.508 MJ $kg^{-0.75}$ d^{-1} for ME_m, and 31 MJ/kg for weight gain. It was assumed that feed intake of cattle (in g $kg^{-0.75}$ d^{-1}) is 1.33 times that of sheep (in proportion to their maintenance requirements). In the first step of the analysis, the feeds are ranked according to their individual values of intake of metabolizable energy (IME). After this ranking, the program enters a stepwise procedure. In step 1, a certain fraction (e.g. 1 %) of the total available feed DM is taken, in step 2 the next 1% is added, etc., until all feed is included. At each step, the program calculates the total amount of feed DM included and its quality (weighted mean of digestibility and N concentration), from which it derives feed intake per animal, the number of animals that can be fed, live weight gain per animal per day, and total production. Input data were the quantities of crop residues given in Table 2.1 and their nutritive values (Tables 2.2 and 2.3). Four situations have been analysed:

A: Current quantity and average nutritive value of each crop residue were used. This reflects the utilisation of crop residues in ruminant feeding without application of any special technology.

A-20: The quantities of cowpea and groundnut haulms were assumed 20 % higher. This reflects the target of extension services for the Soudanian zones, mainly through the introduction of forage legumes, i.e. dolic (*Dolichos lablab*) and dual-purpose cowpea (DVA, 1997).

B: The effect of selective consumption on system productivity was examined by considering stems and leaves of cereal residues separately.

B-20: Scenario B with the quantities of cowpea and groundnut haulms assumed 20 % higher.

Table 2.1. Area, yields and total quantities of residues in the different agro-ecological zones of Burkina Faso

Crop residue	Sahelian zone			Sub-Sahelian zone			North Soudanian zone			South Soudanian zone		
	A	Y	Q	A	Y	Q	A	Y	Q	A	Y	Q
Legume residues												
Cowpea	9.4	747	7	65.0	939	61	168.5	1294	218	58.8	1123	66
Groundnut	2.6	775	2	26.7	1161	31	136.0	1434	195	66.2	1254	83
Bambara groundnut	2.3	864	2	7.9	880	7	18.9	951	18	22.6	931	21
Cereal residues												
Maize	2.2	928	2	12.1	1736	21	69.5	2130	148	162.3	2132	346
Millet	209.7	1416	297	205.0	1395	286	715.8	2094	1499	245.2	2349	576
Rice	0.7	1500	1	0.6	1687	1	14.4	2437	35	10.7	2531	27
Sorghum	138.2	1440	199	279.0	2025	565	836.7	2688	2249	359.0	2571	923

A = crop area (10^3 ha); Y = yield of crop residue (kg ha^{-1}); Q = Total amount crop residue (10^6 kg)

Table 2.2. Average, lowest and highest nutritive values of crop residues reported in consulted papers

Crop residue	OM (% DM)			CP (% in OM)			ME (MJ kg^{-1} OM)			OMD (%)		
	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max
Legume residues												
Cowpea	89	88	92	15.6	13.9	21.7	9.7	9.2	11.7	61	58	74
Groundnut	88	85	90	12.6	8.5	25.3	9.0	8.7	10.8	57	55	68
Bambara groundnut	88	84	92	6.4	5.5	10.1	8.7	7.9	9.5	55	50	60
Cereal residues												
Maize	91	87	95	4.8	4.6	6.5	7.1	6.3	8.7	45	40	55
Millet	90	89	93	5.2	4.8	9.3	7.5	4.6	10.0	47	29	63
Rice	83	77	86	5.4	2.3	8.6	7.5	6.7	9.0	47	42	57
Sorghum	91	90	94	4.4	2.8	7.0	8.1	6.8	10.3	51	43	65
Weighted mean (cereals)	*90*			*4.7*			*7.8*			*49.2*		

OM = organic matter; CP = crude protein; ME = metabolizable energy estimated from digestible organic matter (1 g DOM equivalent to 15.8 kJ ME). OMD = organic matter digestibility; Avg. = average; Min = minimum; Max = maximum.

Sources: Rivière (1978); Kaasschieter *et al.* (1994; 1998); Kaasschieter and Coulibaly (1995); Ouédraogo (1990); Camara (1996); Kaboré (1996); De Leeuw (1997).

Table 2.3. Proportions and nutritive values of stems and leaves of cereal stovers used in the calculations

Crop residue	Stem					Leaf				
	P	OM	CP	OMD	ME	P	OM	CP	OMD	ME
Millet	70	93	3.8	38	6.0	30	86	6.6	59	9.4
Sorghum	71	95	2.6	41	6.5	29	87	5.4	46	7.3
Maize	65	95	4.0	40	6.3	35	85	5.0	52	8.3
Rice	40	82	3.7	40	6.3	60	75	4.8	55	8.7
Weighted mean	*70*	*94*	*3.1*	*40*	*6.3*	*30*	*86*	*5.8*	*52*	*8.2*

P= proportion (% of OM); OM = organic matter (% in DM); CP = crude protein (% in OM); ME = metabolizable energy (MJ kg^{-1} OM) estimated from digestible organic matter (1 g OM equivalent to 15.8 kJ ME). OMD = organic matter digestibility (%).
Sources: Kaasschieter *et al.* (1994; 1998); Savadogo *et al.* (1999).

In all situations, it was assumed that the nutritive value of the crop residues was constant throughout the feeding period. The length of the period was set to 210 days, the average duration of the dry season.

2.3 Results

Quantities of crop residues in the agro-ecological zones

Cereal crops, i.e. millet (*Pennisetum glaucum [L.] R.Br.*), sorghum *(Sorghum bicolor [L.] Moench*) and maize (*Zea mays L.*) are predominant in all four agro-ecological zones. Depending on the zone, these crops occupy 28 - 58 %, 39 - 58 %, and 0.4 to 17 %, respectively, of the total cultivated land area (Table 2.1). Millet is the principal crop in the Sahelian zone, but somewhat less important further south. Maize as % of the total area is most important in the South Soudanian zone and sorghum in the intermediate zones. The legume crops, i.e. cowpea (*Vigna unguiculata [L.] Walp*), groundnut (*Arachis hypogaea L.*) and bambara groundnut (*Voandzeia subterranea*) occupy in all zones less than 15 % of the crop area. Cowpea is often inter-cropped with sorghum or millet. The intercropping consists of various spatial arrangements of millet/sorghum and cowpea. The yields of the residues in t ha^{-1} range from 1.4 to 2.3 for millet, 1.4 to 2.7 for sorghum, 0.9 to 2.1 for maize, 0.7 to 1.3 for cowpea, 0.7 to 1.4 for groundnut, and 0.8 to 0.9 for bambara groundnut.

Better quality residues are those of cowpea and groundnut, with 15.6 and 12.6 % crude protein (CP), 61 and 57 % digestibility of organic matter (OMD), and 9.7 and 9.0 MJ metabolizable energy (ME) per kg OM, respectively (Table 2.2). Cereal residues that represent more than 85 % of all residues in all agro-ecological zones are lowest in nutritive value, i.e. 4.4 - 5.4 % CP, 45 – 51 % DOM and 7.1- 8.1 MJ ME per kg OM. Residues of bambara groundnut are of intermediate nutritive value, i.e. 6.4 % CP, 55 % DOM and 7.9 MJ per kg OM. For situations A and A-20 the weighted mean nutritive value of cereal residues given in Table 2.2 was used in the calculations. For situations B and B-20, where leaves and stems of cereal residues are distinguished, weighted mean values of stems and leaves were used (Table 2.3).

Composition of rations

When the objective is to maintain the maximum number of animals, i.e. provide a ration meeting the requirements for maintenance only, 7 % of the total amount of crop residues available in the Sahelian zone could be used in the current situation (A). This consists of all legume haulms (cowpea, groundnut and bambara groundnut) combined with 5 % of the cereal stovers (Table 2.4). Due to the larger quantities of haulms, a larger fraction of the cereal stovers could be used in the other zones: 30, 28 and 20 %, respectively, while 37, 35 and 27 % of the total feed could be used in the Sub-Sahelian, North Soudanian and South-Soudanian zones, respectively. The assumed nutritive value of cereal stovers is below maintenance requirements and due to their large quantities, only a small proportion could be combined with the small quantities of haulms. Even when the amount of haulms was increased by 20 % (situation A-20), only 9 % of the total amount of feed in the Sahelian zone can be used and 32 – 43 % in the other zones. The distinction between leaves and stems of stovers allows inclusion of a higher proportion of the stovers, and hence a higher proportion of the total amounts of feed. The increase in proportion of total feed that could be used was more important in the Sahelian zone (by a factor 4.6) than in the Sub-Sahelian, and Soudanian zones. In the Sub-Sahelian and Soudanian zones 7-10 % of the cereal stems could be used. Under situation B-20 (selective utilisation of cereal leaves and 20 % increase in the quantity of haulms), only a slightly larger proportion of the stems could be used.

When the objective is to maximise animal production, even smaller proportions of cereal residues can be used. Under the current situation (A), in the Sahelian zone, the total proportion of bambara groundnut was less than 1 % of the total residues and only 60 % of that could be used. Also in the Sub-Sahelian zone, only 74 % of the bambara groundnut haulms could be included and only 10 % of the total feeds were used. When availability of haulms was assumed 20 % higher, only slight changes resulted. Distinction between leaves and stems in stovers led to an increased contribution of cereal residues to the diets. Up to 71 and 81 % of stover leaves could be used in situations B and B-20, respectively, in the North Soudanian zone, and 30 – 58 % in the other zones.

Carrying capacity of the different zones

- Sahelian zone

When maximising total production, a maximum of 64 10^3 livestock units could be fed in the Sahelian zone in situation B (Table 2.5), corresponding to 12 % of the current livestock population (550 10^3 TLU). The associated daily weight gain was 97 g per TLU. It would be possible to feed a higher number of animals (76 10^3) for similar daily weight gain when the quantities of haulms were increased by 20 % and leaves and stems of cereal residues distinguished. Under situation A, 9 10^3 TLU could be fed to gain 526 g per TLU per day for maximum total production or a maximum of 43 10^3 TLU at maintenance level.

Table 2.4. Proportion of feeds included in the ration when feeding aims at maintaining the maximum number of animals (HS) or maximum total liveweight gain (TP). Cowpea and groundnut haulms are fully used in all rations.

Crop residue	Sahelian zone		Sub-Sahelian zone		North Soudanian zone		South Soudanian zone	
	HS	TP	HS	TP	HS	TP	HS	TP
Situation A[1]								
Total feed	7	2	37	10	35	11	27	10
Bambara groundnut haulms	100	60	100	74	100	100	100	100
Cereal stovers	5	0	30	0	28	1	20	0
Situation A-20								
Total feed	9	2	43	15	41	12	32	12
Bambara groundnut haulms	100	77	100	100	100	100	100	100
Cereal stovers	7	0	35	3	33	0	25	2
Situation B								
Total feed	32	11	43	22	43	29	41	17
Bambara groundnut haulms	100	100	100	100	100	100	100	100
Cereal leaves	100	30	100	45	100	71	100	31
Cereal stems	1	0	10	0	10	0	7	0
Situation B-20								
Total feed	33	13	46	21	46	33	43	26
Bambara groundnut haulms	100	100	100	100	100	100	100	100
Cereal leaves	100	36	100	35	100	81	100	58
Cereal stems	2	0	14	0	13	0	9	0

[1] A: current quantities of feed, no distinction between leaves and stems of cereal residues; A-20: as A with legume residue assumed 20 % higher; B: current quantities of feed with distinction between leaves and stems of cereal residues; B-20: as B with legume residues assumed 20 % higher.

Allowing selective consumption of stover leaves (situation B) results in an increase in this maximum herd size by a factor 4.6. Increasing haulms availability by 20 % (situation A-20) results in a 33 % increase in herd size. Up to 37 % of the current ruminant stock in this zone could be fed at maintenance level if the amounts of haulms could be increased by 20 % and selective consumption of the stover leaves were allowed. In this zone, only a small total production could be derived from the available crop residues.

Table 2.5. Potentials of crop residues as ruminant feed in the different agro-ecological zones

Agro-ecological zone	At maximum TP			Maximum HS fed at maintenance
	HS	DWG	TP	
Sahelian zone				
A	9	526	1	43
A-20	9	583	1	57
B	64	97	1	198
B-20	76	98	2	206
Sub-Sahelian zone				
A	90	526	10	441
A-20	148	374	12	522
B	225	246	12	503
B-20	213	302	14	551
North Soudanian zone				
A	464	427	42	1872
A-20	505	478	51	2235
B	1386	174	51	2259
B-20	1602	180	61	2476
South Soudanian zone				
A	205	342	15	675
A-20	252	333	18	814
B	370	213	18	1009
B-20	592	173	22	1075

[1] A: current quantities of feed, no distinction between leaves and stems of cereal residues; A-20: as A with legume residues assumed 20 % higher; B: current quantities of feed with distinction between leaves and stems of cereal residues; B-20: as B with legume residues assumed 20 % higher.

HS: Herd size in 10^3 TLU (a hypothetical animal of 250 kg body weight); DWG: daily weight gain in g d^{-1} per TLU; TP: total production in 10^6 kg.

- Sub-Sahelian zone

Maximum potential liveweight gain was estimated at 10 10^6 kg in situation A, 12 10^6 kg in situations A-20 and B, and 14 10^6 kg for B-20. This production was obtained with 90, 148, 225 and 213 10^3 TLU, respectively, corresponding to 11, 18, 27 and 26 % of the current ruminant population in this zone (817 10^3 TLU). These optimum herd sizes were associated with daily weight gains per animal of 302 - 526 g. When the quantity of haulms was increased by 20 % or leaves of the cereal stovers were distinguished from stems, or both, the number of animals that give maximum production increased by a factor 1.64-2.50, but the associated daily weight gain per animal decreased so that the total production increased by only a factor 1.17-1.36. A maximum of 54 % of the current population could be fed at maintenance level in situation A. Situation B-20 allowed maintenance of 67 % of the current livestock population. The current availability of crop residues cannot maintain the current livestock population in the dry season in this zone with the assumed nutritive value, even when selective consumption is allowed.

- North Soudanian zone

This zone has the highest potential. In situation A, 98 % of the current 1 901 10^3 livestock units could be fed at maintenance level.

If 20 % more cowpea and groundnut haulms would be available, or when selective consumption of cereal stover is assumed, or both, it would be possible to maintain all the current ruminants in this zone. Total potential production varied between 42-61 10^6 kg. Optimum herd size associated with the highest potential production ranged from 464 to 1602 10^3 TLU.

- South Soudanian zone

In situation A, maximum production was attained with 205 10^3 TLU, associated with 342 g daily weight gain per animal. If 20 % more legume haulms would be available (A-20), the optimum herd size would increase to 252 10^3 TLU. Similar trends were observed when selective consumption was assumed. When the target was to maximise herd size fed at maintenance, 76, 92, 114, and 121 % of the current livestock population (887 10^3 TLU) could be maintained in situations A, A-20, B and B-20, respectively. Optimum herd sizes for maximum regional production, however, would be 205, 252, 370 and 592 10^3 TLU, respectively, corresponding to 23-67 % of the current population. These herd sizes were associated with daily weight gains of 342, 333, 213 and 173 g per animal, giving 15 10^6 kg total production from 210 days feeding in situation A, 18 10^6 kg in A-20 and B, and 22 10^6 kg in B-20.

2.4 Discussion

Crop residue yields per ha estimated in this study, are slightly lower than those reported by Kossila (1988), Van Duivenbooden (1992) and Camara (1996), because different straw/grain ratios have been used. Yields of crop residues are quite substantial compared to the average yields of natural forages in the same period. Winrock International (1992) estimates the latter at 0.2 to 0.5 t ha^{-1} in the arid and semi-arid zones, and 0.72 to 0.76 t ha^{-1} in the sub-humid and highland zones. Leloup (1994) reported a forage yield of 2.3 t per ha natural grassland in Southern Mali at peak biomass. Cowpea and groundnut haulms are of reasonable quality, both in terms of digestibility and protein content, allowing acceptable levels of animal production when fed alone. However, the quantities available are insufficient to compensate for the low nutritional value of the cereal crop residues.

In the Soudanian zone, especially the northern part, crop residues represent an important feed resource for ruminants. In addition to the larger quantities produced as compared to the Sahelian zone, there seems scope for expanding the area of cowpea and groundnut haulms and/or other forage legumes, because of the more favourable climatic conditions. In the present calculations, it was assumed that all crop residues produced are available for ruminant feeding and that their nutritive values are constant throughout the dry season. This assumes an intensive management of these residues, which is not the case in current practice. However, the results indicate production potential and the associated number of animals that could be supported in each zone.

To increase the possibilities of using crop residues for ruminant feeding, physical, chemical and biological treatments have been tested in many developing countries (Owen and Jayasuriya, 1989). Chopping increases dry matter intake, but has a variable effect on digestibility and weight gain; the effectiveness of treatment with urea in terms of increased digestibility is variable (Ouédraogo, 1990; Smith, 1993; Singh and Schiere, 1995) and does not always result in increased weight gain, due to the interactions with nutrient availability. Urea treatment improves the availability of energy, but the low level of true protein may hamper the conversion of this energy into animal products. As urea treatment is also expensive, it is not widely used (De Leeuw, 1997). Other treatments such as grounding, soaking, wetting, addition of NaOH, KOH, urine, composting and ensiling have been developed (Smith, op. cit.), but these are often unknown by smallholders and/or impractical and costly.

Results of the present study suggest that the North and South Soudanian zones are well endowed with crop residues that may allow meeting the feed requirements of the current ruminant population in the dry season, even without application of any of these technologies. This requires that animals be allowed to eat leaves of stovers selectively. In that situation, between 31 and 81 % of the leaves would be included in the diet when maximising animal production. When the feeding system aims at maximising the number of animals fed at maintenance level, for which rations of lower quality can be used, even some of the stems can be included in the diets (maximum about 10 %). A substantial part of the cereal residues is of such inferior quality that it doesn't contribute to the possibilities for maintaining animals. In these zones, intensive management of crop residues can contribute to intensified ruminant livestock production, which may lead to increased recycling of nutrients, if all nutrients in animal excreta could be returned to the crop land. Recycling, however, is associated with unavoidable losses. Hence, more intense recycling also leads to greater losses in absolute terms. Therefore, this recycling may lead to higher nutrient availability for crops in the short run, but contributes to more efficient mining in the long run. The degree to which more intensive management of crop residues will be adopted depends on possibilities to collect and transport residues, conservation techniques and the value attached by farmers to the different alternative uses of these residues.

2.5 Implications

Optimising use of crop residues has for a long time been a major concern in the Semi-arid West African Research and Development programs. Various measures can be suggested that can help to improve the contribution of crop residues to ruminant feeding:

1. The first step towards improved utilisation of crop residues would be to improve residue collection and conservation techniques that minimise the reduction in nutritive value, especially of the scarce highest quality residues. Collected and conserved under good conditions, the nutritive value of cowpea and groundnut haulms can be quite high (> 20 % crude protein and 60-70 % organic matter digestibility). Also losses of cereal leaves can be minimised by appropriate collection and storage.

2. Improvement of animal production in systems based on crop residues during the dry season requires an increase in the availability of better quality feed (residues of leguminous crops). In the Sahelian and Sub-Sahelian zones, very little scope seems to exist for such an improvement because of unfavourable climatic conditions. In the other zones, some possibilities may exist although availability of soil nutrients may be a major limiting factor. Introduction of monocultures of cultivated forages meets difficulties related to the shortage of suitable land and labour, but legume-cereal inter-cropping as already applied by farmers, could be successfully used (Schetty *et al.*, 1995; Singh, 1997). In addition to taking advantage of N fixation by legumes, intercropping of cereals and legumes reduces the competition for land. Intercropping of maize and *Dolichos lablab* for example has attracted great interest in South Mali (ESPGRN, 1994). The utilisation of dual-purpose varieties (cultivated for both grain and forage), i.e. *Vigna unguiculata* types Vital, Vita3, and 58-74 selected in Burkina Faso (DVA, op. cit.), reduces the land area and labour needed. Moreover, the lower cereal yields that may result from intercropping are compensated by higher animal production. Yields of dolic in maize-dolic intercropping in Mali reached 3-6 t forage, and 0.5-1 grain/seed per ha. Increasing the amount of legume haulms is an alternative for using concentrate, which requires much working capital. Specified animal production levels can be attained by various combinations of cereal stovers and legume haulms. Optimum utilisation of on-farm resources implies a choice or compromise between maximising animal production and maximising animal numbers. Maintaining animals in the dry season may be an important production objective, because it gives more manure and so has a value for cropland productivity.

3. In the Soudanian zones, where availability of cereal stover is higher, it may be profitable to take advantage of the capacity of animals to use feeds selectively by excess feeding, to

increase quantity and quality of intake by allowing animals to consume only leaves. Subba Rao *et al.* (1994a) have shown that selective consumption of the better part of millet stover by sheep allows energy intake levels close to their maintenance requirements. Bhargava *et al.* (1988) indicated that intake of digestible organic matter by sheep fed excess barley straw, so that animals can select, is comparable to that realised after treating straw with alkali. This feeding technique should be combined with improved refusal management so that refused organic matter can be effectively returned to cropland.

Chapter 3

Optimising crop residue use at animal level: Single feeds[1]

3.1 Introduction

About 80 % of the rural population of semi-arid West Africa raise ruminants (Winrock International, 1992). The main constraint to livestock production is the limited availability of suitable feeds. Especially in the dry season (November - June), the digestibility, the concentration of crude protein and the edibility of rangeland forages are very low. The concentration of crude protein may fall to well below 6% (< 1% N). Also the quantity of forage available decreases with 25-50 % as compared to the rainy season (Wolf *et al.*, 1991). Crop residues are an important alternative to overcome shortages in that period. The main crop residues are stover of cereals such as sorghum (*Sorghum bicolor L. Moench*), maize (*Zea mays*) and millet (*Pennisetum typhoides*), haulms of leguminous crops such as cowpea (*Vigna unguiculata L. Walp*), groundnut (*Arachis hypogaea*), and bambara groundnut (*Voandzeia subterranea*), and other straws such as rice (*Oriza sativa*) and cotton (*Gossipium hirsutum*). The amount produced in Sub-Saharan West Africa ranges from 2 to 3 t ha^{-1} (Sansoucy, 1992; Smartt, 1994; MARA, 1996; Williams *et al.*, 1997).

The utilisation of straws depends on their nutritive value, feeding strategies and the eating behaviour of animals. Under conditions of in-situ grazing, about 60 % of the straws may be wasted due to trampling, termites and nutrient depletion by weathering (Sansoucy, op. cit.). Hand feeding is now becoming a widespread practice in many areas. It is important to find suitable feeding methods for optimal utilisation of stored residues (Lufadeju, 1992). Much work has been done to improve the nutritive value of crop residues, including studies on physical, chemical or biological treatment of these materials. The major treatments are chopping and treatment with urea or ammonia. An alternative is to supplement low quality feeds with concentrates. However, the rate of adoption of these technologies by farmers remains low. Some of the reasons of this low adoption are the risks involved (intoxication with urea/ammonia), high costs of materials and high labour requirements (Sundstøl and Owen, 1984; Schiere and Nell, 1993).

Several authors have shown that intake of coarse heterogeneous forages can be considerably increased by excess feeding and stimulating selective consumption. This applies to green and dried leguminous forages (Zemmelink, 1980; Mero and Udén, 1998b), as well as grasses (Zemmelink *et al.*, 1972; Schiere *et al.*, 1990; Mero and Udén, 1998a), and cereal straws (Wahed *et al.*, 1990; Badurdeen *et al.*, 1994) and stoversd (Fernàndez-Riviera *et al.*, 1994; Subba Rao *et al.*, 1994; Osafo *et al.*, 1997). Zemmelink (1986) proposed that the relationship between amount of feed offered and the corresponding intake of digestible dry matter (or

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[1] This chapter is adapted from: Savadogo, M., Zemmelink, G., Nianogo, A.J., 1999. Effect of selective consumption on voluntary intake and digestibility of sorghum (*Sorghum bicolor L. Moench*) stover, cowpea (*Vigna unguiculata L. Walp*) and groundnut (*Arachis hypogaea L.*) haulms by sheep. Accepted by *Animal Feed Science and Technology*.

organic matter) can be used to derive optimum feeding levels, giving maximum intake of digestible energy for production (and consequently, maximum animal production) per unit of feed available. Bosman *et al.* (1995) used this method for the evaluation of gliricidia and leucaena forages. Mbile and Udén (1997), and Mero and Udén (1998a,b) used similar procedures to determine optimum feeding levels for various tropical legumes and grasses. This paper reports studies with residues (straws) of sorghum, cowpea and groundnut.

3.2 Material and methods

The feeds were tested in three experiments with twelve rams of the Djallonké breed (Dumas and Raymond, 1974) weighing 20-22 kg and averaging 18 months of age. In all experiments, animals were randomly allocated to 12 levels of feed allowance, ranging from 30 to 110 g organic matter (OM) $kg^{-0.75}d^{-1}$ for sorghum stover (SS), 37 to 189 g OM $kg^{-0.75}d^{-1}$ for cowpea haulms (CH), and 30 to 194 g OM $kg^{-0.75}d^{-1}$ for groundnut haulms (GH). Each experiment consisted of an adaptation period of 2 weeks followed by a measurement period of 10 days. Animals were weighed at the beginning and at the end of the measurement periods. The average of these two weights was used to calculate metabolic weight (kg live weight to the power 0.75).

The forages were not chopped, but sorghum stover was cut into three parts of about 60 cm length for accommodation in the feeding troughs. All forages had been bound in bundles of about 4 kg before storage. Every second day of the measurement period, one whole bundle of the offered feed was analyzed for morphological composition. Sorghum stover was cut into three parts (bottom, middle and top) and each of these was divided into stems, leaf sheaths, leaf blades, central leaf nerves and (for the top part) ears (empty of grains). For cowpea and groundnut haulms, three components (bottom stems, other stems and leaves) were distinguished. Feed refusals were kept separate per individual animal. Refusals collected on two consecutive days (day 1 and 2, day 3 and 4, etc.) were mixed for sampling and analysis. The same sampling procedure was followed for faeces. Feed refusals were analyzed for the same morphological fractions as the offered feed, but no distinction was made between bottom, medium and top part of the sorghum plant. Samples of (morphological components of) offered and refused feed, and faeces were ground and analyzed for dry matter (DM), organic matter (OM) and crude protein (CP, 6.25 * N). Chemical analysis was conducted according to AOAC (1975). Amounts of refused OM (ROM) were deducted from offered OM (OOM) to calculate intake of OM (IOM) by individual animals. Similarly, the amount digested (intake of digestible organic matter, IDOM) was estimated by subtracting faecal OM from IOM.

The NLREG program (Sherrod, 1994) was used to fit the model of Zemmelink (1980) for the relation between IOM (y) and OOM (x):

$$y = m\,(1 - \exp(-(px/m)^h))^{1/h} \qquad (1)$$

in which m is the upper limit (asymptote) for y, p is the edible fraction of the forage and h is a shape parameter, such that at the critical level of feeding $x = m/p$, $y = m * (1 - e^{-1})^{1/h}$.

The effect of selective consumption on digestibility of ingested organic matter (DOM, %) was studied by relating DOM to the level of excess feed (ROM) expressed as proportion (%) of OOM, using the model:

$$DOM = a + b * ROM, \qquad (2)$$

in which a represents DOM under conditions of non-selective consumption and b the linear increase in DOM at increasing levels of ROM. The effect of selective consumption on the concentration of CP in the ingested feed (CP, % of IOM) was studied in the same way. Least squares estimates of IDOM as a function of OOM were derived by relating actual IDOM values to IOM predicted by Eq. 1 (IOMpr), using the model:

$$IDOM = IOMpr * (a + b * ROM), \qquad (3a)$$

or

$$IDOM = IOMpr * (a + b * ROMpr), \qquad (3b)$$

where ROMpr is the predicted level of refusal: 100*(OOM-IMOpr)/OOM. In both cases, the parameter a represents again DOM under conditions of non-selective consumption and b the linear increase in DOM at increasing levels of ROM, but in models 3a and 3b the estimates result from least squares models for IDOM instead of DOM itself, as in Eq. 2. Model 3b has the advantage that not only IOM, but also DOM and IDOM are predicted from OOM only and those predicted values for the three variables are mutually consistent at all levels of OOM. Least square estimates of IDOM according to Eq. 3b were used to calculate also the relative value for animal production (VAP) according to Zemmelink (1986):

$$VAP = (IDOM - IDOM_m)/OOM \qquad (4)$$

in which $IDOM_m$ is the amount of digestible organic matter required for maintenance. $IDOM_m$ was assumed to be 24 g $kg^{-0.75}$ d^{-1}. As explained by Zemmelink (1986), optimum levels of feeding, giving maximum animal production per unit of feed available (including both the material eaten and that which is not eaten) may be defined as the level of OOM were VAP reaches its maximum (VAP_{max}).

3.3 Results

Morphological and chemical composition of feeds

Sorghum stover (SS) consisted of 70.6 % stems, 15.5 % leaf sheaths, 12.5 % leaves (subdivided in 6.5 % blades and 6.0 % nerves) and 1.4 % ears (Table 3.1). CH contained 64.2 % stems (including 4.1% bottom stems) and 35.8 % leaves, while these proportions for GH were 50.1 and 49.9 %, respectively. In the case of sorghum stover, leaf blades were highest in CP and stems lowest. The CP of leaf nerves and leaf sheaths was only slightly higher than that of stems. Leaves of the top and medium parts of the plant were higher in CP (9.0-9.4 % in DM) than

Table 3.1. Morphological and chemical composition of sorghum stover, cowpea and groundnut haulms

Forage Components	Proportion (% of OM)		OM[1] (% in DM)		CP (% in DM)	
	Mean	SE	Mean	SE	Mean	SE
Sorghum						
Stems						
Bottom	40.1	0.53	95.3	0.41	2.0	0.09
Medium	20.4	0.20	95.5	0.11	1.5	0.34
Top	10.1	0.03	94.3	0.35	2.1	0.26
Sheaths						
Bottom	3.9	0.68	87.5	0.92	1.8	0.11
Medium	6.5	0.40	87.7	1.36	2.2	0.48
Top	5.1	0.60	87.7	0.93	3.4	0.37
Leaf Blades						
Bottom	1.6	0.29	89.5	0.98	5.3	0.64
Medium	2.9	0.41	88.9	1.61	9.0	0.67
Top	2.0	0.12	88.3	1.99	9.4	0.58
Leaf nerves						
Bottom	1.6	0.32	92.9	0.51	2.4	0.18
Medium	2.9	0.67	95.3	0.58	3.6	0.52
Top	1.5	0.50	95.4	0.77	3.6	0.62
Ears	1.4	0.38	95.3	0.60	5.9	2.70
Whole straw	100	0.76	94.9	0.46	3.9	0.35
Cowpea						
Bottom stems	4.1	0.08	92.9	0.39	8.0	0.22
Other stems	60.1	0.61	93.1	0.34	11.1	0.91
Leaves	35.8	0.44	89.4	0.36	18.1	1.02
Whole straw	100	0.13	91.8	0.77	12.4	1.94
Groundnut						
Bottom stems	19.5	0.25	86.7	0.86	8.9	0.46
Other stems	30.6	0.18	90.8	0.15	9.5	1.01
Leaves	49.9	0.20	86.7	0.37	11.2	0.26
Whole straw	100	0.26	88.1	0.65	9.9	0.45

[1]OM = organic matter (%); CP = crude protein; DM = dry matter; SE= Standard error.

leaves of the bottom part (5.3 %). Similar, but smaller differences were found for the other fractions: 1.5-2.1 % for stems, 1.8-3.4 % for leaf sheaths, and 2.4-3.6 % for nerves. Ears had intermediate CP concentrations (mean value 5.9 %). The fractions with >5 % CP in DM (leaf blades and ears, mean CP content 7.8 %) represented only 7.9 % of the total organic matter. The CP concentration in CH was much higher: 8.0 % for bottom stems, 11.1 % for other stems and 18.1 % for leaves. For GH, these values were 8.9, 9.5 and 11.2 %, respectively.

Intake of organic matter

For all three feeds the parameter p in Equation (1) was estimated at 1. This implies that there were no really inedible portions. For CH and GH this is in agreement with the fact that animals on the lowest levels of feeding ate the full amounts of leaves and stems offered (Fig. 3.1). In the case of SS, however, even animals on extremely low feeding levels refused some of the stems. At feeding levels up to about 100 g OM $kg^{-0.75}$ d^{-1}, animals still ate (nearly) all leaves, but much less than the full amount of stems offered. In the case of SS, intake of stems decreased to less then 20% of the amount offered. This was also true for GH but only at higher levels of feeding when also considerable amounts of leaves were refused. The estimated maximum IOM (m) was much lower for SS (47.3 g $kg^{-0.75}$ d^{-1}) then for CH and GH (85.9 and 81.6 g $kg^{-0.75}$ d^{-1}, respectively) (see Table 3.2). Also the parameter h was lower for SS (1.75) than for CH (2.76) and GH (3.88), implying that when the amount of organic matter offered equalled m, animals refused a larger fraction of the SS (23%) than of CH (15%) and GH(11%) (see also Fig. 3.2).

Concentration of crude protein and digestibility of ingested organic matter

The increasing leaf/stem ratio in the consumed material at higher levels of excess feed led to significant increases in the concentration of CP in the ingested organic matter for CH and GH ($P<0.01$), but not in the case of SS ($P>0.05$) (Table 3.2). Changes in DOM (when this itself was treated as dependent variable) with level of excess were found significant for SS ($P<0.05$) and CH ($P<0.01$) but not for GH ($P>0.05$). When changes in DOM were studied with models where IDOM was the independent variable, estimates of the coefficients of regression of DOM on level of excess feeds were somewhat lower, especially in the case of SS (0.19 as compared to 0.27; see Table 3.2).

Intake of digestible organic matter

Individual IDOM values are plotted against level of feeding (OOM) in Fig. 3.2, together with least squares curves according to the model based on Equation 3b. Animals on SS reached the maintenance level of intake (IDOM = 24 g $kg^{-0.75}d^{-1}$) only at high levels of feeding (87 g OM $kg^{-0.75}d^{-1}$) where nearly half (47%) of the offered feed was refused. At that point VAP=0 (by definition). For CH and GH this point was reached at much lower feeding levels (36 and 39 g OM $kg^{-0.75}d^{-1}$, respectively), where nearly all was eaten (<2% refusal). The estimated maximum Value for Animal Production (VAP_{max}) for SS is very low (0.02) and was only reached at OOM=160 g $kg^{-0.75}d^{-1}$, where only 30% of the offered OM was eaten. VAP_{max} for CH and GH (0.32 and 0.26, respectively) was reached at OOM values of 96 and 91 g $kg^{-0.75}d^{-1}$ where animals left 20 and 16% of the offered OM uneaten (Fig. 3.3). IDOM values for SS, CH and GH at the feeding level where VAP_{max} was reached were 26.8, 54.3 and 48.0 g $kg^{-0.75}d^{-1}$, respectively, or 1.1, 2.3 and 2.0 times maintenance. For CH and GH these levels of IDOM were accompanied by satisfactory levels of CP (ratio intake of CP/IDOM 0.233 and 0.202, respectively). For SS, this value was very low (<0.06) at all levels of feeding.

Table 3.2. Least squares estimates (± standard error) of parameters of the models describing intake of organic matter (IOM), concentration of crude protein (CP) in IOM, digestibility of consumed organic matter (DOM) and intake of digestible organic matter (IDOM).

Parameter	Sorghum stover	Cowpea haulms	Groundnut Haulms
IOM (g $kg^{-0.75}$ d^{-1})[a]			
m	47.3 ± 1.52	85.9 ± 4.04	81.6 ± 3.33
h	1.75 ± 0.16	2.76 ± 1.12	3.88 ± 2.49
rsd	2.53	8.03	8.12
R^2	0.906	0.863	0.856
Probability	<0.001	<0.001	<0.001
CP in IOM (%)[b]			
a_{cp}	2.7 ± 0.16	14.8 ± 0.45	11.7 ± 0.42
b_{cp}	0.006 ± 0.004	0.080 ± 0.014	0.059 ± 0.012
rsd	0.25	0.97	0.89
R^2	0.210	0.763	0.716
Probability	>0.05	<0.01	<0.01
DOM (%)[c]			
a_{dom}	39.5 ± 4.29	66.4 ± 1.30	60.2 ± 2.62
b_{dom}	0.272 ± 0.103	0.172 ±0.041	0.390 ± 0.073
rsd	6.43	2.78	5.56
R^2	0.410	0.644	0.027
Probability	<0.05	<0.01	>0.05
IDOM (g $kg^{-0.75}$ d^{-1})[d]			
a_{idom}	43.3 ± 5.51	68.2 ± 1.92	64.9 ± 2.78
b_{idom}	0.194 ± 0.122	0.138 ± 0.054	-0.050 ± 0.072
rsd	2.72	2.32	3.56
R^2	0.831	0.983	0.949
Probability	>0.05	<0.05	>0.05
IDOM (g $kg^{-0.75}d^{-1}$)[e]			
a_{idom}	43.3 ± 6.78	67.4 ± 6.10	62.6 ± 0.03
b_{idom}	0.191 ± 0.149	0.151 ± 0.165	-
rsd	3.13	6.93	7.82
R^2	0.777	0.850	0.741
Probability	>0.05	>0.05	>0.05

[a] $IOM = m * (1-\exp(-((OOM/m)^h)))^{1/h}$ (model 1 in text); [b] $CP = a_{cp} + b_{cp} * ROM$ (model 2)
[c] $DOM= a_{dom}+ b_{dom} * ROM$ (model 2); [d] $IDOM = IOMpr * (a_{idom} + b_{idom} * ROM)$ (model 3a)
[e] $IDOM = IOMpr * (a_{idom} + b_{idom} * ROMpr)$ (model 3b); OOM: offered organic matter (g $kg^{-0.75}$ d^{-1}); ROM: refused organic matter (% of OOM)

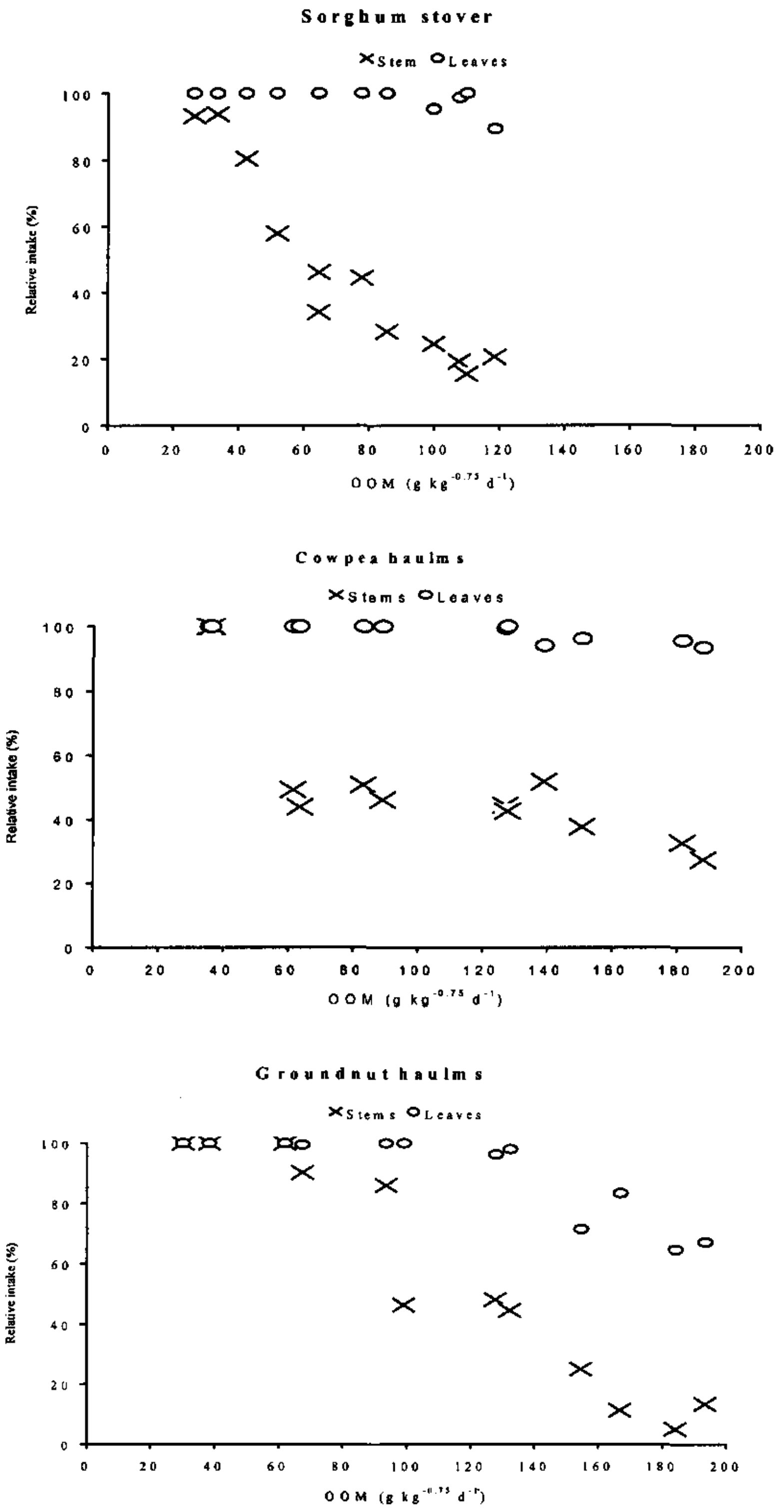

Figure 3.1. Effect of level of feeding (amount of offered organic matter, OOM) on relative intake of leaves and stems (amount consumed expressed as proportion of amount offered)

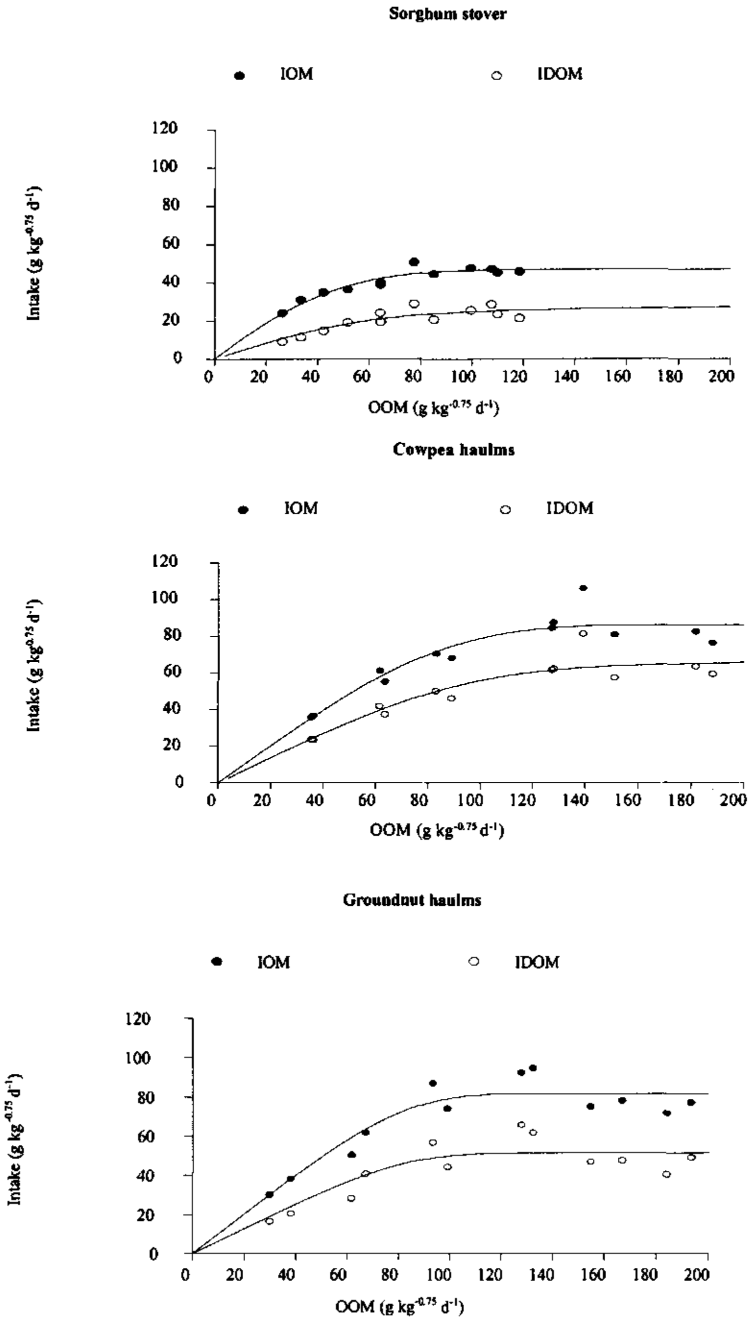

Figure 3.2. Effect of level of feeding (amount of offered organic matter, OOM) on intake of organic matter (IOM) and intake of digestible organic matter (IDOM).

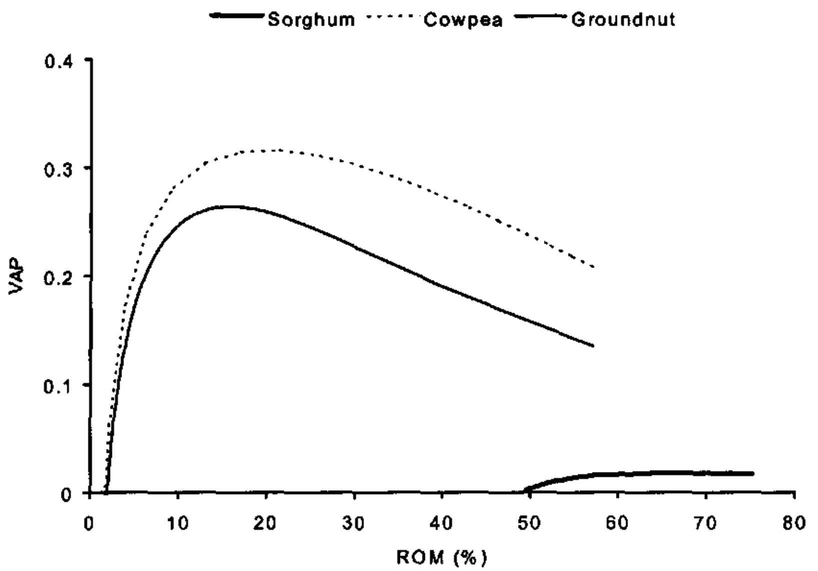

Figure 3.3. Effect of level of excess feeding (proportion of refused organic matter, ROM) on VAP (Value for Animal Production)

3.4 Discussion and conclusions

Feed intake is the first parameter that determines animal production; it is a function of animal, feed and environmental factors. This study examined the effect of selective consumption on intake of crop residues by sheep. Laredo and Minson (1973) showed that, when leaves and stems of grass are separated, animals eat more of the leaves than of the stems. Also when these two fractions are not separated mechanically, animals are effective in selecting leaves. This holds for grasses and legumes, and for sheep as well as cattle (Zemmelink *et al.*, 1972; Zemmelink, 1980; Mbwile and Udén, 1997; Mero and Udén, 1998a,b). For most forages, leaves are more nutritious (higher N content, higher digestibility) than stems (see also Van Soest, 1994). The leaf/stem ratio is therefore an important factor determining the value of forages and care should be taken that appropriate methods are used for collection and storage of feeds in order to minimise loss of leaves (Schiere *et al.*, 1994). Higher leaf fractions not only increase the average quality of the whole forage, but also the fraction that is preferred by the animal.

Selective consumption is a complicating factor in the measurement of intake and digestibility of forages. When forages are chopped, selection of the more nutritious parts becomes more difficult, but even then it may occur, especially in experiments with sheep or goats. Therefore, chopping is traditionally combined with low levels of excess feed to assure that animals do not select (Minson, 1990). Such methods for experimental work do not necessarily lead to valid estimates of the feeding value of coarse heterogeneous forages (Zemmelink, 1980; 1986). Also, under practical farming conditions, such forages are often consumed selectively and provided that sufficient feed is offered, this may lead to significant increases in the amount and quality of material ingested. With many tropical feeds, animal production is only possible because animals select. The degree to which this occurs depends on the morphological and nutritional heterogeneity of the feed concerned and the amount of excess feed given. Experiments should be designed to quantify the effects of selection and to determine optimum degrees of selection, rather than being based on the a priori assumption that selection should be avoided.

The responses for sorghum stover observed in this study, confirm the importance of selective consumption of feeds. When selection was avoided by offering only small amounts of excess feed, intake of digestible organic matter was far below maintenance requirements. Feeding at that level cannot be sustained for any length of time. When larger amounts were offered, sorghum straw, if fed alone, still does not support animal production, but due to increased intake of organic matter as well as digestibility, energy requirements for maintenance can be met. Similar increases in IDOM by increasing feed allowance were obtained in feeding barley straw to goats or sheep (Wahed *et al.*, 1990), finger millet stover to cattle (Subba Rao *et al.*, 1994a), rice straw to cattle (Badurdeen *et al.*, 1994) and pearl millet stover leaves to sheep (Fernàndez-Rivera *et al.*, 1994). The magnitude of improvement was in many cases comparable to that which is usually achieved by treating straw with alkali (Bhargava *et al.*, 1988; Wahed *et al.*, 1990).

The positive effects of selective eating behaviour are fully accepted by biologists and also in grassland science. Animal nutritionists tend to emphasize that allowing animals to select, implies that part of the feed is not eaten and that fewer animals can be fed with a given amount of feed. The present results illustrate, however, that when coarse low quality forages are fed alone, selection is not a waste but a prerequisite for animal production or even for maintaining animals. Allowing selective consumption of basal rations may also reduce the amount of scarce supplements needed to produce a certain amount of animal product, because it is then avoided that a large part of the supplement is used for body maintenance. The disadvantage of the smaller number of animals that can be fed must be weighted against the higher level of energy intake that can be achieved. Leftovers of feed can be used for bedding or composted and used as a source of soil organic matter. Farmers also use feed refused by sheep for feeding donkeys.

The results for cowpea and groundnut haulms are indicative for the high value of these feeds. The amount of OM required to meet energy requirements for maintenance is less than half of the amount of sorghum stover needed for the same purpose and VAP_{max} values are as high or higher than those measured with sheep for tropical grasses, as well as forage legumes by Zemmelink (1986), Bosman *et al.* (1995) and Mero and Udén (1998a,b). The IDOM levels associated with VAP_{max} indicate that these feeds, when fed alone, can support animal production systems with relatively high levels of production per animal (2 times maintenance). Such systems could, however, not utilize the large amount of lower quality crop residues such as sorghum stover produced in the same areas. Experiments in which varying levels of feeding cowpea and groundnut haulms are combined with diverse amounts of sorghum stover can be used to determine optimum combinations of the two classes of feeds.

Chapter 4
Optimising crop residue use at animal level: mixed rations

4.1 Introduction

In Sub-Saharan Africa, livestock account for about 25-35 % of the agricultural domestic product (Winrock International, 1992; Lebbie, 1996; James, 1997; Kyomo, 1997). In the past, livestock was mainly kept in pastoral and agro-pastoral systems. As expansion of crop areas due to population growth has reduced grazing lands, pastoralists have started to grow crops. As a result, the two specialized activities (pastoralism and arable cropping) are both developing towards mixed crop-livestock systems (Winrock International, op. cit.; De Grandi, 1996). This leads to increased competition for forage. To alleviate feed shortage in the dry season, farmers collect crop residues and store them for later use in stall feeding (Camara, 1996; Meuldijk, 1997; Songué, 1997; Onwuka *et al.*, 1997). Sorghum and millet are the major cereal crops in Burkina Faso. Their stover can only cover the energy maintenance requirements of sheep and cattle, if large amounts are offered, allowing selective consumption (Kaasschieter *et al.*, 1994; Kaasschieter and Coulibaly, 1995; Chapter 3). For production, higher quality supplements are needed.

Suitable supplements are residues of legume crops, and industrial by-products. Use of cultivated forages by smallholders is limited, due to shortage of land and high costs of inputs (Dembélé, 1995; James, op. cit.; Songué, op. cit.; Williams *et al.*, 1997). Use of agro-industrial by-products is also low, as they are often exported or not accessible to farmers due to poor infrastructure and marketing, and high prices (Kiéma, 1994; Compaoré, 1991; Kyomo, 1997). Cowpea *(Vigna unguiculata L. Walp.*) and groundnut (*Arachis hypogaea L.*) are important crops in Sub-Saharan Africa (Cook and Crosthwaite, 1994; Ehlers and Hall, 1997; Mortimore *et al.*, 1997; Stalker, 1997), grown either as monoculture or intercropped with cereals. The use of their residues as a supplement to cereal straws in animal production has been described by several authors (Doyle, 1994; Owen and Jayasuriya, 1989; Stares *et al.*, 1992; Joshi *et al.*, 1994; N'Jai, 1998; Kaasschieter *et al.*, 1998). Kaasschieter and co-workers (op. cit.) combined various levels of supplementation with cowpea haulms and cotton seed cake with varying degrees of selection in basal feed (millet stover and rice straw) fed to cattle. The present study aimed at determining the effects of different levels of supplementation with cowpea and groundnut haulms on voluntary intake and digestibility of sorghum stover under varying degrees of selective consumption by sheep. The experiments served as a basis for determination of optimum combinations of sorghum stover and supplements.

4.2 Materials and methods

Forages

Cowpea haulms, groundnut haulms and sorghum (*Sorghum bicolor L. Moench*) stover were used. The cowpea and groundnut haulms included all parts of the plant remaining after the pods had been removed (leaves, roots, stems). All forages originated from farmers' fields in the North Soudanian zone of Burkina Faso, characterised by a single rainy season with 600-800 mm rainfall in the period of May to October. After threshing, the crop residues were collected and sun-dried. Sorghum stover was cut in pieces to match the length of the feeding through (80 cm).

Experimental design

Forty (40) adult Djallonké rams, weighing 20-25 kg were purchased in a local market. During the first 4 weeks (preparation period), animals grazed natural pasture 5 hours per day and received 500 g of cotton seed cake per animal (92.8% dry matter; 35.2 % CP and 70 % digestible organic matter in dry matter). Animals were vaccinated and treated for intestinal parasites in this period. Separate trials of similar design using cowpea and groundnut haulms as supplements were conducted. As only 12 individual feeding places were available, both experiments consisted of 3 periods of 21 days each, comprising 12 days of adaptation and 9 days of measurement. For the first period, 12 animals were randomly selected from the 40 available, for the second period, 12 animals from the remaining 28, and for the third period 12 from the then remaining 16. The animals had free access to water and a mineral block, and were equipped with faeces collection bags. In each trial, 6 levels of feeding sorghum stover (25, 40, 60, 90, 120, and 160 g OM $kg^{-0.75}$ d^{-1}) were combined with 6 levels of supplementation (0, 5, 12.5, 20, 40, and 60 g OM $kg^{-0.75}$ d^{-1}). The 36 treatments were divided among periods as shown in Table 4.1.

Table 4.1. Experimental design

Amount of supplement offered (g $kg^{-0.75}$ d^{-1})	Amount of sorghum stover offered (g $kg^{-0.75}$ d^{-1})					
	25	40	60	90	120	160
0	1*	2	3	1	2	3
5	2	3	1	2	3	1
12.5	3	1	2	3	1	2
20	1	2	3	1	2	3
40	2	3	1	2	3	1
60	3	1	2	3	1	2

* period

Data collection and analysis

Intake of feed was estimated from the amounts offered on days 1 to 7 and refusals weighed on days 2 to 8. The forage was stored in bundles of about 4 kg. Each second day, one bundle of each forage was sampled to determine its morphological composition: proportion (dry weight basis) of stems, leaf sheaths, leaf blades and leaf nerves for sorghum; roots, stems, and leaves for cowpea and groundnut. Also every second day, morphological composition of the combined refusals of that day and the preceding day was determined. From these data, quantities of different components ingested were estimated. Samples of faeces, and morphological components of offered feed and refusals, were analysed for dry matter (DM) by drying to constant weight at 105 °C in a forced air oven. Ash and crude protein (CP) were estimated by AOAC (1984) procedures. In vitro digestibility of morphological components of offered feed was estimated according to Tilley and Tierry (1963).

Non-linear regression models were used to describe the relation of intake of organic matter (IOM) and digestible organic matter (IDOM) with the amounts of stover (x) and supplements (s) offered. The model of Zemmelink (1980) was used to describe intake of unsupplemented stover:

$$y = m * (1 - \exp(-(p*x/m)^h))^{1/h} \quad (1)$$

in which y is the intake of stover, m is the upper limit (asymptote) for y, p is the edible fraction of the stover, and h is a shape parameter, such that $y = m * (1 - \exp(-1))^{1/h}$ at the critical level of feeding (x= m/p); y and x are both expressed in g OM $kg^{-0.75}$ d^{-1}. Supplements offered were fully ingested. To account for the effect of supplementation on intake of stover, m and h were replaced by a function of the amount of supplement (s, also in g OM $kg^{-0.75}$ d^{-1}) offered. For m, two models were applied:

$$m = a_m - b_m * s \quad (2a)$$
$$m = a_m - s - b_m * \exp(-c_m * s) \quad (2b)$$

a_m, b_m and c_m are regression constants. The first model (2a) assumes a linear substitution of stover by supplement. The second model (2b) allows for the possibility that intake of stover increases at low levels of supplementation (s) and decreases at higher levels. For h, an exponential function was used:

$$h = b_h * \exp(-c_h * s) \quad (3)$$

where b_h and c_h are regression constants. Least squares estimates of total intake of digestible organic matter (IDOM) as a function of the amounts of stover and supplement offered, were derived by relating actual IDOM values to x and s, using the model:

$$IDOM = s * d_{su} + y * d_{st} \quad (4a)$$

in which d_{su} and d_{st} are digestibility (g g^{-1}) of the supplement and of the consumed stover, respectively. To allow for the possibility of varying d_{st} due to varying degrees of selective consumption, it was expressed as a function of the fraction of stover refused:

$$d_{st} = a_d + b_d * (x-y)/x \quad (4b)$$

where a_d and b_d are regression constants.

Determination of optimum combinations of feeds

The relationship of IDOM with x and s was used to derive iso-production curves, showing which combinations of x and s give the same IDOM. The least cost criterion was used to determine the optimum combinations of supplements and basal feed for selected production targets.

4.3 Results

Morphological and chemical composition of forages

Sorghum stover used in the first trial contained 64.3 % stems, 20.3 % leaf sheaths, 10.8 % leaf blades, and 4.6 % leaf nerves (Table 4.2). CP content of these morphological fractions varied from 1.8 % for stems to 5.4 % for leaf blades, with intermediate values for leaf sheaths (2.9 %) and leaf nerves (3.0 %), and 3.3 % for the whole stover. Similarly, *in vitro* organic matter digestibility (IVOMD) varied from 40.0 % (leaf nerves) to 58.4 % (leaf blades). The quality of the sorghum stover in the second trial tended to be slightly lower (higher proportion of stem, lower CP and IVOMD). Cowpea haulm was composed of 18.4 % roots, 36.3 % leaves and 45.3 % stems (Table 4.3). CP content of roots (7.7 %) and stems (7.8 %) was much lower than that of leaves (14.6 %). The whole haulm contained 91.1 % OM and 10.0 % CP, with 67.5 % IVOMD. Digestibility varied from 63.9 (stems) to 72.0 % (leaves). Groundnut haulms contained more leaves (48.1 %) than cowpea (Table 4.3). However, CP content and digestibility of leaves and stems were lower. The whole groundnut haulm contained 8.2 % CP, with 61.2 % IVOMD.

Intake

Supplements offered were completely ingested. In trial 1, maximum intake of stover (m) was estimated at 50.7 g OM $kg^{-0.75}$ d^{-1} without supplement. It decreased significantly ($P<0.01$) with level of supplementation (s), at the rate of 0.424 g per g of cowpea haulm offered (Table 4.4). Within the range of supplement given, maximum total intake of organic matter was 85 g $kg^{-0.75}$ d^{-1}, consisting of 60 g OM $kg^{-0.75}$ d^{-1} supplement and 25 g OM $kg^{-0.75}$ d^{-1} stover. In the second trial, maximum intake of stover (m) without supplementation was estimated at 45.7 g OM $kg^{-0.75}$ d^{-1}; in this case m decreased at the rate of 0.413 g per g supplement (groundnut haulm) offered. The shape parameter of the intake curves (h) without supplementation was estimated at 2.735 and 4.365, in the first and second trial, respectively. With supplementation, the value of h decreased. This implies that for higher s, not only maximum intake of stover (m) decreased, but also intake expressed as a fraction of m (y/m) at x = m. This can be interpreted as animals becoming more selective when offered supplement. The refusals consisted mainly of stems (Fig 4.1).

Digestibility

Estimated digestibilities of cowpea and whole stover in the first trial were similar to those obtained in *in vitro* analysis: 69.9 and 46.5 %, respectively, compared to 67.5 and 49.7 %.

Table 4.2. Morphological and chemical composition of sorghum stover

	Stem		Leaf sheath		Leaf blade		Leaf nerve		Whole straw	
	Mean	SE[†]	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Trial 1										
Proportion (% of total DM*)	64.3	4.27	20.3	0.92	10.8	1.25	4.6	0.49	100	-
Composition										
Dry matter (%)	92.3	1.11	93.2	0.84	93.4	0.87	93.5	0.48	93.1	0.39
Organic matter (%DM)	92.4	0.48	91.1	0.27	90.9	0.37	93.9	0.19	92.3	0.48
Crude protein (% DM)	1.8	0.32	2.9	0.22	5.4	0.32	3.0	0.08	3.3	0.42
IVOMD** (%)	51.3	5.79	42.1	3.41	58.4	4.06	40.0	2.96	49.7	3.25
Trial 2										
Proportion (% of total DM)	71.2	0.51	17.8	0.06	7.6	0.01	3.4	0.44	100	-
Composition										
Dry matter (%)	93.2	0.24	92.4	0.14	94.3	1.02	93.4	0.67	93.3	0.33
Organic matter (%DM)	93.3	0.81	91.7	0.76	86.4	0.38	93.4	0.16	91.2	0.89
Crude protein (% DM)	1.7	0.12	1.7	0.18	5.6	0.36	2.7	0.29	2.7	1.15
IVOMD (%)	43.6	3.53	38.5	3.08	54.5	2.09	32.2	3.73	43.1	2.95

* Dry Matter; ** *In Vitro* Organic Matter Digestibility; [†] Standard error

Table 4.3. Morphological and chemical composition of cowpea and groundnut haulms

	Root		Stem		Leaf		Whole hay	
	Mean	SE[ϑ]	Mean	SE	Mean	SE	Mean	SE
Cowpea haulm								
Proportion (% of total DM*)	18.4	1.67	45.3	3.74	36.3	4.73	100	–
Composition								
Dry matter (%)	91.5	1.97	93.4	1.33	93.2	0.75	92.7	0.78
Organic matter (%DM)	92.7	0.36	91.9	1.18	88.5	0.29	91.1	0.75
Crude protein (% DM)	7.7	1.03	7.8	1.07	14.6	1.31	10.0	1.28
IVOMD** (%)	67.3	1.80	63.9	1.15	72.0	1.81	67.5	1.78
Groundnut haulm								
Proportion (% of total DM)	21.7	1.11	30.2	0.65	48.1	1.18	100	-
Composition								
Dry matter (%)	93.1	0.50	92.5	0.14	93.4	0.09	93.0	0.20
Organic matter (%DM)	91.9	0.24	92.6	0.22	87.2	0.32	90.5	0.86
Crude protein (% DM)	8.1	0.35	5.9	0.60	10.7	0.36	8.2	0.74
IVOMD (%)	60.5	1.83	58.4	1.84	64.4	2.67	61.2	1.91

* Dry Matter; ** *In Vitro* Organic Matter Digestibility; [ϑ] Standard error

Estimates from actual intakes and refusals also gave similar results (Table 4.4). Refusals increased with level of feeding of stover and supplement and varied from 0 to 58 %.

Table 4.4. Least squares estimates of models[1] describing intake of stover organic matter (y) and total intake of digestible organic matter (IDOM) for sorghum/cowpea rations (Trial 1) and sorghum/groundnut rations (Trial 2); (± standard errors)

Parameters	Trial 1		Trial 2	
	Predicted[¶]	Actual[♀]	Predicted[¶]	Actual[♀]
Y (g $kg^{-0.75}d^{-1}$)				
a_m	50.7 ± 1.66		45.7 ± 1.85	
b_m	0.424 ± 0.076		0.413 ± 0.082	
b_h	2.735 ± 0.665		4.365 ± 2.226	
c_h	0.0235 ± 0.0065		0.0319 ± 0.0116	
Rsd	4.08		5.21	
R^2	0.897		0.817	
Probability	<0.01		<0.01	
IDOM(g $kg^{-0.75}d^{-1}$)				
d_{su}	0.699 ± 0.021	0.698 ± 0.014	0.621 ± 0.023	0.621 ± 0.010
a_d	0.465 ± 0.036	0.475 ± 0.020	0.398 ± 0.038	0.422 ± 0.013
b_d	0.198 ± 0.070	0.184 ± 0.039	0.167 ± 0.071	0.127 ± 0.025
Rsd	3.21	2.10	3.42	1.41
R^2	0.937	0.974	0.884	0.983
Probability	<0.01	<0.01	<0.01	<0.01

[1] $y = m * (1 - \exp(-(p * x/m)^h))^{1/h}$ (model 1 in text)

in which p (edible fraction; for feeds in present study = 1)

$m = a_m - b_m * s$ (model 2a)

$h = b_h * \exp(-c_h * s)$ (model 3)

$IDOM = s * d_{su} + y * (a_d + b_d * (x-y)/x)$ (model 4a,b),

¶ Estimates when predicted intake of organic matter and related predicted refusal was used in the IDOM models.

♀ Estimates when actual intake of organic matter and actual refusal was used in the IDOM models

Effects of excess feeding and supplementation are interactive: If at a given supplementation level, intake of stover is low because small amounts were offered (low refusals of stover), then digestibility is low; if intake of stover is low because more supplement has been given (high refusals of stover), digestibility of ingested stover is higher. This leads to significant ($P<0.01$) increases in digestibility of ingested stover, i.e. 0.198 percent per percent refusals.

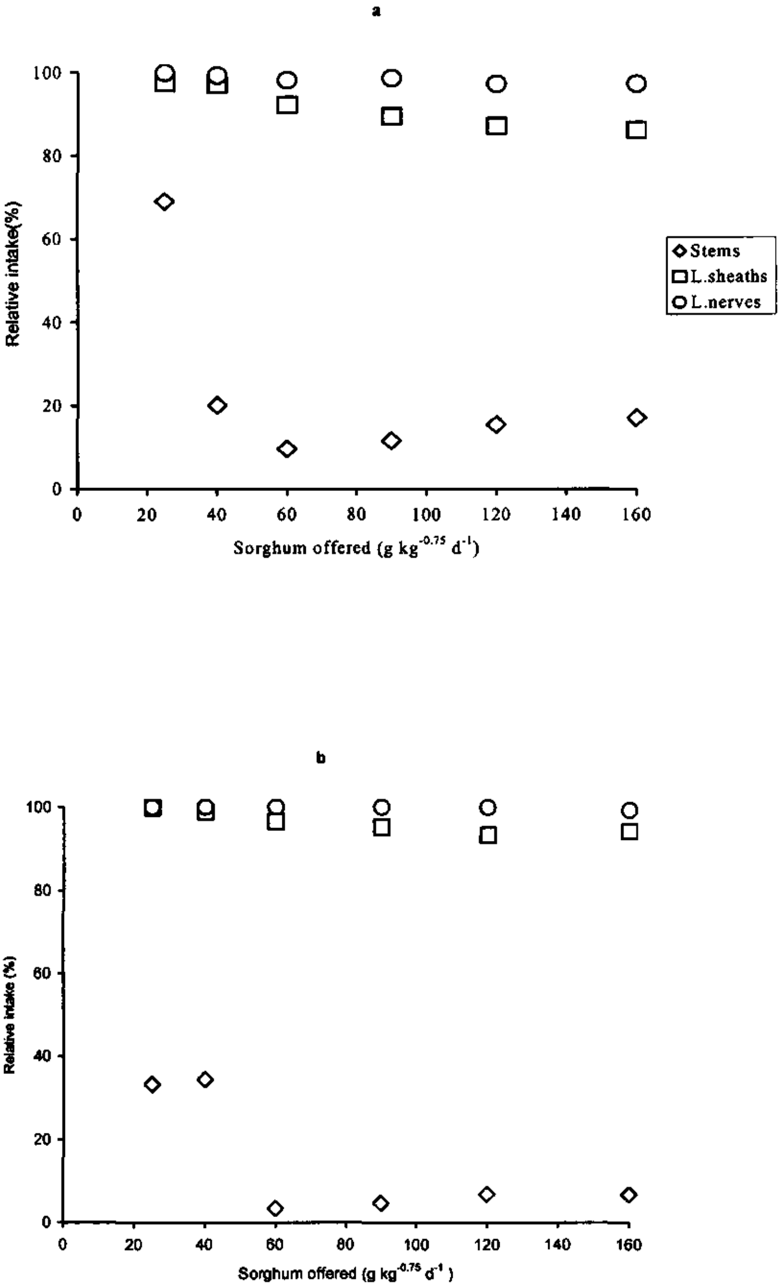

Figure 4.1. Effect of the amount of sorghum stover offered on the relative intake (intake expressed as % of the amount offered) of its components in the first (a) and the second (b) trial.

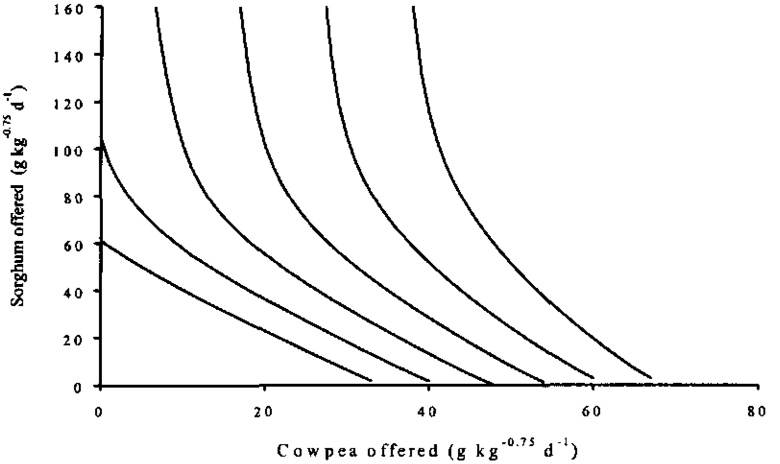

Figure 4.2a. Iso-production curves for sorghum stover and cowpea haulm, i.e. intake of digestible organic matter corresponding to 1, 1.2, 1.4, 1.6, 1.8 and 2 times maintenance (= 24 g kg$^{-0.75}$ d^{-1}), respectively from left to right.

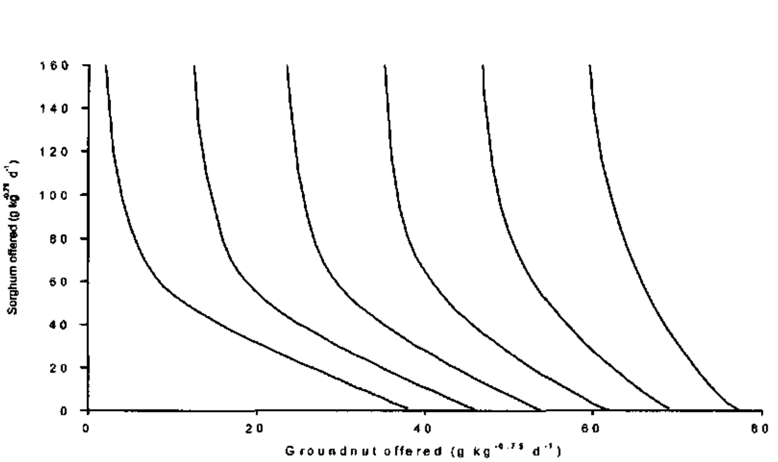

Figure 4.2b. Iso-production curves for sorghum stover and groundnut haulm, i.e. intake of digestible organic matter corresponding to 1, 1.2, 1.4, 1.6, 1.8 and 2 times maintenance (= 24 g kg$^{-0.75}$ d^{-1}), respectively from left to right.

Similar results were observed in the second trial. Digestibility of groundnut haulms and stover were estimated at 62.1 and 39.8 %, respectively. Also here, stover digestibility increased with level of refusals: 0.167 percent unit per percent increase in feed refusal.

Iso-production curves and optimum rations

The iso-production curves from the first trial (Fig. 4.2a) indicate that maintenance (IDOM = 24 g OM $kg^{-0.75}$ d^{-1}) could be reached with 61 g OM $kg^{-0.75}$ d^{-1} sorghum, without cowpea. With this amount of sorghum, about 10, 20, 30, 40 and 50 g of cowpea were needed to reach 1.2, 1.4, 1.6, 1.8 and 2.0 times maintenance, respectively. To reach maintenance with stover alone, this had to be offered in excess, so that animals could select: of the 61 g stover OM $kg^{-0.75}$ d^{-1} offered, 23 % was refused. To reach IDOM equal to 1.2 – 2.0 times maintenance with the amounts of supplement indicated above, even stronger selection of stover was required: up to 58 % refusal to reach 2 times maintenance with 48 g OM $kg^{-0.75}$ d^{-1} of cowpea. To avoid such large refusals of stover, the amount of cowpea in the diet had to be increased. Due to the slightly lower digestibility of stover and groundnut haulms, more supplement and/or higher refusal rates of stover were required to reach the same IDOM levels in trial 2 (Fig. 4.2b). In Burkina Faso, prices of cowpea and groundnut haulms are about 4 times higher (0.4 FF per kg) than of sorghum stover (0.1 FF). The results of Trial 1 indicate that, if the least cost criterion is used and animals are fed at 1.2 times maintenance, 72 g sorghum OM (per kg metabolic weight per day) should be combined with 7 g cowpea haulms. For feeding at 1.6 times maintenance this would be 70 + 26 g, and for 2 times maintenance 54 + 50 g, respectively. Similarly, optimum combinations (g OM $kg^{-0.75}$ d^{-1}) of sorghum stover and groundnut haulms for the same levels of IDOM would be 58 + 24, 51 + 47, and 11 + 78, respectively.

4.4 Discussion

The forages used in this study had lower CP and digestibility than those used in the trials of Chapter 3. Such variation in quality of crop residues may be due to many factors, i.e. genetic characteristics (De Jong and Van Bruchem, 1993; Badve *et al.*, 1994; Doyle, 1994; Singh, 1994; Singh and Schiere, 1995; Subba Rao *et al.*, 1994a), environmental factors (soil characteristics, rainfall) and crop management (level of fertilisation, plant density, stage of maturity at harvest, methods of harvesting, and storage) (Harika and Sharma, 1994; Schiere *et al.*, 1994; Walli *et al.*, 1994a; 1994b). Dembélé (1995), Camara (1996), Kaboré (1996), and Kaasschieter *et al.* (1998) reported CP values ranging from 7.8 to 21.7 % for cowpea and from 5.6 to 29.2 % for groundnut. FAO (1981) reports 3.7-4.3, 14.4, and 9.9 % CP for sorghum stover, cowpea and groundnut haulms, respectively. Manyuchi *et al.* (1997a) reported intermediate values for groundnut haulms (13.1 % CP, 65 % digestibility). Under practical farming conditions the nutritive value is often low, because cowpea and groundnut are grown primarily for their grains. Thus, in practice, residues have often a lower proportion of leaves and lower CP content than those from research stations. The material in the present study was similar to that from practice.

In this study, supplementation with cowpea or groundnut haulm did not result in increased intake of sorghum stover. At the lowest levels of supplementation, stover was substituted by supplement in both trials. The substitution rate was close to 0.4 units of stover per unit supplement. This is consistent with results of Umunna *et al.* (1995) who used *Lablab purpureum* as supplement to oats hay and observed a substitution rate of 0.37. Bosma and Bicaba (1997), who used dried leaves of *Leucaena leucocephala* as supplement to chopped sorghum stover in Burkina Faso, observed a decrease in stover intake when supplement was offered at 10 % and 30 % of the diet, which contained also 30 % concentrate. Chriyaa *et al.* (1997) observed substitution rates of 0.26 to 0.65 when supplementing wheat straw with shrub foliage containing 10.8-13.7 % CP. However, when the protein content of the supplement was high (> 20 %), it tended to stimulate basal roughage intake (Masama *et al.*, 1997; N'Jai, 1998).

Although supplementation suppresses intake of sorghum stover, total intake of organic matter increased. Also ration digestibility increased, because sorghum was replaced by higher quality supplements. In addition, higher levels of supplementation led to increased digestibility of the stover ingested, due to increased selection for leaves. The overall effect was doubling of total intake of digestible organic matter at the highest level of supplementation, compared to feeding stover only. Allowing selective consumption of sorghum stover requires it to be offered in excess of what animals eat. Such a feeding system requires additional labour for transportation and more storage space (Onwuka *et al.*, 1997). However, on a diet of sorghum stover only, animals can only maintain weight when allowed to select. Moreover, when animals are allowed to eat sorghum stover selectively, much smaller amounts of higher quality supplements per animal are needed to reach the same level of IDOM. For example, in the second trial, IDOM equivalent to 1.4 times maintenance required 54 g OM $kg^{-0.75}$ d^{-1} from groundnut haulms, when animals ingested 90 % of the sorghum stover, but only 29 g OM $kg^{-0.75}$ d^{-1} when the amount of offered stover was increased and animals ingested only 50 %. Other suggested possibilities to increase intake of low quality crop residues are physical treatment (chopping, grinding, pelleting), chemical treatment (with sodium hydroxide, urea/ammonia, sodium carbonate), and biological treatment (Doyle, 1994; Schiere *et al.*, op. cit.; Singh and Schiere, op. cit.). However, in Sub-Saharan Africa, these techniques are not economically viable, because of the high costs and low availability of urea and other suitable chemical products, and the variable and often disappointing effects on animal production (Williams *et al.*, 1997). Therefore, animal production should be optimised by optimum utilisation of available products, in combination with taking advantage of the selective eating behaviour of animals. The refusals can be used for bedding (animal comfort and absorption of urine) and/or for soil conservation (Pieri, 1986; Bationo and Mokwunye, 1991; Bationo *et al.*, 1993; Lamers and Bruentrup, 1996; Lamers *et al.*, 1998). In this way, efficient utilization of crop residues for animal production does not compete with maintaining soil fertility. As in this system animals eat mainly leaves, harvesting and storage techniques are required that prevent losses of leaves. Grain legumes tend to shed their leaves early, even before grain maturity. Introduction of dual-purpose legumes may reduce these losses (Ehlers and Hall, 1997; Stalker, 1997), which improves their value as ruminant feed.

The models describing the effect of supplementation on voluntary intake include many parameters; this reflects the complexity of animal intake behaviour in response to feed heterogeneity. The basic exponential model for the relationship between feed intake and amount offered (Eq. 1) for single feeds can easily be expanded to include the effect of supplementation on intake of straw. In the present study, maximum intake of straw (m), i.e. intake at high levels of excess feed, decreased linearly with the amount of supplement given (s), while the shape parameter of the model (h) was best described by an exponential function of s. However, other models to describe the relationship of m and h with s can also be fitted easily.

The iso-production curves that were derived from these models give all possible combinations of amounts of sorghum stover and cowpea or groundnut haulms on offer for selected values of IDOM. The curves can be used to select optimum combinations depending on criteria such as objectives of feeding, availability of different forages and their prices.

4.5 Conclusion

The results of this study indicate that excess feeding of heterogeneous basal feeds, allowing selective consumption of these materials, combined with supplementation, can be an appropriate strategy for maximizing benefits from feeding crop residues. Experiments in which diverse amounts of both basal feed (e.g. sorghum straw) and supplements (e.g. cowpea or groundnut haulms) are offered can be used to derive iso-production curves. Combined with information about prices of basal feeds and supplements, these curves can be used to derive optimum feeding levels for a defined level of production.

Chapter 5

Allocation of crop residues at farm level in Sub-Saharan crop-livestock systems: A case study in Zoundwéogo province

5.1 Introduction

Agricultural systems in semi-arid West Africa are characterised by limited endowment with natural resources and low external input. Expansion of the crop area combined with judicious use of shifting cultivation, fallowing and pastoralism has up to recently provided sufficient staple food for the population, while at the same time maintaining the resource base. In many areas, this balance comes under increasing pressure, due to land shortage and the associated decline in resource quality, triggered, by among other factors rapid population increases (Meertens *et al.*, 1996; Williams *et al.*, 1998). Among the production systems currently considered promising, mixed crop-livestock farming occupies a prominent place (Beets, 1990; Reijntjes *et al.*, 1992; De Grandi, 1996; Renard, 1997; Breman and Sissoko, 1998). In most semi-arid regions, crops and livestock have always been complementary through exchange of food, crop by-products, manure, draught power, capital, etc. Very often, these interactions take place, however, between different specialised systems, i.e. pastoralism and arable farming. The current trend is integration of crop and livestock components in the same production unit, to maintain/improve the biological capacity of the whole system through integrated management of all on-farm resources (Reijntjes *et al.*, op.cit.).

Optimum use of crop residues is recognised as a key factor in this integration (Winrock International, 1992; Latham, 1997), but is also faced with limitations. Firstly, in most of the semi-arid areas of West Africa, the amounts of crop residues produced appear to be too low to cover all system needs such as animal feed, soil amendments, fuel, building materials, etc. (De Leeuw, 1997). Secondly, socio-economic constraints limit the possibilities to fully benefit from technologies developed to improve the quality of crop residues for ruminant feeding (Schiere, 1995). Egan (1997) pointed out that the different alternative uses appear more often conflicting than complementary. At the same time, few alternatives exist either for soil amendment or animal feeding for the smallholders in these areas (Powell *et al.*, 1995). Recent studies in Niger have shown that farmers try to maximise the benefits from crop residues in the system through multipurpose use. Animals use often the more nutritious parts and the remainder, combined with manure is used for soil fertilisation; and when the residues are left in the field, bare plots are given priority (Lamers and Bruentrup, 1996; Lamers *et al.*, 1998). The present study was conducted to evaluate crop residue availability in Burkina Faso and to identify factors determining their allocation to different alternative uses at farm and household levels.

5.2 Methods

The study area

The study was conducted in Zoundwéogo province of Burkina Faso, located in the North-Soudanian climatic zone (Fig. 5.1) between 11° and 12° northern latitude. Total annual rainfall is variable with an average for the last 20 years of 813 mm. The average daily temperature varies from 23 to 41°C. The total area (345 300 ha) is composed of 54 % grazing lands, 29 % crop lands, 10 % protected forests (National park), and 7 % residential areas, roads and rivers. In 1993, 80 % of the potential cropland was actually cultivated (MARA, 1996). The natural vegetation consists predominantly of savannah. The high population density, estimated at 54 inhabitants/km^2, leads to over-exploitation of the land and related resources (Sahelconsult, 1991; De Graaff, 1996).

Site selection

A preliminary survey was held to identify suitable criteria for selection of the study samples. Secondary data were first reviewed, and interviews were conducted with the local offices of rural development and extension organisations/services (*Services Provincial des Ressources Animales, de l'Agriculture, de l'Organisation et de la Formation Professionnelle; Projet de Développement Intégré du Zoundwéogo*). Analysis of this information resulted in identification of three main agro-pastoral zones, varying with regard to management of crop residues, because of differences in land tenure and in ethnic groups: (1) the Mossi zone in the north-west of the province; (2) the Bissa zone in the south-east and (3) the North East zone, where land use is planned by the Office National de l'Aménagement du Territoire (ONAT). In this latter zone, the population is composed of migrants (spontaneous or stimulated by government schemes), settled between 1974 and 1976, after the zone had been cleared of river blindness. The preliminary survey also indicated that management of crop residues seems to be influenced by the intensity of extension activities in these zones. Taking this information and financial constraints into account, 2 villages per zone were selected, one where extension organisations/services were actively present, and one where they were not present.

Village meetings

In each of the 6 villages, a semi-detailed inquiry was conducted with different socio-professional groups (livestock keepers, youth, women, animal traders, administrative and cultural leaders of the villages). Interviews were conducted with representatives of each of these groups. The objective of these interviews was to identify the main criteria influencing management of crop residues at village level, while the objectives and methods of the study were explained to all participants.

In-depth survey

An in-depth survey was conducted with 60 households, i.e. 10 households per village, randomly selected from the heads of households that attended the meetings described above. This survey consisted of detailed inquiries and field measurements. The questions focused on identification of household resources: number of persons per age class, number of livestock per species, and ownership of means of transport.

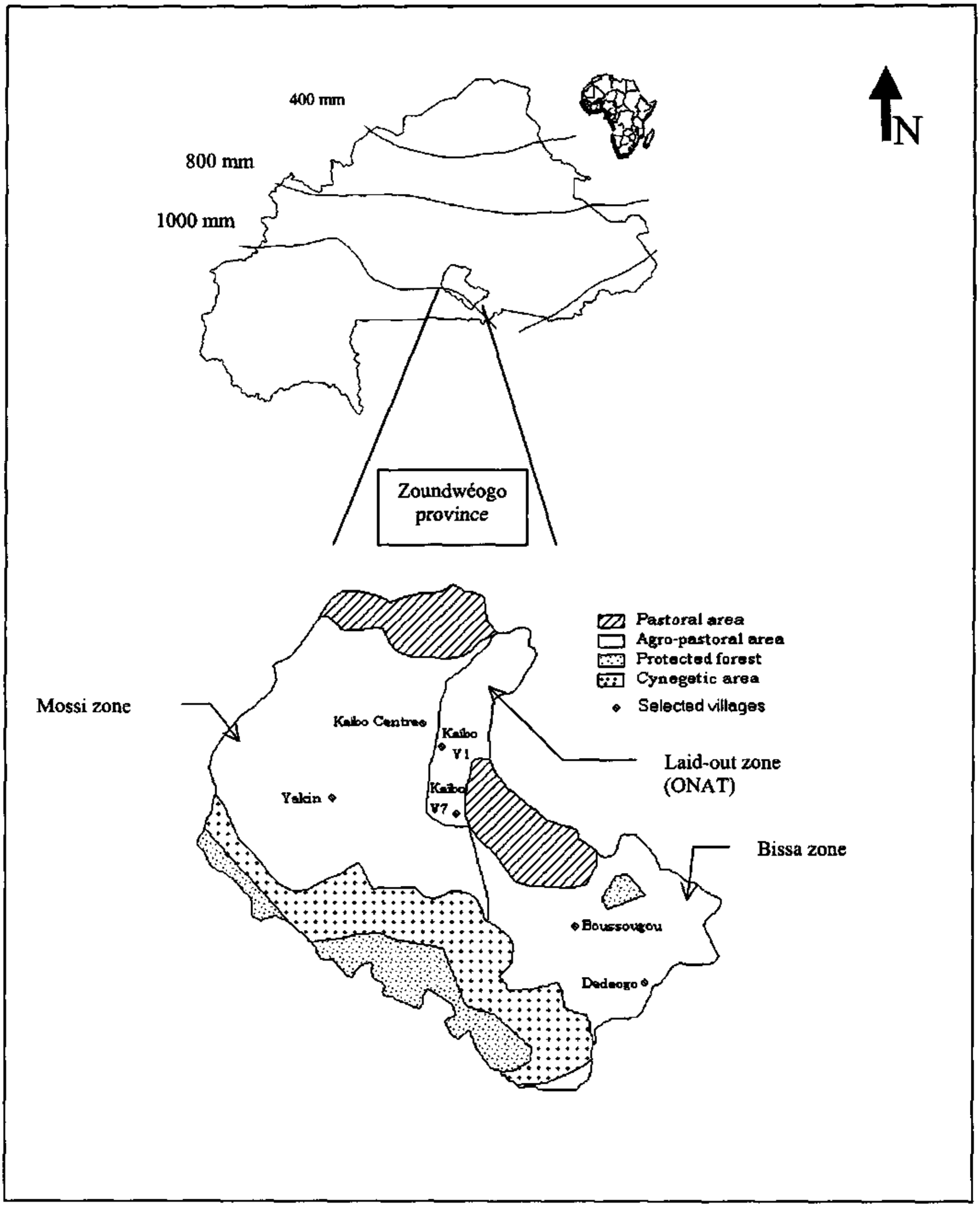

Figure 5.1: Location of Zoundwéogo province and the selected villages

The allocation of crop residues to alternative uses and the constraints encountered in crop residue management were also recorded, as well as the number of persons per age class involved and the time spent in residue collection and storage. Field measurements consisted of the identification of the different fields and assigning them to 3 classes according to their location, i.e. distance from the homestead: homestead (≤ 1 km), village (> 1 - 3 km) and bush fields (> 3 km). The head of the household estimated the area of each field. In the sowing period, three plots of 25 m^2 each per crop and per household were laid-out. The grains and stover/haulms of these plots were harvested separately, and their average yields used to estimate the total amounts of crop residues produced per crop and per household. The amounts of crop residues collected and stored were estimated at the end of the harvest period, after the residues had been transferred to the homestead. The number of bundles per type of residue (stover of millet and sorghum and haulms of cowpea and groundnut) was counted per household. The average weight per bundle of each type of residue was estimated by weighing 10 bundles, each randomly picked from the stocks. Additional observations on the different methods used in residue collection, transport, processing and utilisation were also recorded.

Data analysis

Analysis of variance using SPSS 7.5 was applied to test the differences between the different groups of households with regard to quantitative variables, i.e. crop areas, livestock numbers, family size and labour force, and amounts of crop residues produced and collected. In a first round of analyses, no significant difference was observed between households, when they were grouped per village, per zone or per ethnic group. Therefore, in a second round, households were classified according to ownership of a donkey cart, as in the village meetings it appeared that cart ownership was the main factor influencing the management of crop residues at farm household level. The relations between the amounts of crop residues collected and livestock owned by households was analysed by comparing Spearman correlation coefficients. The relative importance of livestock species and crop areas per class of households, and of various uses of collected crop residues was also analysed.

5.3 Results

Household resources

Social characteristics for households with and without cart were similar. Average household size was 15.1, 17.2 and 14.4 persons for all households and households with and without cart, respectively, corresponding to 8.4, 9.0 and 7.7 labour units (Table 5.1). Labour availability was not significantly different between households with and without cart. The dependence ratio, i.e. the ratio of total number of persons of the household and labour force, was 1.8, 1.9 and 2.7 for all households and households with and without cart, respectively. Households cultivated on average 6.5 ha of land, allocated, in decreasing order of importance, to sorghum (*Sorghum bicolor [L.] Moench*), millet (*Pennisetum glaucum [L.] R.Br.*), cowpea (*Vigna unguiculata [L.] Walp.*), groundnut (*Arachis hypogaea L.*), cotton (*Gossypium spp.*), maize (*Zea mays*) and others (hibiscus and okra, and potato). Most of the households (70 %) cultivated 0.1 to 3 ha sorghum (Table 5.2).

More households with cart grew > 3 ha sorghum than households without (47.1 % vs. 21 %). Almost half of the households with cart did not grow millet, but most of those who did, cultivated > 1.2 ha, while one third of the households without cart had intermediate areas of millet (0.1-1.2 ha). About one third of the households without cart did not grow cowpea and groundnut.

Table 5.1. Household resources

Characteristic	Household class					
	With cart (n = 17)		Without cart (n = 43)		All households (n = 60)	
	mean	sd	mean	sd	mean	sd
Composition						
Household size	17.2	11.40	14.4	10.10	15.1	10.46
Labour units*	9.0	7.70	7.7	6.11	8.4	6.52
Dependence ratio**	1.9		1.9		1.8	
Cultivated land (ha)						
Sorghum	3.03	1.87	2.56	2.41	2.69	2.26
Millet	1.15	1.66	1.19	1.69	1.18	1.67
Cotton	0.56	0.44	0.47	0.62	0.50	0.57
Maize	0.55	0.43	0.46	0.61	0.49	0.57
Cowpea	0.48	0.36	0.76	0.94	0.68	0.83
Groundnut	0.37	0.48	0.67	0.69	0.59	0.65
Others[&]	0.43	0.34	0.36	0.48	0.38	0.44
Farm area	6.54	3.09	6.43	4.86	6.52	4.41
Farm area/capita	0.38		0.45		0.43	
Farm area/labour unit	0.72		0.83		0.78	
Livestock (head)						
Cattle	3.18	2.10	1.93	2.43	2.27	2.39
Sheep	11.12	10.02	9.41	12.11	9.88	11.84
Goat	7.88	7.70	8.64	13.17	8.43	11.51
Donkey	2.71	1.59	1.25	2.33	1.66	2.15

* Each adult (15-64 years) represents a human labour unit; persons between 7 and 15 years are weighted according to the ratio *(age-7)/8;* children under 7 years and persons > 64 are ignored (FAO, 1986); ** The number of consumption units (household size) per labour unit
[&] Hibiscus, okra, potato.

Livestock owned included on average 2.27 cattle, 9.88 sheep, 8.43 goats and 1.66 donkeys (Table 5.1). Differences between the two household types were not significant. Most households with a cart (52.9 %) owned more than 2 head of cattle (Table 5.3). Of the households without cart, 38.6 % did not own cattle and 40.9 % 1-2 head. Most cattle were entrusted to herdsmen in the dry season and used as draught animals in the rainy season. Only 5.9 and 18.2 % of the households with cart and without, respectively, did not own sheep, while 54 % of all households owned 1-10 sheep. About two thirds of both groups of households owned goats. Because donkey carts are used in the area, all households owning a cart owned also at least one donkey. Also two thirds of the households without a cart owned 1 to 2 donkeys; these are used to carry people/materials on their back or to pull a borrowed cart.

Table 5.2. Distribution of households (% of total number per class) according to area of various crops.

	Area (ha)	Household class		
		With cart (n= 17)	Without cart (n = 43)	All households (n = 60)
Sorghum	0	0	2.3	1.7
	0.1 - 3	52.9	76.7	70.0
	> 3	47.1	21.0	28.3
Millet	0	52.9	37.2	41.7
	0.1- 1.2	5.9	34.9	26.7
	> 1.2	41.2	27.9	31.6
Maize	0	11.8	22.7	19.7
	0.1- 0.5	58.8	52.3	53.9
	> 0.5	29.4	25.0	26.4
Cowpea	0	23.5	30.2	28.3
	0.1- 0.5	53.0	34.9	40.1
	> 0.5	23.5	34.9	31.6
Groundnut	0	52.9	27.9	35.0
	0.1- 0.5	23.5	37.2	33.4
	> 0.5	23.6	34.9	31.6
Cotton	0	11.8	22.7	19.7
	0.1- 0.5	35.3	47.8	44.1
	> 0.5	52.9	29.5	36.2

Table 5.3. Distribution of households (% of total number per class) according to number of animals kept.

	Size class (head)	Household class		
		With cart (n = 17)	Without cart (n = 43)	All households (n = 60)
Cattle	0	11.8	38.6	31.1
	1 - 2	35.3	40.9	39.4
	> 2	52.9	20.5	29.5
Sheep	0	5.9	18.2	14.8
	1 - 10	52.9	54.6	54.0
	> 10	41.2	27.2	31.2
Goat	0	23.5	36.4	32.8
	1 - 8	41.2	29.7	32.7
	> 8	35.3	33.9	34.5
Donkey	0	0	34.1	24.8
	1 - 2	70.6	64.1	67.3
	> 2	29.4	1.8	7.9

Factors influencing crop residue management

Based on the information from the different villages, a number of factors influencing the management of crop residues could be identified. The first factor was the strong competition between grazing animals and farmers wanting to collect and store residues. Herds of pastoralists and animals owned by farmers were allowed to graze fields after the grain had been harvested and transported to the homestead. Typically, several herds are herded in the same landscape unit and moved from one field to another, following the harvesting sequence. Hence, the harvest of all fields in a landscape unit had to be synchronised to avoid destruction of unharvested crops by animals. Amounts of residues collected were often small (especially in the case of cereals) because most labour is needed for grain harvest and transport. If not collected, the residues are eaten (and partly damaged) by grazing animals. As a result, the quantities of sorghum and millet residues collected may be determined by the short period available for collection, rather than by household needs. The quality of the residues also influenced their management. Farmers try to collect legume haulms before deterioration by moisture or drought which causes leaf shedding. This results in year-to-year and spatial variability in collectable quantities of haulms, due to variability in rainfall. The local criteria used to judge quality are colour (green is best) and the proportion of leaves (the leafier the better). Also for cereal stovers, the proportion of leaves is considered very important, so that the residues with a high proportion of leaves are collected first. Other factors, such as labour availability, location of the fields, livestock production system and cart ownership also influence the amounts of crop residues collected. Residues of fields less than 1 km from the homestead were collected more often than of more distant fields. When farmers entrust their animals to herdsmen or take out manure contracts, some residues are left in the fields, while farmers aiming at semi-intensive feeding or fattening attach more value to collection of residues, especially those of legumes. Cart ownership is considered an advantage in the management of crop residues, because it allows rapid transportation.

Table 5.4. Quantities of crop residues produced and collected (mean per household)

	Household class					
	With cart (n = 17)		Without cart (n = 43)		All households (n = 60)	
	mean	sd	mean	sd	mean	sd
Quantity produced (t)						
Sorghum	9.09	5.61	7.68	7.23	8.04	6.78
Millet	3.45	4.98	3.57	5.07	3.54	5.01
Cowpea	0.72	0.54	1.14	1.41	1.02	1.24
Groundnut	0.67	0.86	1.21	1.24	1.06	1.17
Quantity collected (t)						
Sorghum	2.96	1.56	2.74	1.68	2.81	1.64
Millet	0.22	0.18	0.24	0.13	0.23	0.14
Cowpea	0.62*	0.15	0.27*	0.09	0.37	0.12
Groundnut	0.58	0.19	0.49	0.14	0.55	0.15
Proportion collected (%)						
Sorghum	33		36		35	
Millet	6		7		6	
Cowpea	86		24		36	
Groundnut	87		40		52	
Labour used**	4.54	3.80	5.98	5.25	4.91	4.72

* Difference significant ($P<0.05$); ** labour used (in man-days) to store a ton of residues.

Availability of crop residues at farm level

The quantities of crop residues produced were not significantly different ($P<0.05$) between households with and without cart, with an average of 12.8 t of cereal stover (sorghum, millet and maize) and 2.1 t of legume haulms per household (Table 5.4). The quantities collected were 2.8 t for sorghum and 0.2 t for millet, i.e. 35 and 6 % of the quantities produced, respectively. Households without cart tended to produce more cowpea and groundnut haulms than households with cart, although this difference was not significant. However, households with cart collected larger quantities, especially of cowpea residues ($P< 0.05$). For groundnut haulms, the quantities collected were similar. Differences in collected quantities of residues of the different crops (6-35 % for stover and 36-52 % for haulms) may be explained by the higher quality of residues of legumes and method and sequence of harvesting. Maize has the shortest crop cycle and was harvested early, when it was still raining, and the residues were not collected because of lack of a suitable storage place. As maize is usually grown near the homestead, some of the residues may be used to supplement animals after they return from grazing on the range. No maize residues were found in the homestead at the time when all crops had been harvested and the residues stored. Cowpea and groundnut were harvested before sorghum and millet. Very often, part of the groundnut crop was transported to the homestead, where haulms and kernels were separated, while the pods of cowpea were harvested in the field and the haulms were collected later. This partly explains why the collected amount of groundnut residues was similar for households with and without a cart. Sorghum and millet stover were often conserved in the field on trees or protected with thorny branches till the end of the harvesting period and later transported to the homestead. Households without cart often borrow a cart after completion of the harvest to collect the cereal residues, while legume haulms had to be picked while harvesting. Leaving those in the field for any length of time is very risky because they would quickly deteriorate after an (off-season) rainstorm and/or be eaten or damaged by roaming animals. The data indicate that the donkey cart is especially used to transport larger quantities of the higher quality cowpea residues.

It appears that households with a higher number of labour units owned more sheep, goats and donkeys (Table 5.5). The amounts of sorghum stover, cowpea and groundnut haulms collected were significantly positively correlated to the number of sheep. Also, the amount of groundnut haulms collected was positively correlated to the number of labour units, the location of the field and the number of sheep, but negatively correlated to the number of cattle.

Allocation of crop residues

Most of the collected residues (80 %) were stored on top of a *hangar* (a traditional shed built from wood and straw), with legume haulms usually placed between layers of cereal stovers to protect them from sunshine. Other storage structures were *fenil* (special structure built for storage of hay and straw). Residues were also stored on roofs and in trees on the homestead or nearby; 8 % of the households stored residues on the roof, 7 % in trees and 5 % in fenil. Collected crop residues were allocated to 4 types of uses: animal feeding, building materials, fuel and sale. An average of 70 % was used for animal feeding, 20 % as building materials (beds, doormats, fences, and crafts), 8 % as a source of energy for cooking and 2 % was sold (Table 5.6).

Crop residues used for animal feeding were allocated to different categories of animals. Cereal stover was mostly used for cattle, sheep and donkeys and less for goats, while cowpea and groundnut residues were given to productive animals, i.e. rams selected for fattening and females directly after parturition. Village herds as well as pastoralists' herds graze residues left in the field during the dry season. Coarse materials, those contamined with animal urine and faeces or damaged by termites were often ploughed in (47 % of households) or redistributed to bare parts of the field (37 %), or burned during field preparation (16 %).

Table 5.5. Correlation (Spearman correlation coefficients) between availability of labour, location of fields, number of animals owned and quantities of crop residues collected.

	Availability of labour[a]	Location of the field (class)[b]	Number of animals owned				Quantities (t) of crop residues collected			
			Cattle	Sheep	Goat	Donkey	Sorghum	Millet	Cowpea	Groundnut
Number of animals owned										
Cattle	-0.013	-	1							
Sheep	0.50**	-	-0.20	1						
Goat	0.51**	-	-0.047	0.52**	1					
Donkey	0.49**	-	0.090	0.30*	0.24	1				
Quantity of crop residues collected										
Sorghum	0.17	0.26*	-0.096	0.34**	0.037	0.24	1			
Millet	0.021	0.14	0.055	0.11	-0.098	0.087	0.063	1		
Cowpea	0.012	0.27*	0.036	0.37**	0.21	0.013	0.25	0.052	1	
Groundnut	0.35**	0.41**	-0.37**	0.29*	0.004	0.14	0.13	0.13	0.34**	1

* Significant ($P<0.05$); ** Highly significant ($P<0.01$); [a] Number of labour units (for definition see Table 3.1); [b] 0: ≤ 1 km and 1: > 1 km

Table 5.6. Proportion of collected stover (%) allocated to the different alternative uses and proportion (%) of households classified according to use of residues left in the field.

Alternative uses	Household class		
	With cart (n = 17)	Without cart (n = 43)	All households (n = 60)
Use of collected stovers			
Animal feeding	82	65	70
Construction	6	23	20
Energy	12	9	8
Sale	0	3	2
Use of field residues*			
Incorporation in soil	53	44	47
Mulching of bare plots	41	35	37
Burnt	6	21	16

* Percentage of households using the indicated practices

5.4 Discussion and conclusions

Results from interviews and village meetings suggested that competition with stubble grazing, labour availability and lack of a cart are factors limiting the quantities of crop residues collected. However, this was not confirmed by the analysis of data from the household survey. Quantities of groundnut haulms collected and stored were significantly related to labour availability. The number of labour units did not significantly affect the quantities of cereal residues collected, possibly because of the possibility for pre-storage in the field. Households without cart may borrow one for transport of cereal stover after the harvest period. However, households owning a cart collected more high-quality cowpea haulms. The type and number of animals owned was related to the quantity and type of crop residues collected. Crop residues represent the main source of feed for a large part of the ruminants in the area during the dry season. The low quality of cereal stovers is partially compensated by farmers through two types of selection: the leafiest residues are preferentially collected, and the highest quality feeds (legume haulms) are used for lactating animals and fattening. The residues used for fuel and construction are generally coarse materials, which can not be used by animals. Stover given to animals is not chopped or milled so that the animals can select the best components (Kaasschieter *et al.*, 1994; Schiere, 1995). In regions where feed shortage in the dry season is more pronounced, i.e. Sahelian and the Sub-Sahelian zones, a larger proportion of residues is stored (Zagré, 1988), and chopping or treatment with urea might be more important.

On average 14.9 t crop residues are produced per household, i.e. 12.8 t stovers and 2.1 t haulms. They are used for animal feeding (grazing or stall-feeding), soil improvement, construction, domestic energy and sometimes sale. Theoretically, at least 2 t organic matter per ha would be required annually to replace the organic matter decomposed in the soil top layer

(Pieri, 1989; Bationo and Mokwunye, 1991; Somda, 1994; De Ridder and van Keulen, 1990). Even complete return of residues can hardly cover that requirement, and at the same time part of the residues is used to feed livestock. The real situation is that whether left in the field or collected and stored, most of the crop residues are not returned to the field. The allocation of the amounts collected to the different uses is largely determined by the quality of the residues. Highest quality residues are given to animals and coarse residues used for other purposes. The increasing herd (higher demand for feed) and the reduced pasture area (lower supply) result in increasing shortage of forage and leads to increased interest in collection and storage of crop residues for utilisation in stall feeding. This is especially true for legumes (Sankara, 1997). The utilisation of crop residues as ruminant feed is thus expected to increase.

Many efforts have been made in developing countries to improve the use of crop residues in ruminant feeding. Saadullah and Siriwardene (1993) reported that in the period 1980-1988, 14 international workshops and seminars on feeding crop residues were organised, which focused mostly on physical and/or chemical treatment of straw. Recently, the workshop organised in Niger by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, Renard, 1997) pointed out that adoption of improved technologies by farmers is low, coining as probable reasons their socio-economic conditions (limited equipment, low income, labour shortage, etc.). The results of this study underline the complexity of the factors influencing the use of crop residues. Socio-economic factors such as availability of labour and equipment, and herdsmen-farmers relationships appear less decisive than the number and type of livestock owned. Increasing human and livestock population will stimulate private utilisation of crop residues. Therefore, it is important to investigate how and to what extent optimal allocation of crop residues can support household needs in an integrated crop-livestock farming perspective.

Chapter 6
Optimising crop residue utilisation: I. Scope and methodology

6.1 Introduction

Agriculture contributes 30 % to GDP (Gross Domestic Product) and 60 % to export earnings of the Sub-Saharan African countries (De Grandi, 1996), while employing 90 % of the active population. The low labour productivity can (at least partly) be attributed to erratic rainfall, low soil fertility, low level of mechanisation, and restricted use of inputs due to low availability and high cost. The rapid increase in human population and the associated increase in livestock population has led to rapid degradation of land through overgrazing and reduced periods of fallow (Zoungrana, 1991; Kessler and Breman, 1995; Stroosnijder, 1996). To mitigate the risks of crop failure, arable farmers have started to keep livestock as a source of cash income, manure, and energy (traction for transport and tillage). On the other hand, pastoralists have started to grow crops to increase household food security, which is no longer guaranteed by the proceeds from their herds. Thus, both specialised systems are shifting towards mixed crop-livestock farming, especially in the sub-humid zones where the greatest advantages of integrating the two components can be expected (FAO, 1983; De Grandi, op. cit.). Some of the assumed advantages are reduced nutrient losses and adaptation to farmers' socio-economic conditions, i.e. higher cash flow and lower external inputs (Beets, 1990; Bationo and Mokwunye, 1991). The sustainability of the integrated system depends on the appropriateness of the technologies with respect to realisation of agro-technical, socio-economic and environmental objectives of farm households and policy makers. One of the criteria used to evaluate sustainability of agricultural systems is efficiency of resource utilisation, expressed as output of useful product per unit of scarce resources (input). Integration of arable farming and animal husbandry that allows efficient nutrient cycling, has been identified as a promising technique for sustainable land use (Winrock, 1992; ILRI, 1997).

Crop residues, which constitute the link between crops, livestock and soil, can be used for many different purposes such as soil improvement (either by direct incorporation or mulching), livestock feeding, protection of young plants from sun and wind erosion, construction of fences and roofs, for doormats, as fuel, and for sale. After burning, the ash may be used as fertiliser. Especially their role in animal feeding and in maintaining soil fertility in Sub-Saharan Africa is well-recognised (Jackson, 1994; Somda, 1994; Powell and Williams, 1995). The nutritive value of crop residues is often low, partly due to poor storage and conservation techniques. Optimal utilisation may be hampered by the labour required for collection, transport, storage and processing. The contribution of crop residues to nutrient cycling depends on the quantities available and their quality, the degree of utilisation by animals and the quantities of nutrients returned, directly or via animal manure, to the soil. Utilisation by animals is affected by feeding methods (allowance for selection). Earlier studies which focused on the role of crop residues as ruminant feed (Fernández-Rivera *et al.*, 1994; Kaasschieter *et al.*, 1994; Kaboré 1996) or as soil amendment, alone or in combination with manure (De Ridder and van Keulen, 1990; Bationo and Mockwunye, op. cit.; Hien *et al.*, 1994; Jackson (op.cit.); Somda (op.cit.); Lompo *et al.*, 1995; Powell *et al.*, 1996) indicate the need for more detailed studies describing the processes at the plant-animal-soil interfaces. Farm surveys (Camara, 1996; Williams *et al.*, 1997) indicate that crop residues contribute significantly to the realisation of several farmers' objectives, i.e. stabilising/increasing food security and income with a minimum of labour and capital. This study investigated how crop residues can best be used in mixed crop-livestock farming systems, taking into account their possible different alternative uses.

6.2 Technique of analysis

The basic technique used is linear programming, which is well recognised as a powerful tool for analysis of resource allocation at farm level (Van Keulen, 1993; Sharifi and Van Keulen, 1994; Van Rheenen, 1995; Van de Ven, 1996). Breman (1995b) discusses 26 models that have been developed to analyse options for sustainable mixed crop-livestock systems. Among these, land use planning models for Mali (Veeneklaas, 1990; Sissoko *et al.*, 1995) applying linear programming, illustrate the potential of this technique for farming systems analysis in Sahelian regions. Basically, linear programming is an optimisation technique where an objective function is optimised subject to a set of constraints. In mixed farming, crop residues may be used as soil amendment (compost, manure or mulch), or as animal feed, and each of the alternatives can be realised through a range of production techniques. Each of these production techniques is characterised by a specific set of inputs and outputs. In MGLP (Multiple Goal Linear Programming) several objective functions can be optimised. The desired solution, characterised by the optimal combination of goal attainments for a particular user, is obtained after a series of iteration cycles. In the first cycle, the lower bounds on all considered goals are set to their minimum values to ascertain that feasible solutions are obtained. This first cycle yields the "ideal" and "anti-ideal" values[1] which, combined, define the solution area of each goal. To get more realistic solutions, in subsequent iteration cycles each objective function is optimised in turn while tightening restrictions on the others. Thus, the solution area is progressively reduced, depending on the choice of the goals that are restricted and the degree to which they are tightened, reflecting the specific interests of the user, for example farm household members or policy makers. All selected objective functions are so gradually optimised, until a compromise solution is found. De Wit *et al.* (1988) and Van Keulen (1993) have given detailed descriptions of the use of MGLP in agricultural research, while its utilisation at farm household level has been well described by Van Rheenen (op. cit.), Van De Ven (op. cit) and Sissoko (1998).

The main aim of the model developed in this study was to determine the effect of various ways of using crop residues, including as animal feed (as single feeds and in various

[1] The ideal value is the best attainable value of an objective function, considering the direction of the optimisation (maximise or minimise); the anti-ideal value represents the worst value of the objective function.

combinations), on farm productivity, economics and sustainability. The trade-offs among agro-technical output (crop and animal production), economic benefit (gross margin), and environmental effects (organic matter and nutrient budgets) of the alternative activities were assessed. The analysis was performed at farm household level, because it is at that level that decisions on crop residue management are taken. The MGLP model developed for this analysis is referred to as HOREB (Household level Optimal crop REsidue allocation in Burkina Faso) and is intended as a tactical/strategic decision support tool (Sharifi and van Keulen, op. cit.).

6.3 Scope of HOREB

HOREB explores different scenarios for utilisation of crop residues to identify the ones that optimally benefits for the household and long-term productivity of the cropland. It takes into account the effect of the quantities of crop residues offered on feed intake and digestion (effects of selective consumption as described in Chapters 3 and 4), the subsequent effect on animal weight gain, the quantities of nutrients – organic matter (OM), nitrogen (N) and phosphorus (P) - excreted, the return of nutrients to cropland and nutrient budgets at farm level. Utilisation of crop residues as soil amendments in the form of mulch or ashes, with or without manure/compost and mineral fertilisers, is also considered.

The system studied, is a crop-livestock farming system in the North Soudanian zone of Burkina Faso. The main crops grown are maize, millet, sorghum and cowpea as food crops (mainly for home consumption), groundnut (home consumption and cash) and cotton as cash crop. The residues of all crops, except cotton and maize, can be used for stall feeding of ruminants. Cotton residues are not used in this way, because it looses its leaves early, leaving only coarse stems, which are mainly used as fuel. Maize residues are mostly grazed in situ, because at its harvest, it is often still raining while appropriate storage structures are not available. Livestock is the main source of cash income of the household; animals provide security in case of crop failure and manure to sustain cropland productivity. In the rainy season, animals graze natural rangelands in daytime, while part of the faeces and urine are deposited at the homestead at night. In the dry season, depending on feeding system, part of the animals continue to graze on rangelands and croplands, while others receive crop residues and purchased feeds in stall feeding (semi-intensive systems). For the current study, sheep have been selected as stall-fed livestock component, for the following reasons:

(1) In recent years, there has been a shift from cattle to small ruminants, especially in sedentary mixed farming and an increasing interest in dry season fattening of rams (De Grandi, op. cit.). (2) Small ruminants are better adapted to smallholders' resources and socio-economic conditions and are easier to purchase or sell. They are also more productive per unit investment due to their early sexual maturity, short duration of the reproduction cycle and young age at slaughter. They have smaller carcasses than other livestock; hence, marketing is easier, because a slaughtered animal can be consumed in a short period. The large Muslim population, that prefers mutton in most situations (Savadogo, 1991), guarantees a steady demand, although with periodical fluctuations due to the cycle of religious festivities. (3)

Nutrient flows in the soil-plant-animal system are dependent on the degree of utilisation of crop residues by the animals; this is governed by the nutritive value of the residues and the intake behaviour of animals. The nutritive value of feeds depends on the morphological composition. The quality of the material eaten depends on the nutritional heterogeneity and the animal's capacity for selective intake (Zemmelink, 1980; Wahed *et al.*, 1990; Fernández-Rivera *et al.*, op. cit.; Kaasschieter *et al.*, op. cit.; Osafo *et al.*, 1997). Sheep have a high capacity for selective consumption in stable feeding. (4) Sheep have a strong flocking instinct, which allows stabling, feeding and herding by all categories of the population, including children and older members of the family, so that labour can be used more efficiently.

The main characteristic of the system is the integration of crop and livestock components. This is taken into account in HOREB through 2 processes:
(1) Crop residues are used as feed for stabled sheep. Animal production levels are determined by feed quality, and the quantity of feed offered, using animal response models based on the experiments described in Chapter 4. (2) Manure and feed refusals are collected for cropland fertilisation. The quality of these organic fertilisers depends on the processing methods, comprising application as such (mulch), manure or compost, and with or without addition of mineral fertiliser.

The principal driving forces behind the various interactions, that may be synergistic or conflicting, are the amounts of different crop residues, their alternative uses, and requirements of labour/capital for their management.

6.4 Data collection

Socio-economic data

Surveys were conducted (Chapter 5) to quantify relevant household characteristics and to identify prevalent views on the objectives of farmers and on constraints with regard to utilisation of crop residues. Information on resource availability and environmental issues included farm area, the quantities of different crop residues produced, quantities stored, allocation of stored residues, distance from field to homestead, labour spent for storage of crop residues (including collection and transport) and availability of labour. Methods of collection, transport, storage and management of residues (stored and left in the field), their allocation to the alternative uses, constraints and farmers' aspirations were also assessed. Two types of households (with and without cart for residue and manure transport), as characterised in Table 6.1, were considered. The price of sheep was set to 400 FCFA (4 FF) per kg body weight (price estimated when animals were purchased for the experiments described in Chapters 3 and 4). Prices for grains (millet, maize, and sorghum) and seeds (cowpea) and unshelled nuts (groundnut) were derived from the Antenne Sahélienne market survey data (Table 6.2). The price of cotton (lint + seed) was recorded from SOFITEX (Société des Fibres Textiles), while the farm gate price of fertiliser was used (240 and 200 FCFA kg^{-1} for NPK and urea, respectively).

In the model calculations, the average farm size for each type (with cart, without cart and overall mean) was used. Land allocation to different crops was first fixed at the current situation, while optimising utilisation of crop residues. Labour input for sheep activities was estimated on the basis of survey data (feed collection, storage, treatment, animal herding) and feeding trials (feed allowance).

Table 6.1. Main characteristics of the two types of households

Characteristics	Type of Households					
	With cart (n = 17)		Without cart (n = 43)		All households (n = 60)	
	mean	sd	mean	sd	mean	sd
Demography						
Household size*	17.2	11.40	14.4	10.10	15.1	10.46
Labour units**	9.0	7.70	7.7	6.11	8.4	6.52
Cultivated land (ha)						
Sorghum	3.03	1.87	2.56	2.41	2.69	2.26
Millet	1.15	1.66	1.19	1.69	1.18	1.67
Cotton	0.56	0.44	0.47	0.62	0.50	0.57
Maize	0.55	0.43	0.46	0.61	0.49	0.57
Cowpea	0.48	0.36	0.76	0.94	0.68	0.83
Groundnut	0.37	0.48	0.67	0.69	0.59	0.65
Others[&]	0.43	0.34	0.36	0.48	0.38	0.44
Farm area	6.54	3.09	6.43	4.86	6.52	4.41
Livestock (head)						
Cattle	3.18	2.10	1.93	2.43	2.27	2.39
Sheep	11.12	10.02	9.41	12.11	9.88	11.84
Goat	7.88	7.70	8.64	13.17	8.43	11.51
Donkey	2.71	1.59	1.25	2.33	1.66	2.15
Crop residues produced (t)						
Sorghum	9.09	5.61	7.68	7.23	8.04	6.78
Millet	3.45	4.98	3.57	5.07	3.54	5.01
Cowpea	0.72	0.54	1.14	1.41	1.02	1.24
Groundnut	0.67	0.86	1.21	1.24	1.06	1.17
Proportion of crop residues collected and stored (%)						
Sorghum	33		36		35	
Millet	6		7		6	
Cowpea	86		24		36	
Groundnut	87		40		52	

* Number of persons; ** Each adult (15-64 years) represents one human labour unit, persons between 7 and 15 years are weighted according to the ratio *(age-7)/8*. Children under 7 years and persons > 64 are ignored (FAO, 1986); [&] Hibiscus, okra, potato; **Source**: Chapter 5.

Estimates of labour requirements for crop activities were based on Maatman and Schweigman (1995) and Songué (1997). All labour data were expressed on a monthly basis to allow for periods of peak labour demand. Sources of income are livestock, crop grains, seeds, lint and residues and off-farm income.

Table 6.2. Average prices of different crop products (grains for millet, sorghum, maize; seeds for cowpea; unshelled nuts for groundnuts; lint + seeds for cotton) in Manga (Zoundwéogo)

Crop	Average (FCFA kg^{-1})	Coefficient of variation
Cowpea	145	0.40
Cotton	150*	-
Groundnut	114	0.51
Maize	66	0.49
Millet	89	0.37
White sorghum	73	0.35
Red sorghum	69	0.36

* Official price of the SOFITEX (Société des Fibres Textiles, Burkina Faso)
100 FCFA = 1 FF; **Source**: Antenne Sahélienne market surveys, 1992-1996.

Technical coefficients for livestock production

Crop residues used in sheep feeding during the dry season are those of sorghum, millet, cowpea, and groundnut, that can either be grazed or used for stall feeding. In actual farmers' practice, varying quantities of cereal stover are offered to sheep, which allows varying degrees of selective consumption of leaves. The refusals are generally fed to donkeys or mixed with animal excreta in compost pits and later incorporated into the soil. Technical coefficients for the feeding activities included in the model were determined as follows:

- Relation between the quantity of feed offered and intake under different feeding methods.

The equation described by Zemmelink (1980) was used to describe the relationship offer-intake for unchopped residues of sorghum, cowpea and groundnut as single feeds, as well as sorghum-cowpea and sorghum-groundnut mixtures (Chapter 4). Kaasschieter *et al.* (op. cit.) used a similar experimental design to study the offer-intake relationship for cattle, fed residues of millet and cowpea, or millet and cotton seed cake (CSC). Their data were reanalysed using the models described in Chapter 4 of this thesis (Zemmelink, unpublished). The estimated maximum intake (parameter m) obtained by Kaasschieter *et al.* (op. cit.) was divided by 1.33 to account for the lower intake of sheep compared to cattle, in proportion to their assumed maintenance requirements (24 and 32 g DOM $kg^{-0.75}$ d^{-1}, respectively). The parameters of the intake model for sorghum-CSC and millet-groundnut were assumed to be the same as those for millet-CSC and sorghum-groundnut, respectively. To include the possibility of chopping and urea treatment, the relationship between amounts offered and intake for chopped and urea-treated sorghum and millet, and millet-cowpea, millet-groundnut, millet-CSC, sorghum-cowpea, sorghum-groundnut and sorghum-CSC was estimated as follows: (1) For millet and sorghum as single feeds, both in chopped and urea-treated form, it was assumed that animals eat the full quantity offered until this exceeds the maximum intake (m); this m was then assumed equal to that for untreated feeds; (2) for mixed feeds, intake depends on the quality of the basal feed and the substitution rate of the basal feed by the supplement, which is determined by the quality of both the basal feed and the supplement. Berge and Dulphy (1985) in their study on the interactions between forage and concentrates in sheep, described the substitution rate (R) as a function of crude protein (CP, % DM) and crude fibre (CF, % DM) content of the ration according to the following equation:

$$R = 2.41 - 0.036 * CP - 0.047 * CF \quad (n = 98; r = 0.748; rsd = 0.27).$$

The relation between intake of chopped or treated stover (Y) and the quantity of supplement offered (S) can then be written as:

$$Y = m - R * S,$$

where m is the maximum intake estimated from the feeding trials described in Chapter 4; also for CP content of sorghum, cowpea and groundnut, values of Chapter 4 were used. CP content of millet and CSC were derived from Kaasschieter *et al.* (op. cit.). CF contents were estimated at 41, 40, 35, 32 and 13 % for millet, sorghum, cowpea, groundnut and cotton seed cake, respectively (Kaboré, 1996).

- Intake of digestible organic matter (IDOM)

IDOM of the different rations was calculated as:

$$IDOM = S * d_S + Y * d_B$$

where d_S and d_B are the digestibility of the supplement (cowpea, groundnut or cotton seed cake) and of the basal feed (millet or sorghum stover), respectively. The digestibility values of untreated basal feeds were described as a function of the proportion refused (Chapter 4), that of urea-treated sorghum was assumed constant (Ouédraogo, 1990), while for chopped and urea-treated millet values derived from Kaasschieter *et al.* (op. cit.) were used.

- Relation between IDOM and weight gain

Animal weight gain was estimated from IDOM, as an indicator of intake of metabolizable energy (IME). Although ME requirements for weight gain vary with the quality of the ration (q = ME/gross energy), under ad libitum feeding where higher q values are associated with higher intake, live weight gain tends to be proportional to IME minus maintenance requirements (Ketelaars and Tolkamp, 1991; Zemmelink *et al.*, 1991). Maintenance and growth requirements of the breed used (Djallonké) were assumed to be similar to those of West African Dwarf goats, i.e. 24 g DOM $kg^{-0.75}$ d^{-1} and 2.4 g DOM g^{-1}, respectively (Zemmelink *et al.*, op. cit.).

- Optimum level of feed allowance

Residues of cereal crops (sorghum and millet) must usually be combined with higher quality products (cowpea, groundnut haulms and CSC) to reach IDOM levels required for production. Similar IDOM levels can be obtained with different combinations of sorghum/millet residues and the higher quality products. The optimum level of feed allowance was derived from iso-production curves (different amounts of two feeds giving the same IDOM level), and the iso-cost line based on the prices of the two feeds (Chapter 4). The equations used to derive the iso-production curves are summarised in Tables 6.3 and 6.4. In principle, the optimum use of input is the point where the marginal value of the output equals the price of that input. The prices of cereal stover, cowpea and groundnut haulms, and cotton seed cake were set to 10, 40 and 60 FCFA, respectively, based on prices when these materials were purchased for the feeding trials.

- Organic matter and nutrients excreted

The quantities of refused feed and faeces corresponding to the optimum combination of cereal stover and supplements were derived from intake of organic matter (IOM) and IDOM, by subtracting IOM from OOM (offered organic matter) and IDOM from IOM, respectively. These were combined with N contents of refusals as found in our experiments. The quantities of N excreted in faeces (FN) were estimated by subtracting digestible nitrogen (DN) from ingested N (IN). DN was estimated from:

DN (g/100 g DM) = 0.9 * N (g/100 g DM) - 0.51. (Based on 20 equations reported by Boekholt, 1976)

N excreted in urine was derived by subtracting the quantities retained in the body and FN from IN. A concentration of 2.5 % N in body tissue was assumed (Boekholt, op. cit.; Ketelaars and Tolkamp, op. cit.). To estimate the quantities of P excreted in the faeces, the quantities retained in the body (7.4 mg P per g liveweight gain; Efdé, 1996) and excreted in urine (2 mg per kg live weight per day; ARC, 1980) were subtracted from the quantity of P ingested. P concentrations of feeds were taken from Rivière (1978).

Technical coefficients for crop production

A number of crop production techniques were identified for the study area on the basis of farm surveys and interviews with rural development agencies. Sorghum, millet, maize, cowpea, groundnut and cotton were included. Their yields were calculated following the procedure described by Struif Bontkes (1999). The different land units distinguished were homestead, village and bush fields (based on distance from the homestead), and lowlands. Homestead fields are often luvisols, where maize and sorghum are planted; village and bush fields are on lixisols and cambisols and often used for millet, cotton, cowpea or groundnut; lowlands are vertisols and used for sorghum in combination with cowpea.

Table 6.3. Models used to derive iso-production curves of feeding sorghum-cowpea, sorghum-groundnut, and sorghum-cotton seed cake (CSC) rations

Feeding method	Sorghum-cowpea	Sorghum-groundnut	Sorghum-CSC
Excess feeding	IDOM = 0.699 S + d_B Y	IDOM = 0.621 S + d_B Y	IDOM = 0.668 S + 0.465 Y
	d_B = 0.465 + 0.198 (X - Y)/X	d_B = 0.398 + 0.167 (X - Y)/X	
	$Y = m(1-exp(-(X/m)^h))^{1/h}$	$Y = m(1-exp(-(X/m)^h))^{1/h}$	$y = (m(1-exp(-(X/m)^h))^{1/h})/1.33$
	m = 50.7 - 0.424 S	m = 45.7 - 0.413 S	m = 71.6 - S -15.2 exp(-0.1066 S)
	h = 2.735 exp(-0.0235 S)	h= 4.365 exp(-0.0319 S)	h = 2.474
Chopping	IDOM = 0.699 S + 0.465 Y	IDOM= 0.621 S + 0.398 Y	IDOM= 0.668 S + 0.465 Y
	Y = m - R S	Y = m - R S	Y = m - R S
	R = 2.41- 0.036 CP - 0.047 CF	R= 2.41 - 0.036 CP - 0.047 CF	R = 2.41- 0.036CP - 0.047CF
Urea treatment	IDOM= 0.699 S + 0.510 Y	IDOM= 0.621 S + 0.510 Y	IDOM = 0.668 S + 0.510 Y
	Y = m- R S	y = m - R S	Y = m - R S
	R = 2.41-0.036 CP-0.047 CF	R = 2.41- 0.036 CP - 0.047 CF	R = 2.41- 0.036 CP - 0.047 CF

IDOM= Intake of digestible organic matter; X = Quantity of basal feed offered; Y = intake of X; S = Quantity of supplement consumed; R = rate of substitution of X by S. IDOM, X, Y, and S are expressed in g $kg^{-0.75}$ d^{-1}; CP and CF represents the crude protein and fibre content of the ration (% in dry matter).

Table 6.4. Models used to derive iso-production curves of feeding millet-cowpea, millet-groundnut, and millet-cotton seed cake (CSC) rations.

Feeding method	Millet-cowpea	Millet-groundnut	Millet-CSC
Excess feeding	IDOM = 0.646 S + 0.470 Y	IDOM = 0.621 S + 0.470 Y	IDOM = 0.668 S + 0.470 Y
	$Y = (m(1\text{-}\exp(-(X/m)^h))^{1/h})/1.33$	$y = (m(1\text{-}\exp(-(X/m)^h))^{1/h})/1.33$	$y = (m(1\text{-}\exp(-(X/m)^h))^{1/h})/1.33$
	m = 68.7 - S - 20.2 exp(-0.0664 S)	m = 68.7- S - 20.2 exp(-0.0664 S)	m = 71.6 - S - 15.2 exp(-0.1066 S)
	h = 1.348	h = 1.348	h = 2.474
Chopping	IDOM = 0.646 S + 0.470 Y	IDOM = 0.621 S + 0.470 Y	IDOM = 0.668 S + 0.470 Y
	Y = m - R S	Y = m - R S	Y = m - R S
	R = 2.41- 0.036 CP - 0.047 CF	R = 2.41- 0.036 CP - 0.047 CF	R = 2.41- 0.036 CP - 0.047 CF
Urea treatment	IDOM = 0.646 S + 0.510 Y	IDOM = 0.621 S + 0.510 Y	IDOM = 0.668 S + 0.510 Y
	Y = m - R S	Y = m - R S	Y = m - R S
	R = 2.41- 0.036 CP - 0.047 CF	R = 2.41- 0.0368 CP - 0.047 CF	R = 2.41- 0.0368 CP - 0.047 CF

IDOM= Intake of digestible organic matter; X = Quantity of basal feed offered; Y = intake of X; S = Quantity of supplement consumed; R = rate of substitution of X by S. IDOM, X, Y, and S are expressed in g $kg^{-0.75}$ d^{-1}; CP and CF represents the crude protein and fibre content of the ration (% in dry matter).

Organic matter and nutrient resources included in HOREB are crop residues in the form of mulch, ash (after burning), feed refusals and animal excreta (manure or compost), and inorganic fertilisers (compound NPK fertiliser: 12: 24: 12). Details of the crop activities and calculations of input-output coefficients are given in Appendix A. Special attention is paid to organic matter, nitrogen and phosphorus balances as human-dependent sustainability criteria (Van Keulen, 1995). These balances were assessed, considering their flows at 2 levels:

(1) Animal production level: Nutrient balances were quantified, according to the procedures described in the preceding sections. Two management systems were distinguished: (a) animal excreta (faeces and urine) and feed refusals are left as such (manure), and (b) animal excreta and feed refusals are mixed with household waste and stored in a pit for composting. It was assumed that 60 % of the N in manure is lost by volatilisation and leaching and 14 % in the case of compost; average losses of 10 % for P were assumed for both management techniques (Romney *et al.*, 1994).

(2) Soil and crop production level: Processes at this level include mineralisation, biological nitrogen fixation, nitrogen volatilisation, atmospheric deposition and uptake. These processes were quantified using the procedures described by Verberne *et al.* (1990) and Van Keulen (op. cit.). Initial organic matter and nitrogen contents of the different land units, and climate parameters were derived from the Antenne Sahélienne database.

6.5 Model specifications

Objective functions

Three categories of objective functions were considered, i.e. agro-technical, economic and environmental (Table 6.5).

Table 6.5. Objective functions

Category	Specification	Unit (per year)	Optimisation
Agro-technical	Total crop production	t	Maximise
	Staple production	t	Maximise
	Livestock weight gain	kg	Maximise
Economic	Gross margin: Livestock	kF*	Maximise
	Crop	kF	Maximise
	Total	kF	Maximise
Environmental	Organic matter balance	kg ha^{-1}	Maximise
	Nitrogen balance	kg ha^{-1}	Maximise
	Phosphorus balance	kg ha^{-1}	Maximise

* 1kF = 1000 FCFA (10 FF).

The agro-technical objective functions refer to total crop production (grains of millet, sorghum, maize; seeds of cowpea; unshelled nuts of groundnuts; lint + seeds of cotton), staple crop production (grains of millet, sorghum, maize; seeds of cowpea), animal production (total liveweight gain for 6 months stall feeding). The economic objective functions are gross margin from crops and livestock. The environmental objectives are OM, N and P balances, also referred to as sustainability indicators.

Activity matrix

Two categories of activities were included:

- Animal (sheep) production activities. Levels of outputs (kg weight gain, OM, N and P) were related to feeding technique, availability and quality of crop residues and concentrates. Sheep production activities included in the matrix comprise a range of feeding techniques defined by various combinations of cereal stover and cowpea/groundnut haulms or cotton seed cake (Table 6.6). Feeding methods included were (a) excess feeding of unchopped stover (allowing selective consumption), (b) chopping and (c) urea treatment. In principle, 6 levels of feeding were considered, corresponding to 1, 1.2, 1.4, 1.6, 1.8 and 2 times maintenance.
- Crop activities. Levels of crop production are quantified as a function of soil organic matter and nutrient (N and P) availability and the partitioning of N and P between soil, grains and straw, taking into account climatic conditions. Crop activities are defined in production techniques characterised by various combinations of land units, crop types, and types and quantities of fertiliser (Table 6.7). All the animals are herded (grazing) in the rainy season. In the dry season, sheep were assumed to be stall fed; donkeys and goats were assumed to roam freely and cattle entrusted to herdsmen. Donkeys and cattle are both used as draught animals.

The quantities of OM, N and P excreted at night (assumed 50 % of the total quantity per animal) by cattle (only for the rainy season), donkeys and goats were included, as well as household organic waste.

Constraints

The resource constraints with respect to land and labour availability were set equal to the current average situation. Working capital was set to the actual value (13 kF) according to MARA (1996). From this working capital, 82 % is assumed available for crop activities and the remainder for livestock. The constraints are classified as: (1) Household resource constraints or normative constraints (Van Rheenen, 1995): farm land area, availability of labour (mandays per month), and working capital. (2) Agro-technical constraints, that limit production levels of crops and livestock: weather (rainfall and evapo-transpiration as defined for normal, dry and wet years), soil quality (soil organic matter, N and P contents, infiltration capacity of the different land units) and nutritive value of feeds. (3) Goal constraints, representing the minimum or maximum values set to the objective functions.

Table 6.6. Definition criteria for sheep activities

Feed combination	Excess feeding						Chopping						Urea treatment					
	1M	1.2M	1.4M	1.6M	1.8M	2M	1M	1.2M	1.4M	1.6M	1.8M	2M	1M	1.2M	1.4M	1.6M	1.8M	2M
Sorghum stover (SS)	+	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Millet stover (MS)	+	+	-	-	-	-	+	-	-	-	-	-	+	+	-	-	-	-
Cowpea haulm (CH)	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+
Groundnut haulm (GH)	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+
Cotton seed cake (CSC)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SS + CH	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
SS + GH	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
SS + CSC	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
MS + CH	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
MS + GH	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
MS + CSC	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

M = maintenance (IDOM= 24 g $kg^{-0.75}$ d^{-1}); + included in the model; - not included or not attainable.

Table 6.7. Definition criteria for crop activities

Definition criterion	Options
Land units	luvisol, lixisol, cambisol, vertisol
Field locations	homestead fields, village fields, lowlands
Crops	cotton, cowpea, groundnut, maize, millet, sorghum
Organic matter/nutrient sources	Manure, compost, mulch, ash, NPK (12:24:12)

6.6 Model utilisation

Definition of solution areas

Two production systems were studied:

(1) Sheep feeding (Section 7.2). The objective was to identify optimum feeding strategies, using the current amounts of cowpea, groundnut, millet and sorghum residues. A set of runs with HOREB was executed considering only sheep stall-feeding (during 6 months of the dry season), for three specific situations. In the first, the quantities of crop residues collected were set to the mean current values, for households owning a cart (A) and households without cart (B) as described in Table 6.1. In subsequent runs, the proportion of cowpea and groundnut haulms collected for animal feeding was set to 86 % of the quantities produced, while the quantities of millet and sorghum stovers used were set to 80 % of the quantities produced, to determine potential animal production under intensive utilisation of crop residues (C). Maximum utilisation rates somewhat below 100 % were considered reasonable, because of unavoidable losses during collection, transport and storage, and very coarse materials being left in the field. The solution areas, defined by the ideal and the anti-ideal values of each objective function, were obtained by maximising each of the specified objectives (total live weight gain; livestock gross margin; organic matter (OM), nitrogen (N) and phosphorus (P) outflows from faeces, urine and feed refusals in turn, subject to total labour requirement ≤ total family labour. In a first round of optimisations, it was assumed that working capital is not available to purchase concentrate; in the second round concentrate could be used.

(2) Integrated crop-sheep farming (Section 7.3). The objective was to identify optimum strategies for utilisation of crop residues in an integrated farming perspective, with respect to the effects on livestock and crop production, farm gross margin and nutrient (OM, N and P) budgets. First, the solution areas of each objective function were determined for situations A, B and C described above. However, in addition to the criteria used previously, allocation of land to different crops was also optimised (Table 6.8). Also, 70 % of the total proportion of cereal crop residues collected in situations A and B are assumed to be used in animal feeding, the remainder being used for other purposes, according to the actual allocation (Chapter 5). The crop area was set to 6.2 ha, because okra and hibiscus referred to as others in Table 5.1 were not included. To illustrate the consequences of the erratic climatic conditions in the region, the model was run with weather data sets for normal (860 mm rainfall), dry (719 mm rainfall) and wet years (991 mm rainfall).

Table 6.8. Definition criteria for the situations A, B and C examined in crop-sheep farming

Constraints	Situation A	Situation B	Situation C
Land area (ha)	≤ 6.2	≤ 6.2	≤ 6.2
Allocation of land (ha)			
Sorghum	≤ 2.7	≤ 2.7	U*
Millet	≤ 1.2	≤ 1.2	U
Cowpea	≤ 0.7	≤ 0.7	U
Groundnut	≤ 0.6	≤ 0.6	U
Maize	≤ 0.5	≤ 0.5	U
Cotton	≤ 0.5	≤ 0.5	U
Proportion of crop residues collected for animal feeding (%)			
Sorghum	≤ 25	≤ 25	≤ 80
Millet	≤ 4	≤ 4	≤ 80
Cowpea	≤ 86	≤ 24	≤ 86
Groundnut	≤ 52	≤ 52	≤ 86
Maize	= 0	= 0	= 0
Cotton	= 0	= 0	= 0
Available labour (mandays per month)	≤ 210	≤ 210	≤ 210
Working capital (kF)			
For fertiliser	≤ 14	≤ 14	U
For concentrate	≤ 3	≤ 3	U

1kF = 1000 FCFA (10 FF); * Unconstrained

Sensitivity analyses

Sensitivity analyses were carried out to examine the impact of household resources (land area, availability of labour and working capital) and prices on the values of the different objective functions. For integrated crop-sheep farming analysis, the sensitivity of the results (especially those of the different scenarios) to the basic assumptions used in energy requirements for growth (MEg) and in N content of weight gain was also examined according to the ranges given by NRC (1985) and CAB (1980): (a) MEg set at 2.4 g DOM per g weight gain, 2.5 % N in weight gain (basic assumptions); (b) MEg set at 2.4 g DOM per g, 3.6 % N in weight gain; (c) MEg set at 2.0 g DOM per g, 2.5 % N in weight gain; (d) MEg set at 2.0 g DOM per g, 3.6 % N in weight gain.

Scenarios

When studying sheep feeding only, two scenarios were considered with respect to the objectives of farmers, i.e. maintenance of body weight and intensive feeding for weight gain. The first scenario reflects the situation where the farmer aims at intermediate functions of animals (manure, security, and savings), thus giving priority to animal maintenance during the dry season, while relying on rangelands in the wet season for production. This was implemented in HOREB by maximising OM outflow, while setting both capital input for purchase of concentrate and gross margin from animals to zero. The intensive feeding scenario reflects the situation where the farmer aims at maximum gross margin. Gross margin was first maximised under conditions of zero external input; in a second run, concentrates could be used. Both scenarios were examined for the 3 situations defined previously (A, B, and C); also their sensitivity to availability of labour was studied.

Table 6.9. Definition criteria for the different scenarios

Parameters	Scenarios			
	FS I	FS II	SP I	SP II
Objective functions				
Total crop production	U⁎	U	U	U
Staple crop production	Maximise	≥ 2.9	≥ 2.9	≥ 2.9
Livestock weight gain	U	U	U	U
Crop gross margin	U	U	U	U
Livestock gross margin	U	U	U	U
Total gross margin	U	Maximise	Maximise	Maximise
Organic matter balance	U	U	≥ 0	≥ 0
Nitrogen balance	U	U	U	≥ 0
Phosphorus balance	U	U	U	U
Constraints				
Farm size (ha)	≤ 6.2	≤ 6.2	≤ 6.2	≤ 6.2
Allocation of land (ha)				
Sorghum	≤ 2.7	≤ 2.7	≤ 2.7	≤ 2.7
Millet	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2
Cowpea	≤ 0.7	≤ 0.7	≤ 0.7	≤ 0.7
Groundnut	≤ 0.6	≤ 0.6	≤ 0.6	≤ 0.6
Maize	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5
Cotton	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5
Crop residues collected for animal feeding (%)				
Cereal stovers	= 0	≤ 80	≤ 80	≤ 80
Legume haulms	= 0	≤ 86	≤ 86	≤ 86
Labour availability (manday per month)	≤ 210	≤ 210	≤ 210	≤ 210
Working capital for fertilisr (kF[1])	= 0	≤ 14	= 0	U
Working capital for concentrate	= 0	≤ 3	= 0	U

⁎ Unconstrained; [1] 1kF = 1000 FCFA (10 FF); see Table 6.4 for the units of the objective functions

For the case of integrated crop-sheep farming, four scenarios were constructed (Table 6.9): (1) food security and sheep not stall fed (FS I); (2) food security under integrated crop-sheep farming (FS II); (3) sustainable integrated crop-sheep farming without external inputs (SP I); (4) sustainable integrated crop-sheep farming with external inputs (SP II). For all 4 scenarios the current farm size and land allocation are assumed. FS I aims at maximum production of staple crops without working capital, without restrictions on production of other crops, gross margins and nutrient balances and without stall feeding of sheep in the dry season. FS II aims at maximum total gross margin (from crops and stall feeding of sheep) with limited working capital (MARA, 1996) and the restriction that a minimum of 2.9 t staples should be produced. SP I aims also at maximum total gross margin, but without working capital for fertiliser and concentrate, and the extra restriction of a zero or positive OM balance. In SP II, there is no restriction on use of working capital, but also the N-balance should be zero or positive.

Chapter 7
Optimising crop residue utilisation: II. Results

7.1 Introduction

In this chapter, HOREB was applied to identify the possibilities for optimum utilisation of crop residues for sheep stall feeding (Section 7.2) and integrated crop-sheep farming perspective (Section 7.3). In both cases, the solution areas of each objective function are first presented for situations A, B and C as described in Chapter 6. The trade-offs among the different objective functions and the sensitivity of the results to availability of labour and working capital, and animal price are examined for situation C (optimal). Finally, values of the objective functions for the different scenarios are presented.

7.2 Sheep feeding

7.2.1 Situations A and B

The quantities of crop residues available for feeding are 3000, 620, 580 and 220 kg for sorghum, cowpea, groundnut and millet, respectively. With these values and assuming that no cash is available to purchase concentrate, the highest gross margin is 95 kF (Table 7.1), attained by feeding 30 animals at 2 times maintenance (2 M) (17 on excess sorghum + cowpea, 7 on chopped sorghum + groundnut and 6 on chopped sorghum + cowpea) and 2 animals on excess millet at 1.2 M, using in total 174 md labour per month. The lowest gross margin in this situation is 42 kF corresponding to maximum N outflow, where 42 animals are fed using 183 md labour per month. The solution areas for weight gain, OM, N and P outflows cover the ranges 157 to 278 kg, 2256 to 2577 kg, 28 to 35 kg and 4.6 to 6.8 kg, respectively. When concentrates are available, the estimated maximum attainable gross margin is 129 kF, achieved using excess feeding of millet + cotton seed cake, excess sorghum + cowpea, excess sorghum + groundnut, and urea-treated of millet + cowpea and urea-treated sorghum + groundnut, all at the highest level of feeding (2 M). This corresponds to 687 kg live weight gain from 40 animals fed during 6 months. Under this feeding strategy, 3263 kg of OM, 108 kg of N and 7.8 kg of P are available (outflows in faeces, urine and feed leftovers), requiring 152 kF investment in purchase of cotton seed cake and utilisation of all family labour (210 md per month) in animal feeding. The lowest gross margin (0) is associated with the strategy aiming at maximum P outflow. Gross margin is also far below maximum when outflows of OM and N are maximised.

For the household without cart (situation B), the quantities of crop residues used are 2700, 270, 490 and 240 kg of sorghum, cowpea, groundnut and millet, respectively. Without concentrate, the solution areas are 24 to 59 kF gross margin, 105 to 181 kg live weight, 1941 to 2190 kg OM, 21 to 27 kg N and 3.8 to 5.8 kg P (Table 7.2). The highest gross margin is achieved with a feeding strategy similar to that of households with cart, but a lower number

Table 7.1. Solution areas for situation A (households with cart, current quantities of crop residues)

Objective function	Unit*	Gross margin	Weight gain	Organic matter outflow	Nitrogen outflow	Phosphorus outflow
Without concentrate[†]						
Gross margin	kF[¶]	**95**	95	77	<u>42</u>	53
Weight gain	kg	278	**278**	230	<u>157</u>	186
Organic matter outflow	kg	2357	2357	**2577**	2311	<u>2256</u>
Nitrogen outflow	kg	<u>28</u>	<u>28</u>	30	**35**	33
Phosphorus outflow	kg	5.1	5.1	<u>4.6</u>	6.4	**6.8**
With concentrate						
Gross margin	kF	**129**	110	34	37	<u>0</u>
Weight gain	kg	687	**705**	621	705	<u>430</u>
Organic matter outflow	kg	3263	3304	**4033**	<u>2598</u>	2655
Nitrogen outflow	kg	108	121	<u>99</u>	**180**	130
Phosphorus outflow	kg	7.8	8.2	<u>7.5</u>	8.2	**8.5**

Bold= ideal values; Underlined= anti-ideal values; [¶] 1 kF = 1000 FCFA; * For 6 months feeding; [†] Concentrate refers to cotton seed cake or urea of animals can be fed. The labour requirement is 40 % of total household labour. The anti-ideal gross margin is achieved when N outflow is maximised. Also when P is maximised, the gross margin is very low. If no concentrate can be purchased, lack of a cart for residue transport, leading to smaller quantities of crop residues collected, especially cowpea, results in a decrease in maximum gross margin of 38 %, from 95 to 59 kF. Ideal weight gain decreases by 35 %, OM by 15, N by 23 and P by 15. The solution areas when concentrate is available are 0 to 93 kF for gross margin, 341 to 599 kg for total weight gain, 2245 to 3567 kg for OM, 86 to 153 kg for N and 6.5 to 7.3 kg for P (Table 7.2).

The relative differences in ideal values of the objective functions between households with a cart and without are smaller when concentrate is not available, i.e. 28 % for gross margin, 15 for liveweight, 12 for OM, 15 for N and 14 for P. These differences are mainly due to the larger quantities of haulms for households with cart, that enables them to feed more animals (40 animals compared to 34). Also when concentrate can be fed, ideal values are smaller for households without cart because of the relatively lower availability of stover. However, households with cart must invest 25 kF more in purchasing cotton seed cake and urea to enable utilisation of all their stover. Ideal gross margin increases from 95 to 129 kF for households with cart and from 59 to 93 kF for households without cart, corresponding to a remuneration of 0.27-0.28 kF gross margin per kF invested.

7.2.2 Situation C

In this situation, 80 and 86 % of stover and haulms, respectively are assumed to be stored. The quantities of crop residues were then 6400, 2800, 877 and 912 kg of sorghum, millet, cowpea and groundnut, respectively. The solution areas without concentrate are 0 to 161 kF for gross margin, 74 to 461 kg for total weight gain, 2935 to 4101 kg OM, 22 to 46 kg N and 6.1 to 8.8 kg P (Table 7.3). When concentrate is used, the solutions areas are 0 to 182 kF gross margin, 687 to 801 kg live weight gain, 2559 to 6678 kg OM, 83 to 185 kg N and 7.8 to 10.2 kg P. The higher ideal values as compared to situations A and B are due to the larger quantities of stover available, but require more than 50 % of the total family labour and 101 kF to buy concentrate.

Trade-offs among the objective functions

Without concentrate, the maximum attainable gross margin is 161 kF. The available crop residues are allocated to animals using 4 different rations. All available millet stover is given as a single feed in excess feeding to 22 animals at 1.2 M; part of the sorghum stover is given in excess feeding in combination with cowpea haulms to 4 animals at 1.4 M; the remaining sorghum stover is chopped to match the available quantities of groundnut haulms and the remaining cowpea haulms for 21 animals at 2 M. As no concentrate is used, weight gain and gross margin are not conflicting. The best attainable quantity of OM (4101 kg) is obtained by changing the feeding strategy, i.e. 22 animals fed with excess millet at 1.2 M, 20 animals with excess sorghum + cowpea at 1.6 M, and 8 animals with excess sorghum at maintenance

Table 7.2. Solution areas for situation B (households without cart, current quantities of crop residues)

Objective function	Unit*	Gross margin	Weight gain	Organic matter outflow	Nitrogen outflow	Phosphorus outflow
Without concentrate[†]						
Gross margin	kF[¶]	**59**	59	39	<u>24</u>	28
Weight gain	kg	181	**181**	132	<u>105</u>	115
Organic matter outflow	kg	2058	2058	**2190**	2001	<u>1941</u>
Nitrogen outflow	kg	<u>21</u>	<u>21</u>	24	**27**	26
Phosphorus outflow	kg	4.1	4.1	<u>3.8</u>	5.4	**5.8**
With concentrate						
Gross margin	kF	**93**	74	27	29	<u>0</u>
Weight gain	kg	580	**599**	563	599	<u>341</u>
Organic matter outflow	kg	3003	3048	**3567**	<u>2245</u>	2340
Nitrogen outflow	kg	95	109	<u>86</u>	**153**	104
Phosphorus outflow	kg	6.6	7.0	<u>6.5</u>	7.0	**7.3**

Bold= ideal values; Underlined= anti-ideal values; [¶] 1 kF = 1000 FCFA; * For 6 months feeding; [†] Concentrate refers to cotton seed cake and/or urea

Table 7.3. Solution areas for situation C (80% of cereal and 86 % of leguminous residues collected)

Objective function	Unit*	Gross margin	Weight gain	Organic matter outflow	Nitrogen outflow	Phosphorus outflow
Without concentrate[†]						
Gross margin	kF[¶]	**161**	161	86	110	0
Weight gain	kg	461	**461**	278	325	74
Organic matter outflow	kg	3516	3516	**4101**	3332	2935
Nitrogen outflow	kg	22	22	24	**46**	34
Phosphorus outflow	kg	7.7	7.7	7.0	6.1	**8.8**
With concentrate						
Gross margin	kF	**182**	22	7	0	0
Weight gain	kg	687	**801**	801	801	801
Organic matter outflow	kg	2559	3362	**6678**	3750	3750
Nitrogen outflow	kg	83	101	112	**185**	185
Phosphorus outflow	kg	7.8	9.5	10.2	10.2	**10.2**

Bold= ideal values; Underlined= anti-ideal values; [¶] 1 kF = 1000 FCFA; * For 6 months feeding; [†] Concentrate refers to cotton seed cake and/or urea level. This results in small changes in the N and P outflows, but reduces gross margin by almost 50 %. Maximum outflow of N is realised by feeding 41 animals on unchopped stover. Unchopped millet is combined with cowpea to reach 1.4 M for 31 animals, while sorghum is combined with groundnut to reach 1.8 M for 9 animals; 1 animal is fed unchopped sorghum at maintenance level. This leads to large quantities of refusals, but the corresponding OM outflow is still lower than its maximum value. When N outflow is maximised, P outflow is reduced from a maximum of 8.8 to 6.1 kg. Maximimum P outflow is achieved by feeding more animals on chopped stover that leaves less refusals. The outflow of OM (2935 kg) is mainly in animal faeces. Also weight gain and gross margin reach their lowest values when P is maximised, because all animals are then fed at maintenance or 1.2 M. The main observation for the situation without concentrate is that the range in P outflow in the solution area is narrow and depends on the number of animals fed. For N, however, the ideal value is twice the anti-ideal value (obtained when maximising gross margin). Increasing OM in manure does not automatically imply an increase in nutrients. The difference between the extreme values of N (24 kg) is equivalent to 52 kg urea, which corresponds to about 10 kF, which is far less than the associated increase in gross margin (51 kF). This means that only a relatively small part of the extra gross margin is needed to compensate the lower N outflow. Also because most of the N is excreted in urine, maximising N outflow should be combined with a management system that minimises volatilisation of urinary N.

When concentrate is available, the differences between the extreme values of the objective functions are larger. Maximisation of gross margin conflicts with all the other objective functions. The low values for OM, N and P outflows are due to the low refusals, as urea treated and chopped stovers are used in all selected rations in combination with cotton seed cake, for 41 animals at 2 M level. Maximum weight gain is also achieved when OM, N and P outflows are maximised; 285 kF is used to buy cotton seed cake when maximising OM, and 296 kF when N and P outflows are maximised. In all cases, 57 animals are fed. When OM outflow is maximised, unchopped stover is used, leading to larger quantities of refusals. Higher N and P outflow, compared to the situation without cash input, is associated with utilisation of urea-treated stover in combination with cotton seed cake. Maximum weight gain does not results in maximum gross margin because of the high price of urea (0.20 kF per kg).

Household resources and the objective functions

The effect of availability of labour and capital, and animal prices on the value of the objective functions was assessed at various levels of input. Without concentrate, increased labour availability results in a linear increase in gross margin up to 100 md per month (Fig. 7.1a), corresponding to a maximum return to labour (gross margin per unit of labour invested) of 0.20 kF per md. This value is 50 % below the current labour wages in the study area, and suggests that animal feeding may not be economically attractive, if alternative economic activities are available. Beyond 100 md, the return to labour sharply decreases. When 10 to 50 kF is available to buy concentrate, the slope of the curves hardly changes. The level of 100 md per month corresponds to the point where all available legume haulms can be fed.

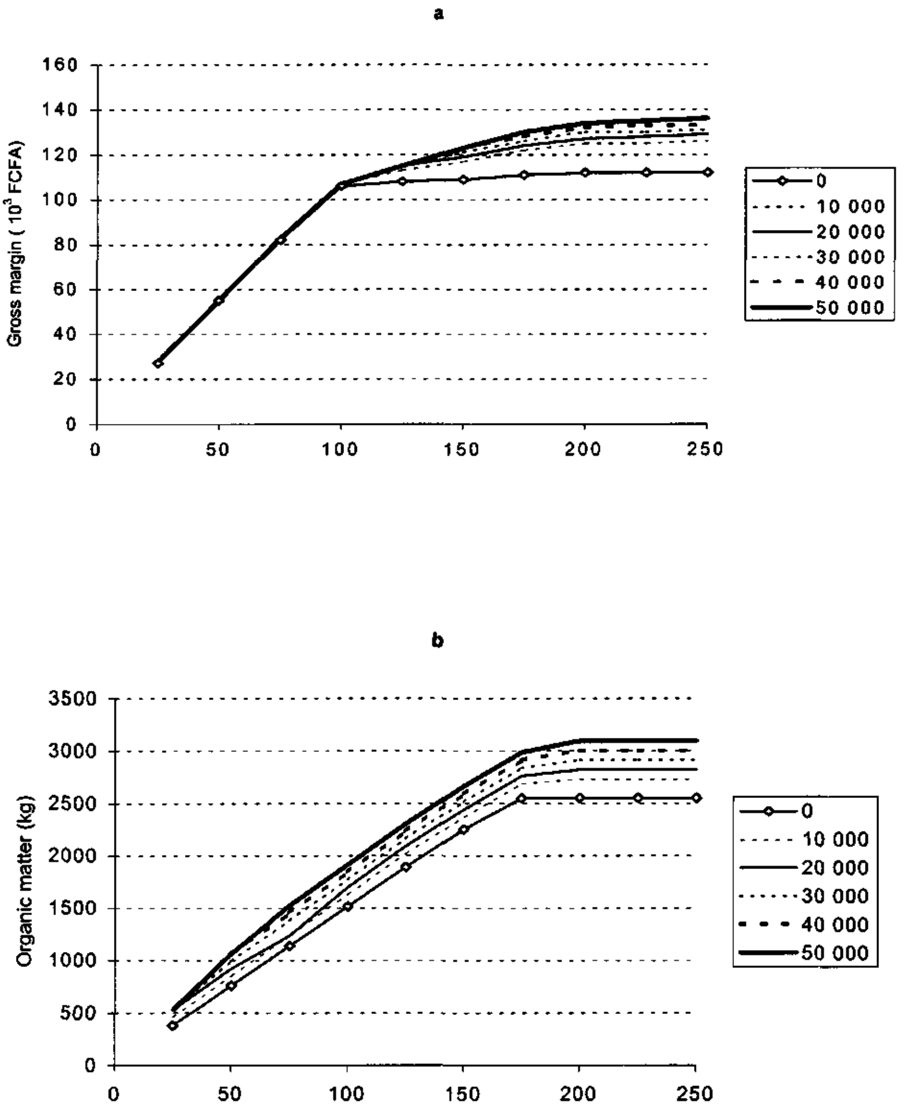

Figure 7.1. Effect of availability of labour and working capital (FCFA) on maximum attainable gross margin (a) and outflow of organic matter (b).

These results suggest that availability of labour is the major limiting factor for maximisation of gross margin for a given quantity of crop residue (especially legume haulms). High levels of production per animal using concentrate is remunerative, although less than when cowpea and groundnut haulms are available.

In practice, however, utilisation of concentrates by farmers is faced with constraints, such as low availability of concentrate and/or cash required, combined with large variation in prices of animals. Under the specified feed availability and price conditions, optimum labour input level in animal feeding is 100 md per month. Without concentrate, increasing labour availability results in a linear increase in OM outflow by 14.6 kg per md till 175 md (Fig. 7.1b). Feeding concentrates increases only slightly OM outflow, because of their high organic matter digestibility.

In the above calculations, sheep were valued at 0.40 kF per kg body weight (based on the price of the animals purchased for the feeding trials in Chapters 3 and 4). When no concentrate is used, increasing this price results in a proportional increase in gross margin. For example, if the price is a factor 2 higher as is common at the time of Ramadan and Tabaski, and the household invests 25 md per month, the calculated gross margin is 50 kF instead of 24 kF.

7.2.3 Scenarios

Maintenance feeding

Households owning a cart, under current land use and quantities of stored crop residues (A) can maintain 39 animals if 200 md labour per month is available, 20 animals with 75 md, and 14 and 8 animals with 50 and 25 md respectively (Fig. 7.2). Thus, to maintain the current sheep flock (12 animals, Table 6.1) with stall feeding crop residues, a household with cart should invest 40 md per month (about 1 adult and a child) in animal feeding. Most of this labour is required for chopping stover, as feeding chopped millet and sorghum stover at maintenance in combination with cowpea and groundnut haulms for feeding at 1.2 M is selected by the model. In this situation, 2039 kg of OM, 27 kg N and 5.9 kg P are available (outflows). For households without cart (B), maximum flock size is 33, 17, 12 and 7 animals for 200, 75, 50 and 25 md, respectively. Thus, its current sheep flock (9 animals) can be maintained on the current quantities of crop residues stored, if almost 40 md per month is available for animal feeding, leading to 1755 kg OM, 21 kg N and 5 kg P outflows.

In situation C, 59 animals can be fed using excess unchopped sorghum for maintenance feeding, requiring 200 md labour per month. A maximum of 3732 kg OM, 34 kg N and 6.2 kg P may become available. In comparison to the preceding situations, this leads to an increase of 83 and 113 % for OM, 24 and 61 % for N, and 5 and 24 % for P, respectively for households with cart and without. The best strategy is feeding unchopped (excess feeding) sorghum and millet in combination with cowpea and groundnut to reach 1.2 M.

The quantities of residues available dictate the method in which stover is used (excess feeding, chopping, treatment with urea). In situations A and B, due to the low availability of crop residues, chopping is preferred, while the higher availability of residues in situation C allows utilisation of excess feeding.

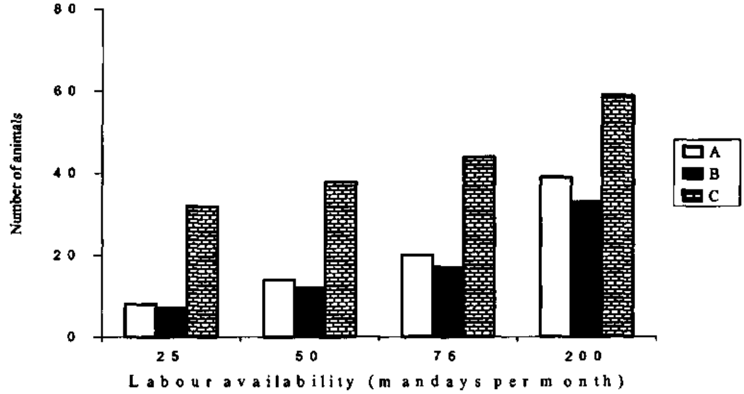

Figure 7.2. Effect of availability of labour on maximum flock size for the scenario maintenance feeding in situations A, B and C (see text for explanation)

In all situations, under low labour availability (≤ 25 md per month), excess feeding is selected. Beyond 25 md labour per month, chopped rations are used in proportion to the additional labour available.

Intensive feeding

For situation C, a maximum gross margin of 180 kF is attained with 200 md per month and 72 kF utilisation for purchase of concentrate (Fig. 7.3).

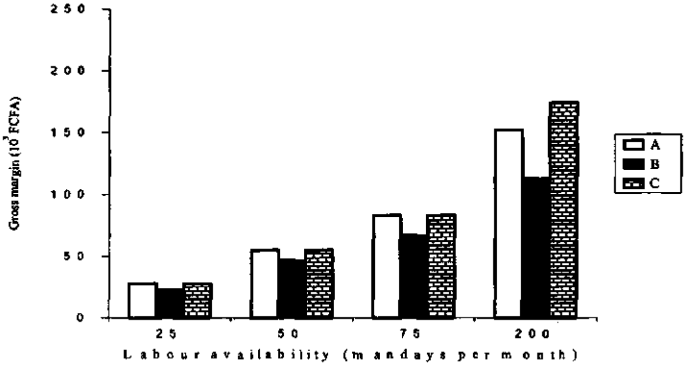

Figure 7.3. Effect of availability of labour on maximum attainable gross margin for the scenario intensive feeding, in situations A, B and C (see text for explanation).

If only 25, 50 or 75 md are available, 28, 55, and 83 kF can be attained by feeding 4, 8 and 12 animals at 2 M level. The lowest gross margins are attained in situation B, i.e. 23, 47, 67 and 94 kF, respectively for 25, 50, 75 and 200 md labour. At each level of labour availability, similar feeding activities are selected for the three situations. With 25 md labour per month, excess millet + cowpea and excess sorghum + groundnut are selected. With 50 md labour per month, excess millet + cowpea, excess sorghum + groundnut and chopped millet + cowpea are preferred. With 75 and 200 md per month, in addition to the preceding rations, chopped sorghum + groundnut is selected.

7.3 Integrated crop-sheep farming

7.3.1 Situations A and B

Ideal staple crop production for households owning a cart exceeds household requirement (2.9 t, Table 7.4). Ideal values for total and staple crop production require supply from external sources of 167-186 kg OM, 15-16 kg N and 1.0-1.1 kg P per ha to maintain balanced OM and nutrient budgets. Maximally 378, 439 and 437 kg total liveweight gain and 725, 900, and 814 kg OM surpluses per ha are attained in dry, normal and wet years, respectively. Detailed results for a normal year are given in Table 7.5. Maximum OM or nutrient surpluses are associated with < 1 t crop production, because of the small area sown, i.e. 1 ha, consisting of 0.5 ha maize, 0.4 ha sorghum and 0.1 ha groundnut. Hence, also only 3 animals can be fed at 1.2 M throughout the dry season. Ideal animal production results from 19 animals fed chopped sorghum + cowpea, 4 animals fed excess millet + cowpea, and 3 animals fed chopped sorghum + groundnut, all three rations at the highest level of feeding (2 M). Maximising livestock production or livestock gross margin is associated with a balanced P budget, while maximising crop production or crop gross margin is associated with strongly negative nutrient balances as a result of crop area expansion.

For households without cart (situation B), ideal values of total liveweight gain are much lower: 155, 199 and 265 kg in dry, normal and wet years, respectively (Table 7.4), associated with the smaller quantities of legume haulms. The detailed results for a normal year (Table 7.6) show also conflicts between crop production and gross margin on the one hand, and nutrient balances on the other. Livestock weight gain is maximised by feeding 7 animals on excess sorghum + cotton seed cake, 5 on chopped sorghum + cowpea, 5 on chopped sorghum and groundnut and 1 on excess millet + cowpea. In this situation, concentrate is required to maximise animal production because of the low availability of legume haulms. In situation A, the quantities of legume haulms are sufficient to supplement all the cereal stovers collected, therefore no concentrate is used, as the model does not allow utilisation of concentrate without roughage.

7.3.2. Situation C

Best attainable staple crop production is 6.5, 9.0 and 9.1 t in dry, normal and wet years, respectively (Tables 7.4 and 7.7), corresponding to 2-3 times the household staple requirement. For that purpose, the crop area is allocated to maize (4.1 ha) and sorghum (2.1

ha) under all climate conditions. Highest attainable livestock production is 694, 799 and 804 kg in dry, normal and wet years, respectively.

Table 7.4. Ideal values of the objective functions for integrated crop-sheep farming in dry, normal and wet years for situations A, B and C.

Objective function	Unit (per year)	Dry year	Normal year	Wet year
Situation A				
Total crop production	t	3.5	3.7	3.8
Staple crop production	t	3.2	3.4	3.5
Livestock weight gain	kg	378	439	437
Crop gross margin	kF¶	288	312	317
Livestock gross margin	kF	135	159	158
Total gross margin	kF	410	425	430
Organic matter balance	kg ha^{-1}	725	900	814
Nitrogen balance	kg ha^{-1}	20	27	20
Phosphorus balance	kg ha^{-1}	2.0	2.8	1.8
Situation B				
Total crop production	t	3.5	3.7	3.8
Staple crop production	t	3.2	3.4	3.5
Livestock weight gain	kg	155	199	265
Crop gross margin	kF	287	312	317
Livestock gross margin	kF	49	66	92
Total gross margin	kF	336	372	401
Organic matter balance	kg ha^{-1}	715	896	814
Nitrogen balance	kg ha^{-1}	13	16	17
Phosphorus balance	kg ha^{-1}	1.4	2.0	1.9
Situation C				
Total crop production	t	6.5	9.0	9.1
Staple crop production	t	6.5	9.0	9.1
Livestock weight gain	kg	694	799	804
Crop gross margin	kF	411	446	453
Livestock gross margin	kF	189	194	194
Total gross margin	kF	492	515	522
Organic matter balance	kg ha^{-1}	794	852	731
Nitrogen balance	kg ha^{-1}	32	51	52
Phosphorus balance	kg ha^{-1}	2.5	5.5	2.6

¶ 1 kF = 1000 FCFA (10 FF)

Table 7.5. Solution areas of the objective functions for integrated crop-sheep farming in normal years for situation A.

Objective function	Unit (per year)	TCP	SP	WG	CGM	LGM	TGM	OMB	NB	PB
Total crop production (TCP)	t	**3.7**	3.6	2.2	3.5	2.2	3.4	0.9	<u>0.5</u>	<u>0.5</u>
Staple crop production (SP)	t	3.4	**3.4**	2.0	3.0	2.0	3.1	0.9	<u>0.5</u>	<u>0.5</u>
Livestock Weight gain (WG)	kg	185	246	**439**	137	436	332	<u>30</u>	148	148
Crop gross margin (CGM)	kF[¶]	297	280	184	**312**	187	304	52	<u>44</u>	<u>44</u>
Livestock gross margin (LGM)	kF	60	83	157	43	**159**	121	<u>7</u>	49	49
Total gross margin (TGM)	kF	356	363	341	355	346	**425**	<u>59</u>	93	93
Organic matter balance (OMB)	kg ha^{-1}	-186	-167	-134	-206	-141	<u>-205</u>	**900**	745	745
Nitrogen balance (NB)	kg ha^{-1}	<u>-16</u>	-15	-1	-15	-1	-13	<u>-16</u>	**27**	27
Phosphorus balance (PB)	kg ha^{-1}	-1.1	-1.0	0.1	<u>-1.2</u>	0.1	-1.0	0.2	2.8	**2.8**

Bold = ideal values; Underlined = anti-ideal values; [¶] 1 kF = 1000 FCFA (10 FF)

Table 7.6. Solution areas of the objective functions for integrated crop-sheep farming in normal years for situation B.

Objective function	Unit (per year)	TCP	SP	WG	CGM	LGM	TGM	OMB	NB	PB
Total crop production (TCP)	t	**3.7**	3.6	2.9	3.5	2.8	3.4	0.9	0.6	0.6
Staple crop production (SP)	t	3.4	**3.4**	2.7	3.0	2.6	3.0	0.9	0.6	0.6
Livestock Weight gain (WG)	kg	116	104	**199**	123	197	183	21	41	41
Crop gross margin (CGM)	kF[¶]	297	280	247	**312**	245	311	51	46	46
Livestock gross margin (LGM)	kF	34	28	66	39	**66**	62	37	10	10
Total gross margin (TGM)	kF	330	308	312	351	311	**372**	55	56	56
Organic matter balance (OMB)	kg ha^{-1}	-208	-196	-226	-208	-232	-210	**896**	810	810
Nitrogen balance (NB)	kg ha^{-1}	-18	-18	-9	-15	-9	-15	-18	**16**	15.9
Phosphorus balance (PB)	kg ha^{-1}	-1.3	-1.3	-0.8	-1.2	-0.8	-1.2	0.1	2.0	**2.0**

Bold = ideal values; Underlined = anti-ideal values; [¶] 1 kF = 1000 FCFA (10 FF)

Table 7.7. Solution areas of the objective functions for integrated crop-sheep farming in normal years for situation C.

Objective function	Unit (per year)	TCP	SP	WG	CGM	LGM	TGM	OMB	NB	PB
Total crop production (TCP)	t	**9.0**	9.0	2.4	6.7	<u>1.3</u>	6.0	2.2	1.9	<u>1.3</u>
Staple crop production (SP)	t	9.0	**9.0**	1.5	6.7	<u>1.3</u>	5.9	2.2	1.4	<u>1.3</u>
Livestock Weight gain (WG)	kg	<u>0</u>	<u>0</u>	**799**	<u>0</u>	532	268	494	718	532
Crop gross margin (CGM)	kF¶	313	313	101	**446**	58	417	80	<u>36</u>	58
Livestock gross margin (LGM)	kF	0	0	<u>-200</u>	0	**194**	98	17	-74	194
Total gross margin (TGM)	kF	313	313	<u>-99</u>	446	252	**515**	97	-38	252
Organic matter balance (OMB)	kg ha^{-1}	-90	-90	137	<u>-241</u>	315	-236	**852**	290	315
Nitrogen balance (NB)	kg ha^{-1}	<u>-45</u>	<u>-45</u>	23	-38	29	-42	12	**51**	29.0
Phosphorus balance (PB)	kg ha^{-1}	-1.4	-1.4	2.4	<u>-2.8</u>	5.5	-2.2	3.3	3.9	**5.5**

Bold = ideal values; Underlined = anti-ideal values; ¶ 1 kF = 1000 FCFA (10 FF)

In a dry year, this is attained by feeding 43 animals on excess millet + groundnut at 1.4 M and 23 animals on excess millet + cotton seed cake at 2 M, requiring high inputs of concentrate: 6.5 t cotton seed cake costing 392 kF per year. In a normal year, up to 81 animals can be fed: 58 on excess millet + groundnut at 1.4 M and 23 on excess sorghum + cotton seed cake at 2 M. The situation is similar for a wet year where 1 more animal can be fed on excess millet + groundnut.

The optimised objective function determines the land allocation patterns. When staple crop production is maximised, the total land is allocated to maize and sorghum only, because of their higher response to fertiliser than the other crops. However, when animal production is maximised, maize is not planted, because maize stover is assumed not to be collected for stall feeding. This assumption was based on the fact that maize is often harvested when it is still raining, while a suitable storage structure is lacking. Also in dry years, millet and groundnut are planted to allow maximisation of livestock weight gain, because of their resistance to drought and their values as animal feed. Ideal total gross margin of the farm in a normal year is 515 kF, consisting of 80 % from crops and 20 % from livestock. For that purpose, farm land is allocated to maize (3.6 ha), cowpea (1.1 ha), millet (0.6 ha), sorghum (0.5 ha) and groundnut (0.4 ha). The corresponding staple crop production is 5.9 t, one third lower than the ideal value, but still twice the food requirement of the household. This allows feeding of 3 animals with excess sorghum + groundnut and 12 animals with chopped millet + cowpea, both at 2 M. Highest attainable values of OM, N and P surpluses (852, 51 and 5.5 kg ha^{-1} for OM, N and P, respectively) are associated with a small cultivated area.

7.3.3 Nutrient budgets and farm productivity

There is a conflict between nutrient budgets and crop production, and also between crop and livestock production (Table 7.7). Maximisation of crop production is associated with expansion of the crop area, leading to labour shortage in the harvest period to manage crop residues. As a consequence, no animals can be stall fed and only the OM, N and P from residues left in the fields at the onset of the rainy season, manure from grazing animals and household organic wastes are returned to cropland. Availability of labour is the main constraint for the integration of crop and livestock stall feeding. To maximise production, some external inputs are required, which may result in a lower gross margin. The negative relation between crop and livestock production on the one hand and gross margin on the other is the result of output:input price ratios.

More details on trade-offs between nutrient budgets and farm production indicators are obtained by progressively tightening OM, N and P balances, while maximising farm gross margin. Figure 7.4a shows that potentially 6.2 t total crop production can be attained in a normal year with balanced OM, N and P budgets on 5.2 ha. Similar or higher levels of production can be attained with negative nutrient balances, by expanding the crop area. Sustainable production (in terms of balanced OM, N and P budgets), which requires investment of labour (and/or capital) in crop residue, manure and fertiliser management, is

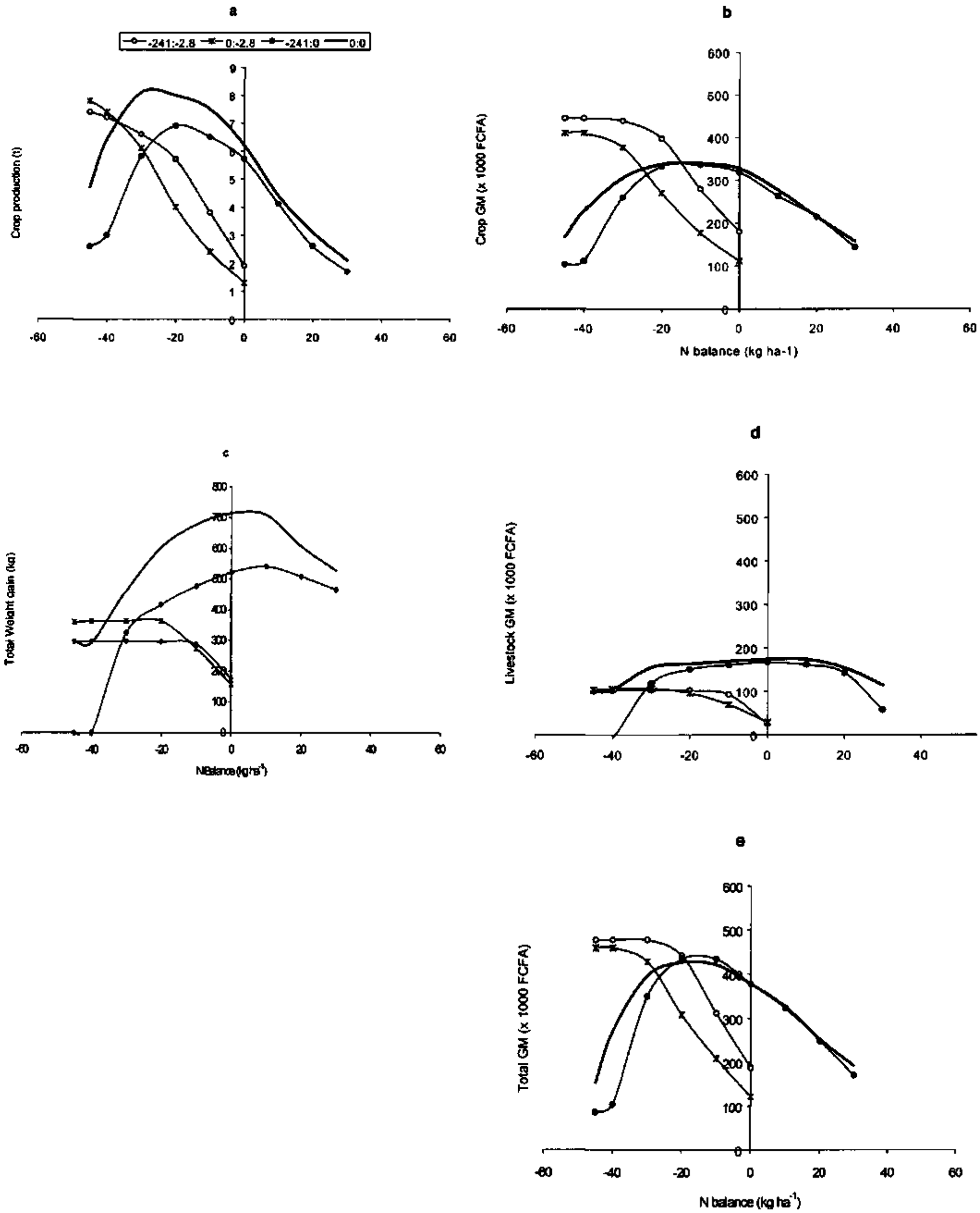

Figure 7.4. Total crop production (a) and crop gross margin (b), livestock weight gain (c) and livestock gross margin (d), and total farm gross margin (e) as affected by nitrogen (N) and organic matter:phosphorus (OM:P) balances for a normal year in situation C.

associated with higher yields per unit area and smaller crop areas. Lack of such investments leads to soil nutrient depletion and the lower yields per ha lead to expansion of the crop area (to its upper bounds in the present case) to attain the same level of production. It appears that P is the most limiting factor for crop production in the region. Maximum crop production under balanced nutrient budgets (6.2 t) corresponds to 327 kF gross margin. With a slighly higher production, crop gross margin can be increased to 439 kF when 241 kg OM, 30 kg N and 2.8 kg P per ha are "mined" from the soil (Fig. 7.4b). This clearly indicates that application of inorganic fertilisers at current prices is not remunerative, although it results in higher yields and may sustain long-term productivity of the soil.

For livestock (Fig. 7.4c), a maximum of 714 kg total liveweight gain is attained in a production system with balanced OM, N and P budgets. The production is lower under nutrient depletion conditions, as the associated larger crop area causes labour shortage in the harvest period, hence smaller quantities of crop residues are available for stall feeding. The utilisation of concentrates increases OM, N and P outflow from animal feeding, and reduces inorganic fertiliser requirement. Maximum total gross margin under balanced nutrient budgets is associated with maximum livestock gross margin (173 kF). However, the higher livestock gross margin attained does not compensate for the lower crop gross margin, leading to lower total gross margin than in the extensive production situation (377 vs 477 kF). Hence, a 21 % reduction in farm gross margin, combined with investment in labour for residue management and capital for purchase of external inputs (fertilisers and concentrate), must be accepted to intensify crop-livestock production under balanced nutrient budget conditions.

7.3.4 Management of organic matter resources and the objective functions

Four specific organic matter management techniques are included in HOREB: composting, sheep feeding, mulching and burning. Organic matter available within the household comprises household waste, animal faeces and refusals from stall fed sheep, and manure from grazing animals, which may be used as compost or manure. Crop residues remaining in the field are used as such (mulch and incorporated in the soil by ploughing) or burned. This gives the combinations compost-mulch, compost-ash, manure-mulch and manure-ash. Differences in values of the objective functions for these combinations are small for indicators related to crop production (Table 7.8). This is partly due to the small quantities of organic matter left in the field at the end of the dry season (removed by grazing, hence very little is ploughed in or burnt). Also the labour shortage associated with maximising crop production limits the number of animals fed, hence manure or compost availability. Burning leads to lower OM balances. The main determining factor for N and P budgets is the choice between composting and utilisation of animal excreta as manure. Utilisation as manure leads to high losses of nutrients, resulting in lower maximum attainable balances. In terms of sustainability indicators, the combination compost-mulch is the best strategy.

7.3.5 Household resources and the objective functions

Availability of labour

When maximising total gross margin, values of the objective functions in the situation without external inputs are highly sensitive to labour availability (Table 7.9).

Table 7.8. Ideal values of the objective functions for integrated crop-sheep farming for different organic matter resource management techniques in a normal year.

Objective function	Unit (per year)	CM	CA	NM	NA
Total crop production	t	9.0	9.3	9.0	9.4
Staple crop production	t	9.0	9.3	9.0	9.4
Livestock weight gain	kg	799	780	810	810
Crop gross margin	kF¶	446	448	443	446
Livestock gross margin	kF	194	194	196	196
Total gross margin	kF	515	515	514	515
Organic matter balance	kg ha^{-1}	870	657	858	647
Nitrogen balance	kg ha^{-1}	51	51	23	23
Phosphorus balance	kg ha^{-1}	2.6	2.6	2.3	2.3

CM = compost-mulch; CA= compost-ash; NM= manure-mulch, NA= manure-ash.
¶ 1 kF = 1000 FCFA (10 FF)

Table 7.9. Values of the objective functions in a normal year, when maximising total gross margin, at various levels of labour availability.

Objective function	Unit (per year)	Labour availability (mandays per month)					
		50	100	150	200	250	300
Total crop production	t	0.1	1.8	4.0	5.0	7.3	7.1
Staple production	t	0.1	1.8	3.8	4.8	7.3	7.1
Livestock weight gain	kg	0	187	209	232	337	498
Livestock gross margin	kF¶	0	68	76	85	123	182
Crop gross margin	kF	7	111	267	403	459	450
Total gross margin	kF	7	179	343	488	582	631
Organic matter balance	kg ha^{-1}	800	185	-144	-196	-185	-162
Nitrogen balance	kg ha^{-1}	-3	-15	-30	-35	-48	-40
Phosphorus balance	kg ha^{-1}	0.1	-0.1	-1.4	-2.0	-2.2	-1.6

¶ 1 kF = 1000 FCFA (10 FF)

Restriction of labour availability to 50 md per month results in negligible crop production (0.1 t). The current family staple requirements could be met with 150 md per month labour, corresponding to 343 kF gross margin, composed of 76 from livestock and 267 from crops. Crop and livestock production and gross margin increase with increasing labour availability up to 250-300 md, associated with increasingly negative OM and nutrient balances, due to expansion of the crop area. With 50 md labour per month, 0.2 ha can be cultivated with sorghum and no animal can be fed. When 100 md labour is available, 1.8 ha is used, for cowpea (0.6 ha), millet (0.6 ha) and maize (0.6 ha) and allows feeding of 11 animals, using chopped millet + cowpea at 2 M. The crop area increases to 4 ha with 150 md labour availability and reaches the maximum (6.2) when 250 md labour is available. The maximum return to labour is 0.20 kF per manday, corresponding to 200 md, where the total farm is cultivated. At the point of maximum return to labour, the quantities of N lost could be valued at 97 kF (at urea price), which represents 20 % of farm gross margin. Increasing labour availability results in higher gross margin through expansion of crop area, at the expense of soil nutrients.

Availability of working capital

When maximising total gross margin, availability of working capital when ≤ 50 kF has only a small effect on the objective functions (Table 7.10). Only a small part of the capital available for crop production is used, because utilisation of fertilisers is not remunerative, and at the same time the required labour for livestock production is limited by the necessary expansion of crop area. A maximum of 16 kF is used to purchase fertiliser, and because only small quantities of cereal stovers could be stored, no concentrate is used. These results illustrate that labour availability is the major factor limiting the integration of crops and animal stall feeding.

Table 7.10. Values of the objective functions in a normal year, when maximising total gross margin, at various levels of working capital availability

Objective function	Unit (per year)	Availability of working capital (kF)				
		0	50	100	200	400
Total crop production	t	5.5	5.7	5.7	5.7	5.7
Staple production	t	5.4	5.6	5.6	5.6	5.6
Livestock weight gain	kg	263	254	254	254	254
Livestock gross margin	kF¶	96	93	93	93	93
Crop gross margin	kF	416	423	423	423	423
Total gross margin	kF	512	516	516	516	516
Organic matter balance	kg ha^{-1}	-249	-217	-217	-217	-217
Nitrogen balance	kg ha^{-1}	-38	-38	-38	-38	-38
Phosphorus balance	kg ha^{-1}	-2.0	-2.0	-2.0	-2.0	-2.0

¶ 1 kF = 1000 FCFA (10 FF)

Availability of land

Crop production increases with increased availability of land (Table 7.11) till 6 ha, when labour availability becomes constraining. Gross margin from livestock decreases when land area increases. This is due to reduced labour availability for crop residue collection and storage when the crop area expands. Livestock production and gross margin decrease with the increase in crop production and gross margin, because increased crop production is associated with expansion of crop area. This illustrates the competition for labour between animal feeding and cropping activities, mainly in the harvest period when at the same time crop residues must be collected and stored. The surplus labour is only invested in animal production, when there is no opportunity for off-farm employment in that period. Organic matter balance decreases with increasing crop area and is negative beyond 2 ha land. Maximisation of total gross margin results in negative N and P balances at all levels of land availability. When cultivated land is ≥ 4 ha a balanced OM budget can be attained at 125 md per month labour (Fig. 7.5). When farm size ≥ 4 ha and more than 125 md labour is available, OM balance is negative. With ≥ 150 md, OM balance tends to increase with labour availability for farms of 2 and 4 ha, because additional labour is available for management of more crop residues. These results indicate that households cannot attain a balanced OM budget using the current total land area of 6.2 ha.

Table 7.11. Values of the objective functions in a normal year, when maximising total gross margin, at various farm sizes

Objective function	Unit (per year)	Farm size (ha)				
		2	4	6	8	10
Total crop production	t	1.5	4.1	5.9	5.7	5.7
Staple production	t	1.5	4.1	5.9	5.6	5.6
Livestock weight gain	kg	460	315	276	254	254
Livestock gross margin	kF¶	168	115	101	93	93
Crop gross margin	kF	142	312	412	423	423
Total gross margin	kF	310	427	512	516	516
Organic matter balance	kg ha^{-1}	217	-91	-319	-217	-217
Nitrogen balance	kg ha^{-1}	-15	-48	-45	-38	-38
Phosphorus balance	kg ha^{-1}	-1.2	-2.2	-2.2	-2.0	-2.0

¶ 1 kF = 1000 FCFA (10 FF)

7.3.6 Scenarios

Food security with extensive sheep feeding (FS I)

In an extensive feeding situation, animals roam freely during daytime and are housed in the night throughout the dry season, the main objective being maximisation of staple crop production. A substantial part (≥ 50 %) of the faeces and urine is excreted during grazing. Maximum attainable staple production is sufficient to meet the household requirement for staple food (Table 7.12). The optimum land allocation of the farm that matches this objective is 2.7 ha sorghum, 1.2 ha millet, 0.7 ha cowpea and 0.5 ha maize. These results suggest that food requirements can be met with 5.1 ha, hence 1.1 ha could be left as fallow land. In this scenario, food security is achieved in normal years, but this results in high soil nutrient depletion. The maximum staple production attained in dry and wet years just meets household food requirements.

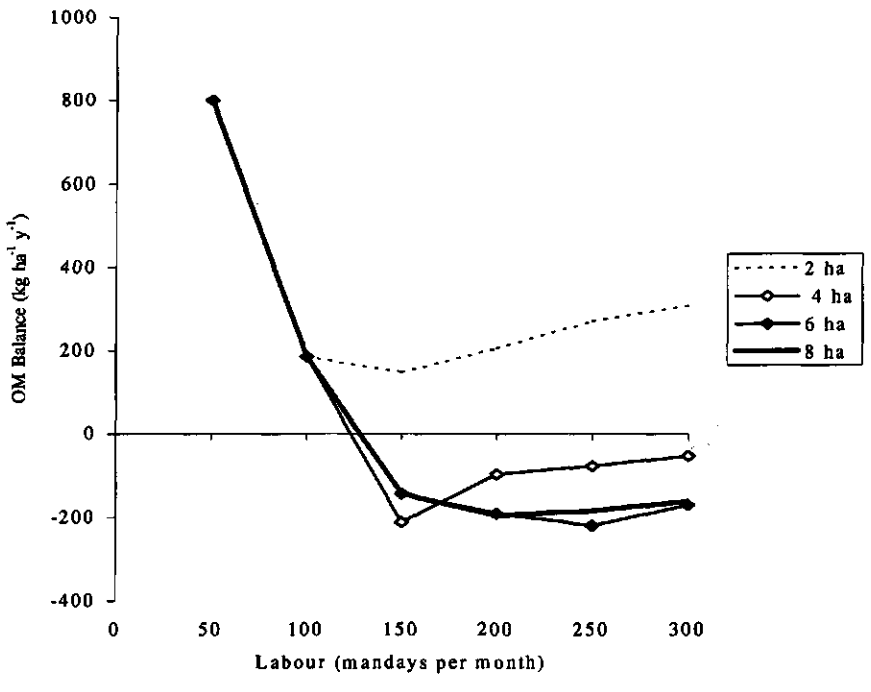

Figure 7.5. Effect of labour availability and farm size on organic matter balance for a normal year, when maximising total gross margin.

Taking into account unavoidable losses during transport and storage, food security is critical in such years. Organic matter loss is 200-344 kg per ha, corresponding to a total annual loss of 1.0-1.7 t for the 5.1 ha cultivated land. Also 15-21 kg N per ha is lost, while P loss is estimated at 1.5-1.8 kg per ha.

Food security with stall feeding of sheep (FS II)

In this scenario, sheep are assumed to be stall-fed while maximising total gross margin. Under all climate conditions, 5.7 ha land is used, for sorghum (2.7 ha), millet (1.2 ha), cowpea (0.7 ha), groundnut (0.6 ha) and maize (0.5 ha), leaving the remaining 0.5 ha as fallow. Maximum crop production attained is 3.2 t in dry years and 3.5 t in normal and wet years, composed of 3.1-3.3 t staple and 0.1-0.2 t groundnut (Table 7.13). The 14 kF available to buy fertiliser is not actually used, because fertiliser is not remunerative. In a dry year, 15 animals can be maintained at a medium level of production (1.6 M), using excess sorghum + cowpea (7 animals), excess sorghum + groundnut (7 animals) and excess millet (1 animal), while 3 animals are at 2 M, using excess millet + cowpea (2) and excess sorghum + cowpea (1). This is possible because haulms are available, as 0.7 ha and 0.6 ha, respectively, are allocated to cowpea and groundnut. This results in 180 kg total weight gain, providing an additional 60 kF to the household.

Table 7.12. Optimisation results for the scenario food security with extensive feeding of sheep (FS I), when maximising staple production.

Objective function	Unit (per year)	Dry year	Normal year	Wet year
Total crop production	t	2.9	3.2	2.9
Staple crop production	t	2.9	3.2	2.9
Livestock weight gain	kg	0	0	0
Crop gross margin	kF¶	231	253	239
Livestock gross margin	kF	0	0	0
Total gross margin	kF	231	253	239
Organic matter balance	kg ha^{-1}	-335	-344	-200
Nitrogen balance	kg ha^{-1}	-19	-21	-15
Phosphorus balance	kg ha^{-1}	-1.7	-1.8	-1.5

¶ 1 kF = 1000 FCFA (10 FF)

Table 7.13. Optimisation results for the scenario food security with stall feeding of sheep (FS II), when maximising total gross margin

Objective function	Unit (per year)	Dry year	Normal year	Wet year
Total crop production	t	3.2	3.5	3.5
Staple crop production	t	3.1	3.3	3.3
Livestock weight gain	kg	180	246	250
Crop gross margin	kF¶	265	282	287
Livestock gross margin	kF	60	87	88
Total gross margin	kF	325	369	375
Organic matter balance	kg ha^{-1}	-176	-175	-192
Nitrogen balance	kg ha^{-1}	-13	-15	-12
Phosphorus balance	kg ha^{-1}	-1.1	-1.2	-1.1

¶ 1 kF = 1000 FCFA (10 FF)

In normal and wet years, similar areas of cowpea and groundnut are cultivated, but their higher yields allow feeding of 19 animals, i.e. 9 on excess sorghum + groundnut at 1.6 M, 8 on excess sorghum + cowpea at 2 M, 1 on excess sorghum + cowpea at 1.6 M and 1 on excess millet at 1.4 M. Total weight gain realised is 246 and 250 kg, corresponding to 87 and 88 kF gross margin in normal and wet years, respectively. A total of 16 md labour per month is required to store residues, while 108 md per month is used for feeding in the period of December to May. The availability of legume haulms is sufficient to supplement all collected cereal residues, hence no concentrate is used. The most constraining factor appears labour availability during the harvest period, as only labour not required for cropping can be used for residue collection. In comparison to FS I, total gross margin is on average 18, 24 and 23 % higher, respectively in dry, normal and wet years. OM and nutrient outflow from sheep stall feeding reduced the deficits by 4-91 % for OM, 25-46 % for N and 25-46 % for P. However 175-192 kg OM, 12-15 kg N and 1.1-1.2 kg P per ha are mined annually from cropland.

Sustainable integrated crop-sheep farming without external inputs (SP I)

In this scenario, 3.1 t crops (grains, seeds and unshelled nuts) can be produced in a normal year (Table 7.14), using 5.1 ha of land, for sorghum (2.7 ha), millet (1.2 ha), maize (0.5 ha), cowpea (0.4 ha) and groundnut (0.3 ha). Thus 1.1 ha can be left as fallow land. This allows feeding of 26 animals, on excess millet at 1.2 M (17 animals) and excess sorghum + cowpea at 1.6 M (9 animals). As an advantage compared to the FS I scenario, 149 kg total weight gain is produced, yielding 44 kF gross margin, and 2.2 t organic matter outflow from animal manure and refusals. This allows to attain a balanced OM budget, compared to the deficit of 344 kg ha^{-1} in FS I, but requires investment of 18 md labour for residue collection and 114 md per month for feeding. In dry years, land is allocated to sorghum (2.7 ha), millet (1.2 ha), cowpea (0.7 ha), maize (0.5 ha), groundnut (0.3 ha) and 0.7 fallow. Hence, food requirements can be met in dry years, by slightly expanding the crop area.

Table 7.14. Optimisation results for the scenario sustainable crop-sheep farming without external inputs (SP I), when maximising total gross margin (1 kF = 1000 FCFA (10 FF)).

Objective function	Unit (per year)	Dry year	Normal year	Wet year
Total crop production	t	3.0	3.1	3.0
Staple crop production	t	2.9	3.0	3.0
Livestock weight gain	kg	157	149	131
Crop gross margin	kF	241	247	229
Livestock gross margin	kF	47	44	37
Total gross margin	kF	288	291	266
Organic matter balance	kg ha^{-1}	0	0	0
Nitrogen balance	kg ha^{-1}	-15	-18	-6
Phosphorus balance	kg ha^{-1}	-0.9	-1.0	-0.8

Animal production techniques comprise feeding 17 animals using excess millet at 1.2 M and 10 animals using excess sorghum + cowpea at 1.6 M, giving 157 kg total weight gain, 47 kF gross margin and 2.2 t organic matter. To achieve sustainability in terms of N and P balances, 6 to 18 kg N and 0.8-1 kg P per ha should be supplied from external sources annually. The negative N balance, at a balanced OM budget is associated with an increase in C/N ratio of soil OM, which eventually will lead to a lower rate of decomposition.

Sustainable integrated crop-sheep farming with external input (SP II)

In this scenario, food security was combined with OM and N balances set to ≥ 0, while maximising total gross margin (Table 6.9). In dry years, 5 ha is actually cultivated, with sorghum (2.4 ha), millet (1.2 ha), cowpea (0.7 ha), groundnut (0.6 ha), and maize (0.1 ha), giving a total staple production of 2.9 t (Table 7.15). This production requires 77 kF for fertiliser. Animal production techniques consist of feeding excess sorghum + cowpea (12 animals), chopped sorghum + groundnut (6 animals), chopped millet + cotton seed cake (3 animals), urea-treated millet + cotton seed cake (3 animals), all rations at the highest level of feeding (2 M). This yields 404 kg total weight gain, 181 kF gross margin and 1.7 t OM in the form of manure (faeces and feed refusals). This level of animal production requires 25 kF for concentrate. The required labour for residue collection and storage is a factor 3.4 higher than in scenario SP I (61 vs 18 md), because of the higher number of animals required to minimise fertiliser utilisation (required balanced OM and nutrient budgets). In normal years, higher total gross margin is attainable, as higher crop production is possible. Farm land is then allocated to sorghum (2.7 ha), millet (1.2 ha), cowpea (0.7 ha), groundnut (0.6 ha), maize (0.1 ha) and 0.9 ha fallow.

Table 7.15. Optimisations results for the scenario sustainable crop-sheep farming with external inputs (SP II), when maximising total gross margin

Objective function	Unit (per year)	Dry year	Normal year	Wet year
Total crop production	t	3.0	4.7	3.8
Staple crop production	t	2.9	4.5	3.6
Livestock production	t	404	382	408
Crop gross margin	kF¶	122	227	216
Livestock gross margin	kF	181	139	148
Total gross margin	kF	303	367	364
Organic matter balance	kg ha^{-1}	0	0	0
Nitrogen balance	kg ha^{-1}	0	0	0
Phosphorus balance	kg ha^{-1}	0.5	1.0	0.8

¶ 1 kF = 1000 FCFA (10 FF)

The larger quantities of residues induce different feeding strategies. Excess sorghum + cowpea is fed to 16 animals, excess sorghum + groundnut to 6 animals, and urea-treated sorghum + groundnut to 1 animal, all at 2 M. Only 0.25 kF is used for urea, because of the higher availability of legume haulms compared to dry years. In wet years, maximum farm gross margin is associated with a smaller crop area (4.5 ha), allowing collection of a larger quantities of crop residues: 1.7 ha sorghum, 1.2 ha millet, 0.7 ha cowpea, 0.6 ha groundnut, 0.3 ha maize, while 11 kF is invested in fertiliser. A total of 23 animals is fed, on excess sorghum + cowpea (16 animals), excess sorghum + groundnut (2 animals), chopped sorghum + groundnut (3 animals) and urea-treated sorghum + groundnut (2 animals). Despite the slightly higher weight gain than in a normal year, livestock gross margin is lower, because of the costs of purchased urea.

Especially in the SP II scenario, cereal crop residues are offered in 3 different ways, i.e. unchopped, chopped and treated with urea. Because in actual practice, a farmer will usually select one way, in subsequent runs the alternative feeding methods were considered separately. In a normal year, restricting animal feeding activities to unchopped stover (excess feeding) does not significantly change the values of any of the objective functions (Tables 7.15 and 7.16). When only chopped stover is offered, livestock gross margin decreases slightly because of the investment in concentrate, while with excess feeding no concentrate is required. With the option of urea-treated stover only, values of all objective functions are lower, especially that of livestock gross margin, because use of urea for stover treatment is not remunerative. Under the current urea price and labour availability conditions, excess feeding is the best method for sustainable crop-sheep farming.

Table 7.16. Effect of feeding methods on values of the objective functions in the scenario sustainable crop-sheep farming with external inputs (SP II) in a normal year, when maximising total gross margin

Objective function	Unit (per year)	Excess feeding	Chopping	Treatment with urea
Total crop production	t	4.9	4.8	3.9
Staple crop production	t	4.6	4.6	3.7
Livestock weight gain	t	381	382	62
Crop gross margin	kF¶	227	225	184
Livestock gross margin	kF	139	128	1
Total gross margin	kF	366	354	185
Organic matter balance	kg ha^{-1}	0	0	0
Nitrogen balance	kg ha^{-1}	0	0	0
Phosphorus balance	kg ha^{-1}	1.1	1.1	1.3

¶ 1 kF = 1000 FCFA (10 FF)

7.3.7 Animal nutrient requirements and the objective functions

Calculations of technical coefficients for animal production were based on the assumption that animals require 2.4 g digestible organic matter per g liveweight gain and 1 g live weight contains 0.025 g N (Chapter 6). Assuming that 2.0 g digestible organic matter is required per g liveweight gain, livestock production increases with 20 %, livestock gross margin with 22-27 % (depending on the scenario) and total gross margin with 4-8 %. Values related to crop production and nutrient balances are hardly affected (Table 7.17).

7.3.8 Sustainability indicators and economic objectives

Sustainable land use as defined in the present study (balanced budgets of OM, N and P) conflicts with economic profitability at current prices. In extensive production (SF I), farm gross margin (only crop production) attains 253 kF in normal years at the expense of soil nutrients (Fig. 7.6a). Up to 344 kg OM, 21 kg N and 1.8 kg P are mined per ha cultivated land. Introduction of stall feeding of sheep without external inputs (FS II) results in an additional 87 kF gross margin from animal production while crop gross margin increases to 282 kF, hence total gross margin increases to 369 kF. This livestock gross margin corresponds to a return to labour of 0.37 kF per md that is lower than the labour wage in the region. This is associated with nutrient depletions of 175 kg OM, 15 kg N and 1.2 kg P per ha, corresponding to 269 kF when valued at fertiliser and stover (for OM) prices, or 27 % of the farm gross margin. A balanced OM budget without external inputs (SP I) is associated with lower total gross margin than FS II (291 kF), because of a substantial decrease in livestock gross margin (87 vs 44 kF). This is due to the shift from high levels of feeding to maintenance feeding, necessary to meet the crop land OM requirements. Availability of external input (SP II) results in improvement of farm gross margin compared to SP I. The attained total gross margin is comparable to that attained without external inputs (FS II), but balanced nutrient budgets can be attained. This requires a total of 600 kg fertiliser (NPK 12: 24: 12), corresponding to 144 kF, 125 md labour per month for animal feeding, and a total of 61 md labour for crop residue collection and storage. Crop residue management in stall feeding in sustainable farming perspective is very labour intensive and associated with low remuneration for labour. The farmer may be willing to invest that labour, because no off-farm employment opportunities exist. However, then he may still not be able to invest in the required quantities of fertilisers and concentrates.

7.4 Comparison of model results with current situation

The objective of the present study was to assess the possibilities for optimum management of crop residues in sustainable crop-livestock production perspective. Stall feeding was especially examined as livestock component.

Table 7.17. Effect of digestible organic matter requirements per g liveweight gain/concentration (%) of nitrogen in the liveweight gain, on values of the objective functions in the different scenarios

Objective function	Unit (per year)	2.4/2.5	2.4/3.6	2.0/2.5	2.0/3.6
Scenario FS II					
Total crop production	t	3.5	3.5	3.5	3.5
Staple crop production	t	3.3	3.3	3.3	3.3
Livestock weight gain	t	246	246	295	295
Crop gross margin	kF¶	282	282	282	282
Livestock gross margin	kF	87	87	106	106
Total gross margin	kF	369	369	388	388
Organic matter balance	kg ha^{-1}	-175	-175	-175	-175
Nitrogen balance	kg ha^{-1}	-15	-16	-15	-16
Phosphorus balance	kg ha^{-1}	-1.2	-1.2	-1.2	-1.2
Scenario SP I					
Total crop production	t	3.1	3.1	3.1	3.1
Staple crop production	t	3.0	3.0	3.0	3.0
Livestock weight gain	t	149	149	179	179
Crop gross margin	kF	247	247	247	247
Livestock gross margin	kF	44	44	56	56
Total gross margin	kF	291	291	303	303
Organic matter balance	kg ha^{-1}	0	0	0	0
Nitrogen balance	kg ha^{-1}	-18	-18	-18	-19
Phosphorus balance	kg ha^{-1}	-1.0	-1.0	-1.0	-1.0
Scenario SP II					
Total crop production	t	4.7	4.6	4.7	4.5
Staple crop production	t	4.5	4.4	4.4	4.3
Livestock weight gain	t	382	387	460	467
Crop gross margin	kF	227	222	225	218
Livestock gross margin	kF	139	141	170	172
Total gross margin	kF	367	363	395	391
Organic matter balance	kg ha^{-1}	0	0	0	0
Nitrogen balance	kg ha^{-1}	0	0	0	0
Phosphorus balance	kg ha^{-1}	1.0	1.1	1.1	1.2

¶ 1 kF = 1000 FCFA (10 FF)

The results show that potentially, a household can produce 9 t grains and seeds in normal years, if 45 kg N and 1.4 kg P per ha can be supplied from external sources to maintain equilibrium in soil nutrient stocks (situation C, Table 7.7). Simulation of the current situation results in 2.9-3.2 t staple crop production, depending on rainfall (scenario FS I, Table 7.12). Crop production meets the staple food requirements of the household in normal years, but is critical in dry and wet years (post-harvest losses and seed requirements are not taken into account). Comparison between SP I and SP II in a normal year (860 mm rainfall) shows that fertilisers increase crop production (3.1 (544 kg per ha) vs 4.7 t (921 kg per ha) but result in slightly lower crop gross margin, suggesting that fertilisers are not remunerative. Utilisation of concentrate in animal feeding is remunerative, although the returns to labour are lower than current labour wages.

These results are consistent with information on the current situation in the region. Food security is generally attained in most years in Zoundwéogo (De Graaff, 1997). Using crop yields reported by MARA (1995), the total staple production attained in normal year (850 mm, 1986) was 4.3 t, which is a factor 1.5 higher than households staple requirements. This level of production is in the range values obtained in the different scenarios. The most important issue in the area is nutrient depletion, which is connected to longer run food security. Under extensive production system (scenario FS I), 200-344 kg OM, 15-21 kg N and 1.5-1.8 kg P per ha is mined from cultivated land (scenario FS I, Table 7.12), depending on rainfall. These results are consistent with those reported by Stroosnijder (1995) and De Graaff (op. cit.), i.e. N losses of 20-23 kg per ha (under 700 mm rainfall, which correspond to dry years in this study) when soil conservation measures (stone bunds) are not applied and 14-15 kg with stone bunds (estimations based on Stoorvogel and Smaling, 1990).

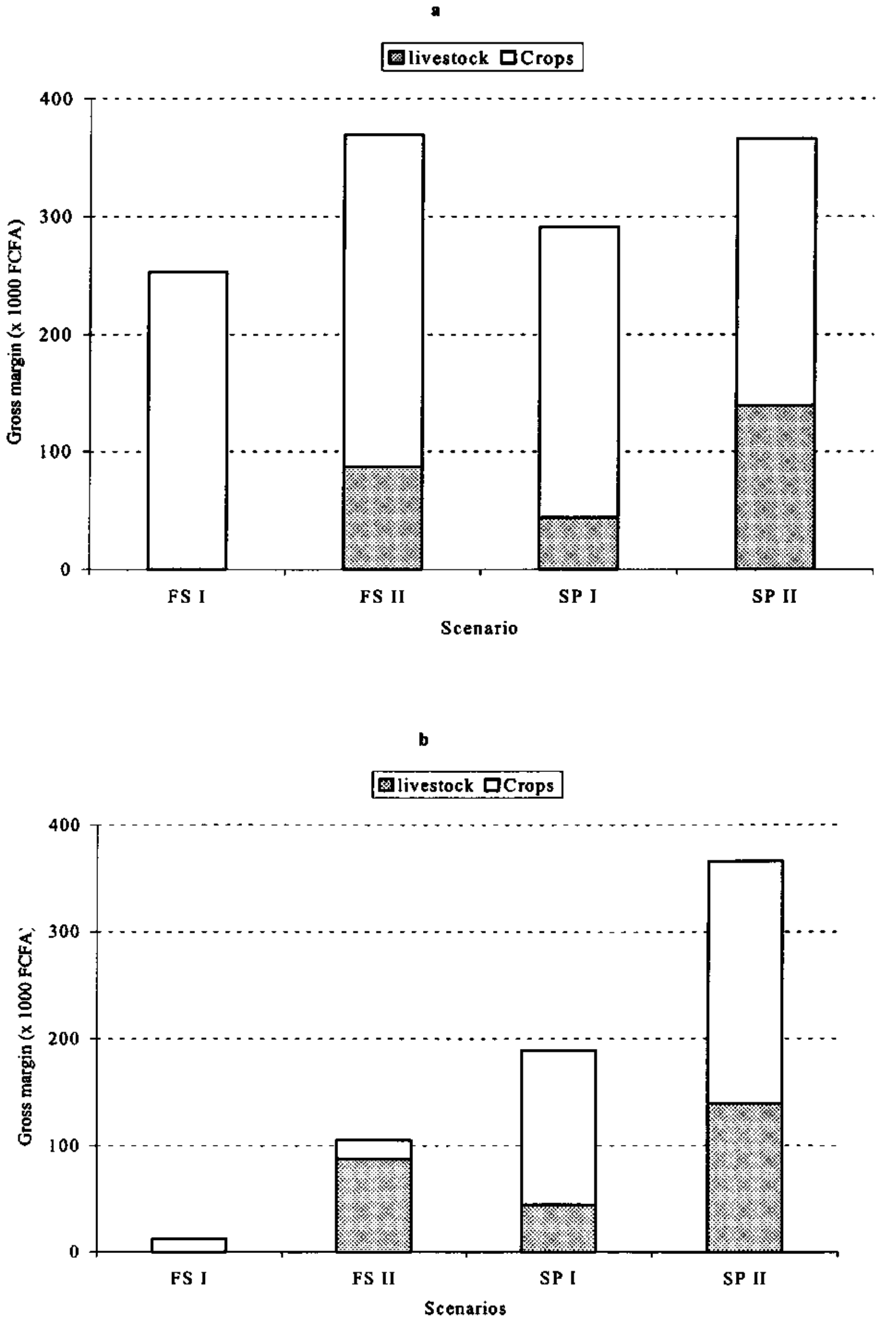

Fig. 7.6. Contribution of crops and livestock to farm gross margin in the different scenarios, when soil depletion is not valued (a) or is valued at fertiliser and stover prices (b) for a normal year

Chapter 8
General Discussion

8.1 Nutrient depletion in Sub-Saharan Africa

The decline in soil fertility in Sub-Saharan Africa has been widely addressed in the last decades (Penning de Vries and Djitèye, 1982; Pieri, 1989; Stoorvogel and Smaling, 1990; Van Duivenbooden, 1992). Nutrient balance studies reviewed by Bationo *et al.* (1998) show that nutrient outputs generally exceed inputs, with average losses of 22 kg N and 2.5 kg P per ha per year. An analysis of Van der Pol (1992) indicates nutrient depletion rates of 14-40 kg N and 2 kg P per ha per year in sub-humid Mali. Similar results were reported from recent farm household level analyses of Defoer *et al.* (1998) and Sissoko (1998). The traditional systems, based on transfer of nutrients by grazing animals from rangeland to cropland, combined with fallowing, collapsed under the influence of the rapid increase in the population. In most of the semi-arid and sub-humid zones, the 15-45 ha rangeland per ha cropland required to maintain soil fertility (Powell *et al.*, 1996; Mohamed Saleem, 1998) is not available anymore. In response to the low productivity of the soils, interacting but separate specialised livestock and cropping systems are being replaced by integrated crop-livestock systems, although details of this process depend on resource endowments, market opportunities, policy support, etc. (Barbier and Hazell, 1998; Williams *et al.*, 1998; Sumberg, 1998). These integrated crop-livestock systems and the associated nutrient cycling are often advocated as a sustainable alternative for traditional system (Beets, 1990; Reintjes *et al.*, 1992; Winrock International, 1992; De Grandi, 1996; ILRI, 1997). Bosma *et al.* (1995) suggested that the number of stall fed animals should be increased to sustain cropland productivity, postulating that this practice will also reduce livestock pressure on the scarce natural forage in the dry season. However, more animals may result in a higher grazing pressure in the rainy season.

The continuous decline in soil productivity is an important issue for semi-arid Africa, and every effort should be made to avoid collapse of the system. This decline is associated with a decline in soil organic matter content. It has been demonstrated that large amounts of organic material are required to build up soil organic matter: 14.7, 31.4 and 55 t per ha of straw, animal manure, or compost, respectively are necessary to increase C in the top 20 cm of a soil by 1 g per kg (De Ridder and Van Keulen, 1990). Janssen (1993) estimated an annual requirement of 5.4 and 8.4 t farmyard manure to maintain soil organic matter at 15 and 35 g per kg in loamy and clay soil, respectively.

The objective of the present study was to analyse the possibilities for optimal management of crop residues from a sustainable crop-livestock farming perspective in the North Soudanian zone of Burkina Faso. This chapter discusses the main results and draws the main conclusions from the different studies described in this thesis.

times maintenance (33.6 g DOM $kg^{-0.75}$ d^{-1}) when animals ingested 90 % of the sorghum stover, but only 29 g groundnut OM $kg^{-0.75}$ d^{-1} was needed when the amount of stover offered is so high that only 50 % is eaten. The overall effect can double the IDOM at the highest level of supplementation, compared to feeding stover only. The optimum combinations of sorghum stover and cowpea or groundnut haulms were calculated using a stover:haulms price ratio of 4:1. These results underline once again the importance of excess feeding of crop residues for animal production (Winrock International, op. cit.; Renard, 1997; Manyuchi *et al.*, 1997b). Improved use of crop residues and other low quality forages, together with protein supplementation from legume forages grown on farm, is a key issue for livestock feeding in semi-arid and sub-humid zones of sub-Saharan Africa (Winrock International, op.cit.). As forage production is constrained by shortage of land, labour and capital (Williams *et al.*, 1997), haulms of cowpea and groundnut, which are primarily grown for their seeds and already integrated in farmers' practices, can play a significant role in improvement of animal production. For all crop residues, the proportion of leaves determines the extent to which they can contribute to animal production. In grazing systems, where animals rapidly pass when searching for the best components during first access, the total amount of crop residue useful for animals, rapidly decreases through trampling and destruction by termites (stimulated by contamination with animal excreta). When stored, these losses can be restricted, especially when harvesting and storage techniques that prevent losses of leaves are used.

The empirical models used to describe the relation between intake and amount offered for single feeds (Chapter 3) allow quantification of the optimum level of feeding, where the highest relative value for animal production (VAP), defined by Zemmelink (1986), is obtained. The concept of VAP integrates the benefits of allowing more selection (higher production per animal) and the costs in terms of quantity of organic matter offered; the maximum VAP corresponds to the maximum ratio returns/cost of feeding. When two feeds of different quality are combined, the optimum combination is set using the least-cost criterion for a desired intake level (IDOM). This approach, based on the isoquant concept, is commonly applied in least-cost ration formulation (Boggess *et al.*, 1983; Anaman, 1988; Amir and Knipscheer, 1989; Kaasschieter *et al.*, 1994). Such models also help to quantify more accurately the technical coefficients of feeding activities, for quantitative analysis of crop-livestock systems.

8.4 Optimising crop residue use at farm level

Farm surveys in Zoundwéogo province, located in the North-Soudanian zone, indicate that on average, of the total of 11.5 and 2.1 t of cereal stovers (millet and sorghum) and legume haulms (cowpea and groundnut) produced per farm, 3 and 0.9 t were stored (Chapter 5). Sankara (1997) reported ranges of 2-8 t for stored cereal stovers and 0.5-4 t for stored legume haulms, depending on rainfall. Availability of a means for transportation (donkey cart) allowed storage of significantly more high quality feeds. Up to 86 % of the cowpea haulms produced by households owning a cart, is stored. The stored legume haulms are all used for animal feeding. The major part (70%) of the stored cereal stovers also served as animal feed, the remainder being used as building material, as a source of energy for cooking or sold. The crop residues remaining in the fields are usually grazed and only the non-edible portions serve as soil amendment. Factors such as relationships between farmers and herdsmen, location of fields, herd composition and production system, and available means of transportation determine the quantities stored. These results agree with those reported by Powell *et al.*, (1995) and Renard (op. cit.).

The residues remaining in the field at the end of the dry season are used as such (serving as mulch or ploughed in) or burned. When fed to animals, feed refusals and animal excreta can be returned to cropland in the form of manure or compost (combined with household organic wastes). Therefore, four alternative management strategies were examined: manure-mulch, manure-ash, compost-mulch, and compost-ash, with emphasis on compost-mulch. Multiple Goal Linear Programming was used to study the trade-offs among different objectives and the effect of farm household constraints (Chapter 6). In the analysis, attainable crop production, livestock production (weight gain) and farm gross margin were calculated for an average farm household in Zoundwéogo province with 6.2 ha arable land and a labour force of 210 mandays per month, in relation to availability of working capital and sustainability indicators (OM, N and P balances). The model (called HOREB) has been applied to an average farm in Zoundwéogo province.

Crop production

Results of HOREB show that, with current extensive cropping systems, enough can be produced to meet household staple food requirements (2.9 t per year for 15 persons). This is in line with actual data. Staple crops in this study refer to sorghum, millet, maize and cowpea. On a farm with 210 md labour per month, where crop residues are not collected for stall feeding in the dry season and no capital is available to buy fertiliser, a maximum of 3.2 t staple can be produced from 2.7 ha sorghum, 1.2 ha millet, 0.7 ha cowpea and 0.5 ha maize. The remaining 1.1 ha is allocated to cash crops, which are not considered when maximising staple crop production (scenario FS I, Section 7.3). In scenario FS II where it was assumed that the farmer does collect crop residues for stall feeding of sheep and aims at maximum total farm gross margin, staple production hardly changes. In this scenario, the animal manure helped to reduce depletion of nutrients from the soil, but nutrient balances were still negative. The available working capital is not used because fertiliser is not remunerative, while the available amount of legume residues is sufficient to supplement all the collected cereal stovers. In this scenario, some of the land (1.1 ha) is left fallow because it is more profitable to use excess labour (after meeting requirements for staple production) on feeding more animals than growing more crops. As a result, during the harvest period (when competition for labour is greatest) excess labour is used for collection of crop residues rather than harvesting more crops. In scenario SP I, where it is required that the OM budget is balanced without working capital for external inputs, both crop production and animal production are lower than in scenario FS II. Again, some land (0.5 ha) is left fallow because of labour shortage. The farm could produce 4.5 t staples (SP II), when maximising total gross margin under balanced OM and nutrients budgets, if sufficient working capital would be available to buy external inputs necessary to maintain balanced soil nutrient budgets. Only 5 of the 6.2 ha is then cultivated, again because of the labour required to collect crop residues for stall feeding, in this case also in order to produce more manure and thereby minimise utilisation of high cost fertiliser. The lower area that can be cultivated is compensated by higher yields per ha. Food security (in the short run) can be ensured in normal and wet years under all crop residue management strategies. However, when sheep are not stall fed, food security is critical in dry years, taking into account losses during harvest and storage. Model results suggest that reduction of the crop area by 0.5 to 1.2 ha (depending on restrictions imposed on nutrient budgets) is necessary to allow integration of sheep stall feeding, because of the required labour for residue collection. Thus, integration of sheep stall feeding could contribute to limit the expansion of the crop area without compromising food security.

Livestock production

Livestock production in this section refers to liveweight gain during the 6 months dry season. In the current situation, an average household collects 3.6 t of cereal stover (millet and sorghum) and 0.8 t of legume haulms (cowpea and groundnut) for stall feeding in the dry season, when a cart is available. Using these quantities, the current flock of 12 sheep (Table 5.1) can be fed at maintenance level during 6 months in the dry season, with 40 md labour per month, or at 2 times maintenance with 75 md (situation A, Section 7.2). Potentially, nearly 60 sheep could be stall fed at 2 M throughout the dry season if 80 % of the produced cereal stover (9.2 t) and 86 % of the legume haulms (1.8 t) could be collected and 72 kF would be available to buy concentrate (situation C, Section 7.2). Model results for integrated farming systems, where crop activities and livestock feeding activities are combined, indicate a conflict in labour use during the harvest period. The possibilities for residue storage, and hence, the attainable level of livestock production are dictated by labour required for grain harvest, determined by crop area and crop yields. In situations without restrictions on nutrient budgets, livestock production can potentially reach 799 kg per farm in a normal year, but at the expense of a low staple production (only 1.5 t), because only small areas of cereal crops can be grown, due to labour constraints (situation C, Table 7.8). Under the restriction of short term food security and no restrictions on nutrient budgets (scenario FS II), 246 kg total liveweight is attained, from feeding 19 animals, when aiming at maximum total gross margin. Hence, there is considerable scope for increasing livestock production if collected residues are appropriately allocated. The 246 kg liveweight gain in scenario FS II is obtained with 9 animals fed on excess sorghum + groundnut at 1.6 M, 8 on excess sorghum + cowpea at 2 M, 1 on excess sorghum + cowpea at 1.6 M and 1 on excess millet + groundnut at 1.4 M. By using all these different rations the high investment in labour for collection is optimally valued. When the farmer aims to increase manure availability to maintain a balanced OM budget on cropland (scenario SPI), a lower production (149 kg live weight, Table 7.15) should be accepted while feeding more animals (26). Part of the flock (9 animals) is then fed at 1.6 M while the other animals are fed at 1.2 M. A similar strategy is actually used by farmers, where selected rams are intensively fed (*mouton de case*) and the other animals are just maintained to increase the availability of manure (Sahelconsult, 1991; Elskamp, 1995; Sankara, op. cit.).

The choice between excess feeding, chopping and urea treatment of cereal stovers depends on the availability of labour, the objectives of rearing animals and the price of urea. Chopping is selected when the farmer aims at maximum availability of manure, security or savings; in that case animals are fed at maintenance. This requires investment of labour for chopping to allow feeding the maximum number of animals. Treatment with urea requires, in addition to chopping, working capital to buy urea. This option was hardly selected because of the combined limitations of labour, capital and low remuneration. At the current urea price and labour availability conditions, excess feeding is the best method of feeding in all scenarios examined. In practice, chopping is sometimes used in the region, while urea treatment is not. This is due to the cost of urea, but the technology is also not well known by farmers. Another acknowledged reason for not using urea is possible intoxication by ammonia (Sundstøl and Owen, 1984; Schiere and Nell, 1993). Extension of these methods should then address these constraints, which are coined as main reasons for the low rate of adoption in sub-Saharan Africa (Williams *et al.*, 1998).

Nutrient balances

In the situation where animals graze throughout the dry season, most of the nutrients (especially N) contained in their excrements are lost, while three quarters of the crop residues disappear. This will be dramatic in the long term, as soil fertility will decrease, with the associated decline in crop yields. From 200- 344 kg OM, 15-21 kg N and 1.5-1.8 kg P per ha are lost annually from the system under this extensive feeding system (scenario FS I, Table 7.12). When crop residues are collected for stall feeding and the farmer aims at maximum total gross margin, 175-192 kg OM, 12-15 kg N and 1.1-1.2 kg P per ha are still lost annually (scenario FS II, Table 7.13). Results of the present analysis clearly illustrate that intensive management of crop residues in integrated crop-livestock farming systems cannot maintain the soil nutrient status. Nutrients from external sources are necessary, either in the form of concentrate or fertiliser. This is consistent with earlier arguments of Breman (1990, 1992 and 1995a) and Van Keulen and Breman (1990). In the short run, an individual farmer can reduce soil nutrient depletion by collecting and feeding crop residues in the dry season, but his animals have to rely on rangelands in the wet season (part of the herd also in the dry season). In fact, intensified nutrient cycling, using animals, contributes to soil mining when external inputs are not available; 15 to 30 % of the ingested N is retained in the animal body and consequently is lost from the system. The extent to which the remainder is effectively returned to cropland depends on the methods of management. There is evidence that animal manure may alleviate soil fertility constraints (Bationo and Mokwunye, 1991; Christianson and Vlek, 1991; Reijntjes *et al.*, op. cit.), but the required quantities are often not available. Farmers use animals to transfer nutrients from rangelands to the homestead, which are then combined with nutrients available from intensive management of crop residues (collection, transport, feeding and possibly chopping), to maintain an acceptable level of crop yields for household subsistence. Recent studies in Niger indicate that the scarce organic matter available (farmyard manure, compost and crop residues left in the field) is concentrated on the degraded portions of the fields to ensure reasonable yields (Lamers and Bruentrup, 1996; Lamers *et al.*, 1998; Gandah, 1999). The increasing intensive management of crop residues by farmers is also partly related to the decrease of manure available from pastoralists, due to the deterioration of farmer-herdsmen relations (Delgado, 1989; Breusers *et al.*, 1998). This subsistence strategy might be sustainable when the economic environment would be conducive for effective utilisation of external inputs.

Farm economics

Integration of crop and livestock production has widely been suggested as avenue towards intensification under low external input conditions (Reijntjes *et al.*, 1992; Winrock International, 1992), because of the expected improvement in land productivity and the economic conditions of farmers. Based on the current quantities of crop residues collected for animal feeding by households with a cart, a maximum gross margin from livestock of 95 kF could be attained without concentrate (Table 7.1). The availability of a cart for residue transport is very important. Without cart, the maximum attainable gross margin is 59 kF, because of the limited quantities of legume haulms, which are necessary for animal production, that can be collected. Maximum gross margin per manday of labour invested is 0.20 kF, which is much lower than the actual labour wages in the area. Hence, if off-farm employment is available, stall feeding of sheep is not an economically attractive alternative. In practice, farmers try to increase the profitability of stall-fed sheep by exploiting the spatial and temporal variation in animal prices. Therefore, the so-called "strategic fattening system" is applied, matching the end of the feeding period to religious festivities, when the price of animals may increase with a factor 2. Economic profitability can be improved if capital availability allows utilisation of concentrate, i.e. 0.28 kF extra gross margin can be attained per kF invested in cotton seed cake. The potential attainable gross margin when crop residues would be optimally collected (80 % of the cereal stovers and 86 % of the legume haulms produced, as estimated in Chapter 5) is 182 kF. The analysis from an integrated crop-sheep farming perspective shows similar results. When capital is not available to buy concentrate, 60-88 kF gross margin can be obtained from stall feeding of sheep (Table 7.13), because of the limited quantities of crop residues that can be collected, corresponding to 18-24 % of total farm gross margin.

As illustrated in the preceding paragraph, external inputs are required for sustainable production. However, while utilisation of concentrate is remunerative, that of fertiliser is not. For example, when fertilisers are used to maintain balanced nutrients budgets, the calculated gross margin from crop production is 63 kF per ha (or a total of 327 kF, Fig. 7.4), which is much lower than that attained from a larger area and without fertiliser (71 kF per ha, or a total of 439 kF). Hence, under current price conditions, there is no economic incentive to invest in fertilisers. When labour availability allows, stall feeding is applied, using crop residues, possibly supplemented by concentrate to take advantage of the higher animal prices during religious festivities.

Maximising crop gross margin is always associated with soil mining, so that 20-27 % of the calculated farm gross margin originates from soil mining, if soil nutrients and organic matter are valued at inorganic fertiliser and stover prices, respectively. This value is lower than that reported by Van der Pol (op. cit.) for Southern Mali. Shapiro and Sanders (1998), analysing data from Burkina Faso, concluded that use of inorganic fertiliser on sorghum fields is hardly profitable under current price conditions. Delgado (1989) argued that farmers will choose between manure and fertiliser, and between mixed farming and off-farm employment, in the light of their own analyses of the opportunity costs involved. Following this argument, it is clear that the prospects for sustainable crop-livestock production in the region are strongly related to the price of external inputs, availability of working capital and off-farm employement opportunities.

8.5 Towards sustainable land use

Integration of crops and livestock is often considered as a step towards sustainable agricultural production, because of the associated intensified organic matter and nutrient cycling. Residues of the different crops represent the main on-farm source of organic matter and nutrients. In most Sub-Saharan production systems, animals play a vital role as capital asset for security and means of savings, cash income and in nutrient flows. Management of crop residues in the region is closely related to their utilisation in animal feeding. Utilisation of crop residues in animal production is obviously associated with unavoidable losses of nutrients, i.e. retained in animal products or lost during manure management. The main advantage of the integration of livestock and crops is the added value derived from crop residues (especially those of legumes) in terms of animal products and income. To maintain the system, however, nutrients from external sources should be added. In the past, this was possible through fallowing and manuring contracts with pastoralists. The growing demand for feed by the increasing herd (of both arable farmers and pastoralist), the shrinking area of cropland per capita and declining crop yields dictate the scope for improvement through integration of crops and livestock. Nearly all crop residues are eaten by animals, either by grazing animals directly from the field or by stall fed animals after collection and storage. Arable farmers intensify crop residue use for their animals to alleviate the constraints associated with the decline in soil productivity, i.e. as a means of subsistence. Sustainable production requires external inputs, either as inorganic fertiliser or concentrates or both. However, the current price ratios of fertiliser and grains are hardly conducive for utilisation of fertilisers. Development of institutional and physical infrastructure for cost-effective use of fertilisers and concentrate is required to trigger sustainable land use in the region. Use of concentrate is remunerative for farmers, but they cannot afford to buy it, due to limited availability of cash. Improved credit facilities for farmers may stimulate intensification of livestock production and thereby increase availability of nutrients for cropland. Further research is necessary to identify nutrient management techniques that minimise losses during the different processes involved in manure storage and application to cropland.

8.6 Conclusions

The major conclusions of the studies described in this thesis can be summarised as follows:

(1) When cereal stovers are fed alone, allowing selective consumption of leaves is a prerequisite for animal production and even for maintenance of animals.

(2) Cowpea and groundnut haulms can serve as alternative supplements to cereal stovers in low external input conditions. When haulms are combined with selective consumption of leaves of cereal stovers, intake of digestible organic matter can be significantly increased to reduce the quantities of concentrates required for higher levels of production.

(3) Utilisation of urea for stover treatment is not remunerative under current price conditions. The choice between chopping and excess feeding depends on the availability of labour in the period that residues must be collected and stored, the feeding objectives and the availability of working capital for supplements (concentrates). Under the current conditions, excess feeding of cereal stovers suplemented with cowpea and groundnut haulms, is the most relevant feeding strategy in integrated crop-sheep farming.

(4) With the current production systems in Zoundwéogo province, staple requirements of households can be met, in the short run, in normal years, but food security is critical in dry years. However, this is associated with significant depletion of soil nutrients that, valued at current fertiliser prices, represent 20-27 % of the farm gross margin.

(5) Integration of stall-feeding of sheep in the farming systems gives an added value to crop residues in terms of animal production and income. Farm gross margins can potentially be increased by 46 % without external inputs, but at the expense of soil nutrients.

(6) The availability of labour is the major household-related limiting factor for management of crop residues in integrated crop-livestock farming perspective.

(7) Management of crop residues in an integrated crop-sheep stall-feeding system may alleviate the constraints associated with the decline in soil productivity, but external inputs are necessary to maintain balanced organic matter, nitrogen and phosphorus budgets at farm level.

(8) Sustainable production can only be triggered in the region by external inputs. However, the current price ratios of fertiliser and grains are hardly conducive to fertiliser utilisation. Investment in concentrate is remunerative, but farmers cannot afford to buy it. Improved credit facilities for farmers may stimulate intensification of livestock production and thereby increase nutrient availability for cropland.

References

Ademosum A.A., 1993. The scope for improved small ruminant production in the humid zone of west and central Africa: the approach of the West African dwarf goat project. In: A.O. Ayeni, and H.G. Bosman (Eds.), Proceedings of an international workshop on goat production systems in the humid tropics. Obafemi Awolowo University, Ile-Ife, Nigeria, pp. 2 - 13.

Amir, P., Knipscheer, H.C., 1989. Conducting on-farm animal research: Procedures and economic analysis. Winrock International Institute for Agricultural Development (USA) and International Development Research Centre (Canada). Singapore National Printers Ltd. 244 pp.

Anaman, K. A., 1988. African farm management. Principles and applications with examples. Post-doctoral Research Fellow Report. University of Queensland, St. Lucia, Australia. Ghana University Press. 268 pp.

AOAC (Association of Official Analytical Chemists), 1975. Official methods of analysis, 12th ed. AOAC, Washington, DC.

AOAC (Association of Official Analytical Chemists), 1984. Official methods of analysis, 15th edition, AOAC, Washington DC, USA.

ARC (Agricultural Research Council), 1980. The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux, Slough, UK. 351 pp.

Ayantunde, A.A., 1998. Influence of grazing regimes on cattle nutrition and performance and vegetation dynamics in Sahelian rangelands. Ph.D. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands. 179 pp.

Badurdeen, A.L., Ibrahim, M.N.M. and Schiere, J.B., 1994. Methods to improve utilization of rice straw II. Effects of different levels of feeding on intake and digestibility of untreated and urea ammonia treated rice straw. *Asian-Australian Journal of Animal Science 7: 165-169.*

Badve, V.C., Nisal, P.R., Joshi, A.L., Rangnekar, D.V., 1994. Genotype and environment effects on sorghum stover production and quality. In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues. Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 9 – 19.

Barbier, B., Hazell, P., 1998. Implications of population growth and declining access to transhumant grazing areas for the sustainability of agro-pastoral systems in the semi-arid areas of Niger: A bioeconomic modelling approach. In: ILRI/IFPRI (Eds.), Property rights and livestock development. Proceedings of an International symposium, DSE, Feldfing, Germany, pp. 179-197.

Bationo, A., Mokwunye, A.U., 1991. Role of manure and crop residues in alleviating soil fertility constraints to crop production: With special reference to the Sahelian zones of West Africa. *Fertiliser Research 29: 117-125*

Bationo, A., Christianson, C.B., Klaij, M.C., 1993. The effect of crop residue and fertilizer use on pearl millet yields in Niger. *Fertilizer Research 34: 251 – 258.*

Bationo, A., Lompo, F., Koala, S., 1998. Research on nutrient flows and balances in West Africa: state-of-the-art. *Agriculture, Ecosystems and Environment 71: 19-35.*

Beets, W. C., 1990. Raising and sustaining productivity of smallholder farming systems in the tropics. A handbook of sustainable agricultural development. Agbé Publishing, The Netherlands. 738 pp.

Berge, P.H., Dulphy, J.P., 1985. Etude des interactions entre fourrage et aliment concentré chez le mouton. I. Facteurs de variation du taux de substitution. *Annales de Zootechnie 34: 313 – 334.*

Bhargava, P.K. Orskov, E.R., Walli, T.K., 1988. Rumen degradation of straw. 4: Selection and degradation of morphological components of barley straw by sheep. *Animal Production 47: 105-110.*

Boekholt, H.A., 1976. Nitrogen metabolism of the lactating cow and the role of gluconeogenesis from amino acids. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 207 pp.

Boggess, W.G., Olson, K.D., Heady, E.O., 1983. Gain isoquants and production functions for swine. In: Heady, E.O., Bhide, S. (Eds.), Livestock response functions. The Iowa State University Press, Ames, Iowa, pp. 267-303.

Bosma, R.H., Bicaba, M.Z., 1997. Effect of addition of leaves from Combretum aculeatum and Leucaena leucocephala on digestion of sorghum stover by sheep and goats. *Small Ruminant Research 24: 167 – 173.*

Bosma, R., Bengaly, M., Defoer, T., 1995. Pour un système durable de production au Mali-sud: accroître le rôle des ruminants dans le maintien de la matière organique des sols. In: Powell, J.M., Fernández-Rivera, S., Williams, T.O., Renard, C. (Eds.), Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II. Technical papers. Proceedings of an International conference, Addis Ababa, Ethiopia, pp 171 – 182.

Bosman, H.G., Versteegden, C.J.G.M., Odeyinka, S.M. and Tolkamp, B.J., 1995. Effect of amount offered on intake, digestibility and value of *Gliricidia sepium* and *Leucaena leucocephala* for West African Dwarf goats. *Small Ruminant Research 15: 247-256.*

Boutonnet, J.P., 1995. From farm land to markets: logic and dynamics of sheep husbandry. In: P. Morand-Fehr, R. Rubino, A. El Aich (Eds.), Proceedings of a meeting on systems of sheep and goat production, FAO/CIHEAM network on cooperative sheep and goat research, Thessaloniki, Greece, pp. 19 - 22.

Breman, H., 1990. No sustainability without external inputs. In: Beyond Adjustment: sub-Saharan Africa. Africa Seminar. Maastricht, The Netherlands, pp.124-134

Breman, H., 1992. La fertilité de sol, la capacité de charge et l'avenir de la population de Zoundwéogo. Quelques réflexions pour appuyer la formulation de la 3ème phase du Projet de Développement Intégré du Zoundwéogo (PDI/Z), CABO-DLO, Wageningen, The Netherlands. 18 pp.

Breman, H., 1995a. Opportunities and constraints for sustainable development in semi-arid Africa. UNU/INTECH Working Paper No 18, Workshop on Technology, Environment and Development, Maastricht, 23 pp.

Breman, H., 1995b. Modélisation et simulation dans l'élaboration de systèmes de production animale durables. In: Powell J.M., S. Fernàndez-Rivera, T.O. Williams, C. Renard (Eds.), Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan Africa. Volume II: Technical papers, ICRISAT, Niger, pp. 473 - 492.

Breman, H., De Ridder, N., 1991. Manuel sur les pâturages des pays sahéliens. ACCT-CTA. Editions Karthala, Paris, 485 pp.

Breman, H., Sissoko, K. (Eds.), 1998. L'intensification agricole au Sahel. Editions Karthala, Paris, France. 996 pp.

Breusers, M., Nederlof, S., van Rheenen, T., 1998. Conflict or symbiosis? Disentangling farmer-herdsman relations: The Mossi and Fulbe of the central plateau, Burkina Faso. *Journal of Modern African Studies 36: 357-380.*

Brouwer, B.O., 1991. Java programme. Version 2.7. Department of Animal Production Systems, Wageningen Agricultural University. The Netherlands.

CAB (Commonwealth Agricultural Bureaux), 1980. The nutrient requirements of ruminant livestock. Technical review by an agricultural research council working party. Royal Society, London, England, 351 pp.

Camara, O.S., 1996. Utilisation des résidus de récolte et du fumier dans le Cercle de Koutiala: Bilan des elements nutritifs et analyse économique. Rapport PSS 18, AB-DLO, Wageningen, The Netherlands, 140 pp.

Christianson, C. B., Vlek, P.L.G., 1991. Alleviating soil fertility constraints to food production in West Africa: Efficiency of nitrogen fertilizers applied to food crops. *Fertilizer Research 29: 21-33.*

Chriyaa, A., Moore, K.J., Waller, S.S., 1997. Browse foliage and annual legume pods as supplements to wheat straw for sheep. *Animal Feed Science and Technology 62: 85 - 96*

Compaoré, H., 1991. Etude des circuits de distribution des sous-produits agro-industriels au Burkina Faso. Mémoire de fin d'études, Institut du Développement Rural, Université de Ouagadougou, 105 pp.

Cook, B.G., Crosthwaite, I.C., 1994. Utilization of Arachis species as forage. In: Smartt, W.J., (ed.) The groundnut crop. A scientific basis for improvement, Chapman and Hall editor, London, UK, pp. 1 –23.

De Graaff, J., 1996. The price of soil erosion: an economic evaluation of soil conservation and watershed development. Tropical Resource Management Papers 14, Wageningen, The Netherlands. 300 pp.

De Graaff, J., 1997. Impact assessment of soil and water conservation: A Burkina Faso case study. In: Renard, C., Neef, A., Becker, K., von Oppen (Eds.), Soil fertility management in West African Land Use Systems; Regional Workshop, Niamey, Niger. Margraf Verlag, Weikersheim, Germany. pp. 209-214.

De Grandi, J.C., 1996. L'évolution des systèmes de production agropastorale par rapport au développement rural durable dans les pays d'Afrique Soudano-Sahélienne. Collection FAO: Gestion des exploitations agricoles No 11. 162 pp.

De Jong, R., Van Bruchem, J., 1993. Utilization of crop residues and supplementary feeds in tropical developing countries. Final summary report, Contract TS2-0091-NL Commission of the European Communities, Wageningen, The Netherlands, 171 pp.

De Leeuw, P.N., 1997. Crop residues in tropical Africa: Trends in supply, demand and use. In: Renard, C. (Ed.), Crop residues in sustainable mixed crop/livestock farming systems. CAB international, ICRISAT, ILRI. pp. 41-77

De Ridder, N., van Keulen, H., 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid-tropics (SAT). *Fertilizer Research 26: 299-310.*

De Wit, C.T., Van Keulen, H., Seligman, N.G., Spharim, I., 1988. Application of interactive multiple goal programming techniques for analysis and planning of regional agricultural development. *Agricultural Systems 26: 211 - 230.*

Defoer, T., De Groote, H., Hilhorst, T., Kanté, S., Budelman, A., 1998. Participatory action research and quantitative analysis for nutrient management in southern Mali: a fruitful marriage? *Agriculture, Ecosystems and Environment 71: 215 – 228.*

Delgado, C.L., 1989. The changing economic context of mixed farming in Savannah West Africa. A conceptual framework applied to Burkina Faso. *Quarterly Journal of International Agriculture 28: 351-364.*

Dembélé F., 1995. Etude économique de la disponibilité et de l'utilisation des suppléments dans l'alimentation des bovins au Mali. Etude de cas des éleveurs du Cercle de Koutiala. Rapport PSS No 14, AB-DLO, Wageningen, The Netherlands, 159 pp.

Doyle, P.T., 1994. Variability in nutritive characteristics of slender straws with special reference to genetic variability in wheat straws. In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues.

Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 36 – 52.

Dumas, R. and Raymond, H., 1974. L'élevage des petits ruminants dans les circonscriptions de Kaya, Ouahigouya et du Sahel. Maison Alfort edition, Institut d'Elevage et de Médecine Véterinaire.

DVA (Direction de la Vulgarisation Agricole), 1997. Fiche technique Vigna unguiculata-variétés: Vita 1, Vita3, 58-74. Ouagadougou, Burkina Faso. 2 pp.

Efdé, S.L., 1996. Quantified and integrated crop and livestock production analysis at the farm level. Exploring options for land use of mixed farms on heavy limestone soils south of Malang, East Java, Indonesia. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 230 pp.

Egan, A.R., 1997. Technological constraints and opportunities in relation to class of livestock and production objectives. In: Renard, C. (Ed.), Crop residues in sustainable mixed crop/livestock farming systems. CAB international, ICRISAT, ILRI, pp. 7-24

Ehlers, J.D., Hall, A.E., 1997. Cowpea (Vigna unguiculata L. Walp.). *Fields Crop Research 53: 187 – 204.*

Elskamp, F., 1995. Etude des petits ruminants dans trois systèmes d'élevage dans la province du Zoundwéogo. Rapport M. Sc., Wageningen Agricultural University. 90 pp.

ESPGRN (Equipe Systèmes de Production et Gestion des Ressources Naturelles), 1994. Fiche technique de recherche: La culture fourragère de l'association maïs/dolique. Sikasso, Republique du Mali. 19 pp.

FAO, 1981. Tropical feeds. Feed information summaries and nutritive values. FAO Animal Production and Health Series No 12, 529 pp.

FAO, 1983. Integrating crops and livestock in West Africa. FAO Animal Production and Health Paper 41, 112 pp.

FAO, 1986. Population and the labour force in rural economies. FAO Economic and Social Development Paper 59. 169 pp.

FAO, 1991. Small ruminant production and the small ruminant genetic resource in tropical Africa. FAO Annual Production and Health Paper 88, 231 pp.

Fernández-Rivera, S., Midou, A. and Marichatou, H., 1994. Effect of food allowance on diet selectivity and intake of pearl millet (*Pennisetum glaucum*) stover leaves by sheep. *Animal Production 58: 249-256.*

Gandah, M., 1999. Spatial variability and farmer resource allocation in millet production in Niger. Ph.D. Thesis Wageningen Agricultural University, Wageningen, The Netherlands, 115 pp.

Harika, A.S., Sharma, D.D., 1994. Quality and yield differences in maize stover due to varieties and stage of harvesting. In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues. Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 20 – 28.

Hien V., Sédogo P.M., Lompo, F., 1994. Gestion de la fertilité des sols au Burkina Faso. Bilan et perspectives pour la promotion de systèmes agricoles durables dans la zone Soudano-Sahélienne. In: FAO and CIRAD (Eds.), Compte rendu d'un séminaire régional sur la promotion des systèmes agricoles durables dans les pays d'Afrique Soudano-Sahélienne, Dakar, Sénégal, pp. 47 - 59.

Hien, G.F., 1995. La régénération de l'espace sylvo-pastoral au Sahel: Une étude de mesures de conservation des eaux et des sols au Burkina Faso. Tropical Resource Management Papers 7. Wageningen, The Netherlands. 240 pp.

Ifar, S., 1996. Relevance of ruminants in upland mixed farming systems in East Java, Indonesia. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands, 139 pp.

ILRI (International Livestock Research Institute), 1997. Livestock and nutrient cycling: maintaining a balance. *Livestock Research for Development 4: 1-5*

Jabbar, M.A., 1993. Evolving crop/livestock farming systems in the humid zone of West Africa: Potential and research needs. *Outlook on Agriculture 22: 13-21.*

Jackson, D.L., 1994. On-farm use of crop residues in semi-arid areas and its potential for improvement of soil fertility. *African Crop Science Society Proceedings 1: 100 - 102.*

James, A.D., 1997. Socio-economic problems associated with livestock development in Sub-Saharan Africa. In: CTA (Ed.), Livestock development policies in the humid and sub-humid zones of Sub-Saharan Africa. Proceedings of a seminar, Abidjan, Côte d'Ivoire, pp. 7 – 18.

Janssen, B.H., 1993. Integrated nutrient management: the use of organic and mineral fertilizers. In: van Reuler, H., Prins, W.H. (Eds.), The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa. Dutch Association of Fertilizers Producers, The Netherlands, pp 89-105.

Kaasschieter, G. A., Coulibaly, Y., 1995. Rentabilité de l'utilisation de fane de niébé (*Vigna unguiculata*) comme supplément avec la paille de mil (*Pennisetum typhoides*) par des taurillons. Rapport PSS No 7. AB-DLO Wageningen, The Netherlands. 31 pp.

Kaasschieter, G. A., Coulibaly, Y., Kané, M., 1994. Supplémentation de la paille de mil (*Pennisetum typhoides*) avec le tourteau de coton: effets sur l'ingestion, la digestibilité et la sélection. Rapport PSS 4. AB-DLO Wageningen, The Netherlands. 25 pp.

Kaasschieter, G.A., Coulibaly, Y., Heitkonig, I.M.A., Ketelaars, J.J.M.H., 1998. La supplementation du bétail: une nécéssité! In: Breman, H., Sissoko, K. (Eds.), L'intensification agricole au Sahel. Karthala, Paris, pp. 79 – 105.

Kaasschieter, G.A., Coulibaly, Y., Kané, M., Attema, J., 1998. Modèles d'ingestion fourragère. In: Breman, H., Sissoko, K., (Eds.), L'intensification agricole au Sahel. Edition Karthala, pp. 353 – 375.

Kaboré, C.Y., 1996. Composition chimique et valeur nutritive des herbacées et ligneux des pâturages naturels soudaniens et des sous-produits du Burkina Faso. Thèse Doctorat ès Sciences Naturelles, Université de Ouagadougou, Burkina Faso, 223 pp.

Kessler, J.J., Breman, H., 1995. L'évolution des systèmes de production agro-pastorale par rapport au développement rural durable dans les pays d'Afrique soudano-sahélienne. FAO, 85 pp.

Kessler, J.J., Wiersum, K.F., 1992. The multi-dimensional nature of sylvo-pastoral areas in the Sahel regions. In: R. de Jong, T. Volan and J. van Bruchem (Eds.), Natural resource development and utilization. Future research and technology management in soil-plant-animal-human systems. Proceedings of the Commission of European Communities Coordination Workshop, pp 143 - 145.

Ketelaars, J.J.M.H., Tolkamp, B.J., 1991. Towards a new theory of feed intake regulation in ruminants. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands, 254 pp.

Kiéma, A., 1994. Etude des petits ruminants dans trois systèmes d'élevage traditionnel en zone Soudano-sahélienne. Paramètres zootechniques, utilisation des espaces sylvopastoraux par le bétail. Mémoire de fin d'Etudes d'Ingénieur du Développement Rural. Université de Ouagadougou, Burkina Faso. 137 pp.

Kossila, V., 1988. The availability of crop residues in developing countries in relation to livestock populations. In: J.D. Reed, B.S. Capper, P.J.H. Neate (Eds.), Plant breeding and the nutritive value of crop residues. Proceedings of a Workshop, ILCA, Addis Ababa, Ethiopia, pp. 29 - 39.

Kruseman, G., Ruben, R., Kuyvenhoven, A., Hengsdijk, H., van Keulen, H., 1996. Analytical framework for disentangling the concept of sustainable land use. *Agricultural Systems 50: 191-207.*

Kyomo, M.L., 1997. Global and African trends in the livestock sector: opportunities and challenges for development. In: CTA (Ed.), Livestock development policies in Eastern and Southern Africa. Proceedings of a seminar, CTA/OUA/IBAR, Swaziland, pp. 17 – 34.

Lamers, J.P.A., Bruentrup, M., 1996. Comparative advantage of single and multiple uses of millet stover in Niger. *Agricultural Systems 50: 273 – 285.*

Lamers, J.P.A., Bruentrup, M., Buerkert, A., 1998. The profitability of traditional and innovative mulching techniques using millet crop residues in the West African Sahel. *Agriculture, Ecosystems and Environnment 67: 23 – 35.*

Laredo, M.A. and Minson, D.J., 1973. The voluntary intake, digestibility, and retention time by sheep of leaf and stem fraction of five grasses. *Australian Journal of Agriculture Research 24: 875-888.*

Latham, M., 1997. Crop residues as a strategic resource in mixed farming systems. In C. Renard (Ed.), Crop residues in sustainable mixed crop-livestock farming systems. Proceedings of an International Workshop at Addis Ababa, ICRISAT, ILRI, CABI, pp. 181-196

Lebbie, S.H.B., 1996. Livestock and food security in smallholder production systems in Africa: Beyond meat and milk. In: Meissner, H.H. (Ed.), Food security in Africa: challenges, opportunities and targets for animal production. Proceeding, second All Africa Conference on Animal Agriculture, Pretoria, South Africa. pp 381 – 396.

Leloup, S.J.L.E., 1994. Multiple use of rangelands within agropastoral systems in southern Mali. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 101 pp.

Lompo, F., Sédogo, P.M., Hien, V., 1995. Expériences et perspectives de maintien de la productivité du sol dans l'agriculture au Burkina Faso. In: Ahenkorah Y., E. Owusu-Bennoah, G.N.N. Dowuona (Eds.), Sustaining soil productivity in intensive African agriculture, Seminar proceedings, Accra, Ghana, pp. 79 - 88.

Lufadeju, E.A., 1992. Development of low technology crop residue-based feeds for ruminants. In: R. de Jong, T. Nolan, and J. van Bruchem (Eds.), Natural resource development and utilisation, future research and technology management in soil-plant-animal-human systems. Proceedings of the Commission of European Communities Co-ordination Workshop, International Agricultural Centre, Wageningen, the Netherlands, pp. 146-149.

Maatman, A., Schweigman, C., 1995. Etude des systèmes de production agricole du plateau central au Burkina Faso. Application de la programmation linéaire. Tome 1. Document de recherches, Réseau SADOC, Ouagadougou, Burkina Faso.178 pp. + annexes.

MAE (Ministère de l'Agriculture et de l'Elevage), 1990. Enquête nationale sur les effectifs du cheptel. Volume 1: résultats et analyses. Direction des Etudes et de la Planification, CNDA, Burkina Faso, 250pp.

Mando A., 1997. The role of termites and mulch in the rehabilitation of crusted Sahelian soils. Tropical Resource Management Papers 16. Wageningen, The Netherlands. 101 pp.

Manyuchi, B., Deb Hovell, F.D., Ndlovu, L.R., Topps, J.H., Tigere, A., 1997a. Napier or groundnut hay as supplements in diets of sheep consuming poor quality natural pasture hay. 1. Effect on intake and digestibility. *Livestock Production Science 49: 33 - 41.*

Manyuchi, B., Debhovell, F.D., Ndlovu, L.R., Topps, J.H., Tigere, A., 1997b. The use of groundnut hay as supplement for sheep consuming poor quality natural pasture hay. *Animal Feed Science and Technology 69: 17-26.*

MARA (Ministère de l' Agriculture et des Ressources Animales), 1996. Enquête Nationale de Statistiques Agricoles (E.N.S.A). Rapport général, Direction des Statistiques Agro-Pastorales (DSAP), Burkina Faso. 100 pp.

MARA (Ministère de l'Agriculture et des Ressources Animales), 1995. Performances de l'agriculture 1984-1994. Projet amélioration des instruments du DIAgnostic PErmanent pour la sécurité alimentaire Régionale III (DIAPER III), CILSS-CE, Département des statistiques agro-pastorales, Ouagadougou, Burkina Faso.

Masama, E., Topps, J.H., Ngongoni, N.T., Maasdorp, B.V., 1997. Effects of supplementation with foliage from the tree legumes *Acacia angustissima, Cajanus cajan, Calliandra calothyrsus* and *Leucaena leucocephala* on feed intake, digestibility and nitrogen metabolism of sheep given maize stover ad libitum. *Animal Feed Science Technology 69: 233 – 240.*

Mbile, R.P and Udén, P. 1997. The effect of feeding level on intake and digestibility of Rhodes grass (*Chloris gayana*, cv Kunth) by dairy cows. *Animal Feed Science and Technology 66: 181-196.*

Meerman, F., van der Ven, G. W. J., van Keulen, H., Breman, H., 1996. Integrated crop management: an approach to sustainable agricultural development. *International Journal of Pest Management 42: 13-24*

Meertens, H.C.C., Fresco, L.O., Stoop, W.A., 1996. Farming systems dynamics: impact of increasing population density and the availability of land resources on changes in agricultural systems. The case of Sukumaland, Tanzania. *Agriculture, Ecosystems and Environment 56: 203-215.*

Mero, R.N. and Udén, P., 1998a. Promising tropical grasses and legumes as feed resources in Central Tanzania: IV. Effect of feeding level on digestibility and voluntary intake of four herbaceous legumes by sheep. *Animal Feed Science and Technology 70: 97-110.*

Mero, R.N. and Udén, P., 1998b. Promising tropical grasses and legumes as feed resources in Central Tanzania: IV. Effect of feeding level on digestibility and voluntary intake of four herbaceous legumes by sheep. *Animal Feed Science and Technology 70: 97-110.*

MET (Ministère de l'Environnement et du Tourisme), 1991. Plan d'Action National pour l'Environnement (PANE). Tome I. Comité National de Lutte Contre la Désertification, Burkina Faso. 100 pp.

Meuldijk, R., 1997. Animal production practices in the Kaïbo region, Burkina Faso. M.Sc. Thesis, Wageningen Agricultural University, The Netherlands, 79 pp.

Minson, D.J., 1990. Forage in Ruminant Nutrition. Academic Press, Inc., San Diego/London.

Mohamed Saleem, M.A., 1998. Nutrient balance patterns in African livestock systems. *Agriculture, Ecosystems and Environment 71: 241-254.*

Mortimore, M.J., Singh, B.B., Harris, F., Blade, S.F., 1997. Cowpea in traditional cropping systems. In: Singh B.B., MahanRaj, D.R., Dashiell, K.E., Jackai, L.E.N. (Eds.), Advances in Cowpea Research, IITA, JIRCAS, pp. 99 – 113.

N'Jai, O., 1998. Comparisons of groundnut hay, sesame seed cake, *Leucaena leucocephala*, and *Gliricidia sepium* as protein sources for rams. In: Daniel, J.N., Roshetho, J.M. (Eds.), Nitrogen fixing trees for fodder production. Proceedings of an International workshop, FACTnet / Winrock International/ BAIF. FACTnet reports, special issue, pp. 170 – 180.

NRC (National Research Council), 1988. Nutrient requirements of dairy cattle, 6th revised ed. National Academy of Science, Washington, D.C., USA.

NRC (National Research Council), 1985. Ruminant nitrogen usage. Subcommitee on nitrogen usage in ruminants. Committee on Animal Nutrition Board on Agriculture, Washington, D.C., USA. 138 pp.

Onwuka, C.F.I., Adetiloye, P.O., Afolami, C.A., 1997. Use of household wastes and crop residues in small ruminant feeding in Nigeria. *Small Ruminant Research 24: 233 – 237.*

Osafo, E.L.K., Owen, E., Said, A.N., Gill, M., Sherington, J., 1997. Effects of amount offered and chopping on intake and selection of sorghum stover by Ethiopian sheep and cattle. *Animal Science 65: 55 - 62.*

Ouédraogo, C. L., 1990. Influence du traitement des pailles à l'urée sur la croissance et la digestibilité chez les petits ruminants. Mémoire d'Ingénieur du Développement Rural, Université de Ouagadougou, Burkina Faso, 78 pp.

Owen, E., Jayasuriya, M.C.N., 1989. Use of crop residues as animal feeds in developing countries. *Research and Development in Agriculture 6: 129 - 138.*

Penning de Vries, F.W.T., Djitèye, M.A. (Eds.), 1982. La productivité des pâturages Sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelles. Agricultural Research Report 918, PUDOC, Wageningen, The Netherlands. 525 pp.

Pieri, C., 1986. Fertilisation des cultures vivrières et fertilité des sols en agriculture paysanne subsaharienne. *L'Agronomie Tropicale 41: 1- 20.*

Pieri, C., 1989. Fertlité des terres de savannes. Bilan de trente ans de recherche et de développement au Sud du Sahara. Ministère de la Coopération et CIRAD-IRAT, Paris, France. 444 pp.

Powell, J.M., Williams, T.O., 1995. An overview of mixed farming systems in Sub-Saharan Africa. In : Powell J.M., S. Fernàndez-Rivera, T.O. Williams, C. Renard (Eds.), Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan Africa. Volume II: Technical papers, ICRISAT, Niger, pp. 21 - 35.

Powell, J.M., Fernández-Rivera, S., Hiernaux, P., Turner, M.D., 1996. Nutrient cycling in integrated rangeland/cropland systems of the Sahel. *Agricultural Systems 52: 143 – 170.*

Powell, J.M., Fernández-Rivera, S., Williams, T.O. and Renard C. (Eds.), 1995. Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, vol. 2: Technical papers. Proceedings of an International Conference, ILCA, Addis-Ababa, Ethiopia. 568 pp.

Reenberg, A., Rasmussen, K., 1992. Problems of defining and evaluating sustainability of agricultural systems. In: A.M. Lykke, K. Tybirk and A. JØrgensen (Eds.), Proceedings of the 4th Sahel workshop on sustainable development in the Sahel. AAU reports 29, pp. 53 - 62.

Reijntjes, C., Haverkort, B., Waters-Bayer, A., 1992. Farming for the future. An introduction to low-external-input and sustainable agriculture. MacMillan Press Ltd./ ILEIA, London. 250 pp.

Renard, C. (Ed.), 1997. Crop residues in sustainable mixed crop/livestock farming systems. ICRISAT, ILRI, and CABI. 322 pp.

Rivière, R., 1978. Manuel d'alimentation des ruminants domestiques en milieu tropical. Collection Manuels et précis d'élevage, Ministère de la Coopération Française, 519 pp.

Romney, D.L., Thorne, P.J., Thomas, D., 1994. Some animal-related factors influencing the cycling of nitrogen in mixed farming systems in sub-Saharan Africa. *Agriculture, Ecosystems and Environment 49: 163 – 172.*

Saadullah, M., and Siriwardene, J.A.S., 1993. Reasons for success and failure of straw treatment and straw feeding in Bangladesh and Sri-Lanka. In: Singh, K., Schiere, J.B., (Eds.), Feeding of ruminants on fibrous residues. Aspects of treatment, feeding, nutrient evaluation, research and extension. Proceedings of an international workshop, National Dairy Research Institute, Karnal (Haryana-India), pp. 277-296

Sahelconsult, 1991. Etude prospective des zones pastorales de la province du Zoundwéogo. Rapport de consultations, PDI/Z, Manga, Burkina Faso. 59 pp.

Sankara, E., 1997. Impact de la vulgarisation agro-pastorale sur les activités d'élevage dans la province du Zoundwéogo. Cas du village de Kaïbo-sud. Centre de Formation de Formateurs de Jeunes Agriculteurs (CFFJA)/ Antenne Sahélienne, Ouagadougou, Burkina Faso. 48 pp.

Sansoucy, R., 1992. Systèmes d'alimentation basés sur les residus de récoltes de céréales et les sous-produits agro-industriels. In: CTA (Ed.), L'intégration de l'élevage à l'agriculture en reponse à la pression démographique croissante sur les ressources disponibles. Actes d'un Séminaire, Ile Maurice, pp. 11-14.

Savadogo, M., 1991. Influence des niveaux énergétique et azoté de la ration sur la croissance et les rendements carcasses des agneaux Mossis. Mémoire de fin d'études Institut du Développement Rural, Université de Ouagadougou, Burkina Faso. 94 pp.

Savadogo, M., Zemmelink, G., Nianogo, A.J., 1999. Effect of selective consumption on volontary intake and digestibility of sorghum (*Sorghum bicolor L. Moench*), cowpea (*Vigna unguiculata L. Walp*) and groundnut (*Arachis hypogaea L.*) straws by sheep. *Animal Feed Science and Technology, Accepted*

Schetty, S. V. R., Ntane, B.R., Bationo, A., Renard, C., 1995. Millet and cowpea in mixed farming systems of the Sahel: A review of strategies for increased productivity and sustainability. In: Powell J. M., S. Fernández-Rivera, T. O. Williams and C. Renard (Eds.), Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan Africa. Volume II: Technical papers. Proceedings of an International Conference, ILCA, Addis Ababa, pp. 293-303.

Schiere, J.B., 1995. Cattle, straw and system control: a study of straw feeding systems. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 216 pp.

Schiere, J.B. and Nell, A.J., 1993. Feeding of urea treated straw in the tropics. I. A review of its technical principles and economics. *Animal Feed Science and Technology 43: 135 – 147.*

Schiere J.B., Joshi, A.L., Seetharam, A., 1994. Feeding value of fibrous crop residues and their economic implications for crop production. In: A. Seetharam, J.B., Schiere, (Eds.), Crop improvement and its impact on the feeding value of straw and stovers of grain cereals in India. Proceedings of a Workshop, Indian Council of Agricultural Research, New Delhi, India, pp 1 – 15.

Schiere, J.B., Silva, K.A.I.D., Badurdeen, A.L. and Ibrahim, M.N.M., 1990. Dry matter intake and digestibility of Kikuyu grass (*Pennisetum clandestinum*) offered at increasing levels. *Indian Journal of Animal Nutrition 7: 311-314.*

Shapiro, B.I., Sanders, J.H., 1998. Fertilizer use in semiarid West Africa: Profitability and supporting policy. *Agricultural Systems 56: 467-482.*

Sharifi, M.A., Van Keulen, H., 1994. A decision support system for Land Use Planning at Farm Entreprise Level. *Agricultural Systems 45: 239-257.*

Sherrod, P. H., 1994. Non linear regression analysis program, 1992-1994, version 3.2.

Singh M., 1994. Feeding value of untreated rice straw of different cultivars. In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues. Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 29 – 35.

Singh, B. B., 1997. Cowpea and its improvement: key to sustainable mixed crop/livestock farming systems in West Africa. In: Renard, C. (Ed.), Crop residues in sustainable mixed crop/livestock farming systems. CAB International, ICRISAT, ILRI, pp. 79-100.

Singh, K., Schiere, J. B. (Eds.), 1995. Handbook for straw feeding systems. Principles and applications with emphasis on Indian livestock production. ICAR, DPS/WAU, 428 pp.

Sissoko, K., 1998. Et demain l'Agriculture? Options techniques et mesures politiques pour un développement agricole durable en Afrique subsaharienne. Cas du Cercle de Koutialia en zone sud du Mali. Tropical Resource Management Papers 23, The Netherlands. 184 pp + annexes.

Sissoko, K., Bakker, E.J., Touré, M.S.M., Quak, W., 1995. La programmation linéaire à buts multiples pour un développement durable dans le cercle de Koutiala: ressources, options techniques de production durable et premiers résultats. In: Equipe de Modélisation des Systèmes, Modélisation et politique de développement, Perspectives d'un développement agricole durable, "cas du Cercle de Koutiala". Projet Production Soudano-Sahélienne, Bamako & Wageningen, rapport PSS No 10, AB-DLO: 9 - 81.

Slingerland, M., 1996. Mulching: Widespread and well adapted to farmers' means in Burkina Faso. *Indigeneous Knowledge and Development Monitor 4: 3 - 5.*

Smartt, J., 1994. The groundnut crop. A scientific basis for improvement. Chapman & Hall edition, UK, 734 pp.

Smith, O. B., 1993. Feed resources for intensive smallholder systems in the tropics: the role of crop residues. In: Baker, M. J. (Ed.), Grassland for our world, SIR Publishing. Pp. 740-746.

Somda, Z.C., 1994. Nutrient cycling through livestock in semi-arid West Africa. A postdoctoral fellowship report. International Livestock Center for Africa, Sahelian Center, Niamey, Niger. 230 pp.

Songué, Y., 1997. Les mutations socio-économiques du système agricole: un modèle d'intégration culture-élevage. Doctorat 3ème cycle, Université de Ouagadougou, Burkina Faso, 206 pp.

Stalker, H.T., 1997. Peanut (*Arachis hypogaea L.*). *Field Crops Research 53: 205 – 217.*

Stares, J.E.S., Said, A.N., Kategile, J.A.(Eds.), 1992. The complementarity of feed resources for animal production in Africa. Proceedings of the Joint Feed Resources Networks workshop, Gaborone, Botswana. African Feeds Research Network. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.

Stoorvogel, J.J., Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in Sub-Saharan Africa, 1983-2000. SC-DLO report 28, vol. 1, Wageningen, The Netherlands, 173 pp.

Stroosnijder, L., 1995. Quantification of nutrient erosion. In: MED (Mediterranean Erosion and Desertification). Proceeding of a Conference on Erosion and Land degradation in the Mediterranean, University of Aveiro, Portugal, pp. 89-100.

Stroosnijder, L., 1996. Modelling the effect of grazing on infiltration, runoff and primary production in the Sahel. *Ecological Modelling 92: 79 - 88.*

Struif Bontkes, T., 1999. Modelling the dynamics of agricultural development: a process approach. The case of Koutiala (Mali). Tropical Resource Management Papers No 25. Wageningen University and Research centre, The Netherlands. 233 pp.

Subba Rao, A., Pbhu, U.H., Sampath, S.R., Schiere, J.B., 1994a. The effect of allowance on the intake and digestibility of finger millet (*Eleusine coracana*) straw in crossbred heifers. *Animal Feed Science and Technology 49: 37-41*

Subba Rao, A., Prabhu, U.H., Gowda, B.T.S., Seetharam, A., 1994b. Genetic and managemental influence on straw quality and quantity of finger millet (*Eleucine corana*). In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues. Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 1 – 8.

Sumberg, J., 1998. Mixed farming in Africa: the search for order, the search for sustainability. *Land Use Policy 15: 293 – 317.*

Sundstøl, F. and Owen, E., (Eds.), 1984. Straw and other fibrous by-products as feed. Developments in Animal and Veterinary Sciences, 14. Elsevier, 604 pp.

Tilley, J.M.A., Tierry, R.A., 1963. A two stage technique for in vitro digestion of forage crops. *Journal of British Grassland Society 18: 104 - 111.*

Umunna, N.N., Nsahlai, I.V., Osuji, P.O., 1995. Degradability of forage protein supplements and their effects on the kinetics of digestion and passage. *Small Ruminant Research 17: 145 – 152.*

UNDP, 1997. Human development report 1997. Human development to eradicate poverty. Oxford University Press, New York, 245 pp.

Van Bruchem, J., Zemmelink, G., 1994. Towards sustainable ruminant livestock production in the tropics: Opportunities and limitations of rice straw based systems. In: Zemmelink, G., Leegwater P.H., Ibrahim M.N.M., van Bruchem, J. (Eds.), Constraints and opportunities for increasing the productivity of cattle in small-scale crop-livestock systems. Proceedings of an internal mid-term workshop, ICE, Sri Lanka, pp. 124-140.

Van De Ven, G.W.J., 1996. A mathematical approach to comparing environmental and economic goals in dairy farming on sandy soils in the Netherlands. Ph.D. Thesis. Wageningen Agricultural University. The Netherlands. 239 pp.

Van der Pol, F., 1992. Soil mining. An unseen contributor to farm income in southern Mali. Royal Tropical Institute Bulletin 325, Amsterdam, The Netherlands, 28 pp + appendices.

Van Duivenbooden, N., 1992. Sustainability in terms of nutrient elements with special reference to West Africa. Report No 160, CABO-DLO, Wageningen. The Netherlands, 216 pp.

Van Keulen, H., 1993. Options for agricultural development: a new quantitative approach. In: F.W.T. Penning de Vries, P.S. Teng (Eds.), Systems approaches for agricultural development, Kluwer Academic Publishers. The Netherlands, pp. 355 - 365.

Van Keulen, H., 1995. Sustainability and long-term dynamics of soil organic matter and nutrients under alternative management strategies. In: Bouma, J., Kuyvenhoven, A., Bouman, B.A.M., Luyten, J.C., Zandstra, H.G., (Eds.), Eco-regional approaches for sustainable land use and food production. Systems Approaches for Sustainable Agricultural Development 4, Kluwer Academic Publishers, The Netherlands, pp. 353 - 375.

Van Keulen H., Breman, H., 1990. Agricultural development in the West African Sahelian region: a cure against land hunger? *Agriculture, Ecosystems and Environment 32: 177- 197.*

Van Rheenen, T., 1995. Farm household optimal resource allocation; an explorative study in the limestone area of East Java. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 145 pp.

Van Soest, P.J., 1994. Nutritional Ecology of the Ruminant 2nd edn., Cornell University Press, Ithaca/London, 476 pp.

Veeneklaas, F.R., 1990. Compétition pour des ressources limitées: le cas de la cinquième Région du Mali, rapport 3: Description formelle du modèle d'optimisation MALI5. CABO, Wageningen et ESPR, Mopti, Mali. 63 pp.

Verberne, E.L.J., Hassink, J., de Willigen, P., Groot, J.J., van Veen, J.A., 1990. Modeling organic matter dynamics in different soils. *Netherlands Journal of Agricultural Science 38: 221 - 238.*

Wahed, R. A., Owen, E., Naate, M., Hosking, B.J., 1990. Feeding straw to small ruminants. Effects of amount offered on intake and selection of barley straw by goats and sheep. *Animal Production 51: 283-289.*

Walli, T.K., Harika, A.S., Subba Rao, A., Sharma, D.D., 1994a. Feeding value of crop residues and feeding systems. In: A. Seetharam, J.B. Schiere (Eds.), Crop improvement and its impact on the feeding value of straw and stovers of grain cereals in India. Proceedings of a Worshop, Indian Council of Agricultural Research, New Delhi, India, pp. 38 – 53.

Walli, T.K., Harika, A.S., Sharma, D.D., 1994b. Influence of crop management practices and post-harvest techniques on quantity and quality of straws. In: A.L. Joshi, P.T. Doyle, S.J. Oosting (Eds.), Variation in the quantity and quality of fibrous crop residues. Proceedings of a national seminar, Baif Development Research Foundation, Pune (Maharashtra-India), pp. 53- 66.

Williams, O. T., Fernàndez-Rivera, S., Kelley, T.G., 1997. The influence of socio-economic factors on the availability and utilization of crop residues as animal feeds. In Renard C. (Ed.), Crop residues in sustainable mixed crop-livestock farming systems. Proceedings of an International Workshop held at Addis Ababa, Ethiopia, ICRISAT, ILRI, CABI, pp. 25-39.

Williams, T.O., Hiernaux, P., Fernández-Rivera, S., 1998. Crop-livestock systems in Sub-Saharan Africa: determinants and intensification pathways. Paper presented at the International symposium on property rights, risk and livestock development. ILRI, IFPRI, Göttingen University, DSE, Feldafing, Germany, pp. 35-51

Winrock International, 1992. Assessment of animal agriculture in Africa. Morrilton, Arkansas, USA, 125 pp.

Wolf, J., Breman, H., and Keulen, H. van, 1991. Bio-economic capability of West-African drylands. CABO, The Netherlands, 83 pp.

Woomer, P. L., Swift, M.J., 1994. The biological management of tropical soil fertility. Tropical soil and fertility program. Wiley-Sayce, UK. 311 pp.

Zagré, Z.A., 1988. Rôle des résidus de récoltes dans la zone nord-soudanienne du Burkina Faso. Mémoire d' Ingénieur du Développement Rural, Université de Ouagadougou, Burkina Faso. 120 pp.

Zemmelink, G., 1980. Effect of selective consumption on voluntary intake and digestibility of tropical forages. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 100 pp.

Zemmelink, G., 1986. Measuring intake of tropical forages. In: C.C. Balch and A.J.H. van Es (Eds.), Recent advances in feed evaluation and rationing systems for dairy cattle in intensive and extensive production systems. International Dairy Federation, Brussels, Bulletin 196, pp. 17-21.

Zemmelink, G., Brouwer, B.O., Ifar, S., 1992. Feed utilisation and the role of ruminants in farming systems. In: Ibrahim, M.N.M, de Jong, R., Van Bruchem, J., Purnomo, H. (Eds.), Livestock and feed development in the tropics. Proceedings of the international seminar held at Brawijaya University, Malang, pp: 444-451.

Zemmelink, G., Haggar, R.J. and Davies, J.H., 1972. A note on the voluntary intake of *Andropogon gayanus* hay by cattle, as affected by level of feeding. *Animal Production 15: 85-88.*

Zemmelink, G., Tolkamp, B.J. and Ogink, N.W.M., 1991. Energy requirements for maintenance and gain of West African Dwarf goats. *Small Ruminant Research 5: 205-215.*

Zongo, P., 1997. Contribution à l'optimisation de l'utilisation des residus de récoltes dans la province du Zoundwéogo. Mémoire d'Ingénieur du Développement Rural, option élevage. Institut Polytechnique de Bobo-Dioulasso, Burkina Faso, 110 pp.

Zoungrana, I., 1991. Recherche sur les aires pâturées du Burkina Faso. Thèse Doctorat de l'Université de Bordeaux III, France. 277 pp.

Summary

Introduction

Traditional agricultural production systems in Sub-Saharan Africa were based on transfer of nutrients by grazing animals from rangeland to cropland, combined with fallowing. These systems are under increasing pressure as a result of rapid population increase. In most of the semi-arid and sub-humid zones, the area of rangeland, required to maintain cropland productivity, is not available anymore. The associated continuous decline in soil productivity induces risks of food shortage and irreversible soil degradation, and every effort should be made to avoid further deterioration of the resource base. Integration of crops and livestock and the associated intensified nutrient cycling are often advocated as desirable developments towards sustainable land use. Performance of these integrated systems hinges on the management of crop residues and manure, which represent the main source of organic matter and nutrients for animal and soil. The objective of the present study was to analyse the consequences of alternative management techniques of crop residues, from a sustainable crop-livestock farming perspective in the North Soudanian zone of Burkina Faso. The specific objectives were: (1) To establish response curves describing the effect of (varying degrees of) selective consumption of crop residues (as single feeds and in various combinations) on animal production; (2) to evaluate the effect of alternative systems of feeding crop residues on labour requirements and household income; (3) to evaluate the effect of alternative systems of feeding residues on crop production and on organic matter, nitrogen and phosphorus balances at farm level; (4) to determine the trade-offs among various objectives associated with alternative crop residue management techniques.

The approach

The potential contribution of crop residues to ruminant feeding in the four agro-ecological zones distinguished in Burkina Faso was estimated, applying the Java Program developed at the Animal Production Systems Group of Wageningen University (Chapter 2). The number of animals that can be fed and their production were estimated on the basis of availability and quality (digestibility and N content) of crop residues (cereal stovers and legume haulms).

Feeding trials were carried out with sheep to determine the relationships between the quantities of crop residues offered on the one hand, and intake and digestibility of ingested material on the other hand. In Chapter 3, the effect of selective consumption on intake and digestibility of sorghum, cowpea and groundnut residues is described. Two additional feeding trials were conducted as a basis for optimising the use of cowpea and groundnut haulms as supplement to sorghum stover (Chapter 4). The models used for analysis of the data allow description of the combined effects of animal selectivity for the better fractions of cereal stover, and of supplementation, on intake and digestibility of ingested material. Results of the feeding trials complemented by literature data served as the basis to derive iso-production curves. Based on the isoquant concept, least-cost rations were derived for a range of combinations of cereal stovers and supplements.

The possibilities for optimal utilisation of crop residue at farm level was analysed using a linear programming technique. To quantify the relevant household resources, constraints and objectives, farm surveys were conducted (Chapter 5). The above-mentioned iso-production curves served as the basis for quantification of the technical coefficients for animal feeding activities, while for crop activities various models from the literature were applied to the region under consideration. A Multiple Goal Linear Programming (MGLP) model (referred to as HOREB, Household level Optimal crop REsidue allocation in Burkina Faso) was developed to determine the effect of various crop residue management techniques on farm productivity, economics and sustainability, in terms of balanced organic matter, nitrogen and phosphorus budgets (Chapters 6 and 7). The main results are discussed in Chapter 8, with special attention for the contribution of crop residues to sustainable land use in Sub-Saharan Africa.

Contribution of crop residues to ruminant feeding at regional level

On the basis of current crop production, 54 and 98 % of the current ruminant population can potentially be maintained during the dry season in the Sub-Sahelian and North-Soudanian zones, respectively. There might even be scope for increasing the contribution of crop residues to animal production in these areas, by increasing production of legume haulms and allowing selective use of stover leaves. It may also be profitable to take advantage of the capacity of animals to use feeds selectively by excess feeding. This requires, however, collection techniques and conservation structures that minimise the reduction in nutritive value of the scarce highest quality residues (legume haulms). The objective of rearing animals, either maximisation of animal production or maintaining the maximum number of animals, determines the most suitable feeding techniques. Maximising animal production is associated with inclusion of smaller quantities of cereal stovers in the ration and with a smaller number of animals kept. Maintaining the maximum number of animals allows the use of more cereal stovers and results in higher manure availability for arable fields, and so may contribute to maintaining cropland productivity.

Optimising crop residue use at animal level

Results of the feeding trials show that unsupplemented sorghum stover can hardly be used for animal production, due to its low intake and digestibility, and its low protein content. Even maintenance can only be reached if selective consumption of leaves is allowed; In our trials, sheep reached the maintenance level only when 87 g OM $kg^{-0.75}d^{-1}$ was offered, of which only 53 % was eaten. Offering cowpea and groundnut haulms, maintenance can be achieved with 36 and 39 g OM $kg^{-0.75}d^{-1}$, respectively. These results illustrate, that when coarse, low quality forages are fed alone, selection is not a waste, but a prerequisite for animal production and even for maintaining animals. Excess feeding of sorghum stover (allowing selective consumption of leaves), significantly reduced the quantity of supplement (cowpea and groundnut haulms) needed to reach a desired level of intake of digestible organic matter (IDOM). Up to 54 g OM $kg^{-0.75}$ d^{-1} of groundnut haulms was needed for 1.4 times maintenance (33.6 g DOM $kg^{-0.75}$ d^{-1}) when animals ingested 90 % of the sorghum stover, but only 29 g OM $kg^{-0.75}$ d^{-1} was needed, when animals were allowed to eat only 50 % of the sorghum stover offered.

Optimising crop residue use at farm level

The results of farm surveys indicate that availability of a donkey cart for transport allowed storage of significantly more high quality crop residues (cowpea haulms). The stored residues served as animal feed (100 % for legume haulms and 70 % for cereal stovers), the remainder being used as building material, source of fuel for cooking, etc. Crop residues remaining in the fields are commonly grazed and only the non-edible parts serve as soil amendment. Factors such as relationships between farmers and herdsmen, location of fields, herd composition and production system, and available means of transportation determine the quantities of crop residues collected.

On a farm (6.2 ha available land) with 210 md available labour per month, where crop residues are not collected for stall feeding in the dry season and no capital is available to buy fertiliser, a maximum of 3.2 t staple food can be produced in normal (average rainfall) years. When the household does collect crop residues for sheep stall feeding and aims at maximum gross margin, attainable staple production hardly changes, when no external inputs are used. The household could produce 4.5 t staple, when maximising total gross margin under balanced OM and nutrient budgets, provided sufficient working capital to buy external inputs is available. Model results suggest that reduction of the current crop area by 0.5 to 1.2 ha (depending on the restrictions imposed on nutrients budgets) is necessary to allow integration of sheep stall feeding, because of the required labour for residues collection. Integration of sheep stall feeding could then contribute to restriction of the expansion of the crop area without compromising households food security.

Availability of labour for crop residue collection and storage is the major limiting factor for the integration of crops and stall feeding of sheep. Labour availability dictates, in combination with the objectives of animal keeping, the selection among the different feeding techniques. Chopping, requiring substantial investment in labour, is selected when the farmer aims at maximising availability of manure, security or savings, for which a maximum number of animals is fed at maintenance. Treatment with urea requires, in addition to chopping, working capital to buy urea. This option is hardly ever selected because of the combined limitations of labour, capital and low remuneration. At the current urea price and labour availability conditions, excess feeding is the best method of feeding in all scenarios.

Maximising crop gross margin is always associated with soil mining; 20-27 % of calculated farm gross margin originates from soil mining, if soil nutrients and organic matter are valued at inorganic fertiliser and stover prices, respectively. From 200- 344 kg OM, 15-21 kg N and 1.5-1.8 kg P per ha are lost annually from the system when animals are not stall fed (extensive feeding system). When crop residues are collected for stall feeding of sheep and the farmer aims at maximum total gross margin, annual losses are 175-192 kg OM, 12-15 kg N and 1.1-1.2 kg P. The results of these analyses clearly illustrate that intensive management of crop residues in integrated crop-livestock farming systems cannot maintain soil nutrient status. Nutrients from external sources are necessary, either in the form of concentrate or fertiliser. Moreover, maximum gross margin per manday of labour invested in sheep feeding activities is 0.20 kF, which is much lower than the actual labour wages in the area. Hence, if off-farm employment is available, stall-feeding of sheep is not an economically attractive alternative. Economic profitability can be improved if capital availability allows utilisation of concentrate, i.e. 0.28 kF extra gross margin can be attained per kF invested in cotton seed cake. Potentially, attainable gross margin from sheep feeding is 182 kF per household, when crop residues would be optimally collected (80 % of the cereal stovers and 86 % of the legume haulms produced).

Conclusions

Integration of crops and livestock is often considered as a step towards sustainable agricultural production, because of the associated intensified organic matter and nutrients cycling through intensive crop residue management. The main advantage of the integration of livestock and crops is the added value derived from crop residues (especially those of legumes) in terms of animal products and income. Intensive management of crop residues in integrated crop-livestock farming appears a means of guaranteeing subsistence in an environment characterised by growing competition for organic matter and nutrients between animals and soil. Sustainable production, at regional level, can only be triggered by external inputs. However, the current price ratios of fertiliser and grains are hardly conducive to fertiliser utilisation. The prospects for sustainable crop-livestock production are intimately linked to the price of external inputs and to the low availability of working capital. Investment in concentrate is remunerative, but lack of cash is a serious constraint for their acquisition. Improved credit facilities for farmers may stimulate intensification of livestock production and thereby increase nutrient availability for cropland, and hence sustainable land use practices.

Samenvatting

Inleiding

Traditionele landbouwproductiesystemen in Afrika ten Zuiden van de Sahara waren gebaseerd op transfer van nutriënten door weidend vee van natuurlijke weiden naar akkerland, gecombineerd met braakperioden. Deze systemen staan onder toenemende druk als gevolg van de snelle bevolkingstoename. In het grootste deel van de semi-aride en sub-humide zone's is het areaal natuurlijke weiden dat nodig is om de productie van het akkerland op peil te houden, niet meer beschikbaar. De daarmee samenhangende achteruitgang in de productiviteit van de bodem leidt tot verhoogde risico's voor voedseltekorten en onomkeerbare degradatie van de bodem, en alles moet in het werk gesteld worden om verdere achteruitgang van de kwaliteit van de natuurlijke hulpbronnen te voorkomen. Integratie van veehouderij en akkerbouw, en de daarmee gepaarde gaande intensivering van het circuleren van voedingsstoffen, wordt vaak aangeprezen als een gewenste ontwikkeling in de richting van (meer) duurzaam landgebruik. De mate van succes van die integratie hangt nauw samen met de manier waarop gewasresten en dierlijke mest - de voornaamste bronnen van voedingsstoffen en organisch materiaal, voor zowel het dier als de bodem - worden gebruikt. Het doel van de hier beschreven studie was de consequenties te analyseren van alternatieve gebruiksmethoden van gewasresten, in het kader van de ontwikkeling van duurzame gemengde bedrijfssystemen in de Noordelijke Soedanzone van Burkina Faso. De specifieke doelstellingen waren: (1) het bepalen van responscurven die het effect beschrijven van (verschillende mate van) selectieve opname van gewasresten (als individuele voeders en in verschillende combinaties) op dierlijke productie; (2) het evalueren van het effect van verschillende voedertechnieken voor gewasresten op de arbeidsbehoefte en het gezinsinkomen; (3) het evalueren van het effect van verschillende manieren om gewasresten te gebruiken op gewasproductie en op de balansen van organische stof, stikstof en fosfor op bedrijfsniveau; (4) het bepalen van de uitruilwaarden tussen verschillende doelstellingen op bedrijfsniveau bij verschillende vormen van gebruik van gewasresten.

De methode

De potentiële bijdrage van gewasresten aan de voeding van herkauwers in de vier in Burkina Faso onderscheiden agro-ecologische zone's is geschat met behulp van het computerprogramma Java, ontwikkeld bij de Groep Dierlijke Productiesystemen van Wageningen Universiteit. (Hoofdstuk 2). Het aantal dieren dat gevoed kan worden en hun productieniveau werden geschat op grond van de beschikbaarheid en de kwaliteit (verteerbaarheid en stikstofgehalte) van gewasresten (enerzijds graanstro en anderzijds stro van de vlinderbloemigen koeieboon (cowpea) en pinda).

Om na te gaan wat de mogelijkheden zijn voor benutting van gewasresten op dierniveau, zijn voederproeven uitgevoerd met schapen om het verband te bepalen tussen de hoeveelheid aangeboden voer enerzijds, en de voederopname en de verteerbaarheid van het opgenomen voer anderzijds. In Hoofdstuk 3 worden deze verbanden beschreven voor sorghum-, koeieboon- en pindastro. Twee additionele voederproeven werden uitgevoerd om de optimale combinaties van koeieboon- en pindastro enerzijds en sorghumstro anderzijds te bepalen (Hoofdstuk 4). De opzet van deze proeven en de gebruikte analysemethode maakten het mogelijk de gecombineerde effecten te beschrijven van het vermogen van de dieren de kwalitatief betere delen van het graanstro te selecteren en bijvoeding, op voederopname en verteerbaarheid van het opgenomen rantsoen. Op grond van deze beschrijvingen, gecombineerd met literatuurgegevens, werden iso-productiecurven afgeleid en, gebaseerd op de isoquant-benadering werden minimum-kosten rantsoenen bepaald voor een aantal geselecteerde productieniveau's.

De verschillende mogelijkheden voor gebruik van gewasresten op bedrijfsniveau zijn geanalyseerd via een lineaire programmeringstechniek. Voor het kwantificeren van de relevante hulpbronnen, beperkingen en doelstellingen van de gangbare boerenbedrijven in de regio, zijn bedrijfsinterviews uitgevoerd. De eerdergenoemde iso-productiecurven zijn gebruikt als basis voor het kwantificeren van de technische coëfficiënten van dierlijke productieactiviteiten, terwijl voor de akkerbouwactiviteiten gebruik gemaakt is van verschillende modellen uit de literatuur. Een Meervoudig Doelprogrammeringsmodel (HOREB, Household Optimal crop REsidue allocation in Burkina Faso) is ontwikkeld om de effecten te bepalen van verschillende vormen van gebruik van gewasresten op bedrijfsniveau op de opbrengsten, het financieel resultaat en de duurzaamheid, uitgedrukt in termen van de balansen van organische stof, stikstof en fosfor (Hoofdstukken 6 en 7). De belangrijkste resultaten worden besproken in Hoofdstuk 8, met speciale aandacht voor de mogelijke bijdrage van gewasresten aan de ontwikkeling van duurzame landgebruikssystemen in Afrika ten Zuiden van de Sahara.

De bijdrage van gewasresten aan de voedervoorziening van herkauwers op regionaal niveau

Op basis van het huidige gewasproductieniveau kan 54 en 98 % van de huidige veestapel in respectievelijk de Sub-Sahel en de Soedanzone van Burkina Faso, gevoerd worden op onderhoudsniveau gedurende de droge tijd. Er lijken zelfs mogelijkheden voor een verhoging van die bijdrage, wanneer de productie van stro van vlinderbloemigen zou kunnen worden verhoogd, en/of door de mogelijkheden van selectieve voederopname te benutten.Van de capaciteit voor selectieve opname kan geprofiteerd worden door overmaat voer aan te bieden. Dat vraagt echter toepassing van verzameltechnieken en opslagmethoden voor de gewasresten, die de achteruitgang in kwaliteit van met name de gewasresten met de hoogste kwaliteit (vlinderbloemigenstro), minimaliseren. De doelstelling voor het houden van vee, schematisch beschreven als ofwel maximalisering van de dierlijke productie ofwel maximalisering van het aantal dieren gevoerd op onderhoudsniveau, bepaalt de meest geschikte voedermethode. Maximalisering van de dierlijke productie wordt bereikt met een (relatief) klein aantal dieren en gebruik van een relatief klein deel van het graanstro in het rantsoen. Voeren van het maximale aantal dieren op onderhoudsniveau vraagt om het gebruik van een groter deel van het graanstro, en resulteert in een hogere productie van dierlijke mest voor het akkerland, en draagt zodoende bij tot het op peil houden van de productiviteit van de bodem.

Optimalisering van het gebruik van gewasresten op dierniveau

De resultaten van de voederproeven tonen aan dat sorghumstro allééén, nauwelijks gebruikt kan worden voor dierlijke productie, vanwege de lage opname door het dier, de geringe verteerbaarheid en het lage eiwitgehalte. Zelfs het opnameniveau voor onderhoud kan alleen worden bereikt wanneer de mogelijkheden voor selectieve opname door het dier worden benut. In onze proeven bereikten schapen dat opnameniveau alleen wanneer een grote overmaat sorghumstro (87 g Organisch Stof (kg lichaamsgewicht)$^{-0.75}$ d^{-1}) werd aangeboden, waarbij slechts 53% van het aangeboden voer ook inderdaad wordt opgenomen. Met stro van koeieboon of pinda werd opname op onderhoudsniveau gerealiseerd bij een aanbod van respectievelijk 36 en 39 g OS kg$^{-0.75}$ d^{-1}. Deze resultaten illustreren dat, wanneer ruwvoer van lage kwaliteit wordt aangeboden, selectie niet leidt tot verspilling, maar een noodzaak is voor dierlijke productie en zelfs voor opname op onderhoudsniveau. Aanbod van overmaat sorghumstro en selectieve opname van blad leidde tot een significante afname van de hoeveelheid supplement (koeieboon- of pindastro), nodig om een gewenst opnameniveau van verteerbare organischestof te realiseren. Dieren met een geringe mogelijkheid tot selectie in sorghumstro (opname van 90% van de aangeboden hoeveelheid) hadden 54 g OS kg$^{-0.75}$ d^{-1} pindastro nodig voor een voedingsniveau van 1.4 maal onderhoud. Dieren met een ruime mogelijkheid tot selectie (opname van 50% van de aangeboden hoeveelheid sorghumstro) hadden daarvoor slechts 29 g OS kg$^{-0.75}$ d^{-1} pindastro nodig.

Optimalisering van het gebruik van gewasresten op bedrijfsniveau

De resultaten van de bedrijfsenquête's tonen aan dat de hoeveelheden gewasresten die werden verzameld samenhingen met factoren zoals de verhoudingen tussen akkerbouwers en veehouders, de ligging van de percelen, samenstelling van de kudde, productiesysteem en het al of niet beschikbaar zijn van transportmiddelen. Beschikbaarheid van een ezelkar bleek het mogelijk te maken grotere hoeveelheden gewasresten van goede kwaliteit (koeieboon- en pindastro) op te slaan. De opgeslagen gewasresten werden voor verreweg het grootste deel (100% van het vlinderbloemigenstro en 70% van het graanstro) gebruikt als veevoer; de resterende 30% van het graanstro diende als bouwmateriaal, om te koken, enz. De in het veld achtergelaten gewasresten werden voor het grootste deel afgegraasd; alleen het niet-opneembare deel bleef achter als bodemverbeteraar.

De volgende resultaten zijn gebaseerd op analyses met het model HOREB.

Op een gemiddeld bedrijf (bedrijfsareaal 6.2 ha), met 210 mandagen per maand beschikbare arbeid, waar geen gewasresten worden verzameld voor stalvoedering in het droge seizoen, en geen middelen beschikbaar zijn voor aankoop van kunstmest, kan maximaal 3.2 ton voedsel worden verbouwd in een 'normaal' (met gemiddelde regenval) jaar. Wanneer wel gewasresten worden verzameld voor stalvoedering en er wordt gestreefd naar een zo hoog mogelijk bruto bedrijfsresultaat, kan ongeveer evenveel voedsel worden verbouwd, zonder gebruik van externe productiemiddelen. Op het bedrijf kan 4.5 ton voedsel worden verbouwd, wanneer het bruto bedrijfsresultaat wordt gemaximaliseerd, onder de voorwaarde dat de organischestof en nutriëntenbalansen in evenwicht zijn, en er geld beschikbaar is om externe productiemiddelen aan te schaffen. De resultaten van het model suggereren dat inkrimping van het bedrijfsareaal met 0.5 tot 1.2 ha (afhankelijk van de beperkingen die opgelegd worden aan de nutriëntenbalansen) noodzakelijk is om integratie van schapenhouderij en akkerbouw mogelijk te maken, vanwege de concurrentie om arbeid tussen oogsten van de akkerbouwgewassen en verzamelen van stro voor veevoer. Onder die omstandigheden kan stalvoedering van schapen een bijdrage leveren aan vermindering van de uitbreiding van het gewasareaal, zonder de voedselveiligheid van het gezin in de waagschaal te stellen.

De beschikbaarheid van arbeid voor het verzamelen en opslaan van gewasresten is de voornaamste beperkende factor bij de integratie van akkerbouw en stalvoedering van schapen. De arbeidsbeschikbaarheid bepaalt, in samenhang met de doelstellingen van het houden van vee, voor welke voedertechniek wordt gekozen. Hakselen vraagt een aanzienlijke arbeidsinvestering en wordt gekozen wanneer het bedrijf streeft naar maximalisering van de beschikbare hoeveelheid mest, of naar het maximum aantal dieren voor investering en zekerheid. Behandeling met ureum vraagt, naast de arbeid voor hakselen, financiële middelen om ureum te kopen. Deze optie wordt bijna nooit gekozen, vanwege de gecombineerde beperkingen van arbeid, kapitaal en winstgevendheid. Bij de huidige situatie met betrekking tot de prijs van ureum en arbeidsbeschikbaarheid, is overmaat voeren de beste voedermethode in alle scenario's

Maximalisering van het bruto overschot voor de akkerbouw, gaat altijd gepaard met het ' uitmijnen' van de bodem. Wanneer de voedingsstoffen en het organisch materiaal gewaardeerd worden tegen respectievelijk de prijs van kunstmest en stro, kan 20-27% van het berekende bruto bedrijfsoverschot worden toegerekend aan dat mijnen. Wanneer geen stalvoedering wordt toegepast (extensief beweidingssysteem), liggen de jaarlijkse verliezen uit de bodem tussen de 200 en 344 kg organische stof, 15 en 21 kg N en 1.5 en 1.8 kg P per ha. Wanneer gewasresten worden verzameld voor stalvoedering in het droge seizoen, en er wordt gestreefd naar maximalisering van het bruto bedrijfsoverschot, nemen de jaarlijkse verliezen af tot 175 - 192 kg organische stof, 12 - 15 kg N en 1.1 - 1.2 kg P per ha. Deze resultaten van de modelberekeningen illustreren duidelijk dat intensief beheer van gewasresten in gemengde bedrijfssystemen de bodemvruchtbaarheid niet op peil kan houden. Voedingsstoffen moeten worden aangevoerd van buiten het systeem, ofwel in de vorm van kunstmest of in de vorm van krachtvoer. Daarnaast is het maximale bruto overschot per mandag, geïnvesteerd in activiteiten gericht op het voederen van schapen, 200 FCFA, hetgeen veel minder is dan het geldende arbeidsloon in het gebied. Dus, wanneer er werkgelegenheid buiten de landbouw is, is stalvoedering van schapen economisch niet aantrekkelijk. Het economisch resultaat kan worden verbeterd wanneer er kapitaal beschikbaar is om krachtvoer aan te kopen. Per 1000 FCFA, geïnvesteerd in de aankoop van katoenzaadkoek, wordt een extra winst gemaakt van 280 FCFA. Het maximaal haalbare bruto overschot van stalvoedering van schapen bedraagt 182 000 FCFA per huishouden, wanneer zoveel mogelijk gewasresten worden verzameld (80% van het geproduceerde graanstro en 86% van het stro van vlinderbloemigen).

Conclusies

Integratie van akkerbouw en veeteelt wordt vaak beschouwd als een stap in de richting van duurzame landbouwproductie, vanwege de ermee samenhangende intensive recirculatie van organischestof en voedingsstoffen, door intensief gebruik van gewasresten. Het voornaamste voordeel van integratie van akkerbouw en veeteelt is de toegevoegde waarde van de gewasresten (in het bijzonder die van de vlinderbloemigen) in termen van dierlijke productie en daarmee inkomen. Integratie van akkerbouw en veeteelt blijkt daarmee een middel om voedselzekerheid te garanderen in een omgeving waar de concurrentie om organische stof en voedingsstoffen tussen de bodem en vee toeneemt. Duurzame productie op regionaal niveau kan alleen worden gerealiseerd door het gebruik van productiemiddelen (kunstmest en/of krachtvoer) van buiten het systeem. De huidige prijsverhoudingen tussen kunstmest en graan maken het gebruik van kunstmest echter economisch niet rendabel. De vooruitzichten voor duurzame gemengde systemen hangen nauw samen met de prijs van productiemiddelen van buiten het systeem en met de arbeidsbeschikbaarheid. Het gebruik van krachtvoer is economisch rendabel, maar wordt beperkt door beperkte beschikbaarheid en gebrek aan liquide middelen. Verbeterde kredietmogelijkheden zouden een stimulans kunnen zijn voor intensivering van de veehouderij, hetgeen zou leiden tot verhoogde beschikbaarheid van voedingsstoffen voor het akkerland en daarmee tot meer duurzaam landgebruik.

Résumé

Introduction

Les systèmes de production agricoles d'Afrique Sub-Saharienne étaient basés sur le transfert des nutriments par les animaux des pâturages aux terres cultivées, en association avec le système de jachère. Ces systèmes sont sous une pression croissante à cause de la croissance rapide de la population. Dans la plupart des zones semi-aride et sub-humide, la superficie de pâturage nécessaire pour le maintien de la productivité des terres cultivées n'est plus disponible. La dégradation continue des terres qui y est associée induit des risques de déficit alimentaire et une dégradation irreversible du sol, et tous les efforts doivent être faits pour eviter une dégradation plus accrue de la resource de base. L'intégration agriculture-élevage et le recyclage intensif des nutriments qui y est associé sont souvent évoqués comme des évolutions souhaitables vers une utilisation durable de la terre. La performance de ces systèmes repose sur la gestion des résidus de récolte et du fumier, qui représentent la principale source de matière organique et de nutriments pour le sol et le bétail. L'objectif de cette étude était d'analyser les conséquences des techniques alternatives de gestion des résidus de récolte, dans une perspective de production intégrée agriculture-élevage dans la zone nord soudanienne du Burkina Faso. Les objectifs spécifiques étaient: (1) d'établir des courbes de réponse décrivant l'effet de (dégrés variable de) consommation sélective des résidus de récolte (offerts individuellement ou en diverses combinaisons) sur la production animale; (2) d'évaluer l'effet des systèmes alternatifs d'alimentation des animaux avec les résidus de récolte sur les besoins en main d'oeuvre et le revenu du ménage; (3) d'évaluer l'effet des systèmes alternatifs d' alimentation des animaux avec les résidus de récolte sur la production agricole et l'équilibre de la matière organique, de l'azote et du phosphore à l'échelle de l'exploitation agro-pastorale; (4) de déterminer les relations entre les divers objectifs qui sont associés aux techniques alternatives de gestion des résidus de récolte.

L'approche

La contribution potentielle des résidus de récolte à l'alimentation des ruminants dans 4 zones agro-écologiques du Burkina Faso a été estimée, à l'aide du programme « Java » developpé par le Goupe Systèmes de Production Animale de l'Université de Wageningen (Chapitre 2). Le nombre d'animaux qui peut être alimenté et leur production ont été estimés sur la base de la disponibilité et de la qualité (digestibilité et taux de N) des résidus de récolte (pailles de céréales et fanes de légumineuses).

Des essais d'alimentation ont été effectués avec des moutons pour déterminer les relations entre les quantités de résidus de récolte offertes d'un coté, et l'ingestibilité et la digestibilité de l'ingéré de l'autre. Dans le Chapitre 3, l'effet de la consommation sélective sur l'ingestibilité et la digestibilité de la paille de sorgho, des fanes de niébé et des fanes d'arachide est decrit. Deux essais supplémentaires ont été conduits pour servir de base à l'optimisation de l'utilisation des fanes de niébé et d'arachide comme suppléments à la paille de sorgho (Chapitre 4). Les modèles utilisés pour l'analyse des données permettent la description des effets associés de la sélectivité de l'animal pour les meilleures fractions de la paille de sorgho, et de la supplémentation, sur l'ingestibilité et la digestibilité de l'ingéré. Les résultats des essais, completés par des données obtenues dans la litterature ont servi de base pour dériver les courbes d'iso-production. Sur la base du concept d'isoquant, les rations les moins onéreux sont dérivées pour une gamme de combinations paille de céréales et suppléments.

Les possibilités d'utilisation optimale des résidus de récolte à l'échelle de l'exploitation ont été analysées à l'aide de la technique de programmation linéaire. Pour quantifier les paramètres pertinents sur les ressources, les constraintes et les objectifs des ménages, des suivis d'exploitations ont été conduits (Chapter 5). Les courbes d'iso-production ont servi de base pour la quantification des coefficients techniques relatives à l'alimentation des animaux, pendant que pour les activités de production agricole, divers modèles obtenus dans la litterature ont été appliqués à la région considérée. Un modèle de Programmation Linéaire à But Multiple (PLBM), appelé HOREB (Household level Optimal crop REsidue allocation in Burkina Faso) a été développé pour déterminer l'effet des diverses techniques de gestion des résidus de récolte sur la productivité de l'exploitation, les paramètres économiques et la durabilité, en termes d'équilibre des budgets de la matière organique, de l'azote et du phosphore (Chapitres 6 et 7). Les principaux résultats sont discutés au Chapitre 8, avec une attention spéciale sur la contribution des résidus de récolte à l'utilisation durable de la terre en Afrique Sub-Saharienne.

Contribution des résidus de récolte à l'alimentation des ruminants au niveau régional.

Sur la base de la production agricole actuelle, 54 et 98 % de la population actuelle de ruminants peut potentiellement être entretenus pendant la saison sèche dans les zones Sub-Sahélienne et Nord-Soudanienne, respectivement. Il y aurait même la possibilité d'améliorer la contribution des résidus de récolte à l'accroissement de la production animale dans ces zones, par l'augmentation de la production des légumineuses et en favorisant la consommation sélective des feuilles des pailles de céréales. Il pourrait également être profitable d'exploiter la capacité des animaux à utiliser les aliments de manière sélective, en leur offrant des quantités excessives. Ceci nécessite, cependant, des techniques de collecte et des infrastructures de conservation qui permettent de minimiser la dimunition de la valeur nutritive des rares résidus de meilleure qualité (fanes de légumineuses). L'objectif d'élevage, soit la maximisation de la production animale ou l'entretien d'un nombre maximal d'animaux, détermine les techniques d'alimentation les plus appropriées. La maximisation de la production animale est associée avec l'utilisation de petites quantités de pailles de céréales dans la ration et pour un nombre réduit d'animaux. L'entretien d'un nombre maximal d'animaux permet l'utilisation de plus grande quantités de pailles de céréales mais résulte en une plus grande disponibilité de fumier pour les champs, et ainsi contribue à maintenir la productivité des terres cultivées.

Optimisation de l'utilisation des résidus de récolte au niveau animal

Les résultats des essais d'alimentation montrent que la paille de sorgho sans supplément peut difficilement contribuer à la production animale, à cause de sa faible ingestibilité et digestibilité, et de son faible taux de protéine. Même le niveau d'entretien ne peut être atteint, qu'uniquement lorsque la consommation sélective des feuilles est permise; Dans nos essais, les ovins ont atteint le niveau d'entretien, seulement lorsque 87 g de matière organique (MO) $kg^{-0.75}$ j^{-1} était offerte, de laquelle seulement 53 % était ingéré. Lorsque des fanes de niébé et d'arachide sont offertes, le niveau d'entretien peut être atteint avec 36 et 39 g MO $kg^{-0.75}$ j^{-1}, respectivement. Ces résultats illustrent le fait que, lorsque des aliments grossiers, des fourrages de faible qualité sont offertes seuls, la sélection n'est pas un gachi, mais une condition indispensable pour la production animale et même pour l'entretien des animaux. L'offre de quantités excessives de paille de sorgho (permettant la consommation sélective des feuilles), a significativement réduit la quantité de supplément (fanes de niébé et d'arachide) nécessaire pour atteindre un niveau de matière organique ingérée digestible (MOID) souhaité. Jusqu'à 54 g MO $kg^{-0.75}$ j^{-1} de fanes d'arachide était nécessaire pour un niveau de MOID équivalent à 1.4 fois l'entretien (33.6 g matière organique digestible $kg^{-0.75}$ j^{-1}) lorsque les animaux devaient ingérer 90 % de la quantité de paille de sorgho offerte, mais seulement 29 g MO $kg^{-0.75}$ j^{-1} étaient nécessaire, lorsque les animaux pouvaient ingérer seulement 50 % de la paille de sorgho offerte.

Optimisation de l'utilisation des résidus de récolte au niveau exploitation

Les résultats des suivis indiquent que la disponibilité d'une charrette asine pour le transport a permis, de manière significative, le stockage de plus de résidus de meilleure qualité (fanes de niébé). Les quantités stockées ont servi à l'alimentation du bétail (100 % des fanes de légumineuses et 70 % des pailles de céréales), le reste ayant été utilisé comme matériel de construction, comme combustible, etc. Les résidus de récolte restés dans les champs sont généralement pâturés et seulement les parties non-ingestibles servent à amender le sol. Des facteurs tels que les relations entre les cultivateurs et les éleveurs, la localisation des champs, la composition des troupeaux et le système de production, et la disponibilité de moyens de transport détermine les quantités de résidus de récolte collectées.

Sur une exploitation (disposant de 6.5 ha de terre) avec 210 homme-jour de main d'oeuvre mensuelle, où les résidus de récolte ne sont pas collectés pour une alimentation à l'auge pendant la saison sèche et sans capital pour l'achat d'engrais, un maximum de 3.2 t de céréales et niébé (produits céréaliers) peut être produit en années normales (pluviométrie moyenne). Lorsque le ménage collecte les résidus de récolte pour l'alimentation des ovins à l'auge et vise la maximisation de la marge brute, le niveau de production de produits céréaliers ne varie pratiquement pas, lorsqu'aucun intrant externe n'est utilisé. Le ménage pourrait produire 4.5 t de produits céréaliers, tout en maximisant la marge brute totale avec des budgets équilibrés de matière organique et de nutriments, s'il y a suffisamment de liquidité pour acheter des intrants externes réquis. Les résultats du modèle suggèrent qu'une dimunition des superficies cultivées de 0.5 à 1.2 ha (en fonctions des restrictions imposées aux budgets des nutriments) est nécessaire pour permettre l'intégration de l'alimentation à l'auge des ovins dans le système de production, à cause de la quantité de main d'oeuvre requise pour la collecte des résidus. L'intégration de l'alimentation à l'auge des ovins pourrait ainsi contribuer à la limitation de l'expansion des superficies cultivées sans compromettre la sécurité alimentaire des ménages.

La disponibilité de la main d'oeuvre pour la collecte et le stockage des résidus de récolte est le principal facteur limitant de l'intégration de l'agriculture et de l'alimentation à l'auge des ovins. La disponibilité de la main d'oeuvre dicte, en association avec les objectifs d'élevage, le choix entre les differentes techniques d'alimentation. Le hachage, nécessitant un investissement substantiel en main d'oeuvre, est choisi lorsque le paysan vise la maximisation de la disponibilité du fumier, la sécurité ou l'épargne, d'où un nombre maximum d'animaux est alimenté au niveau entretien. Le traitement de la paille à l'urée nécessite, en plus du hachage, de la liquidité pour l'achat de l'urée. Cette option est toujours difficilement choisi à cause des effets associés de disponibilité limitée en main d'oeuvre, en liquidité et la faible rentabilité. Avec le niveau actuel de prix de l'urée et les conditions de disponibilité de main d'oeuvre, l'offre excessive (permettent la consommation sélective des feuilles) est la meilleure méthode dans tous les scénarios.

La maximisation de la marge brute agricole est toujours faite aux dépends des éléments nutritifs du sol; 20-27 % de la marge brute calculée provient de la dégradation du sol, si on valorise les nutriments et la matière organique du sol aux prix des engrais chimiques et des pailles de céréales, respectivement. De 200-344 kg MO, 15-21 kg N et 1.5-1.8 kg P par ha sont perdus du système lorsque les animaux ne sont pas alimentés à l'auge (système d'alimentation extensive). Lorsque les résidus de récolte sont collectés pour une alimentation à l'auge des ovins et le paysan vise la maximisation de la marge brute totale, les pertes annuelles sont de 175-192 kg MO, 12-15 kg N et 1.1-1.2 kg P. Les résultats de ces analyses illustrent clairement que la gestion intensive des résidus de récolte dans les systèmes intégrés agriculture-élevage ne peut pas maintenir le statut nutritionnel du sol. Des nutriments de source externe sont nécessaires, soit sous forme de concentrés ou d'engrais chimiques. De plus, la marge brute maximale par homme-jour investi dans l'alimentation des ovins est de 200 FCFA, ce qui est largement en déça du coût actuel de la main d'oeuvre dans la région. Ainsi, si des possibilités d'emploi hors-exploitation existaient, l'alimentation intensive des ovins ne serait pas une alternative économiquement attractive. Le profit économique peut être amélioré si la liquidité était disponible pour permettre l'utilisation de concentré, i.e. 280 FCFA supplémentaire peut être obtenu par FCFA investi dans l'achat de tourteau de coton. Potentiellement, le niveau maximum de marge brute provenant de l'alimentation des ovins serait de 182 FCFA par ménage, si les résidus de récolte pouvaient être collectés de manière optimale (80 % des pailles de céréales et 86 % des fanes de légumineuses produites).

Conclusions

L'intégration agriculture-élevage est souvent considérée comme une étape vers une production agricole durable, à cause des effets associés du recyclage intensif de la matière organique et des nutriments à travers la gestion intensive des résidus de récolte. L'avantage principale de l'intégration agriculture-élevage est la valeur ajoutée dérivée des résidus de récolte (spécialement ceux des légumineuses), en termes de produits animaux et de revenu. La gestion intensive des résidus de récolte dans une perspective d'intégration agriculture-élevage apparaît comme un moyen de garantir la subsistence dans un environnement caractérisé par une croissance de la compétition pour la matière organique entre les animaux et le sol. Une production durable, au niveau régional, ne peut être stimulée que par les intrants externes. Cependant, le ratio actuel de prix entre les grains et les engrais peut difficilement susciter l'utilisation des engrais. Les prospectives de production intégrée agriculture-élevage durable sont intimement liées aux prix des intrants externes et à la faible disponibilité de liquidité. L'investissement dans les concentrés est rentable, mais le manque de liquidité est une contrainte sérieuse à leur acquisition. L'amélioration de possibilités d'obtention de crédits par les paysans pourrait stimuler l'intensification de la production animale et partant accroître la disponibilité des nutriments pour les terres cultivées, et donc des pratiques d'utilisation durable de la t erre.

Appendix I

Determination of crop yields

The yields per crop are determined as the minimum value of the nutrient limited yields (Ny and Py), the water limited yield (Wy) and the potential yield (Poty) as described by Struif Bontkes (1999).

1- Nitrogen limited yields

The N limited yield is determined by the quantities of N available for the crop (Nav) and N use efficiency (NUE):

Ny = Nav *NUE

Available N corresponds to the differences between supplies and losses of N.

1.1 N supplied encompasses two processes: from natural sources and external sources

- N from natural sources:

  Wet and dry deposition: Ndepo

  N fixed by associated and free living bacteria: Nfix

  Symbiotic fixation: Nbio

- External sources: from compost, manure, mulch, ash, mineral fertiliser (Next)

Nav = Nsup-Nloss

Nsup = Nsol + Ndepos + Nfix + Nbio + Next

NUE = 1/{(Nseed +Nstraw)*[(1-hi)/hi]+Nroot *[1+(1-hi)/hi]/srr}

- Nseed = minimum concentration of N in the seed
- Nstraw = minimum concentration of N in the vegetative part (kg/ha)
- Nroot = minimum concentration of N in the roots
- hi = harvest index (production of seed, fruit etc../total above-ground dry matter)
- srr = shoot/root ratio.

The values of NUE for the different crops are given in Table I.1.

Table I.1. Characteristics of the different crops

	Millet	Sorghum	Maize	Cowpea	Groundnut	Cotton
NUE	19.76	19.76	47.75	9.15	12.28	21.93
PUE	121.19	121.19	262.74	103.38	211.22	74.85
Parameters used in WLp						
c	0.7	0.70	0.70	0.30	0.30	0.40
b	0.75	0.75	0.75	0.65	0.60	0.55
Susceptibility to drought	0.25	0.35	0.50	0.50	0.35	0.50
FLAI	0.30	0.30	0.30	0.30	0.30	0.30
NJLAI	30	30	30	35	40	35
Crop cover factor	0.40	0.60	0.50	0.20	0.50	0.60

-Nsol = (SON * 0.02)/CNR

With SON the stable organic N (based on Wolf *et al.*, 1989) and CNR the C/N ratio; the annual rate of mineralisation is set to 2 %.

-Ndepo: Wet deposition defined as a function of annual rainfall (6.5 g N per mm)

Nrain = rainfall * 0.0065 kg N

-Nfix = 0.2 g per kg aboveground dry matter

-Nbio = 0.25 g per kg applied organic matter (Penning de Vries and Djitèye, 1982)

-Next. N available from from external organic sources was determined on the basis of Nos = 46.5-0.66 (C/N) described by Das *et al.*, 1993.

Organic fertiliser sources are compost, manure, mulch and ash (burnt crop residues) at various levels: 500, 1000, 2000 or 4500 kg per ha; inorganic nutrients are supplied as compound NPK(12:24:12) at 0, 100 or 200 kg per ha.

1.2 Losses of N are through erosion (Nero), volatilisation and denitrification (Nvol) and leaching (Nlea)

- Nero was estimated on the basis of the Universal Soil Loss Equation

N in soil organic matter:

Nsom = erosion (t/ha) * 1000* organic matter soil (%)/100 * fraction of C in OM/(C/N) ratio.

- Universal Soil Loss Equation (USLE) : E = R*K*L*C*P (Wischmeier and Smith, 1960)
- E = erosion in ton /ha

- R = rainfall factor = rainfall*0.5 (Roose, 1977)
- K (See Table I.2)
- L = landscape factor = $(SL/0.3048)^{0.5} * (0.76+0.53*S^2)/100$

  SL = slope length (m) set to 250 m

  S = slope (see Table I.2)
- C = crop cover factor (see Table I.1)
- P = soil management factor set to 0.8 assuming low application of soil and water conservation measures

-Nero (as a fraction of the top soil layer (0.20 m); soil density set to 1400 kg/ m^3) = E/(1400*0.25*10)

-Nvol set at 30 % of total N *(*Hengsdijk *et al.,* 1996*).*

-Nlea set at 0.6 (Hengsdijk *et al.*, 1996).

Table I.2 Characrteristics of the major soil units distinguished in Zoundwéogo (Zerbo *et al.*, 1998)

	Unit	*Luvisol*	*Lixisol*	*Cambisol*	*Vertisol*
Texture	%				
Clay		5.2	8.7	17.7	33.7
Sand		3.5	8.1	5.2	25.0
Loam		26.6	40.6	27.9	10.3
Fine loam		54.0	32.0	36.9	0.8
Fine sand		10.7	10.5	12.2	30.1
Chemical characteristics					
pH (H_2O)		6.5	5.8	7.1	6.1
OM	%	0.7	1.5	1.2	2.0
C	%	0.4	0.9	0.7	1.2
N	%	0.04	0.05	0.08	0.10
C/N		10	18	8	12
P (available)	ppm	85	39	36	40
P total	ppm	377	500	1566	2196
CEC	meq/100g	2.5	6.2	7.6	20.0
USLE parameters					
Slope		1.5	1	2	0.5
Erodability (K)		0.4	0.3	0.5	0.2

2- Phosphorus limited yield

A similar procedure as described in the preceding section was followed.

Pav = Psol + Pdepos + Pfix + Pext – Pero – Pleach

Psol = $(1-0.5*(pH-6)^2)*0.014*$ Ptot + 0.5 * Pavailable

Pdepos = 0.0007 *rainfall

Pfix = 0.1* Nfixed

Pbio = 0.1* Norg

Losses

Pero = 0.1* Nero

Pfer = 0.75 * Papplied

3- Water limited production

Water limited production is based on Tanner and Sinclair (1983):

BM = k*WCR*10000/DPV*RWU *DSF

BM = biomass (kg)

k = constant (kpa) = (0.68*b*c/1.5)*0.8*(1.4/2.2)/10.;

For the factor c and b see Table I.1

0.68 represents the ratio CH_2O/CO_2

DPV = vapour pressure deficit (mbar)

RWU = reduction factor for non-optimal water use = 0.75

DSF (drought susceptibility factor, see Table I.1)

WCR = water available for crop growth = I-perc-EVA (Hoogmoed and Stroosnijder, 1984.)

(perc = percolation in mm/yr; eva=soil evaporation in mm/yr)

Perc = 0.69 * I-45 * H – 22 *PR –7.8 * (H*PR) –74 (I = infiltration in mm/yr, H = water content at field capacity m/m; PR = effective rooting depth in m) (Breman and de Ridder, 1991).

EVA = (ETM*FLAI+ETM*(1-FLAI)*0.5*NJLAI)/DUR

In which, FLAI is the fraction of Etm evaporated at complete canopy cover, i.e. LAI =5, NJLAI the number of days after germination to reach an LAI of 5 and DUR = length of the growing period in days (see Table I.1)

The quantity of rainwater infiltrating in the soil was estimated as follows (Based on Hengsdijk *et al.*, 1996):

PIc = PMc/Nc

PIc is the average rainfall per shower in each shower category (3 categories, i.e. <10 mm, 10-20 mm, >20mm)

PMc is the total annual rainfall per shower category

Nc is the number of days with rainfall per shower category

The maximum infiltration (mm) per shower category and intensity level is calculated as follows:

$Ii,c = S * (60*(Pic/INTi,c)^{-0.5}i,c$

INTi,c is shower intensity per intensity level and category. Four intensity levels having each 25 % chance to occur are distinguished.

S is the absorption capacity of the soil (sorptivity, Van Keulen and Wolf, 1986).

$Ic = (Ii,c/4)*Nc$

$I = \sum Ic$

Rainfall of normal year (860 mm), dry year (719 mm) and wet year (991 mm) derived from Antenne Sahélienne data base (1977 to 1997) was used.

4- Potentiel yield

Potential production is derived by applying the grain/straw ratio to total biomass, calculated as a linear function of absorbed radiation (AbRAD) and radiation use efficiency (RUE)

Biomass = RUE * AbRAD (Van Keulen and Wolf, 1986)

RUE = 1.7g/MJ for C3 crops

2.5 g/MJ for C4 crops

AbRAD = (0.125 *rad * 0.5NJLAI)+ (0.55*rad*0.5NJLAI)+(1*rad*0.75 (DUR-NJLAI)) + (0.5*rad*0.25 (DUR-NJLAI).

The value of the measured radiation (rad) was derived from Antenne Sahélienne data base.

5. Actual yield

Y = Bpest * min (Ny, Py, Wy, Poty)

Y = crop yield (kg/ha)

Bpest is the reduction factor due to pests and diseases (set to 0.8)

References

Breman, H., De Ridder, N., 1991. Manuel sur les pâturages des pays Sahéliens. Karthala/ACCT/CTA. 485 pp.

Das, S.K., Subba Reddy G., Sharma, K.L., Vittal, K.P.R., Venkateswarlu, B., Narayana Reddy, M., Reddy, Y.V.R., 1993. Prediction of nitrogen availability in soil after crop residue incorporation. *Fertilizer Research 34: 209-215.*

Hengsdijk, H., Quak, W., Bakker, E.J., Ketelaars, J.J.M.H., 1996. A technical coefficient generator for land use activities in the Koutiala region of South Mali. DLV-report No 5. DLO/WAU, The Netherlands. 96 pp.

Hoogmoed, W.B., Stroosnijder, L., 1984. Crust formation on sandy soils in the Sahel. I. Rainfall and infiltration. *Soil Tillage Research 4: 5-25.*

Penning de Vries, F.W.T., Djitèye, M.A., 1982. La productivité des pâturages Sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressoure naturelle. Agricultural Research Report 918, Pudoc, Wageningen, The Netherlands, 525 pp.

Roose, E., 1977. Erosion et ruissellement en Afrique de l'Ouest. Vingt années de mesures en petites parcelles expérimentales. Travaux et documents de l'ORSTOM, Paris, 108 pp.

Struif Bontkes, T., 1999. Modelling the dynamics of agricultural development: a process approach. The case of Koutiala (Mali). Ph.D. Thesis, Wageningen Agricultural University, The Netherlands, 233 pp.

Tanner, C.B., Sinclair, T.R., 1983. Efficient water use in crop production: Research or Re-search. Contribution from the University of Wisconsin-Madison, College of Agricultural and Life Sciences, and the USDA Microclimate Project, Ithaca, New York, 45 pp + annexes.

Van Keulen, H., Wolf, J., 1986 (eds.). Modelling of agricultural production: weather, soils and crops. Pudoc Wageingen, The Netherlands, 479 pp.

Wischmeier, W.H., Smith, D.D., 1960. A universal soil-loss estimating equation to guide conservation farm planning. 7th International Congress on Soil Science, vol I, 418 pp.

Wolf, J., De Wit, C.T., Van Keulen, H., 1989. Modeling long-term crop response to fertilizer and soil nitrogen. I. Model description and application. *Plant and Soil 120: 11-22.*

Zerbo, L., Mulders, M., Thiombiano, L., 1998. Etude morpho-pédologique de la province du Zoundwéogo. Echelle 1/100.000. Antenne Sahélienne-INERA, Burkina Faso, 90 pp. + annexes.

Appendix II

Mathematical description of HOREB model

Table II.1: Sets

Set	*Description*	*Elements*
i	Millet production activities	mi1 ......mi200
s	Sorghum production activities	so1 ......so200
z	Maize production activities	ma1 ......ma200
n	Cowpea production activities	ni1 ......ni200
o	Cotton production activities	co1 ......co200
g	Groundnut production activities	gr1 ......gr200
s	Nutrient sources (sheep feeding)	re = refusals; f = faeces; ur = urine
m	Months	m1 = January.....m12 = December
l	Land units	Lu1 = luvisol ....Lu4 = vertisol
x	Excess feeding activities	E1... E49
h	Chopping	C1..... C49
u	Urea treatment	U1..... U42

Table II.2. Parameters

Parameter	*Description*		*Units*
For each crop			
Y	Yield (storage organs)		kg ha^{-1}
YR	Yield (residues)		kg ha^{-1}
COM	Compost requirements		kg ha^{-1}
MAN	Manure requirements		kg ha^{-1}
MU	Mulch requirement		kg ha^{-1}
ASH	Ash requirements		kg ha^{-1}
QF	NPK requirements		kg ha^{-1}
NBAL	N balance		kg ha^{-1}
CBAL	C balance		kg ha^{-1}
PBAL	Pbalance		kg ha^{-1}
LABC(m)	Labour requirements		md per month
AREA(l)	Land requirement		ha
Per feeding activity			
WG	Live weight gain		g d^{-1} per animal
MINPUT	Feed requirements:	millet stover	g d^{-1} per animal
SINPUT		Sorghum stover	g d^{-1} per animal
CINPUT		cowpea haulms	g d^{-1} per animal
GINPUT		groundnut haulms	g d^{-1} per animal
TCINPUT		cotton seed cake	g d^{-1} per animal
UINPUT		urea	g d^{-1} per animal
OMREL	Organic matter released		g d^{-1} per animal
NREL	Nitrogen released		g d^{-1} per animal
PREL	Phosphorus released		g d^{-1} per animal
LABL(m)	Labour requirements per feeding activity		md per month per animal
LABH(m)	Labour requirement for herding		md per month
Ol	OM loss per type of management		%
Nl	N loss per type of management		%
Pl	P loss per type of management		%

Table II.3. Scalars

Scalar	*Description*	*Unit*	*Value*
PF	Price: Fertiliser (NPK)	FCFA kg^{-1}	240
Pmi	Millet		89
Pso	Sorghum		73
Pma	Maize		66
Pni	Cowpea		145
Pgr	Groundnut		114
Pco	Cotton		150
PTC	Cotton seed cake		60
PU	Urea		200
SP	Sheep (live weight)		400
Veto	Veterinary cost	FCFA per animal	600

Table II.4. Variables

Variable	*Description*	*Unit*
Crop		
Supmi	Area used for millet	ha
Supso	sorghum	ha
Supma	maize	ha
Supni	cowpea	ha
Supgr	groundnut	ha
Supco	cotton	ha
Cashc	Cash input	FCFA
Revc	Gross margin	FCFA
Gprod	Crop production	kg
Sprod	Staple production	kg
Sheep		
Lu	Animal units	head
LP	Total weight gain	kg
Cashl	Cash input	FCFA
Revl	Gross margin	FCFA
Tnit	Total nitrogen	kg
Tphos	Total phosphorus	kg
Tmo	Total organic matter	kg
Farm		
Casht	Total cash input	FCFA
Revt	Total gross margin	FCFA
NB	N balance	kg
PB	P balance	kg
OMB	OM balance	kg

Table II.5. Definition of the equations

Category	Symbol	Definition	Number
Objective functions	TP	Total crop production	1
	SP	Staple crop production	2
	CGM	Crop gross margin	3
	LP	Livestock production	4
	LGM	Livestock gross margin	5
	TGM	Total gross margin	6
	OMO	Organic matter outflow	7
	NO	Nitrogen outflow	8
	PO	Phosphorus outflow	9
	OMB	Organic matter balance	10
	NB	Nitrogen balance	11
	PB	Phosphorus balance	12
Constraints	TLAB(m)	Labour balance	13
	TLAND(l)	Land constraints per unit	14
	TSUP	Farm area constraints	15
	CAV	Compost availability	16
	MAV	Manure availability	17
	UAV	Mulch availability	18
	AAV	Ash availability	19
	MISUP	Millet residues (stall feeding)	20
	NISUP	Cowpea residues	21
	GRSUP	Groundnut residues	22
	SOSUP	Sorghum residues	23
	WCC	Working capital (crops)	24
	WCL	Working capital (livestock)	25

Objective functions

$$(1): TP = Prod_i + Prod_s + Prod_z + Prod_n + Prod_c + Prod_g$$

$$(2): SP = Prod_i + Prod_s + Prod_z + Prod_n$$

$$Prod_i = \sum_i Supmi_i * Y_i$$

$$Prod_s = \sum_s Supso_s * Y_s$$

$$Prod_z = \sum_z Supma_z * Y_z$$

$$Prod_n = \sum_n Supni_n * Y_n$$

$$Prod_o = \sum_o Supco_o * Y_c$$

$$Prod_g = \sum_g Supgr_g * Y_g$$

$$(3): CGM = GM_i + GM_s + GM_z + GM_n + GM_o + GM_g$$

$$GM_i = \sum_i Prod_i * Pmi - \sum_i (mQF_i * Supmi_i) * PF$$

$$GM_s = \sum_s Prod_s * Pso - \sum_s (sQF_s * Supso_s) * PF$$

$$GM_z = \sum_z (Prod_z * Pma - \sum_z (zQF_z * Supma_z) * PF$$

$$GM_n = \sum_n Prod_n * Pni - \sum_n (nQF_n * Supni_n) * PF$$

$$GM_o = \sum_o Prod_o * Pco - \sum_o (oQF_o * Supco_o) * PF$$

$$GM_g = \sum Prod_g * Pgr - \sum (gQF_g * Supgr_g) * PF$$

$$(4): LP = 0.180 * (\sum_x xWG_x * Lu_x + \sum_h hWG_h * Lu_h + \sum_u uWG_u * Lu_u)$$

$$(5): LGM = LP * SP - (0.180 * (PTC * \sum_x xTC_x * xLu_x + \sum_h hTC_h * hLu_h + \sum_u uTC_u * uLu_u)$$
$$- \sum_u (UR_u * uLu_u) * PU) - \sum_c Lu_c * Veto$$

$$(6): TGM = CGM + LGM$$

$$(7): OMO = 0.180 * (\sum_x \sum_s xOMrel_{x,s} * Lu_x + \sum_h \sum_s hOMrel_{h,s} * Lu_h + \sum_u \sum_s uOMrel_{u,s} * Lu_u)$$

$$(8): NO = 0.180 * (\sum_x \sum_s xNrel_{x,s} * Lu_x + \sum_h \sum_s hNrel_{h,s} * Lu_h + \sum_u \sum_s uNrel_{u,s} * Lu_u)$$

$$(9): PO = 0.180 * (\sum_x \sum_s x Prel_{x,s} * Lu_x + \sum_h \sum_s h Prel_{h,s} * Lu_h + \sum_u \sum_s u Prel_{c,s} * Lu_u)$$

$$(10): OMB = \sum_i mCbal_i * Supmi_i + \sum_s sCbal_s * Supso_s + \sum_z zCbal_z * Supma_z$$
$$+ \sum_o oCbal_o * Supco_o + \sum_g gCbal_g * Supgr_g + \sum_n nCbal_n * Supni_n + (Ol * OMO)$$

$$(11): NB = \sum_i mnbal_i * Supmi_i + \sum_s snbal_s * Supso_s + \sum_z znbal_z * Supma_z$$
$$+ \sum_o onbal_o * Supco_o + \sum_g gnbal_g * Supgr_g + \sum_n nnbal_n * Supni_n + (Nl * NO)$$

$$(12): PB = \sum_i mpbal_i * Supmi_i + \sum_s spbal_s * Supso_s + \sum_z zpbal_z * Supma_z$$
$$+ \sum_o opbal_o * Supco_o + \sum_g gpbal_g * Supgr_g + \sum_n npbal_n * Supni_n + (Pl * PO)$$

Constraints

$$(13):\sum_i mLabc_{m,i}*Supmi_i+\sum_s sLabc_{m,s}*Supso_s+\sum_z zLabc_{m,z}*Supma_z+\sum_n nLabc_{m,n}*Supni_n)$$
$$+\sum_o oLabc_{m,o}*Supco_o+\sum_g gLabc_{m,g}*Supgr_g+\sum_x xLabl_{m,x}*Lu_x+\sum_h hLabl_{m,h}*Lu_t)$$
$$+\sum_u (uLabl_{m,u}*Lu_u)+Labh_m\le Tlab_m$$

$$(14):\sum_i marea_{l,i}*Supmi_i+\sum_s sarea_{l,s}*Supso_i+\sum_z zarea_{l,z}*Supma_z+\sum_n narea_{l,n}*Supni_n$$
$$+\sum_o oarea_{l,o}*Supco_o+\sum_g garea_{l,g}*Supgr_g\le Land_l$$
$$(15):\sum_l Land_l\le T\sup$$

$$(20):\sum_i mcom_i*Supmi_i+\sum_s scom_s*Supso_s+\sum_z zcom_z*Supma_z+\sum_n ncom_n*Supni_n$$
$$+\sum_o ocom_o*Supco_o+\sum_g gcom_g*Supgr_g\le CAV$$
$$(16):\sum_i mman_i*Supmi_i+\sum_s sman_s*Supso_s+\sum_z zman_z*Supma_z+\sum_n nman_n*Supni_n$$
$$+\sum_o oman_o*Supco_o+\sum_g gman_g*Supgr_g\le MAV$$
$$(17):\sum_i mmu_i*Supmi_i+\sum_s smu_s*Supso_s+\sum_z zmu_z*Supma_z+\sum_n nmu_n*Supni_n$$
$$+\sum_o omu_o*Supco_o+\sum_g gmu_g*Supgr_g\le UAV$$
$$(18):\sum_i mash_i*Supmi_i+\sum_s sash_s*Supso_s+\sum_z zash_z*Supma_z+\sum_n nash_n*Supni_n$$
$$+\sum_o oash_o*Supco_o+\sum_g gash_g*Supgr_g\le AAV$$
$$(19):\sum_i mcom_i*Supmi_i+\sum_s scom_s*Supso_s+\sum_z zcom_z*Supma_z+\sum_n ncom_n*Supni_n$$
$$+\sum_o ocom_o*Supco_o+\sum_g gcom_g*Supgr_g\le OFl+OFw\sum_c MAN_c*Sup_c\le MAV_{hw}+MAV_{hm}$$

$$(20):0.180*(\sum_x \min put_x*Lu_x+\sum_h \min put_h*Lu_h+\sum_u \min put_u*Lu_x\le MIC*\sum_i Supmi_i*YR_i$$
$$(21):0.180*(\sum_x \sin put_x*Lu_x+\sum_h \sin put_h*Lu_h+\sum_u \sin put_u*Lu_x\le MIC*\sum_i Supmi_i*YR_i$$
$$(22):0.180*(\sum_x ninput_x*Lu_x+\sum_h ninput_h*Lu_h+\sum_u ninput_u*Lu_x\le MIC*\sum_i Supmi_i*YR_i$$
$$(23):0.180*(\sum_x ginput_x*Lu_x+\sum_h ginput_h*Lu_h+\sum_u ginput_u*Lu_x\le MIC*\sum_i Supmi_i*YR_i$$

$$(24):PF*(\sum_i mqf_i*Supmi_i+\sum_s sqf_s*Supso_s+\sum_z zqf_z*Supma_z+\sum_n nqf_n*Supni_n+\sum_o oqf_o*Supco_o)$$
$$+\sum_g gqf_g*Supgr_g)\le 0.82*WC$$
$$(25):0.180*((PTC*\sum_x xtc_x*xLu_x+\sum_h htc_h*hLu_h+\sum_u utc_u*uLu_u)$$
$$+\sum_u U_u*uLu_u*PU\le 0.18*WC)$$

Curriculum Vitae

Moumini Savadogo was born on 31 December 1965 in Tougou, Burkina Faso. He finished high school in 1986 at the *Collège de Tounouma*, Bobo-Dioulasso, Burkina Faso, where he obtained his BAC-D in Mathematics and Natural Sciences. After two years at the *Institut National des Sciences de la Nature*, University of Ouagadougou, he continued his studies at the *Institut du Développement Rural* (IDR), where he obtained the degree of Master in Rural Development Techniques in 1990 and of Engeneer of Rural Development, with specialization in animal production, in 1991. As part of his training at IDR, he conducted several farm surveys on animal production systems and milk processing as well as on-station research on animal nutrition (evaluation of feeds) and nutrient use efficiency in intensive sheep feeding. After his graduation, he worked during one year at the *Association Française des Volontaires du Progrès* (NGO), as adviser for integrated rural development in Northern Burkina Faso. From 1992 to 1998, he worked with the Sahel Program (Antenne Sahélienne) of Wageningen University and the University of Ouagadougou, as a research assistant in the Natural Resources Use Group. The studies reported in this thesis were carried out from 1996 to 1999 as part of the Antenne Sahélienne research program. Scientific supervision was provided by the Animal Production Systems Group of Wageningen University, The Netherlands. Moumini Savadogo is married to Halizèta Ouangré.

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