Livestock Feed Resources in West African Sahel: A Review

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Summary

Feed resources for livestock production are diverse and vary markedly across agro-ecological zones in West African Sahel and across season in terms of type, quantity and quality. The main feed resources for grazing ruminants are pastures and crop residues while commercially formulated feeds are increasingly being used in poultry and pig production particularly in peri-urban areas. These feed resources are important to improve the productivity of livestock thereby enhancing the livelihood of smallholder crop and livestock farmers in West Africa Sahelian countries. The objective of this study is to review the existing knowledge on feed resources in West African Sahel across different agro-ecological zones to identify the research gaps and strategies to improve feed resource availability and quality. The reviews were based on published research studies in the region including peer-reviewed articles, students' theses and research reports. In this review we identified and synthesized information on major feed resources, the limitation to optimizing their potentials and further research areas. We also presented constraints associated with several methods of improving the feeding value of some identified feed resources and proposed the pathways of improving livestock feed resources in the Sahel.

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Acronyms

AIBPs	Agro-industrial by-products
CR	Crop residues
IP	Innovation platform
IVODMD	In Vitro Organic Matter Digestibility
WAS	West African Sahel

1. Introduction

Livestock husbandry is critical for many of the smallholder farmers in West African Sahel, often contributing to multiple livelihood objectives and offering pathways out of poverty (Randolph et al., 2007). Livestock provide traction to cultivate fields, manure to improve soil fertility and consequently crop productivity, and nutritious food products for human consumption and income-generation (Sere *et al.*, 2008). In West African Sahel, livestock production systems are diverse, ranging from extensive pastoral systems to mixed crop and livestock systems. Over a decade ago, the report of SWAC-OECD/ECOWAS (2008) indicated that the livestock sector provided between 8 and 15% of overall gross domestic products (GDP), 44% of agricultural GDP and nearly 50% of the workforce are engaged in the sector in West Africa.

Ruminant nutrition depends largely on naturally growing pastures which fluctuate both quantitatively and qualitatively with the season. Besides the natural pastures, many livestock farmers in the region depend on crop residues, which is an important feed resource during the dry season. These crop residues are becoming a dominant feed resources as rangelands are being converted into crop fields in the Sahel. Associated with the seasonal fluctuation in quantity and quality of feed resources is poor nutrition of the animals which is a major constraint to livestock production in West African Sahel. Hence, the cycle of weight gain in the wet season and weight loss in the dry season is a common feature of livestock body weight development in the Sahel.

By 2030, urban beef consumption was projected to grow by more than 361% in developing counties, while rural beef consumption will more than double (FAO 2011). Such a growth in consumption which will largely drive associated growth in demand for feeds. This creates a tremendous opportunity for increasing livestock productivity through feed supply particularly as good quality feed is the most important constraint limiting livestock productivity in the Sahelian countries (Phillip *et al*., 2009). The World Bank (2012) also predicted that changes in beef demand and supply in West Africa will likely result in increased sourcing of ruminant livestock feed from the market (13% in 2030 as compared to 2.5% in 2010) rather than from grazing. For West African Sahel to be well positioned to respond to the present and future increase in demand for livestock products, its feed resource base must be proportionally aligned with such increasing demand.

There have been several studies on evaluating feed resources for livestock production with the emphasis on identification of alternative feed sources in order to minimize production cost without compromising accessibility to animal protein in the long run (CAB, 1997). Other studies have focused on an inventory of indigenous feed resources (Bayala *et al.*, 2014; Ayantunde *et al.* 2011; Aduku 2004; Sanon, 2007; Bayala *et al.*, 2012) in the Sahel and the introduction of improved genotypes especially as fodder bank (Tarawali and Mohamed-Saleem 1994). However, attempts at the introduction of improved forage species have been less successful mainly due to adaptability, agronomic problems and land shortages (Thomas and Sumberg 1995). The aim of this review is to synthesize previous studies on feed resources in West African Sahel, to identify gaps in knowledge and pathways and strategies to increase existing feed resource base. Besides this review aims at generating baseline data and to determine the potential crop residues within the major agro-ecological zones of West Africa.

1.1. Implications of feed challenge on livestock productivity in West African Sahel

In the Sahelian zone of West Africa, naturally occurring herbaceous grasses, legumes, ligneous plants and crop residues are the main feed resources (Teferedegne, 2000). These are greatly associated with marked seasonal variation in terms of availability and quality in the wet season, and scarcity (often with low feeding value) in the dry season (Wanapat *et al.*, 2000). Penning de Vries and Djiteye, (1991) attributed low availability of forage or biomass production from the rangelands to poor soil fertility and inadequate and erratic rainfall. The proportion of crop residues in the animal's diet is related to annual rainfall, the intensity of cropping and the available forage during the dry season (Ayantunde *et al.*, 2000). This seasonal variation of major feed resources results in shortage of supply of quality feed, particularly in the dry season and has implications on the livestock productivity (Fernandez-Rivera *et al.,* 2005). Inadequate nutrition in ruminants has often been associated with heavy economic losses to the farmers because of animal weight and body condition losses, reduced reproductive capacity and increased mortality rates. This condition contributes to increased susceptibility to diseases, migration of flocks and herders contributing to conflict over the use of grazing resources in many West African countries.

According to Smith (2015), poor feeding has limited the ability of livestock to reach their genetic potential and hindered the impact of technology interventions, including artificial insemination and oestrus synchronization. Notably, in the dry season, inadequate nutrition usually results in reduced body weight and body condition scores in adult animals, poor milk yields and long calving intervals in nursing cows, retarded growth and increased mortality rates in calves (Simbaya, 2002). In the same report, Simbaya (2002) associated poor nutrition with increased susceptibility of animals to stress and disease challenges, which result in these animals performing below their expected genetic potential (Simbaya, 2002). Others have demonstrated the nutrition-reproduction interactions as good nutrition increases reproductive efficiency in terms of lowering age at first calving and inter-calving interval, higher productive life leading to higher profitability to farmers (FAO/IAEA, 2003). Bell and Paul, (2016) provided evidence showing that *in utero* nutrition has an impact on productivity and health of offspring later in life in livestock.

2. Methodology

Geographically, our review targeted area within the West African Sahel which covers Senegal, Mali, Burkina Faso and Niger. We concentrated more on Burkina Faso and Niger to deepen the study while we also included relevant information from Senegal and Mali, and probably other countries outside this region. West African Sahel has an annual rainfall ranging from 200 to 600 mm, which is often unevenly distributed in time and space (Redelsperger *et al*., 2006). The region has experienced rapid population growth from 20 to 80 million within 4 decades (Ly *et al.*, 2010). More than 80% of these population are rural dwellers and are practicing small scale farming in mixed-crop livestock systems for their livelihood (Ly *et al.*, 2010).

We recognized that the region refers to as the Sahel is vast and has sub-regions within this expanse, while its borders are transitional zones with the Sudanian agro-ecological zone commonly referred to as "Sudano-Sahelian". To enrich our review, we included this neighboring zone that shares similar livestock feed related issues. These agro-ecological zones are delineated by the amount and distribution of rainfall and number days of growing crops, which largely defines livestock production systems as well as available feed resources (Table 1).

Table1: Characteristics of target sub-agroecological zones in Burkina Faso

Sub-agroecology within the Sahel	**Annual rainfall (mm)**	**Dominant livestock production system**	**Major feed resources**
Northern Sahelian	200 - 400	Pastoral	Natural pasture, crop residues, browse tree
Southern Sahelian	400 -800	Agro-pastoral	Natural pasture, crop residues
Sudano-Sahelian	800- 1000	Mixed crop-livestock production	Natural pasture, crop residues, agro-industrial by-products, household byproducts

Adapted from Zampaligre *et al.*, 2013; Savadogo *et al.*, 1999; Amole and Ayantunde (2016a, b)

2.2. Types and availability of feed resources in West African Sahel

The feed resources in West African Sahel are mainly natural pastures, crop residues, agro-industrial by-products, and browse plants (Bayala *et al.* (2014). Livestock feed resources across West African Sahel can be broadly grouped into naturally grown pastures, cultivated forages browse shrubs/trees, crop residues, agro-industrial by-products, and concentrate. We limited our review to the above-mentioned feed resources based on the existing literature.

2.2.1. Natural pastures

The natural pasture of the Sahel is composed of an herbaceous layer dominated by annual plants (more than 80%), and a scattered population of shrubs and low density of trees (Hiernaux and Le Houérou 2006). These are naturally occurring plants generally found on uncultivated land including both the palatable and non-palatable species which animals have access to for grazing. These natural pastures are found in grazing lands which are often communally owned. The predominant species are grasses with little legumes. In their reports, Amole and Ayantunde (2016b) listed commonly found herbaceous species in the Sahel namely *Alysicarpus* *ovalifolius*, *Commelina forskalaei*, *Zornia glochidiata* and *Eragrostis tremula*. Others have also reported *Zornia glochidiata, Schoenefeldia gracilis, Cenchrus biflorus, Panicum laetum, Cassia obtusifolia, and Alysicarpus ovalifolius* in the communal areas of the Sahel (Zerbo *et al.,* 2016). Species composition in natural pasture differs along the agroecological gradient even within the Sahelian region. In their review, Bayala *et al*., (2014) reported that pastures in the northern part of the Sahel are composed of thorny shrubs/trees dominated by *Acacia seyal, A. senegal, A. raddiana, A. nilotica* and the annual herbaceous are mostly grasses such as *Panicum turgidum, Aristida sieberiana, Cymbopogon schoenanthus, Cyperus jeminicus, Cyperus conglomeratus*. Towards the southern Sahel, natural pasture is dominated by herbaceous grasses with denser tree and shrubs layer (Hiernaux and Le Houérou 2006).

Diop *et al.* (2005) and Dicko *et al.* (2006) had also reported that the available biomass in Sahelian zones of Mali and Senegal could allow a voluntary ingestion of 1.8 to 2.7 kg DM/100 kg of live weight for cattle, 1.7 to 3.2 kg DM/kg live weight for sheep, and up to 6 kg DM/kg live weight for goats. The dry matter of available forage declined to less than half the peak value in the late dry season. The result of feed assessment in Southern Burkina Faso revealed that the major feed resources were natural pasture and crop residues (Figure 1). Naturally occurring green fodder materials such as weeds from cropping areas, roadsides and grasses served as sources of feeds particularly at the onset of rains. However, its availability was generally low from November to June which is the period of dry season.

Variation in forage quality and quantity

Forage nutritive quality is a critical factor affecting ruminant productivity; simply because forages supply most nutrients in ruminant diets (Barnes *et al.*, 2007). Ideally, an increase in the quality of the forage(s) fed to an animal will increase production and potential economic return. This is simplistic, however, because forage quality is only one factor in the complex set of plant and animal factors and their interactions that determine potential animal performance (Moore, 1994). There are many factors influencing the variability of quality and quantity of forage which include but not limited to those discussed below:

Stage of growth

Stage of growth is the most important factor influencing the composition and nutritive value of pasture herbage (McDonald *et al*., 1988). As plants grow there is a greater need for fibrous tissues, therefore the main structural carbohydrate (cellulose and hemicellulose) and lignin increase. As the plant ages, the concentration of protein decreases; there is therefore a reciprocal relationship between the protein and fiber content in a given species, although this relationship can be affected by the application of nitrogenous fertilizers (McDonald *et al.*, 1988).

Morphology

Stems of immature forage grass are generally similar in quality to leaves but declines at a faster rate with maturity than leaves due to differences in anatomy (Minson, 1990). Mc Donald *et al.* (1988) reported that digestibility of grasses was influenced by leaf/stem ratios, while Barnes *et al.* (2007) explained that in both grasses and legumes, leaves are almost always the highest-quality component. Sanderson and Wedin (1989) observed that leaf IVODMD declined at rate of 3 g kg^{-1} for each increasing phonological stage. Breeding or managing forages to have a higher leaf/stem ratio therefore improve forage quality (Barnes *et al.*, 2007). Reduced leaf-to-stem ratio is a major cause of the decline in forage nutritive quality with maturity, and also the loss in quality that occurs under adverse hay curing conditions. Leaves are higher in quality than stems, and the proportion of leaves in forage declines as the plant matures (Bell and Ritche, 1989).

Species and cultivar

Forage species are highly diverse and are distributed widely over the earth, and the nutritive quality of forage varies with the species that are adapted to the climate and soil of a given region (Barnes *et al.*, 2007). Generally, the greatest species differences in forage quality occur between grasses due to variations in total fiber concentration, as well as the amount and composition of lignin, the primary inhibitor of fiber digestion (Barnes *et al.*, 2007). Among the most influential factors affecting the nutritive value of herbage are the plant groups and species (e.g. grasses and legumes, tropical and temperate; Bruinenberg *et al.*, 2002 and Fulkerson *et al.*, 2007). C_4 species are usually associated with a lower nutritive value than C_3 species (Skerman and Riveros, 1990; Lowe and Fulkerson, 2003).

Climatic effect

Temperature has a greater effect on forage nutritive quality than any other environmental variable. Ford *et al*. (1979) reported that higher ambient temperature during growth is normally associated with a decrease dry matter digestibility (DMD), and this is most commonly attributed to higher concentration of cell wall constituents. Temperature can alter the carbohydrate status of metallic sinks by speeding rates of active transport across membranes, by changing the concentration of different enzymes (through modification of gene expression), and by changing enzymes activities (Barnes *et al.*, 2007).

The forage quality trait most affected by water deficit appears to be decreased concentration of NDF due to a reduction in the amount of fixed C incorporated into cell walls (Peterson *et al.*, 1994). Buxton and Fales (1994) observed that both N and soluble carbohydrates are exported out of leaves as they senesce, potentially resulting in a negative effect on forage quality.

However, concentrations of nitrogen in herbage indicate that the concentration of sugars and fructans, for example, can be influenced markedly by the amount of sunshine received by the plant. On a general note, on a dull cloudy day the soluble carbohydrate content of grass will be lower than on a fine sunny day. Calcium, for example, tends to accumulate in plants during periods of drought but present in small concentration when the soil moisture is high. On the other hand, phosphorus appears to be present in higher concentration when the rainfall is high (Buxton and Fales, 1994).

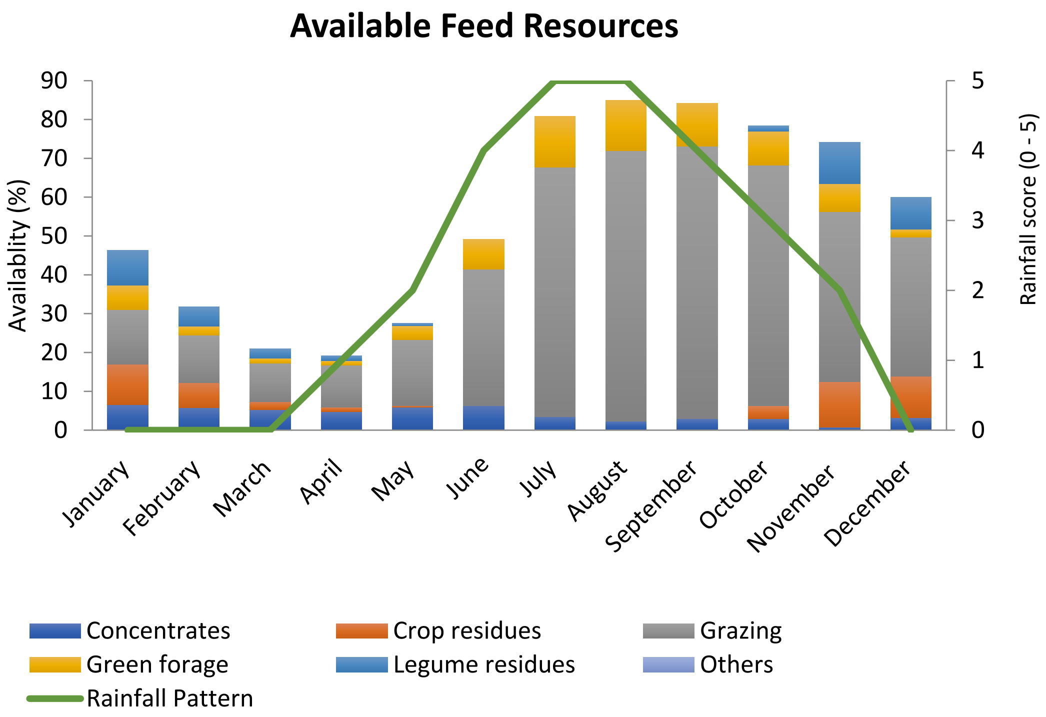

Figure 1: Available Feed Resources in Mahon during the year
(Amole and Ayantunde 2016a).

Natural pasture in the Sahelian rangeland is characterized by seasonal, inter- and intra-annual, and spatial variation which is a key limiting factor to its productivity (Hiermaux, 1996). This is associated with both the temporal and spatial distribution of the precipitations (Bayala *et al.*, 2014), with abundance and good quality during the rainy season and scarcity and poor quality during the dry season. Some publications including but not limited to Konlan *et al*. (2018) and FAO (2014) reported the seasonal effect on the availability and nutrient qualities of livestock feed resources in West Africa. A wide local variation in herbage production from differences in soil type and rainfall has also been reported within in Sahel region (Wylie *et al.,* 1995). Mean primary production ranges from 600 kg DM ha^{-1} in the northern Sahel with 200 mm of rainfall to 2400 kg DM ha^{-1} in the southern Sahel with 600 mm rainfall (Glatzle, 1992). In another report from Diffa administrative district (northern Sahel) Niger, herbage production varied from 305 to 936 kg DM ha^{-}1 among various sites in same district (Wylie *et al.*, 1995). Similarly, penning de Vries and Djiteye (1982) reported a total dry matter of natural pasture from 1.1 to 4 t ha^{-1}across the rainfall gradient in West Africa. Variation within site based on runoff water patterns based on topography and geomorphology, and plant species has also been reported (Breman and de Ridder, 1991). The impact on the nutrient quality of the herbage produced which is often inversely proportional to available soil water and soil type during the growing season has been reported (Breman and de Wit, 1983). This trends on herbage quality along rainfall gradients explained the growth performance of cattle. In Northern Niger at 320 mm rainfall, steers gained up 80 kg during the short rainy season and lost little weight during the dry season provided sufficient forage was available (Klein 1981, Wylie et al. 1983). In contrast, cattle grazing rangelands receiving 400 to 500 mm further south, gained 60 to 90 kg during the rains, but net annual gains per head were much lower due to weight losses of 30 to 50 kg during the dry season (P Hiernaux, unpublished data).

2.2.2. Cultivated pastures

In contrast to natural pastures, cultivated pastures are sown. The pasture is intentionally established for fodder production and contained improved fodder species. Hence, the productivity and the carrying capacity of cultivated pasture are higher than the natural pasture.

Many exotic species have been introduced in the Sahel and screened on-station based on their biochemical and nutritional composition, fertilizer requirements, persistence, management and use as forage legumes (Birie-Habas 1965; Thomas and Sumberg *et al.* 1995). Existing literature shows that most of the forage species were introduced and evaluated in different agro-ecology of West Africa (Sanon and Kanwé 2002; Kouame *et al.* (1992). Bayala *et al* (2014) reported that *Stylosanthes hamata, Digitaria umfolozi, Eulesine indica, Eleusine coracana, Cenchrus ciliaris, M. atropurpureus, M. aterrina, S. gracilis, V. unguiculata, L. purpereus, Brachiaria ruziziensis, Panicum maximum, and Dolichos lablab* were forage species introduced and evaluated in Mali. Feeding calves with green *S. hamata* fodder led to a daily body weight gain of 178 g (Kouriba et al. 2008; Kouriba and Nantoumé 2000).

Most of these experiments have been conducted at plot level and there is a dearth of information on integration of these practices into the livestock systems in the Sahel (Bayala *et al.*, 2014). In addition, most of the reports about cultivating these improving species are in the grey literature, which did not help much with information circulation and consequently, contributing to limited adoption of the tested species in the Sahel (Thomas and Sumberg 1995)

According to Traore (2016) difficulties in adopting cultivated forage crops in Burkina Faso are:

1. Land availability: The inadequate availability of cropland systematically favors cereal cropping as against perennial forage plots. Farmers will prefer to sow cereal for household consumption than to cultivate forage crops
2. Cropping season: The crop calendar for forage species is practically the same as that for cereals. There is then a problem of allocation of labor at the expense of the forage crop.
3. Problem of seed multiplication: The demand for fodder seeds is much higher than the national supply and the import costs are prohibitive. Without the support of the state

structures and technical and financial partners in seed, the establishment of forage plots will be impossible at the farm level

2.2.3. Browse Plants

Browse plants refer to woody perennials, trees, shrubs and dwarf shrubs that small ruminants (goat and sheep) feed on which form an important component of the livestock diet, particularly in the dry season (Le Houérou, 1988; Atta-Krah *et al*, 1986). Their establishment and management require little labor, time, technical know-how or resources and could be promoted for use as animal feed. The multipurpose nature of browses as fuelwood, shade, food (fruits), poles, etc. as well as their potential to improve soil fertility and conservation are added advantages. In terms of utilization as animal feed, browse trees currently play an important role, as animals under confinement often receive one type or another of browse, from fallow lands or around homesteads. Efficient utilization in a complementary way with pastures and crop residues is what needs to be worked out through research, in order to exploit their potential nutritive value. Browsers, particularly goats can consume various parts of woody plants such as leaves, twigs, thorns, bark, wood, bulbs, tubers, roots, flowers, seedpods and fruits (Le Houérou, 1988; Lamidi, 2004). Browse could, therefore, supplement the low energy and protein content of grass forage if used effectively during dry season. Trees are more reliable than herbaceous legumes and grass in providing high-quality protein supplement in the dry season (Arigbede *et al.*, 2007).

The most common woody species in the Sahel and of course Burkina Faso are *Acacia senegal, A. laeta, Calotropis procera, Pterocarpus lucens, Combretum glutinosum, Sclerocarya birrea, Balanites aegyptiaca, Boscia senegalensis, and Commiphora africana in the predominantly sandy environments, and Acacia seyal, A. nilotica, Anogeissus leiocarpus, and Ziziphus mauritiania* in the more alluvial or clay zones (FAO, 2000). These species are often accompanied by *Acacia tortilis, A. erhenbergiana and Leptadenia pyrotechnica* in some areas.

A non-exhaustive list of fodder species fed to livestock in the Sahel and their nutrient profiles have been reported by Bayala *et al.,* (2014). In their report on the contribution of browse to ruminant nutrition across three agro-ecological zones of Burkina Faso, Zampaligré *et al.,* (2013) listed about 75 species of browse trees. Their nutritive value and preference by cattle and small ruminants were also reported. Farmers, through indigenous knowledge, are aware of available browse tree in their locality and usually feed them to their animals particularly in the dry season. Although the total number of browse species identified was high, only a few species contributed significantly to daily browsing time of ruminants. In terms of preference, Acacia sp. (e.g. *Acacia. seyal, A. dudgeoni, and A. gourmaensis*), Combretum *micranthum* and *Balanites aegyptiaca* were highly preferred by small ruminants in the Sahelian and northern Sudanian zone. Abdulrazak *et al.,* (2000) suggested that the relative importance of *Acacia* sp. and *Balanites aegyptiaca* for small ruminants might be due to their abundance, their easy accessibility on pasture and their relatively good nutritive value.

2.2.4. Crop Residues

Crop residues (CRs) are roughages that become available as livestock feeds after grains have been harvested. Thus, the value of crop residues produced in a particular area will depend on the amount and type of crops grown in that area. As smallholder farmers usually practice mixed crop-livestock farming, crop residues are the most commonly available as livestock feed (Simbaya, 2002).

Crop residues found in West African Sahel include stovers of cereals such as millet, sorghum, maize and haulms of leguminous crops such as cowpea and groundnut, and straws from rice. The spatial distribution of these residues follows the agroecological gradients and the particular crops grown majorly in such zones. In most dry areas, millet is most grown than sorghum and maize (Amole and Ayantunde, 2016a) while maize is most abundant in more moist zones within

West African Sahel. Many of these crop residues are often left in the field after harvest. In the study in the Sudanian region of Burkina Faso, Andrieu *et al.* (2015) confirmed that farmers left around 80% of cereal crop residues on their fields. Livestock either owned or contracted are allowed to graze them in the field. Beside its benefit as animal feed, crop residues have several other uses such as fuel and construction (Pichot *et al.*, 1974; Bationo *et al.*, 1995). These other uses are outside the focus of this review and therefore will not be discussed further. According to FAO (1999), more than 1000 million tonnes of cereal residues are being produced annually in the developing world. This may probably not be the same at present. It can be observed that most of the crop residues are abundant during the months of October to December (at the end of rainy season) and are in greatest use during the dry season when the available pasture is low in quantity and quality (Borogo *et al.*, 2006). Figures 2 and 3 indicated availability of different feed resources in Northern Burkina Faso and Southern Niger throughout the year in relation to the rainfall patterns. The results of the feed assessment showed that cereal and legume crop residues are the main feed resource throughout the year especially from September during the harvest to June, the beginning of the rains. At the peak of rainy season, livestock relied mainly on the available green forage resources which were cut-and-carried to the animals where they were confined to prevent damage of crops.

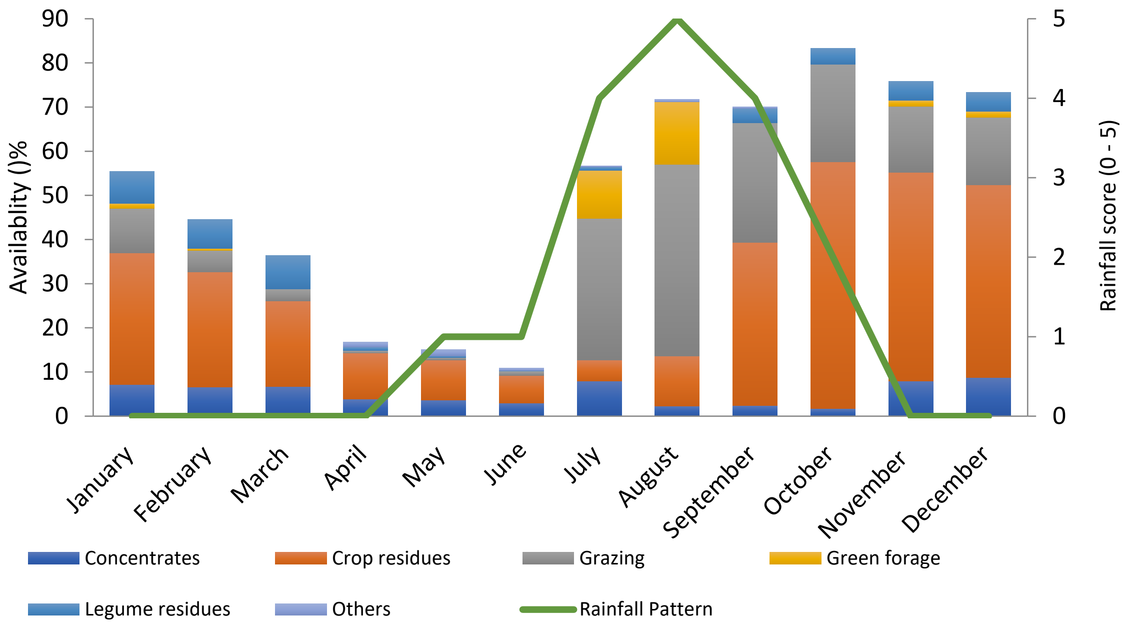

Figure 2: Availability of Feed Resources during the year in Thiou, Burkina Faso (Unpublished Amole and Ayantunde 2015).

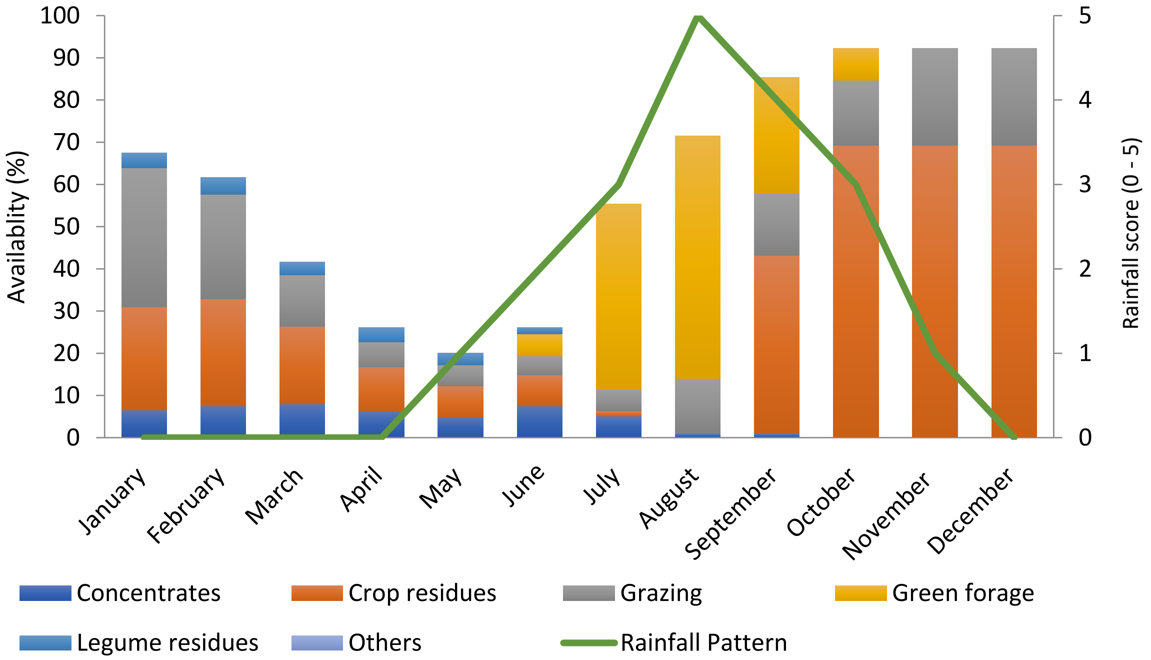

Figure 3: Availability of Feed Resources during the year in Milli, Niger (Amole and Ayantunde 2016b).

Residues can usually be grouped by crop type —cereals (*maize, rice, wheat, millet, sorghum*) grain legumes (*cowpea, soybean, groundnut*), roots and tubers (*yam, cassava, potatoes*).

According to Jayasuriya (2002), feed resource can be categorized into:

1. *High fibre-low protein feeds*: These include fibrous residues arising from crops grown for human consumption, such as straws and stovers from rice, millet, sorghum and maize, and sugarcane bagasse. Crop residues that fall into this group are characterized by their high fibre content (>700 g of cell wall material/kg DM), low metabolizable energy (<7.5 MJ/kg dry matter), low levels of crude protein (20 - 60 g of crude protein/kg DM) and mineral nutrients, and low to moderate digestibility (<30 - 45% organic matter digestibility).
2. *High fibre-high protein feeds*: By-products derived from crop production (tops and haulms from groundnut, cowpea, sweet potato vine, cassava leaves) and industrial processing (bran from cereal milling - rice, wheat and maize bran, brewer's grain), fall into this category of feeds. They are generally less fibrous (below 700 but above 400 g of cell wall material/kg of DM) than those in the first category but have relatively high amounts of crude protein (> 60 g/kg DM). Leaves from tree legumes and browse plants such as Gliricidia, Leucaena and Erythrina, which have around 250 - 350 g/kg of crude protein in DM, can also be considered in this category.
3. *Low fibre-low protein feeds:* These include feed resources derived from crops grown for renewable energy such as sugarcane by-products and root crops. They are generally rich in energy and low in protein content. Examples of feeds in this category include molasses, oil palm juice and waste material arising from the fruit processing industry (citrus pulp, pineapple waste) and root crops (cassava waste).
4. *Low fibre-high protein feeds:* These are the feeds traditionally called concentrates and include oilseed meals and cakes (coconut cake, soybean meal, cotton seed cake, groundnut meal/cake) and animal byproducts (fishmeal, blood meal, feather meal). They are valuable sources of good quality protein for both ruminant and non-ruminant animals.

2.2.4.1. Estimate of crop residue biomass in West Africa Sahel

According to Simbaya (2012), the production of crop residues and by-products can be estimated fairly accurately from estimates of the primary product (e.g. grain), using multipliers which assume grain to residue ratios. The uncertainty of such ratios can be judged by the different multipliers used by different people (Kossila, 1985; Haber *et al.*, 2007). Notwithstanding such discrepancies in the grain to residue ratios for estimating residue yields, it is quite evident that vast quantities of residues are produced as a result of crop cultivation. In 2010, the total quantity of cereal straws was estimated at about 80 million tonnes for all the West African Economic and Monetary Union (known by its French acronym, UEMOA) which includes Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo. Millet ranked first in terms of residue biomass with about half of the cereal residues, then followed by sorghum (Abdoulaye and Ly 2014).

Savadogo *et al.* (1999) in their study estimated the quantities of crop residues in different sub-agroecological zones of Burkina Faso, based on crop areas and grain yields derived from the national agro-pastoral statistics (MARA, 1996). The ratios of 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). Their results, summarized in the graph below, showed that differences in the quantity CR produced across the sub-agroecology of Burkina Faso. According to the Savadogo *et al* (1999), the region within North Sudano-Sahel has the highest potential to produce much feed resource in terms of CR at the time of the study.

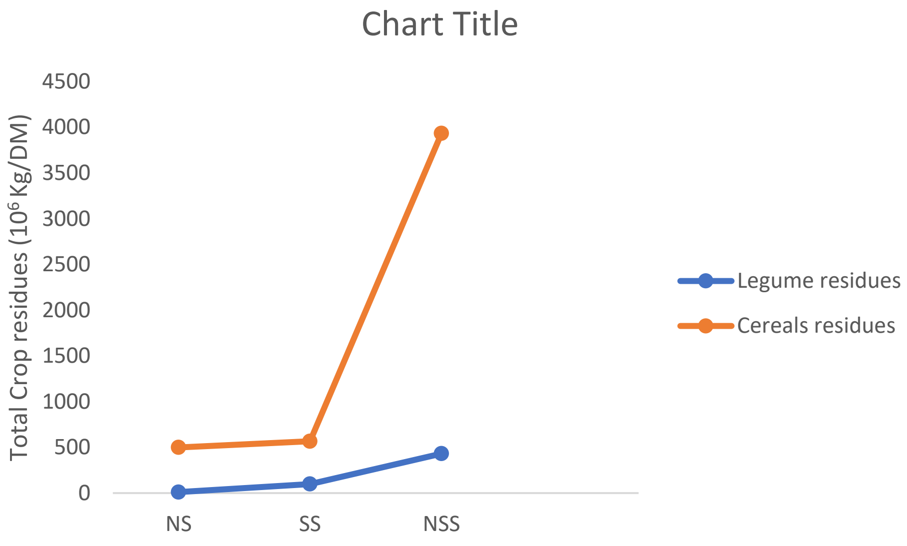

Figure 4: Quantity of crop resides produced across the sub-agroecology of Burkina Faso in 1999
NS: Northern Sahel; SS: Southern Sahel; Sudano-Sahel;

Traore (2016) reported that the only mechanism to monitor the production of crop residues in the Yatenga province of Burkina Faso is the use of the conversion factor and the coefficient of use. The author estimated the average amount of crop residues produced in Yatenga over the last five year (from 2000-2015) which were used as livestock feed as 332,300 tons per year of which 256,900 tons were cereal residues, 12,000 tons were groundnut haulms and 63,400 tons were cowpea haulms.

2.2.4.2. Cereal Crop residues

Millet and sorghum are the most dominant crops in West African Sahel. The stem, sheath and leaves usually refer to as stovers from the cereal crops are used as livestock feed in the target region. Traditionally, pastoralists used to exchange manure and milk for grains (Ayantunde *et* *al.* 2011) or for access to graze crop residues (millet, sorghum, maize and rice) on farmers' fields after grain harvest. By so doing, the farmers benefit from the manure deposited by the animals during grazing of crop residues. The quantity of cereal residue available at a given time will depend on the area of cropped land, the varieties of seed, and management practices that influence the yield. Besides, the quantity of crop residues used by the farmers will depend on some interacting factors such as farmers' preferences; household labour, crop production levels; access to alternative biomass resources; livestock management practices and biomass demand (de Leeuw, 1997; Erenstein *et al.,* 2011). Cereal residues could either be collected or left on the field to be grazed. In the study in the Sudanian zone of Burkina Faso, Andrieu *et al.* (2015) confirmed that farmers left around 80% of cereal crop residues on their fields. In terms of quality, depending on location, stage at harvest and other factors, CP content of 7.8% with digestibility coefficient of 50.4% had been reported for millet stover (Powell and Fussell, 1993). Other results showed 3-5% CP for the same crop residue (Nantoumé *et al.,* 2000) and a range of 2.7 to 5.7% was reported for sorghum stover in the Sahel (Kiema *et al*., 2008).

2.2.4.3. Legume haulms

Common legume crop residues in the Sahel include cowpea hay and groundnut haulms (Fall *et al.,* 2005; Ayantunde *et al.,* 2007). Cowpea hay are an important fodder source for livestock in crop-livestock systems in the Sahel region of West Africa where feed scarcity and seasonality are the major constraints to livestock production (Agyemang, 2002). Cowpea hay can provide adequate protein and energy to sustain ruminant production during an extended dry season (Anele *et al*., 2011). The leaves and stems of the cowpea hay have been reported to contain CP values of 7.7-21.7% (Kaasschieter *et al*., 1998; Savadogo *et al*., 2000) and are often used as a supplement for the low-quality animal feed. The dry matter digestibility of cowpea hay is about 65 to 70% with leaves having a digestibility between 60 and 75% while the stems have a digestibility between 50 and 60% (Karachi and Lefofe, 2004; Savadogo *et al*., 2000). From various experiments in Niger, feeding levels between 300 and 600 g day^{-1} of cowpea hay and 400 g day^{-1} of millet bran were established for a profitable sheep fattening, along with ad libitum feeding of roughage such as bush hay or millet stover (Hiernaux and Ayantunde 2004; Fernández-Rivera *et al.,* 2005).

Groundnut haulm contains protein (8-15%), lipids (1-3%), minerals (9-17%), and carbohydrate (38-45%) at levels higher than cereal fodder as well as nutrient digestibility of 53% (Singh and Diwakar, 1993). In northern Nigeria, where crop residues supply up to 80% of livestock feed in the dry season (Mortimore, 1991), haulms from cowpea and groundnut produced accounted for 30% of the total roughage supply and 75% of the total CP output of livestock (Hendy, 1977). Although, such figures may not apply in the current situation

Therefore, the proportions of leaves and stems in the haulm directly affect its nutritional value (Mullen, 1999; Singh *et al*., 2010). The results from feeding trials by Savadogo *et al.* (2000) showed that the intake of cowpea hay by sheep was 86 g OM/kg BW$^{0.75}$ /d, and the selective consumption of leaves results in higher intakes of protein and digestible OM than expected from the offered haulms (Savadogo *et al*., 2000). In sheep fed 200-400 g/d of cowpea haulms as a supplement to a basal diet of sorghum stover in Northern Nigeria, the resulting average live-weight gain (80 g/d) was twice that obtained with sorghum fodder alone (Singh *et al*., 2003).

Bayala *et al.,* (2014) reviewed 23 publications on various results from trials where crop residues from cereals and legumes were combined into feed rations tested during the dry season in Burkina Faso, Mali, Niger and Senegal. We presented the proximate nutrient composition of various crop residues as reported by some authors in the West Africa context. These results represent a few of several results documented in West Africa. Variations in nutritional profile of crop residue across West Africa is expected as nutrients compositions per time are attributable to different factors such as: stage of harvest, physical composition, i.e. the proportion of stems to leaves ratio, period and mode of storage, cultural practices, harvesting practices, soil fertility (Smith, 1988; Adebowale, 1988).

2.2.4.4. Utilization of crop residue in West African Sahel

The crop residues of cereals may be left in the field as grazing material for livestock. They may be used as mulch, transported to the homestead for stall feeding, used as fencing, building, or roofing materials, or as fuel. The legumes, on the other hand, could be harvested and conserved either for dry-season feeding for the farmers' animals or for sale to other farmers during the critical period of feed scarcity in the mid-to-late dry season (Singh and Tarawali, 1997).

Table 2: Different uses of crop residues in three locations within the West Africa Sahel

	Feeding	Mulching	Burnt	Sold	Gift	Fuel	Construction
Sorghum	66.2	7.7	26.2	0	0	0	0
Millet	60	0	34	0	0	0	0
Groundnut	91.3	7.9	0.8	0	0	0	0
Cowpea	96.2	0	0	3.8	0	0	0
Means of crop residues utilization from three communities in southern Mali (Umutoni and Ayantunde, 2014)							
Sorghum	59	8	2	6	2	28	5
Millet	34	24	2	5	5	22	8
Groundnut	80	0	0	15	5	0	0
Cowpea	70	3	0	25	4	0	0
Mean Crop residue uses (%) in Fakara, Maradi (Niger) and Kano (Nigeria) (Akinola *et al.*, 2015)							
Cereal	68.2	15.7	0	0	0	8.2	0.4
Legume	100	0	0	0	0	0	0
Means of crop residues utilization from three communities in Ouahigouya, Burkina Faso (Unpublished data by Amole and Ayantunde 2015)							

2.2.4.5. Limitations of crop residues as animal feed

Beside the trade-offs and competitive use of crop residues described above, the most obvious limitation to the utilization of CR as ruminant feed is the low feeding value associated with low metabolizable energy, low protein and mineral contents, which cannot support adequate microbial growth or meet the host animal's nutrient requirement for increased performance (Simbaya, 2012). Crop residues are high in fibre and are poorly degraded in the rumen with low nitrogen and minerals resulting in very low intakes.

In addition, seasonal fluctuation in the quantity of crop residues is another major challenge that has been associated with low rainfall and poor soil fertility in the Sahel (Fernandez-Rivera *et al.*, 2005). In studying the seasonal effect on livestock feed resources in Fakara, Southwestern Niger Fernandez-Rivera *et al*. (2005) showed that the end of the growing season for herbage and the peak of availability of millet stover occur simultaneously. Moderate to high amounts of millet stover were available in Gourdjia and Milli in Niger from harvest time to February (middle of the dry season) but the last 3 months (April-June) of dry season were characterized by acute feed scarcity (Amole and Ayantunde, 2016b). Farmers in the study areas also noted that cereal crop residues are more in abundance than legumes. Hence, cereal straws were normally fed to the animal first, while legumes are fed at critical times when the feeds are scarce or as supplement.

Table 3: Seasonal availability of crop residues in West African Sahel

Residues	**Arid – Semi-arid**	**Humid – Sub-humid**
Sorghum straw	October – April	September – April
Millet straw	September – May	September – April
Maize straw	September – May	July – March
Rice straw	January - December	January – December
Cowpea haulm	October - April	August – January
Groundnut haulm	October - April	November – April
Yam peel	n.a	January – December

Cassava peel	n.a	January – December

FAO, 2014; n.a: not available

Another reason for the restricted use of crop-residues in the smallholder livestock production systems is the lack of storage facilities for residues for use in the dry season (Simbaya, 2012). There is also a shortage of labor for handling and storage of crop-residues on the farm. Due to their high bulk density, transportation of these materials to homesteads may not be economical. The distribution of crop-residue production does not often correspond with animal distribution, thereby causing a shortfall in some areas and a surplus in others (Simbaya, 2012). According to Williams *et al.* (1997), availability of crop residues at the farm level depends not just on production levels but also on a variety of social and economic factors, cultural practices, the use of modern crop varieties and the opportunities for market and non-market exchanges. Inter-annual fluctuations in rainfall can also affect crop residue yield, which may in turn affect the ratio between edible and non-edible fractions within residues

Plate 1: Methods of storing crop residues in Milli, Niger
(Photo credit: Tunde Amole/ILRI)

2.2.4.6. Improving the nutritional value and use of crop residues

There are a number of technologies available to improve the nutritional value 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 (Savadogo *et al.,* 1999). The suitability of each of these methods for animal production depends on the availability of crop residues and alternative feeds, availability of labor, availability and cost of water and chemicals, and storage facilities.

2.2.4.6.1. Chemical treatments

The technology includes treatment of crop residues with alkaline chemicals such as sodium and ammonium hydroxides. Even though chemical treatment has proved beneficial in increasing the intake and digestibility of residues, its adoption particularly in rural areas is limited due to the cost and availability of these chemicals (Simbaya, 2002). There is also the danger of toxicity to the animals. The most promising technique is the urea treatment of crop residues or the use of urea/molasses mineral blocks. For decades, there has been a comprehensive report on different methods of treating CR by several authors in West Africa (Aruwayo, 2018; Djibrillou *et al.*,1998)

Table 4: List of different methods of crop residue treatments, constraints and solutions

Methods	Description	Referenced results	Associated problems	Alternative solution
Chemical treatment	The use of sodium hydroxide (NaOH), ammonia (NH_3) and urea	Increases in *in-vitro* as well as *in-vivo* digestibility and intake of treated crop residues with NaOH (Ibrahim and Pearce, 1983; Doyle *et al.*, 1986). Increased crude protein (CP) from 4.6 percent in untreated rice straw to 11.9 percent in urea treated straw (Jaiswal *et al.*, 1988; Ngele *et al.* 2009) It breaks down the lignocellulose bonds of the residue, increasing the rate and extent of rumen microbial digestion (Amata, 2014; Ramirez *et al.*, 2007; Oji *et al*, 2007).	Problems of availability, health risks, costs, handling and additional labor limits The danger of toxicity	A cheaper and relatively available alternative is the use of alkalis available to the farmer such as ashes left after burning of wood, oil palm bunches and cocoa (Smith, 1993).
Physical treatment	Grinding, chopping, pelleting, soaking and densification	Reduction in the soluble cell material and *in vitro* digestibility of cowpea vines. (Ibrahim and Pearce, 1983; Doyle *et al.*, 1986). Increased intakes and performance of sheep (Osafo *et al*., 1994)	The cost and labor involved, energy intensity and marginal ineffectiveness	Market-oriented feed producers. developing inexpensive manual driven or fuel-efficient choppers could be an option More investment at the community level for a simple machine to ease manual chopping
Biological treatment	Enzyme addition, fungal growth, fermentation, composting and ensiling are some of the	Improve digestibility (Ibrahim and Pearce, 1980; Ryu, 1989) *P. ostreatus* treatment for 15 days on corn straw increased crude	Associated with some loss of dry organic matter. Required more technical training for smallholder's farmers.	More research is needed at farm levels.

	biological methods that have been used to increase the digestibility of crop residues	protein (39.5%) and decreased neutral detergent fibre (14.5%). Ramirez-Bribiesca *et al*. (2010)		
Supplementation	Addition of protein-rich feed resource to improve feed intake	Sorghum stover and wheat straw supplemented with urea-molasses and rice straw supplemented with oil palm slurry improve intake and performance. (Kayouli C. 1994).	Inadequate knowledge on appropriate ratios of supplement to basal crop residue, expensive ingredients	Building farmers capacity in ration formulation is essential

Plate 2: Crop residues in the fodder market near Gourdjia, Niger (Photo: Amole Tunde/ILRI)

Plate 3: Fodder market in Niamey, Niger (Photo credit: Abdou Dan-Gomma/INRA**)**

In Niger, Kayouli (1996) observed that the consumption of urea-treated forages during the dry season is often accompanied by an improvement in body condition of the animals and maintenance of live weight. In another trial in the northern part of Nigeria. Singh *et al*. (2011) reported that feeding the residue of cereals alone resulted in a mean weight loss of 14% for sorghum, 16% for maize and 11% for millet, while feeding the residues of cowpea or groundnut alone resulted in the weight gain of about 13 and 12%, respectively. Furthermore, Singh *et al*. (2011) reported supplementing the cereals residues with about 300 g of legume residues per ram per day resulted in a slight gain in weight. The addition of 300 g wheat bran and 300 g legume residues to the cereals in the daily diets of each ram resulted in about 19% mean weight gain.

2.2.4.6.1. Improved conservation method

Conservation is an avenue for ensuring continuity in ruminant feed availability. It ensures the maintenance of ruminant animals at the crucial period especially during the dry season (Aina, 2012). Although the nutritive qualities differ from those of fresh materials, adequate levels of nutrients are retained in conserved feed to merit the use in the dry season (McCullough, 1988). Even though storage aims to preserve the quality and quantity of feed for later use, losses of nutrients, particularly crude protein, during the storage process have been reported. Nevertheless, Antwi *et al.*, (2011) confirmed that storing in a shed system of storage retains the quality and availability of haulm in respect of the dry matter and crude protein contents of dual-purpose cowpea haulm.

2.2.4.6.2. Supplementation of poor-quality livestock feed resources

Nutrient supplements could be used to improve the utilization of poor-quality forage; the nutrient supplements enhance the intake and digestibility of poor-quality forage by promoting the activities of rumen microorganisms. Hay and silage could be supplemented with molasses/urea mixture, whole cottonseed groundnut cakes or other suitable supplements such as mineral supplements, protein supplements, non-protein nitrogen e.g. urea in order boost its nutritional content to increase animal productivity (Fajemisin *et al*., 2011).

2.2.4.7. Market potentials of crop residues

Feed marketing exists at many levels, with informal selling of residues directly off the farms to nearby livestock farmers, marketing of bundled residues along roadsides and in or around livestock markets (Grings *et al*., 2010). These livestock feed markets are normally situated near livestock markets and they mainly sell crop residues such as cowpea hay and groundnut haulms, agricultural by-products such as cottonseed cake and cereal bran, concentrate feed from small scale feed industry, and leaves from various shrubs and green fodder harvested from the natural pastures. Ayantunde *et al.* (2014) reported that feed markets have sprung up in many cities and towns of West African Sahel in response to growing livestock populations in peri-urban areas. In another report from Yatenga province of Burkina Faso, Traore (2016) confirmed the existence of fodder market with many identified actors (collectors, wholesalers, retailer, transporter) supporting their livelihood from fodder marketing.

The sale of crop residues (cowpea hay, groundnut haulms, cakes and bran) is a major source of household income to crop farmers (Williams *et al.* 1997; Ayantunde *et al.* 2007). In their review on fodder and pasture production, Bayala *et al.*, (2014) presented prices of the livestock feed in peri-urban areas of Burkina Faso, Mali, Niger and Senegal. The price from existing fodder market in Mali (Umutoni *et al.*, 2015) and prices of feeds purchased from fodder markets were also reported by Amole and Ayantunde (2016b). In terms of types of fodder marketed, Abdoulaye and Ly (2014), reported that cereal straw is virtually never traded, especially in semi-arid zones, where it is left on the field unless used by the household (fuel, construction, etc.). Yet others have reported sales of cereal residue in Burkina Faso and Niger (Amole and Ayantunde (2016a, b). However, this trend as reported by Abdoulaye and Ly (2004) may be limited to rural communities where most households grow cereals and often leave the residues on the field for grazing by animals. We noted that price of crop residue varies in spatial and temporal.

Nevertheless, key issues around crop residue marketing are the non-availability all year-round which influences the pricing. Generally, the price of crop residues (particularly legumes) corresponded with availability (Grings *et al.*,2010). The highest price was reported during the wet season (June to September) and lowest immediately after harvest (October and November). Other agricultural by-products, such as cottonseed cake and cereal bran, and of concentrate feeds did not vary significantly across the seasons, suggesting adequate year-round availability (Ayantunde *et al.,* 2014). Poor storage methods or lack of facilities limits all-year-round availability of crop residue especially cowpea haulms. Grings *et al.,* (2010) reported that improved storage methods will decrease leaf loss after harvest and could improve the market value of cowpea haulms over a longer period of the year.

Seasonal variation in the quality of the crop residues is observed even in fodder marketing. The survey on the emerging feed markets for ruminant production in urban and peri-urban areas of Northern Ghana by Konlan *et al*. (2018) revealed that there were seasonal variations in the quality of feed resources in the sampled areas. For instance, crude protein (CP) of groundnut haulm was 9.8 and 12.2 % in the early dry season and late dry season, respectively. Notable variations were also recorded for fibre, metabolizable energy (ME) and digestibility of the identified feed resources in Ghana? (Tables 7). In terms of quantity and availability during the dry season, crop residues provided the bulk of feed resources in the Sahel. However, its contribution to dietary dry matter and ME and CP was quite low (Amole and Ayantunde, 2016b). This could probably be attributed to poor quality of the crop residues resulting from factors such as harvest time, poor storage methods and a generally low nutritional status of cereal straws.

2.2.5. Agro-industrial byproducts

Agro-industrial byproducts (AIBPs) are waste products arising from the processing of crop or animal products by industries while some other agro-byproducts are mainly from household processing of some agricultural products (Alhassan *et al*, 1989; Sindhu *et al*., 2002). The use of AIBP as part of livestock feed can reduce the cost of production, improve the quality of feed, ensure regular feed supply even during the period of scarcity and ultimately increase the profit margin of livestock farmers (Sindhu *et al*., 2002).

Generally, agro-industrial by-products are listed as energy, protein and combined protein/energy sources (Aregheore, 1998). Energy sources are rich in fermentable carbohydrates and low in protein. A few examples are molasses, a by-product of the sugar industry, (75 % DM, 4.1 % CP and 12.7 GE MJ/kg DM), cereal byproducts such as brewers' spent grains and bran from wheat, rice and maize (Cheeke, 1991). Some are protein-rich products such as cakes and meals. Examples are soya bean meal which can contain 48% crude protein (Obese, 1998), palm kernel meal (18 % CP) and copra meal (18.8 % CP), cocoa husk (Otchere *et al*, 1986), cotton seed and soya bean cake (Avornyo *et al.,* 2001). Local cereal brans (millet bran, sorghum bran) are examples of household agro-byproducts. With the quantity of bran estimated based on the conversion factors of the quantities of seeds provided (Kossila, 1988), Sahelian countries were reported as the largest producers of cereal bran in West Africa (FAO 2014). Feed resources in Katsina state, Northern Nigeria is chiefly mainly cereal and legume crop residues, concentrate (AIBPs) and green forage in that order and are available in a declining manner as the dry season prevails from January till June (figure 5). The report of feed assessment noted that farmers acquired more livestock after the harvest for fattening between 5 to 6 months (Unpublished Amole and Ayantunde 2014). As the feed quantity declines, farmers dispose their animal to purchase farm inputs in preparation for the next cropping season. In the production system, farmers depend largely on purchased feed (cotton seed cake) for fattening and other AIBPs throughout the year (Unpublished Amole and Ayantunde 2014).

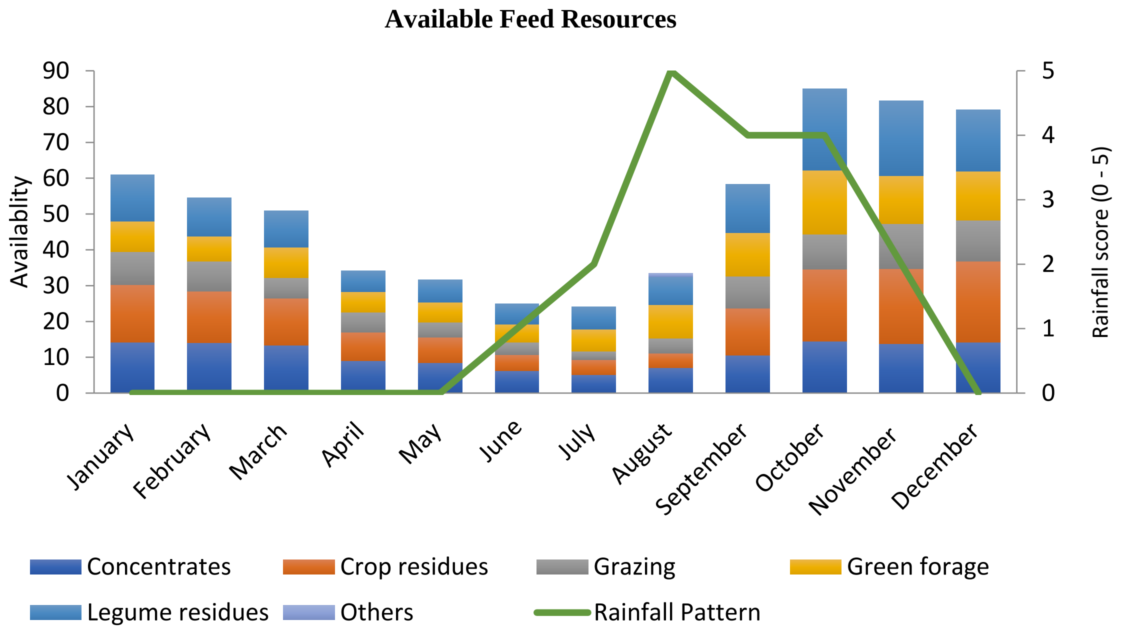

Figure 5: Availability of Feed Resources during the year in Yakubawa, Nigeria (Unpublished Amole and Ayantunde 2014).

2.2.5.1. Constraints to the use of agro-industrial by-products

Apart from the inter-annual variability, there is a great variability in quantities available, due to specificity of crop grown in different areas. Beside the constraints of seasonality and price, there are varieties of anti-nutritional factors, including various toxic compounds, which are deleterious to animal health and performance have been also reported in some AIBPs (Aregheore, 2000). Gossypol, a polyphenolic pigment present in the kernel and coat of the seed has been reported in many cotton by-products and mycotoxins contamination, mostly common Aspergillus flavus in groundnut cake (FAO 2014). Other limitation is the usual unavailability and unaffordability for farmers

However, a number of technologies and methods have been developed to detoxify or at least minimize the effect of these toxins or anti-nutritional factors (Sindhu *et al*., 2002). For example, the high lignin content of unprocessed bagasse (Bhatti and Khan, 1996) which renders it poorly digestible has reportedly been improved by high-pressure treatment. This treatment improved both palatability and digestibility of bagasse (Morrison and Brice, 1984). Another major problem with bran is its relatively low nitrogen content, even though, according to the process, some proteins can be found, namely in rice or wheat bran. Beside this is the risk associated with mould and therefore of fungal contamination during conservation (FAO 2014).

3. Knowledge gaps and lesson learnt in addressing feed challenges in West African Sahel

In this review, we have identified different feed resources, their potentials, challenges and gaps in the knowledge from past to improving the utilization of these resources. However, we discussed under this section other gaps regarding feeds and feeding issues in the West African Sahel and also provide lessons for future efforts in addressing feed challenges in the region.

In most of the reviewed publication on feeds and feeding issues in West African Sahel, feed scarcity was presented as a general problem without adequate information about the trends in supply and demand. Without such information, appropriate long-term strategies for addressing problems of feeds and feeding challenges cannot be developed and implemented. In addition, the assumption of inadequate feed supply in a location premised on the evidence of purchased feed in that location may be faulty because the question of whether the purchased feeds meet the nutritional demand remains unanswered.

Secondly, the efficacy of newly introduced technologies with respect to conservation, storage and processing of different feed resources to mitigate spatial and temporal feed supply, and demand problems is not well understood. In most of WAS, livestock production and the target interventions are not market-oriented, consequently productivity indices are not well-defined to evaluate impact of several interventions. In addition, limitations in knowledge and skills on various aspects of feed such as production, processing, quality assessment marketing has been identified etc.

There is no doubt livestock production requires full participation of women. Despite their considerable involvement and contribution, women's role in livestock production has been underestimated, undervalued and widely under-reported. Women face several challenges in accessing and having control over the resources that are linked to fodder and feed production. These barriers stem from a number of cultural and socio-economic barriers. Women are often constrained by the availability of manual labour and since often, feed improvement techniques involve labour, women are disadvantaged. Access to training can also be problematic either because of their existing workloads or because they require consent from their husbands to participate. Ensuring women's access to extension services, knowledge, credit and technologies is therefore critical. In addition, most feed intervention projects are not well linked to household nutrition and social needs as increase in men's earnings from livestock-related activities may not necessarily translate into improved household nutrition; whereas, women tend to prioritize household well-being. Identifying this gap will provide insight for specific measures at project design to guarantee women's participation.

In solving feed challenges in the Sahelian agro-ecological zone of West Africa in order to meet the future feed demand, we recommend three general approaches namely identification of specific feed interventions suitable for each target area, options to produce more feed resources and ways of improving the existing and the new feed resources by providing basket of options for improving feeding values of CR and strengthening the fodder market structure.

3.1. Identify site-specific feed intervention

In developing good and sustainable technological interventions to address the problem of feed shortage, it is necessary to assess the existing and potential feed resources, use, costs and gaps with respect to ruminant production to meet the requirements of livestock. These evaluations will guide the development of effective strategies to improve nutrition and livestock productivity based on locally available feed resources. Decision-support tools have the potential to play an important role. For example, FEAST (Feed Assessment Tool, https://sites.google.com/a/cgxchange.org/feast) is an example of a decision support tool that presents an evolving methodology for conducting rapid appraisals of livestock feed issues in smallholder livestock systems. FEAST uses a systematic method for assessing local feed resource availability and use with a view to design intervention strategies aimed at optimizing feed utilization and animal production. The results of some FEAST conducted in West African Sahel with an inventory of feed resources in the study areas and priority feed intervention strategies have been documented (Amole and Ayantunde, 2016a, b; Umutoni *et al*., 2015).

3.2. Providing basket of options for improving feeding values of CR

With the dominant role of crop residues in dry season feeding, especially in the late season, Smith (2012) remarked that livestock farmers need to know the options available for them to optimize the available CRs. We reviewed these options and came up with a diagrammatic *"basket of options"* (Figure 6) from which livestock farmers in the Sahel could select according to their preferences based on knowledge and available resources. In fact, a combination of whatever is possible based on farmers' production options and the afore-mentioned criteria will be most appropriate. This could be through the cultivation of more dual-purpose crops and through increased cultivation of fodder species, particularly in peri-urban livestock systems. Combining this option with early harvest of crop residues, best storage methods or facilities and appropriate crop residue treatments or ration formulation could improve the availability of all-year-round quality feed. Multi-partners approach involving research and development partners will be needed to ensure better access to these higher feed producing varieties and other inputs.

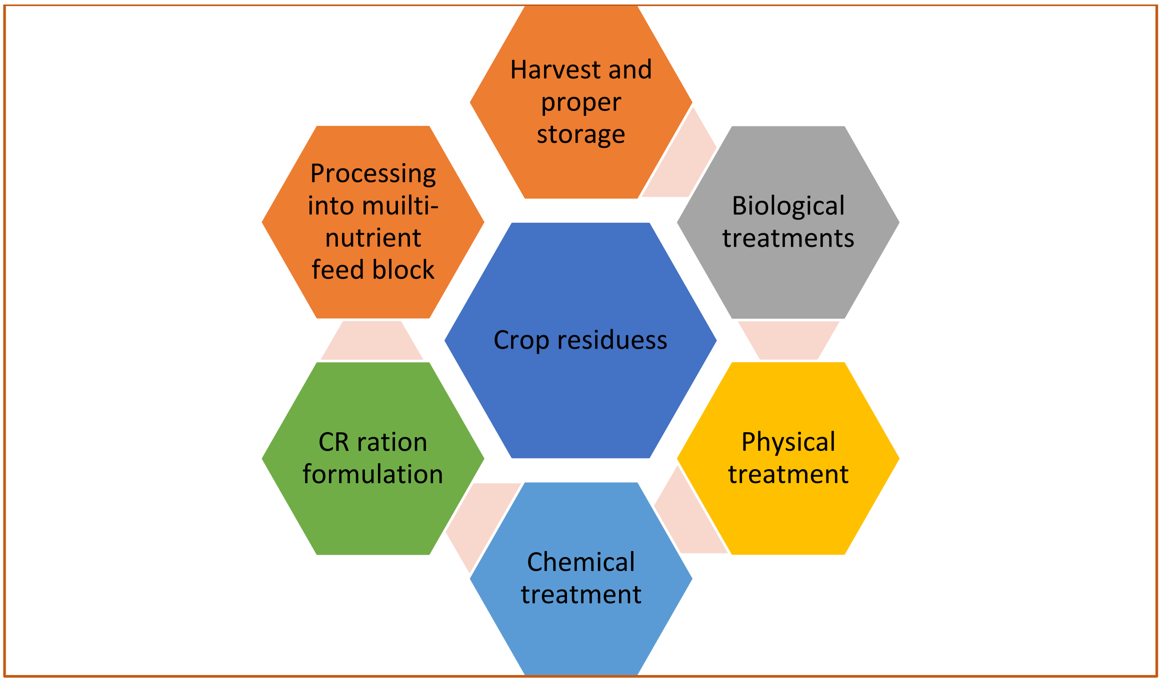

Figure 6: Basket of options for optimizing available crop residues

3.3. Strengthening the fodder market structure.

Fodder markets exist and keep growing in rural areas and cities in the Sahel, from selling of residues at the farm gate to selling of mixed concentrates at designated places (Grings *et al.*, 2010). Samireddypalle *et al.* (2017) highlighted the fact that crop residues are a tradable commodity and constitute a value chain requiring collection from the field, transport by middlemen and trading by wholesalers and retailers. Yet the market is still far away from being well-organized and the value chain is still weak with lots of unprofessional actors. Traore (2016) therefore recommended that institutional support is needed to organize actors in the forage value chain, establishing mechanisms for information, monitoring and analysis of feed prices and strengthening the stakeholders' knowledge of forage processing and conservation. Facilitation of link between all the actors in feed value chain will promote feed densification and utilization (The World Bank, 2012). The livestock production systems have to be market-oriented for there to be an incentive to invest in feeds.

3.4. Institutional and policy landscape

The feed resource sector is largely neglected by the policymakers and suffers from a limited availability of data and statistics, despite its significant contribution to livestock productivity and development. A lack of appropriate policy frameworks is one of the main reasons why scaling up of livestock feed interventions fails or does not happen at the expected scale. Effective and coherent feed policies are crucial to capitalize on the growing opportunities offered to smallholder livestock producers by the increasing demand for animal source food in WA and the developing countries in general. In response to this, livestock-related policies should, therefore, not be designed in isolation. There should be participation of institutions that represent both the poor smallholders and the commercial enterprises and all actors in the livestock and livestock feed value chains.

One of the effective tools for policy influence will be the formation of innovation platforms (IP). Through an iterative process of consultation, IPs provide an opportunity for main actors in a feed value chain to analyze, plan and adopt production and related policy issues. While engaging policymakers at local and national levels to increase understanding of livestock-related issues, IPs can instrumental in identifying shortcomings of existing policies and the need to formulate new ones.

4. Conclusion

Our review presented a number of literature identifying common feed resources for livestock production in West Africa Sahel. Among these feed resources *(naturally occurring pastures, agro-industrial byproducts and household byproduct and crop residues)*, crop residues constitute a major source of livestock feed after pastures particularly due to a long period of dry season. Seasonal variation in availability and quality resulting in low livestock productivity in the region has been a major problem associated with feed resources in the Sahel. As crop production intensifies with improved seed systems and good management practices, there will be a potential increase in the quantity of crop residues in the Sahelian zone. Several proven methods of improving the feeding value of crop residue and possible alternatives to eliminate the challenges associated with adopting some of them were reviewed in this report. Above all, the challenges remain developing new methods and improving the existing storage methods to extend its use in till the end of dry season. Furthermore, with evidence of feed markets at different levels in the Sahelian rural areas and urban cities, we discussed the opportunities around feed marketing as a springboard to promoting a market-oriented feed production system. Strengthening the weak nexus among feed value chain actors is critical for improving feed marketing. Public and private investments are necessary for the dissemination of information and skills through training, machinery, feed storage and transport strategies to facilitate means of improving the production and use of livestock feed.

Given the complex socio-ecological context of the Sahel, making assumptions about animal productivity in relation to anticipated demands for livestock products without basing this on an empirical assessment of the potential of the natural resources to provide the nutritious biomass required could result in unsustainable solution. Every effort towards developing sustainable technological interventions to address the problem of feed shortage in the Sahelian region should assess the existing and potential feed resources, use, costs and gaps with respect to ruminant production to meet the requirements of livestock.

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