Chapter

Sheep Feeding in the Sahel Countries of Africa

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Abstract

With an area estimated to 3.053 million km^2, the Sahel has a quickly growing population. According to CILSS, there will be 100 million people in the region by 2020 and 200 million by 2050, almost four times the current population. The region, frequently struck by drought and food insecurity, is one of the areas most severely affected by global climate change in the coming years. With up to 80% of its people living on less than $2 a day, poverty is more widespread in the Sahel than in most other parts of Africa. Sheep farming is very important for the Sahel countries. It does not require a high input at its beginning, so even women and children are involved in small ruminant raising. They provide food and play important socioeconomic factors. However, productivity of livestock including the one of sheep is low. Nutrition is the most important constraint in sheep farming especially during the dry season when both availability and quality of forages are low. The most complex and limiting production factors in sheep farming for the Sahel countries are those concerning nutrition and feed supplies. The objective of this review chapter was to describe the major nutritional constraints to sheep farming systems in the Sahel countries and explore ways of overcoming the most important constraints for efficient and sustainable sheep feeding. Issues addressed in this review include causes of undernutrition and environmental implications, adaptation by sheep to it, and manipulative strategies to cope with feed scarcity in smallholder sheep farming systems.

Keywords: extensive, feeds and feeding, intensive, nutrition, Sahel, sheep

1. Introduction

Sheep farming is very important for the Sahel countries. It is a popular activity in which even women and children who are the lowest income owner are involved. Besides food and essential nutrients, sheep farming plays an important socioeconomic role in the ceremonies such as baptism and religious and other feasts. Sheep are important assets to the rural poor and play a critical role in both sustainability and intensification of agricultural productivity in most farming systems. Their manure helps maintain soil fertility, and they contribute to the overall farming enterprise in terms of income and employment. Sheep farming provides poor farmers with a flexible reserve and access to markets especially with sheep fattening. However, productivity of livestock including sheep is low. The lack of animal products is not due to a lack of animals per se, because Africa has 12.7% of humans, 13.6% of cattle and buffalo, 28.9% of goats, 19.2% of sheep, and 73.4% of camel population of the world, but due to low productivity [1]. Nutrition is the most important constraint in sheep farming. There are a number of reasons for the low productivity of which insufficient and inefficient use of feed is the major one [2].

The objective of this chapter is to review the major nutritional aspects of sheep farming in the Sahel countries of Africa. It includes a deep review of the sheep farming systems, exploring ways of overcoming the most important constraints for efficient and sustainable sheep feeding based on my own experience, and the available literature. The nutrient (water, energy, protein, minerals, and vitamins) requirements of sheep that vary greatly according to the physiological stage, maintenance, growth, gestation, lactation, fattening, were reviewed. The review covers the characteristics of the common feeds in the Sahel based on their types (roughages and concentrates), their names and classes, their chemical composition, and their nutritive value.

Practical guidelines for sustainable sheep feeding including the following important recommendations are given. During the rainy season (from July to September), forages cover the nutrient requirements for extensive sheep production system except for the lactating ewes and fattening rams. Supplemental concentrate feeds are required during the cool dry season (October to February). During the hot dry season (March to June), both forage and concentrate supplements are required. Lactating ewes and fattening rams are fed using formulated rations to meet their respective nutrient requirements. Issues addressed in the review chapter will include causes of undernutrition and environmental implications, adaptation by sheep to it, and manipulative strategies to cope with feed scarcity in smallholder sheep farming systems.

2. Study area, Sahel defined

The Sahel from its original Arabic name means “flat land.” It includes a band of Africa indicating a floristic and climatic transition between the Sahara in the North and the Sudan savannah in the South in which rainfalls are important. Rainfalls from 200 mm in the North to 600 mm to the South are the limits of the Sahel zone in Africa [3]. This area is characterized with a monomodal distribution of rainfalls that occurs randomly in 90 to 120 days and a long dry season of 8 to 9 months [4]. This alternate of wet and dry periods rhythm and determine animal and plant productions and their modes of management.

The Sahel, in this study, not just covers the band but includes all the entire 10 countries that are Burkina Faso, Chad, Eritrea, the Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, and Sudan as shown in **Figure 1**.

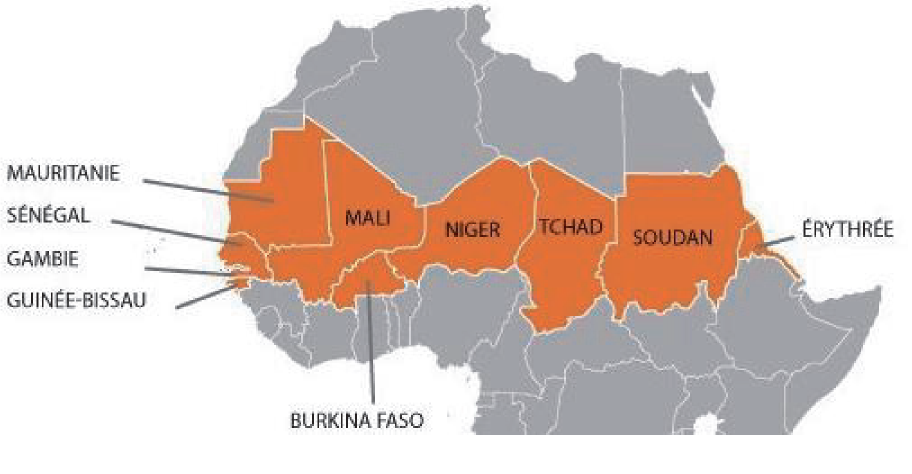

Figure 1.
Map of the Sahel countries.

3. Ecological zones of the Sahel countries

The Sahel countries like Mali include four ecological zones, and characteristics of the range lands fluctuate depending on four ecological zones. The quantity and quality of feedstuffs fluctuate depending on the two seasons (dry and rainy) and the length, amount, and distribution of rainfalls and soil fertility. Sivakumar et al. [5] gave a detailed description of the ecological zones of Mali, and most of them are shared with the different zones of Sahel. The four ecological zones include:

- The arid (Sahara) zone in which the vegetation is scarce and made of herbaceous plants and thorny shrubs: the climate is tropical arid with two seasons, a rainy season of 1 to 2 months and a dry season of 10 to 11 months. The average annual rainfall is less than 200 mm, and there is almost no growing season. Monthly average temperatures vary from 31.1°C in January to 42.4°C in May.

- The semi-arid (Sahel) zone in which the vegetation is an herbaceous stratum composed primarily of grasses and a woody stratum composed of forbs, shrubs, and trees: the climate is tropical and semi-arid with two seasons, a rainy season, hot and humid of 4 months from June to September, and a dry season of 8 months divided into a cold period from October to February and a hot period from March to May. The average annual rainfall is 580 mm with a growing season of 18 weeks. Monthly average temperatures vary from 39.9°C in May to 31.9°C in August.

- The sub-humid (Sudanese) zone in which the vegetation is composed of woody species and herbaceous species: the climate is tropical sub-humid (savannah) with a rainy season of 6 months and a dry season of 6 months. The average rainfall is 1037 mm with a growing season of 24 weeks. Monthly average temperatures vary from 30°C in August to 37.7°C in March.

- The humid (Guinean) zone in which the vegetation is composed of woody species and herbaceous species: the climate is tropical and humid with a rainy season of 7 months and a dry season of 5 months. The average rainfall is 1300 mm with a growing season of 40 weeks. Monthly average temperatures vary from 30°C in August to 37.7°C in March.

4. Sheep production systems in the Sahel

The population growth increases fast in the Sahel. According to CILSS, there will be 100 million people in the region by 2020 and 200 million by 2050; this is almost four times the actual population. More than half of them, 141 million, will live in the three countries Burkina Faso, Mali, and Niger.

Livestock remain one of the most important economic activities of the Sahel with a contribution of 30 to 40% of the agricultural GNP of the countries like Burkina Faso, Cap-Vert, Mali, Mauritania, Niger, Senegal, Soudan, and Chad [6]. Besides this economic contribution, pastoral livestock is one of the most important agricultural productions in the Sahel. The Sahelian countries have an important potential of meat production with livestock estimated in 2006 at 63 million cattle, 168 million small ruminants, and more than 6 million camels [7].

Based on the natural grazing, and some fallows, the livestock of this region is based mainly on the availability of forage that depends on climatic fluctuations, seasonal variations, and grazing intensity as have been demonstrated by the big droughts of years 1970 and 1980 [8]. Those droughts caused the loss of about 80% of the livestock of the region conducting thousands of people to move out of the region [8].

However, the succession of wet years allowed a rapid numeric reconstitution of livestock [9], and in Mali, the number of small ruminants increased from 1990 to 2005 to 26% [6].

Livestock farming in general and sheep farming in particular are very important for the Sahel countries. The most complex and limiting production factors in sheep farming for the Sahel countries are those concerning nutrition and feed supplies. The traditional concept that natural pasture is free and of no value and can, therefore, be put through grazing animals at a production cost approaching zero, with all returns of net profit, is erroneous and contributes in these problems. In addition, most land is government-owned but communally utilized.

The main resources used as sheep feeds include pastures (grazing lands, crop residues, and cultivated forages), concentrate feed, household wastes, and other feed supplements. Their relative importance varies across production systems. The solution to the problem of feed supplies depends on the production system and the ecological zone [10]. Agro-ecology, seasonality, land tenure, and management practices influence feed availability. Generally, sheep are herded during the rainy season and free ranging during the dry season. Criteria as ecological zones, relationship on sheep and crop farming, and the level of importance in sheep farming activities are the basis for making typologies on the sheep farming systems. Each ecological zone and based on how sheep farming depends on it, corresponds to a standard herding practice and a dominant sheep breed. The investment done for sheep farming and the objective of production give a precision on classification within the same ecological zone.

Although there are several livestock systems [11], they can be divided into two main systems of sheep production as has been indicated by Swift et al. [12]:

- A pastoral system in which sheep farming of the range lands provides more than 50% of the feeds of sheep and provided more than 50% of the income.

- An agro-pastoral system in which sheep farming depends primarily on other feed resources and provides from 10 to 50% of the income.

Within each system, depending on the experience and investment of the farmer, there are more or less extensive sheep farming systems. Both systems (pastoral and agro-pastoral) can be divided into extensive, semi-intensive, and intensive depending on the level of input and investment as described by Sangaré [13].

5. Characterization of sheep feeds and feeding

Sheep feed may be defined as any dietary substance that nourishes the sheep body for maintenance, reproduction, and productions. The usual feeds are divided into two categories with entirely different characteristics: roughages and concentrates.

5.1 Roughages

They are feeds containing more than 18% of crude fiber [14] or more than 35% of cell wall on a dry matter basis. They are low in net energy per unit weight because of the high cell wall content. They include pastures, hay straw, haulms, trees, silage, etc. The pastures are used in in situ feeding on the standing herbaceous or tree/browse plants for which quality and quantity fluctuate depending on the season and agroclimatic zones. They are most important feed resources in the Sahel. The can be cut and carried to the animal especially during the dry season. Crop residues are the second most important feed resources that can be grazed in situ or cut and carried to the animals. Their quality and quantity fluctuated depending several factors such as variety, production techniques, area planted, etc.

5.2 Concentrates

They include feeds with less than 18% crude fiber or less than 35% cell wall on a dry matter basis [14]. They may contain less than 20% protein on a dry matter basis and be called energy feeds and contain more than 20% protein on a dry matter basis and be known as protein supplements. The concentrate feeds include agro-industrial byproduct feeds such as rice bran, cottonseed, cottonseed meal, peanut meal, molasses, cereal grains, etc. Concentrates are expensive, are highly digestible, possess a low fiber content, and are rich in proteins. Since many concentrates are used as a staple in human diets, economics usually determine whether concentrates are fed to ruminants. Certainly few of the cereal grains are fed to sheep in the Sahel, but millet grain is known to be used by women for their "mouton de case." On the basis of protein content, concentrates may be divided into carbonaceous feeds with a relatively low protein content such as the cereal grains and nitrogenous feeds that are rich in protein such as the various oil cakes and animal byproducts.

5.3 Feed names

A more complex categorization using several parameters becomes necessary for an efficient use of feeds. The parameters used very often are name, class, chemical composition, and nutritive value of feeds.

A name should clearly state the source of the material and describe any process, alteration, or special circumstance, which affects the nutritional value of that feed. The International Feed Vocabulary as described by Harris et al. [15] is designed to give a comprehensive name to each feed as concisely as possible. Each feed name was coined by using descriptors taken from one or more of six facets that are origin (scientific or common name), part fed to animals, process or treatment, stage of maturity or development, cutting, and grade.

5.4 Feed classes

In the Sahel countries, feed classification is derived from two mean sources. Harris [16] and Harris [17] grouped feeds into eight classes based on their composition in the way they are used for formulating diets. The groups include (1) dry forages and roughages; (2) pasture, range plants, and forages fed green; (3) silages; (4) energy feeds; (5) protein supplements; (6) mineral supplements; (7) vitamin supplements; and (8) additives.

The second source for classification of feeds is that of Baumont et al. [18] from which feeds are divided into two groups that are roughages and concentrates; the roughage group includes five classes that are (1) dry forages; (2) silages; (3) hays; (4) stalks, straw, and haulms; and (5) roots and tuber. The concentrate group includes 10 classes that are (1) dehydrate feeds, (2) cereals, (3) coproducts of cereals, (4) grains, (5) cake and meals, (6) other plant products, (7) coproducts,

N° Classes	Criteria for classification
1. Roughages	All the forages and rangelands, natural or cultivated and green or dry containing more than 18% of crude fiber or containing more than 35% of NDF on a dry matter basis: straws, stalks
2. Silages	Include ensiled forages
3. Energetic feeds	Products containing a small level of protein (less than 20%) and a small amount of crude fiber (less than 18%)
4. Protein supplements	Products from plant sources (cake and meal) and animal sources (blood meal, meat meal), milk products containing a high level of protein (more than 20%)
5. Mineral supplements	Bone meal
6. Vitamin supplements	
7. Feed additives	Hormones, antibiotics, coloring materials, medicaments, etc.

Table 1.
Classes of feeds in Mali.

(8) fat, (9) treated feed, and (10) diverse products. Based on the sources, the appropriate classification for the Sahel countries is as shown in **Table 1**.

5.5 Chemical composition and nutritive value of sheep common feeds

From the classes of feeds (**Table 1**), the most common feeds used in most Sahelian countries are roughages (native grazing lands), agricultural byproducts (rice straw, corn, sorghum, millet stalks) and the agro-industrial byproducts like meals (cotton-seed, peanut) and bran (rice, wheat, millet, and sorghum). Silages, known a long time ago, are not commonly used. Energetic feeds are used only in intensive sheep production such as in fattening sheep. Mineral supplements are used very often; vitamin supplements are less commonly used while feed additives are not used at all. Feeds are analyzed in the Animal Nutrition Lab [19, 20] of Institut d'Economie Rurale (IER). The most common analyses include dry matter, ash, crude protein, crude fiber, crude fat, gross energy, calcium, phosphorus, sodium, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Digestibility values are obtained with sheep (in vivo digestibility) or estimated from chemical composition using the following equations developed by INRA [14]:

$$\text{Grasses: dOM} = 93.2 - 0.104\ \text{CF} + 0.025\ \text{CP} \quad (1)$$

$$\text{Legumes: dOM} = 78.9 - 0.059\ \text{CF} \quad (2)$$

$$\text{Cereals and coproducts: dOM} = 95.8 - 0.191\ \text{CF} - 2.54 \quad (3)$$

$$\text{Peanut meal: dOM} = 87.75 - 0.0314\ \text{CF} - 1.86 \quad (4)$$

$$\text{Cottonseed meal: dOM} = 87.75 - 0.0314\ \text{CF} + 6.22 \quad (5)$$

where d = digestibility; OM = organic matter; CF = crude fiber; and CP = crude protein.

The chemical composition of the common sheep feeds in the Sahel from Nantoumé et al. [13]—unpublished data is given in Annex 1.

5.6 Nutritive value of common sheep feeds

The energy value of feedstuffs and the energy requirements of animals have been expressed in gross energy (GE) using the formula GE = 4516 + 1.646

CP + 70 ± 39. Digestible energy and metabolizable energy were determined using the following equations:

$$DE = GE \times dE/100\ (dE = 1.055\ dOM - 6.833)\ \text{with dOM en\%} \tag{6}$$

$$ME = 0.82\ DE \tag{7}$$

where DE = digestible energy; GE = gross energy; dE = digestibility of energy; dOM = digestibility of organic matter; and ME = metabolizable energy.

For the net energy value, Institut National de la Recherche Agronomique (INRA) of France is recommending the use of forage unit for lactation (UFL) for maintenance, lactation, and animals of medium growth rate and forage unit for meat production (UFV) for fattening lambs and cattle having an average daily gain greater than 750 g/day. One feed unit corresponds to the net energy value of 1 kg barley for maintenance or production.

Under the actual Sahel conditions, the use of the two UF is difficult, and it is recommended to use UFL for all categories of sheep.

In the Sahel countries of Africa, the digestible proteins system is still much in use. The digestible protein system accounts for the apparent digestibility of the protein fraction. To determine digestible proteins, INRA [14] has recommended the following equations:

$$DP\ (g/kg\ DM) = 9.1\ CP - 0.38\ OM\ (\text{OM and CP in\%of DM})\ (\text{for grass plants}) \tag{8}$$

$$DP\ (g/kg\ DM) = 8.7\ CP - 0.41\ OM\ (\text{OM and CP in\%DM})\ (\text{for legume plants}) \tag{9}$$

where DP = digestible protein; DM = dry matter; CP = crude protein; and OM = organic matter.

Since 1979, INRA has been using widely the protein digested in the intestine (PDI) system which accounts for the digestibility of the protein fraction in the small intestine.

The nutritive value of the common sheep feeds in the Sahel from Nantoumé et al. [13]—unpublished data is given in Annex 1.

6. Nutrient requirements of sheep

The nutrient needs of sheep vary greatly according to the physiological stage: maintenance, growth, gestation, lactation, and fattening. The daily requirements can be found in several books. **Table 2**, from Memento de l'Agronome [21], gives the nutrient requirements of the ewe for maintenance, late gestation, and milk production, while **Table 3** gives the nutrient requirements of ram for maintenance, growth, and fattening. The nutrient in consideration is energy expressed in forage unit for lactation, digestible protein (DP), digestible protein in the intestine, calcium (Ca), and phosphorus (P).

Of primary importance in sheep nutrition are water, energy, protein, minerals, and vitamins.

6.1 Water

Water is essential for all livestock and must be planned for an adequate supply of clean water. Ordinarily, sheep consume two to three times as much water as dry

Liveweight (kg)	Performances		UF	DP (g)	PDI (g)	Ca (g)	P (g)
20	Maintenance		0.31	24	25	2.0	1.5
	5th month of gestation		0.38	36	38	2.8	1.9
	Lactation	Milk produced/day					
		300 g	0.51	53	50	3.5	2.2
		600 g	0.72	82	74	5.0	2.8
		900 g	0.92	111	99	6.5	3.5
30	Maintenance		0.42	32	33	2.5	1.8
	5th month of gestation		0.53	48	50	3.4	2.3
	Lactation	Milk produced/day					
		400 g	0.69	71	66	4.5	2.5
		800 g	0.96	110	99	6.5	3.6
		1200 g	1.24	148	131	8.5	4.4
40	Maintenance		0.52	40	41	4.0	2.0
	5th month of gestation		0.66	60	62	4.1	2.5
	Lactation	Milk produced/day					
		500 g	0.86	89	82	5.5	3.1
		1000 g	1.20	137	123	8.0	4.2
		1500 g	1.54	186	164	10.5	5.3

Table 2.
Nutrient requirement of ewes for gestation and lactation with an average energy value of milk of 0.68 UFL/kg and a protein value of 60 g/kg.

matter. A generally applied estimate for water requirement is 2 ml per gram of dry matter consumed [10]. The voluntary intake of water is affected by a number of factors such as ambient temperature, amount of activity, amount of dry matter eaten, level of salt intake, physiological state of animal, availability of water, stage of lactation, and composition of the ration (moisture content) and drinking interval. The needs increase at the end of gestation, during lactation, and during hot dry season. An ewe can drink up to 7 l per day while in gestation and up to 15 during lactation [22]. Water supply, if limited, restricts voluntary feed intake and feed utilization of livestock depending on various factors and mechanisms [23, 24]. An excessive salt intake will increase the amount of water drunk. A safe limit of salts in drinking water is given as 1.5%.

6.2 Energy

The energy needs of sheep vary greatly according to the physiological stage: maintenance, gestation, lactation, or growth. At a given physiological stage, the needs are the same but can be expressed in a different unit. The needs for maintenance correspond to the amount of feed necessary to maintain the weight of the animal. They are estimated in relation to the live weight of the animal. In complete confinement, the maintenance needs are usually stated as 95 kcal metabolizable energy/kg$^{0.75}$ [22] and 1 to 1.2 forage unit for a 100 kg liveweight sheep [25].

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Liveweight (kg)	ADG (g)	UFL	DP (g)	PDI (g)	Ca (g)	P (g)
20	Maintenance	0.31	24	25	2.0	1.5
	50	0.51	40	40	3.1	2.0
	80	0.57	50	50	3.8	2.3
	110	0.62	59	58	4.4	2.6
	140	0.68	69	68	5.1	2.9
	170	0.75	79	77	5.8	3.2
30	Maintenance	0.42	32	33	2.5	1.8
	70	0.72	56	55	4.1	2.5
	110	0.80	65	63	5.0	2.9
	150	0.90	77	74	5.8	3.3
40	Maintenance	0.52	40	41	3.0	2.0
	75	0.95	63	62	4.7	2.9
	110	1.06	71	69	5.5	3.1
	145	1.18	82	79	6.2	3.5

Table 3.
Nutrient requirement of ewes for growth and fattening.

The energy value of feedstuffs and the energy requirements of animals have been expressed in several units such as gross energy, digestible energy, metabolized energy, and net energy using forage unit. One forage unit corresponds to the net energy value of 1 kg barley for maintenance or production. Actually, two units from INRA [26] are used: forage unit for milk production and forage unit for meat production. The major sources of energy for sheep are hay, pasture, crop residues, agro-industrial byproducts, and even grains to raise the energy level of the diet when necessary. Energy deficiencies can cause reduced growth rate, loss of weight, reduced fertility, lowered milk production, and reduced wool quantity and quality.

The energy needs of sheep and the energy value of feedstuffs are expressed in several energy units such as forage unit, calorie, TDN, amidon unit, etc. In balancing rations it is required to use the same unit for both the energy needs of sheep and the energy value of feedstuffs.

6.3 Protein

In sheep rations, the amount of protein is much more important than the quality of protein. However, since sheep is a ruminant and mature, the naturally occurring protein and non-protein nitrogen (urea) are used effectively in their diets. Common sources of natural protein supplements include cottonseed and peanut meals that contain from 20 to 30% protein and are good sources of supplemental protein. High-quality legume hays can contain from 10 to 18% protein and provide adequate protein for most classes of sheep when fed as a complete ration.

Mature sheep can be fed low levels of non-protein nitrogen. In general, supplemental no-protein nitrogen is beneficial only when adequate energy is available. Urea should never make up more than one-third of the ruminally degradable protein in the diet.

Sheep daily protein requirement is estimated to be 0.6 g/kg body weight [25, 26]. Similarly, the protein content of feedstuffs that can be expressed in several units can be found in the literature [14, 25].

6.4 Minerals

Some minerals are essential in sheep nutrition. Minerals essential for ruminants include macro minerals such as calcium, phosphorus, magnesium, sodium, potassium, chlorine, and sulfur and trace minerals such as copper, molybdenum, iron, manganese, zinc, selenium, cobalt, and iodine [27]. Most of these requirements are met under normal grazing and feeding habits in the Sahel countries. The necessity for the addition of minerals to the ration is determined by the character of the feed eaten, including the water consumed [10]. Maintaining optimum rumen fermentation with straw-based rations requires a minimum mineral supply as given by Moss et al. [28]. Those that are most deficient are salt (sodium chloride), phosphorus, and calcium.

Salt is essential for many body functions. When sheep are deprived of salt, they generally consume less feed and water, produce less milk, and grow slowly. Inadequate salt intake may cause decreased feed consumption and decreased efficiency of nutrient use [10]. In general, supplemental salt should be provided to range ewes at a level of 8 to 11 g of salt per head per day. For mixed feeds, an addition of 0.3% to the complete diet or 1% to the concentrate portion is recommended [27].

Pastures and hay are generally low in phosphorus; however, in grains the amount of phosphorous is moderate to high. Since any efficient sheep operation uses a high percentage of roughage or pasture, it is assumed that the sheep need phosphorus supplementation. Phosphorus deficiency causes slow growth, reduced appetite, abnormal bone development, and poor reproductive performance. It may be beneficial to provide phosphorus supplements year-round for the breeding flock.

6.5 Vitamins

Mature sheep require all the fat-soluble vitamins: A, D, E, and K. They do not require supplemental B vitamins, which can be synthesized in the rumen. Normally, the forage and feed supply contain all essential vitamins in adequate amounts, except vitamin A, which is sometimes deficient. Vitamin A does not occur in plant tissue but is synthetized by the animal from chemical precursors in plants, mainly beta carotene [29]. However, sheep can store vitamin A for a considerable time. If ewes have pastured on green forage or have had access to high-quality legume hay, vitamin A is not usually deficient.

6.6 Strategies of feeding sheep

The main resources used as sheep feed in the Sahel include pastures (herbaceous plants, fodder trees/shrubs), crop residues, cultivated forages, concentrate feed (agro-industrial byproducts, grains, feed supplements, etc.), and household wastes. The relative importance of these resources varies across production systems. Agro-ecology, seasonality, land tenure, and management practices at the farm level, among other factors, influence their availability [30]. In the agro-pastoral system, improvement of nutrition is based on the definition of a supplemental feeding strategy and on the improvement of the quality of low-quality forage [22].

6.7 Range grazing

Sheep are natural grazers, and they are easy to control through herding on natural range. In consequence, small children very often are herders. Sheep prefer short grass and have difficulty eating coarse feedstuffs [10]. Sheep frequently obtain critical protein and vitamins from browsing on leaves and fallen pods of different tree species. Grazing on natural ranges and marginal wasteland provides most of the annual feed intake of Sahel sheep. The fact that most grazing land is owned communally complicates improvement efforts.

6.8 Crop residues

The second most important feed resource for Sahel sheep is crop residues [31]. The usual practice is to permit free access to cropland after harvest is completed. This practice is used only partially, and part of the forage is used in other forms of feed. The kind and nature of residues depend on the crops grown. They include cereals (rice, sorghum, millet, corn, barley, wheat) and legumes (cowpea, groundnut).

6.9 Forage preservation and storage

Forage may be used as feed in five forms: pasture, hay, silage, cut and fed in the fresh or green state, and chemically treated. Silage and cut and fed in the fresh or green state are well known and applied in the Sahel countries. Although hay and silage making and forage treatment may have a considerable potential for bridging the dry season feed gap, their use needs further promotion in the Sahel.

Hay is the most important of all harvested roughages. The legume hays (e.g., cowpea and groundnut) are especially valuable, since they are high in protein, calcium, and other nutrients and are both palatable and highly digestible.

Silage results from the preservation of green forage under anaerobic conditions. The best grass silage can be made when the material contains 60 to 75% of moisture.

The concept of silage making is very old but rather less practiced. A pit of 3 m diameter and 2 m depth holds 6 to 8 tons of silage that is sufficient to feed 20 sheep for about 3 months.

The practice of leaving the **straw and stover** of harvested cereal crops in the fields to be grazed over by livestock may not be desired. The collection and stacking of these materials where they could be rationed out to livestock would increase the value of the feed several times. Other ways of increasing the feeding value of straws are through urea treatment [32] and proper supplementation with legume hays [33].

A third most important feed resource for Sahel sheep includes residues from the processing of the various agricultural products that are cottonseeds, cottonseed meal, groundnut meal, brans of cereals, molasses, etc.

6.10 Seasonal consideration in Sahel feed supplies

In the Sahel countries, mixed crop-livestock farming and pastoralism are the dominant forms of agricultural production. In these farming systems, sheep feeding depends mostly on rangeland, fallows, and cropland grazing. Nutritional constraints to grazing sheep are ecological zone variations, feed scarcity, and seasonal fluctuations in feed supply associated with low rainfall and poor soil fertility. The options to improve sheep nutrition vary seasonally in the Sahel countries. Due to seasonal fluctuations in the availability and quality of the feed resources, the intake of energy, protein, and some essential minerals by most ruminant species fall below their maintenance requirements resulting in undernutrition and low productivity in most production systems [34].

During the rainy season, the forage grows and the crops develop. At this stage the quality of the forage available is very high, and the main constraint is herd mobility. Grazing and moving herds to watering points may lead to conflicts between herders and farmers. Transhumance is a common practice in the West African Sahel based on regular seasonal migration from a permanent homestead to access to better range resources in terms of quality and plant species diversity and protection of crops from damage by grazing animals. The wet season grazing areas are also the location of sites for the "cure salé" to cover certain mineral deficiencies [3].

At the end of the rainy season, in the early dry season, all range forages including trees and crop residues are available in large amounts although their quality is relatively low because of lignification. Conserving crop residues and bush hay under cut-and-carry strategies may reduce spoilage and provide feed late in the dry season. Legume (groundnut and cowpea) hays are harvested and highly priced in local markets. They can be used to feed animals with higher protein requirement, such as lactating ewes and fattening sheep.

As the dry season progresses, aboveground forage mass decreases. Animals require longer grazing time and spend more energy walking. At this stage, it is advantageous to restrict walking by keeping animals on fields and feed them with the store feeds.

Late in the dry season, the lack of feed and low protein content limits the efficient use of the feed available. The main option during the late dry season and early rains consists in providing supplementary feeding with crop residues, bush hay, and/or grain byproducts and agro-industrial byproducts. Supplementary feeding with roughages will be determined by the availability of labor and cost of transport, whereas the use of concentrates will be a function of availability and cost of grain and agro-industrial byproducts.

Supplements are defined as special concentrate feeds that are fed to supply nutrients which are deficient in a ration to balance the ration for essential nutrients. Among the most relevant supplements most often needed in the Sahel are minerals, such as calcium and phosphorus and protein from byproducts feeds (oil cakes and cereal milling residues). Molasses can be used to increase energy and palatability and as carrier of non-protein nitrogenous substances such as urea.

6.11 Practical guidelines for feeding

Two types of feed resources available to the farmers can be considered: the on-farm feed resources such as range, fallow, and crop residues and the purchasable resources such as agro-industrial byproducts. The quality and quantity of grass are variable depending on the year, the season, and the ecological zone. However, in the Sahel, there are two main seasons within a year; for animal feeding purposes, the year can be divided into three seasons in the Sahel that are the rainy season from July to September, the dry cool season from October to February, and the dry hot season from March to mid-June. The season associated with the agroclimatic zone is the most important factor that drives feed supply in the Sahel.

6.11.1 Coping with feed scarcity in the Sahel

In the Sahel, aboveground forage is the major or sometimes the sole sheep feed resource. During the rainy season, feed supplies from grazing lands and fallow are

Categories	Rainy season	Dry and cold season	Dry and hot season
Young	0	100 g cottonseed meal	100 g straw + 100 g cottonseed meal
Adult	0	200 g cottonseed meal	200 g hay + 200 g cottonseed meal
Ram	100 g cottonseed meal	200 g cottonseed meal	200 g hay + 200 g cottonseed meal
Lactating	200 g cottonseed meal	400 g cottonseed meal	200 g de grossier + 400 g cottonseed meal

Table 4.
Quantities (g/animal/d) of supplements used for different categories depending on the season.

enough to cover maintenance requirements and even part of the production needs of the grazing sheep. However, the high producing sheep (lactating and fattening animals) may need supplemental feeds.

6.11.1.1 Supplementation

As the rainy season ends, aboveground forage mass decreases in quality because of lignification while the biomass is still available. At first, improving the feeding value of forages through proper preservation and storage may be enough to cover the deficit in nutrient requirements of the animal. High producing sheep may need concentrate supplement feeds.

When the dry season progresses from the cool season to the hot season, both quality and quantity of forages decrease. Therefore, both forages and concentrates may be used as feed supplements. An example of supplemental feeding of sheep in Mali is given in **Table 4**. A 2-year study conducted by Nantoumé et al. [35] using this supplemental feeding gave interesting results. Fertility, birth rate and numeric productivity were improved in ewes receiving supplemental feed. The times of kidding and of kids born per pregnancy were higher in supplemented animals. Feed supplements increased milk production per lactation from 26.1 to 43.2 l for sheep [35].

6.11.1.2 Intensive feeding

The rational feeding of ewes is economically valid only if the farmer knows with precision the physiological stage of the ewes.

6.11.1.2.1 Feeding ewes for gestation and milk production

6.11.1.2.1.1 Gestation

The level of nutrition at the end of gestation has an important effect on the development of the lambs and thus their survival after birth, on the building of body reserves and on the maternal performances of the ewes, which will affect the post-natal growth of the lamb.

The growth of the fetus is especially important during the last third of gestation: 70 to 80% of the total weight gain occurs during this period. The last 6 to 8 weeks of gestation are thus critical in terms of nutrition because the nutrient requirements of the ewe increase tremendously. Supplementation of the ewe with a feed high in energy is extremely desirable. However, the supplementation is difficult to achieve because of the decrease of the ewe's appetite due to a reduction of the rumen capacity and the high cost of the high-energy feed. A low level of nutrition at the

Ration	ADG (g)	Benefit (F.CFA)	References
60% CSM + 40% PH	200	11,020	Nantoumé et al. [36]
45% CSM + 47% PH + 8% Millet	192	9415	Nantoumé et al. [37]
35% BH + 35% NH + 30% ABH	172	6285	Ballo et al. [38]
70% CSM + 30% DH	140	6065	Nantoumé et al. [36]
61% CSM + 39% SS	124	5850	Nantoumé et al. [39]
65% CSM + 25% NH + 10% CS	126	5310	Nantoumé et al. [40]
52% CSM+ 36% PH + 12% SS	142	5065	Nantoumé et al. [40]
51% CSM + 28% SS + 21% Millet	132	5135	Nantoumé et al. [40]
60% CSM + 20% PB + 20% NH	146	4785	Nantoumé et al. [37]
50% CSM+ 39% BH + 11% Millet	142	4395	Nantoumé et al. [40]
57% CSM + 30% PH + 13% MS	135	4220	Nantoumé et al. [37]

CSM = cottonseed meal; PH = peanut haulm; BH = bush hay; DH = dolichos haulm; SS = sorghum straw; NH = niébé haulm; CS = corn straw; and MS = millet straw.

Table 5.
Characteristics of the best fattening rations of a series of sheep fattening experiments.

end of gestation will have negative effects not only on the reproduction performance of the ewe but also on its health.

Normal growth of the fetus allows the lambs to be born with adequate weight. The weight at birth directly influences the vigor of the lamb and its resistance to stress.

6.11.1.2.1.2 Milk production

The mammary tissue grows rapidly at the end of gestation; 95% of the development occurs during the last 6 weeks of gestation. Without adequate nutrition, the udder develops less; as a consequence, it will lower milk production. Good nutrition of the ewe at the end of gestation increases milk production by 20 to 30% in the ewe carrying a single lamb. Besides, the nutrient requirements of the ewe for gestation and milk increase depending on the level of milk production (**Table 3**). Moreover, a good level of nutrition at the end of gestation favors the constitution of reserves that the ewe will utilize during the high-energy requirements of lactation.

Milk production generally increases during the first 3 weeks, reaches a plateau, and starts decreasing rapidly. The form of the curve varies according the breed, the level of nutrition, and the number of lambs suckling. The voluntary intake of most forages in early lactation is generally insufficient to meet the nutrient requirements. A supplementation of 400 to 600 g per day of a high-quality concentrate is needed.

6.11.1.2.1.3 Sheep fattening

In most countries of the Sahel, sheep fattening is a common operation especially during the Muslim's feast. It consists in feeding rams for a rapid weight gain during a short period of time. Fattening rations should be formulated from local supplies at the least cost as far as possible. Several fattening rations were developed throughout the Sahel countries. In the Malian context, 11 fattening rations were developed. Average daily gain (ADG) varied from 124 to 200 g with benefit fluctuating from 4395 to 11,020 FCFA (**Table 5**). After the successful on-station trial, the two best rations have been tested on-farm condition.

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7. Conclusion

The overall results of our study showed that sheep farming is an important economic activity of most of the population. This review shows that seasonal fluctuations of feed resources in the Sahel follow the pattern of vegetation growth that is modified by the availability of rainfall. This resulted in a seasonal pattern of wet season gain and dry season loss of liveweight. Seasonal fluctuation in availability and poor quality of feeds were considered to be the main constraints on sheep farming in the Sahel. Appropriate supplemental feeding improved productivity of ewes. The times of kidding and of kids born per pregnancy were higher in supplemented animals. Feed supplements increased milk production per lactation from 26.1 l to 43.2 l for sheep [35]. For intensive meat production, several rations economically sound were also developed. For health care, the recommendations are known. For infectious diseases such as pasterollesis and peste des petits ruminants, it is mandatory to vaccinate them regularly twice a year for the first and once a year for the second disease. Deworming is also recommended twice, three times, or four times a year depending on the zones (Sahel, soudanian and preguinean) where the sheep are.

Annex 1

Classes	SClasse	Identification	Organic constituents						Mineral constituents			Energy value						Protein value
		Name	DM	OM	CF	CP	CF	NFE	Ash	Ca	P	GE	dOM	DE	ME	UFL	UFV	DP
1. Roughages																		
	• Cereal straws		94.69	92.54	39.48	4.65	1.54	46.87	7.46	0.14	0.31	3975.35	68.58	2604	2135	0.53	0.39	10
		Standard error	0.38	3.54	6.51	1.57	0.48	6.86	3.54	0.1	0.26	209.3	1	130.1	106.7	0.12	0.14	10
	• Legume haulms		65.37	91.08	29.94	12.21	1.48	47.46	8.92	0.64	0.17	3846.77	70.03	2579	2115	0.71	0.61	69
		Standard error	34.95	2.71	5.77	0.71	0.35	5.43	2.71	0.19	0.07	78.7	0.88	69.27	56.8	0.1	0.12	7
	• Bush hay		95	90.76	36	3.77	1.86	49.13	9.24	0.07	0.22	3822.9	69.11	2525	2071	0.59	0.47	1
		Standard error	0.58	2.7	4.85	0.35	0.73	1.97	2.7	0.03	0.09	167.58	0.74	84.48	69.27	0.09	0.11	2
	• Fodder trees		35.48	92.06	32.92	13.16	2.32	43.66	7.94	1.06	0.42	4108.8	69.58	2734	2242	0.67	0.55	85
		Standard error	4.56	4.18	4.94	2.37	0.23	7.31	4.18	0.29	0.37	393.76	0.76	248.8	204	0.09	0.11	21
	• Cultivated grasses		29.46	93.43	37.32	5.22	2.26	48.64	6.57	0.11	0.22	3751.21	68.91	2470	2026	0.58	0.45	12
		Standard error	5.95	0.98	3.54	0.74	0.41	3.69	0.98	0.08	0.13	158.24	0.54	99.88	81.9	0.07	0.08	6
	• Cultivated legumes		27.71	92.45	35.74	11.97	2.69	42.05	7.55	0.89	0.25	3909.88	69.15	2585	2120	0.62	0.5	66
		Standard error	6.6	2.01	7.8	2.72	0.67	7.42	2.01	0.27	0.12	237.52	1.19	162.2	133	0.14	0.17	24
2. Energetic feeds																		
	• Cereal grains		92.95	98.56	3.98	10.61	5.57	78.39	1.44	0.06	0.17	4134.03	74	2945	2415	1.23	1.23	59
		Standard error	0.86	0.24	1.19	1.49	0.07	1.7	0.24	0.03	0.08	1099.2	0.18	792.2	649.6	0.02	0.03	14
	• Cereal bran		92.97	91.16	11.35	13.36	7.1	59.36	8.84	0.17	1.07	4074.95	72.87	2856	2342	1.12	1.09	87
		Standard error	1.51	0.57	2.91	3.07	5.42	5.05	0.57	0.24	0.33	438.61	0.44	324.2	265.8	0.11	0.12	28

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Classes	SClasse	Identification	Organic constituents						Mineral constituents			Energy value						Protein value
		Name	DM	OM	CF	CP	CF	NFE	Ash	Ca	P	GE	dOM	DE	ME	UFL	UFV	DP
3. Protein supplements																		
	• Fish meal		95.14	79.82	0.37	57.77	17.31	4.52	20.18	2.58	1.84	3793.42	74.55	2724	2234	1.49	1.48	495
		Standard error	1.08	7.43	0.12	5.81	7.66	7.77	7.43	0.91	0.75	971.18	0.02	696.7	571.3	0.09	0.09	51
	• Cottonseed meal		94.18	95.1	33.94	24.28	10.61	26.27	4.9	0.09	0.86	4475.63	69.42	2972	2437	0.76	0.64	172
		Standard error	1.64	0.98	5.2	5.26	2.65	7.92	0.98	0.03	0.16	202.21	0.79	128.3	105.2	0.11	0.12	46

SClasse = sub-classes; DM = dry matter; OM = organic matter; CF = crude fiber; CP = crude protein; CF = crude fat; NFE = nitrogen-free extract; Ca = calcium; P = phosphorus; GE = gross energy; DE = digestible energy; ME = metabolizable energy; UFL = forage unit milk; UFV = forage unit meat; and DP = digestible protein.

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