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frontiers | Frontiers in Animal Science

TYPE Original Research
PUBLISHED 11 March 2024
DOI 10.3389/fanim.2024.1354728

OPEN ACCESS

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RECEIVED 12 December 2023
ACCEPTED 19 February 2024
PUBLISHED 11 March 2024

CITATION
Mottet A and Assouma MH (2024) The feed balances sheet: a tool for planning the use of resources and enhancing resilience in tropical grazing livestock. *Front. Anim. Sci.* 5:1354728.
doi: 10.3389/fanim.2024.1354728

The feed balances sheet: a tool for planning the use of resources and enhancing resilience in tropical grazing livestock

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Similarly to other tropical, arid and semi-arid regions of the World, livestock production in the Sahel is based on extensive grazing in rangelands where managing herd mobility (transhumance and nomadism) is key to productivity and sustainability. However, in this region, government planning, impact assessments and climate change adaptation solutions face several methodological limitations and lack of data availability particularly about the feed and forage resources and how there are used by livestock. Existing feed balances at national or regional level in Sub-Saharan Africa are still largely perfectible. To address these limitations, FAO and CIRAD (French Agricultural Research Centre for International Development) have developed a tool called Feed Balance Sheet (FBS) adapted to the Sahelian livestock systems to help countries carry out improved feed balances. This new FBS tool provides the following improvements to existing feed balances in countries: (i) it considers the seasonality of feed availability and quality as well as the seasonality of animal requirements; (ii) it includes protein and energy in addition to dry matter; (iii) it takes into account a wide range of resources, including browsing of woody biomass. This article describes the methodological development and the assumptions underlying this tool, which has already been piloted in 6 countries in Western and Central Africa. It also presents the results from 2 countries (Mali and Chad) and draws conclusions on the tool's relevance and guidance for its application. It can be used to improve the resilience of pastoral communities in the Sahel and better plan responses to droughts and other types of crises. Its use requires dedicated training and partnerships between governments and science organizations for accessing the appropriate input data. Based on the tool's experience in six countries (including 2 for which results are presented in this paper), we have confirmed the key role that CIRAD, FAO and their partners must play during the first few years in coaching the different teams at the country level.

KEYWORDS

Sahel, tropical grazing systems, feed balance sheet, seasonality, feed quality

1 Introduction

Feed availability and accessibility are two of the main challenges for tropical livestock systems, which are often under environmental stress and climatic changing conditions. In arid and semi-arid areas, these systems are Sahel region characterized by a strong rainfall gradient which conditions the production of plant biomass (Hiernaux and Assouma, 2020). In particular, the vegetation growth in Sahelian rangelands is driven by the highly seasonal rainfalls. Mean annual rainfall decreases with increasing latitude, however, all over the Sahel gradient, rainfalls are patchy (Ali et al., 2003) and are highly variable between years (Lebel and Ali, 2009). The dry season lasts 8 to 10 months with very low air humidity associated to mild temperatures from November to February and to extremely hot temperatures from March to the first rains (Guichard et al., 2009). In such environments, animals adapted to the local resource availability and extensive pastoral systems are dominant. Fodder resources from grazing and browsing are at the heart of people's livelihoods. Herders also manage their livestock adaptation to resource scarcity through daily feeding management and transhumance strategies, based on their knowledge and the limited information they have about the available resources (Ayantunde et al., 1999).

Climate change tends to increase the frequency of extreme events: dry episodes during the rainy season but also heavy rains and floods (IPCC, 2019). During the most serious droughts, large numbers of animals can die which can lead to famines. For example, in West Africa, the 2018 drought resulted in fodder deficits, which caused an earlier-than-usual transhumance and contributed to increase food insecurity in the region with more than eight million people affected (FAO, 2019).

Other factors can reduce the availability or accessibility of feed and fodder, and therefore affect animal productivity, thus contributing to increasing food insecurity and malnutrition in populations. Obstacles to pastoral mobility (such as lack of access to water, urban development or the extension of cropland, health crises such as Ebola in 2014 or COVID-19 in 2020, and conflicts) as well as increasing herd size (a common practice to preserve and increase wealth) affect resource availability and access to pasture (Moutari and Giraut, 2013).

The decline in the fertility of cultivated land and the degradation of available pastoral resources (Pierre et al., 2022) as well as the densification of perennial pastoral water points (pumping stations, boreholes, wells, etc.) are occurring throughout the Sahel (Turner et al., 2017).

The exacerbation of social and environmental problems in the Sahel is linked to complex causes of human and eco-climatic origins (FAO, 2019). The increase in livestock numbers and the extension of cultivated areas have led to a change in the relationship between agropastoral and pastoral populations. The prevalence and severity of conflicts related to the use of natural resources and the mobility of herds have increased (Turner et al., 2011; FAO, 2021). The land access context accompanied by the marginalization of community rangelands and the growing "privatization" of cultivated land accompanies this trend.

These trends, climatic, environmental and social, are undermining the resilience of ecosystems and the societies that depend on them, meaning their "ability to absorb and recover from shocks, whilst positively adapting and transforming their structures and means for living in the face of long-term changes and uncertainty" (OECD, 2013). This includes climate change but also shocks from animal disease outbreaks or market prices.

In this context, information about the resources available from rangelands to support pastoral livestock are essential, for herders and also for governments and development partners. Feed balances are used to assess the adequacy between the needs of the herd and the available animal feed resources. Feed resources usually include forages - or biomass – that are grazed by animals such as grass and legumes from pastures and rangelands, as well as fodder, crop residues and by-products from crop production and processing, such as straw, bran, oilseed cakes, brewery residues or molasses, and finally feedstuffs preserved and stored by herders, such as hay or silage before the dry season (FAO, 2020). A feed balance is estimated at a given geographical scale (farm, municipality, territory, province, country or region) over a defined period of time, usually annual. In Sahelian countries, assessment of the feed balance is a mandate assigned to the Ministry in charge of livestock sector. The officers in charge create calculation sheets that allow them to evaluate the available fodder resources at the end of the wet season and the requirements of the animals in dry matter (DM) by using a global norm of 2.5% of the live weight (LW) per day (Rivière, 1991).

Based on such balance, measures can be taken by governments, for example feed distribution, herd mobility or herd destocking. It is also an essential step to assess the consequences of spatio-temporal variations in rainfall on biomass production, which is necessary to estimate the impact of climate change on food production. A feed balance is also used for assessments such as estimating competition between animal and human food (Mottet et al., 2017) or emissions of greenhouse gases (GHG) from livestock (Gerber et al., 2013). The lack of information about animal feed baskets and intakes is one of the main limitations to accurate GHG emissions estimates in tropical livestock systems (Ndung'u et al., 2022).

In the Sahel, in particular, the feed balance is an essential tool for early warning systems. It is usually established annually by government services as a forward-looking tool before the inception of the dry season. It can also help improve the resilience of pastoral communities over the long term, by estimating and mapping structural deficits and/or surpluses of feed and fodder, and project the impact of climate scenarios. The currently used methodologies have shown several limitations (Hiernaux et al., 2016).

This paper reviews the existing methodologies for feed balances and their limitations, and it presents a tool commonly referred to as Feed Balance Sheet, an Excel-based calculation tool developed by FAO and CIRAD and introduced in FAO (2020). The objective of the tool is to provide governments, NGOs, private sector actors, pastoral organizations and pastoralists with an advanced and harmonized method for establishing feed balances to address the limitations of current methodologies. Results from pilots in of the FBS in Chad and Mali are presented and discussed.

2 Methods

2.1 Existing methodologies for estimating feed balances

In general, a feed balance is based on the total annual production of feed, including fodder, at the national or regional level (ACF, 2018; FAO, 2018). The inventory of feed resources starts with identifying the different types of feed and forage. In most cases, this step can be carried out through an analysis of existing documents and interviews with sector actors and country experts. The inventory should distinguish resources from grazing and browsing, and resources from agriculture and the agri-food industry, such as crop residues (e.g. straw) and by-products (e.g. bran, molasses, oilseed meal). This can be done by using official statistics on crop production as well as maps of land use (or land cover) and cropping systems (FAO, 2018).

The plant mass produced on rangelands is generally obtained from remote sensing information using the Normalized Difference Vegetation Index (NDVI) which can be transformed into biomass (kg DM/ha) by linear regression from site measurements on the ground. It is also estimated by the Dry Matter Productivity (DMP) which represents the overall growth rate or increase in the dry biomass of the vegetation directly related to the net primary productivity (NPP) of the ecosystem, with units suitable for agro-statistics (kg/ha/day) (Garba et al., 2015). The plant mass is however not entirely accessible and usable by grazing animals (for example if it is too far from a water point, burned, located on trees and too high to be consumed or coming from unpalatable or toxic plant species). To calculate the accessible and usable plant mass, an average DMP per hectare index is generally used and applied to the entire surface of the rangelands (FAO, 2018), or a coefficient of maximum use of standing vegetation by livestock that takes into account losses due to trampling, consumption by other herbivores and organic decomposition (typically 30% of biomass produced on rangelands, see for example (De Haan et al., 2016). To estimate the nutritional quality of pasture forage, these studies rely on averages and unique herbaceous and legume species composition. A similar methodology is used in the Predictive Early Warning System for Livestock - PLEWS (Matere et al., 2020).

The amount of crop residues and by-products used as feed is usually estimated using crop yields from national crop production data and applying conversion factors between grain yields and other plant parts, such as straw, bran, etc. Not all amounts of crop residues and by-products are used as animal feed. The share of residues and by-products available and usable by livestock is estimated in most studies by applying average factors accounting for other uses (such as building materials, fuel, green manure), which are mainly based on estimates from the literature and expert opinions.

To estimate the needs of animals, studies are generally based on an average daily consumption. In the method used in the Sahel by technical services as well as research institutions (Boudet, 1984), the forage intake by grazing livestock is estimated by a linear function of the animal LW, setting the daily DM intake of ruminant livestock at 25gDM per kg of LW (or 2.5%), often expressed per tropical livestock unit (TLU, i.e. 250 kgLW) as 6.25 kgDM TLU^{-1} d^{-1} (Rivière, 1991). This standard value is supposed to cover the maintenance needs of grazing livestock, including metabolism in tropical conditions, average walking and grazing energy expenses, as well as the breeding energy expenses (Boudet, 1984). The norm is applied on an annual basis to the total LW of the livestock population estimated by census per administrative units and converted in TLUs based on standard LW per animal species, sex and age classes (Jahnke, 1982).

Some more recent studies are based on metabolizable energy (ME) and crude protein (CP), taking into account the specific needs of different species of livestock [see for example the Ethiopia Feed Inventory and Balance Sheet, produced by FAO (2018)].

National and sub-national feed balance mechanisms in the Sahel are based on the approach described above and are managed and used by departments within the Ministries responsible for animal resources, the environment, research or by specialized national structures.

2.2 Limitations of existing methodologies

2.2.1 Seasonality of biomass and animal performances

One of the major weaknesses of existing national mechanisms according to Hiernaux et al. (2016) is the lack of accounting for seasonality.

In West Africa, permanent pastures and rangelands represent two-thirds of agricultural land, offering a mix of grass, legumes, woody species, planted woody fodder species and crop residues (Boudet, 1972; Hiernaux et al., 2009). The available forage mass in the Sahel is the main driver of the voluntary ingestion per livestock species (Dicko et al., 2006). The DM declines during the dry season, as well as fodder digestibility, and the proportion of unpalatable species recorded at the peak vegetative stage ranges from 32 to 61% (Hiernaux et al., 1997; Ayantunde et al., 1999). The late dry season is therefore the most critical period for ruminant nutrition in the Sahel (Le Houérou and Hoste, 1977).

Adapted to the regular seasonality of precipitation, solar radiation, temperature and air humidity, the herbaceous vegetation in the Sahel is largely dominated by annual plants with a short cycle, associated with more or less scattered woody plants, among which deciduous hardwoods dominate (Hiernaux and Le Houerou, 2006). There are relatively few reliable year-round monitoring studies describing the extensive use of vegetation (grasses, trees and shrubs) by livestock in arid and semi-arid climates in sub-Saharan Africa (Ayantunde et al., 1999; Fernández-Rivera et al., 2005; Achard and Chanono, 2006; Schlecht et al., 2006; Hiernaux et al., 2009). Studies monitoring the weight and reproductive performance of cattle such as Wilson (1986), Wilson (1989), Colin de Verdière (1994), Lesnoff (1999), Ezanno et al. (2003); Chirat et al. (2014) and Assouma et al. (2018) all converge to highlight the strong seasonality of animal production and cattle in particular, which reflects the availability of resources and adapted animal feeding practices.

In addition, the use of the standard average value of 25 g DM intake per kg LWdoes not take into account the seasonal change in behavior of animals with regard to selective grazing to adapt to changes in availability and quality of the fodder, which goes from a highly herbaceous green fodder digestible during the wet season to poorly digestible straw and litter during the dry season (Chirat et al., 2014). Assouma et al. (2018) showed that using this method leads to overestimating animal consumption by 20 to 300% depending on location and season.

Another limitation is the non-linearity of metabolizable energy requirements with the weight of the animal (Zemmelink, 1980). In particular, Assouma et al. (2018) showed that this resulted in underestimating the consumption of small ruminants and overestimating the consumption of cattle.

Finally, this approach does not consider that an animal can mobilize its body reserves, can lose weight and eat less than is necessary to cover all metabolic needs. Herders know how to take advantage of the high quality of the fodder of rangelands selectively grazed during the wet season (Ayantunde et al., 1999) to develop and build up fat reserves that the animal will gradually burn over the long dry season (Ezanno et al., 2003). In addition, dietary restrictions influence the metabolism of ruminants and the low quality of feed affects their digestive performance (Goopy et al., 2020). This can also lead to an overestimation of daily forage consumption and, in the case of severe below-maintenance intake, to higher enteric methane emissions per unit of fodder ingested (Goopy et al., 2020).

Not accounting for seasonality can lead to errors in calculations related to the stocks of feed and fodder needed for distribution in times of drought or the impact of climate change on pastoral and agro-pastoral systems, as illustrated in Table 1, from FAO (2021). Animal ingestion and enteric methane emissions were estimated according to average energy requirements on different bases: annual (no seasonality, most common approach), two seasons (wet season and dry season) and three seasons (wet season, and cold and hot dry seasons). They were compared to observations of ingestion made in the field (hand picking method and total collection of faeces). The results in Table 1 show that annual feed rations calculated according to average energy requirements overestimate ingested quantities by 26 to 71% for this system. Modelling over three seasons reduces the overestimation (13%in the wet season), but it remains significant, especially in the hot dry season (55%). Enteric methane emissions calculated with these feed intakes using the Global Livestock Environmental Assessment Model – GLEAM (Gerber et al., 2013) based on Intergovernmental Panel on the climate change (IPCC) were also overestimated by 32 to 76% compared to measurements from the field based on total organic matter digestibility. Such results reveal that current estimates of enteric methane emission intensities for sub-Saharan livestock are inaccurately higher than

TABLE 1 Comparison of field measurements and various seasonality assumptions in modelling animal feed intake and emissions of enteric methane.

	Field observations[a]	Annual[b]	Over-estimate	2 seasons[c]	Over-estimate	3 seasons[d]	Over-estimate
Intake (kgDM/TLU/day)							
Pastoral							
Wet season	4.13	5.22	*26%*	5.34	*29%*	4.67	*13%*
Cold dry season	3.71	5.22	*41%*	6.89	*86%*	4.47	*20%*
Hot dry season	3.06	5.22	*71%*	6.89	*125%*	4.73	*55%*
Agropastoral							
Wet season	3.96	5.39	*36%*	5.13	*30%*	5.03	*27%*
Cold dry season	3.32	5.39	*62%*	6.65	*100%*	4.84	*46%*
Hot dry season	4.16	5.39	*30%*	6.65	*60%*	4.83	*16%*
Enteric CH_4 (gCH_4/TLU/Day)							
Pastoral							
Wet season	87.16	114.86	*32%*	114.03	*31%*	101.4	*16%*
Cold dry season	75.43	114.86	*52%*	141.12	*87%*	120.85	*60%*
Hot dry season	65.27	114.86	*76%*	141.12	*116%*	120.8	*85%*
Agropastoral							
Wet season	87.71	118.65	*35%*	110.35	*26%*	110.53	*26%*
Cold dry season	72.19	118.65	*64%*	136.81	*90%*	106.29	*47%*
Hot dry season	87.84	118.65	*35%*	136.81	*56%*	110.86	*26%*

[a](Assouma et al., 2018); [b](Gerber et al., 2013); [c](FAO and NZAGRC, 2019); [d](FAO, 2021).

actual observations, which may partly be due to the persistent neglect of seasonality, a key parameter of feeding systems is SSA.

2.2.2 Animal numbers and mobility

In response to the highly seasonal availability of biomass, pastoral farming is based on livestock mobility (Turner et al., 2014). In the Sahel, biomass growth is concentrated over only a few months and fodder storage capacity is limited. Mobility is a strategy for adapting to the seasonality of fodder availability (Brottem et al., 2014), but it also constitutes a constraint for productivity and can be a bottleneck in the system when it is reduced for political, economic, conflict or health reasons (Moritz, 2006; Turner et al., 2011; Marega et al., 2018). The expansion of cultivated land also contributes to limiting the mobility of herds.

One of the highest sources of uncertainty in a feed balance is the number of animals. In the Sahel, animal numbers for the most common species -cattle, sheep, goats, horses, and donkey- are difficult to quantify each year for various reasons, mobility being an important one. Systematic censuses of animals are rare and often outdated. Animal numbers reported in national and international statistics are estimated on the basis of an annual growth rate by species and applied on a national scale which conceals external events that strongly influence the dynamics and production of livestock (droughts, epizooties, etc.). This growth rate is generally not reviewed or reassessed regularly.

Feed balance are generally established for administrative units such as countries, regions or provinces, or even districts. Although this has advantages in terms of data collection and planning, this approach masks the seasonal movements of animals, which are often cross-border (Hiernaux et al., 2016). This can lead to overestimates or underestimates in the feed balance. To solve this problem, De Haan et al. (2016) defined specific cross-border geographical units, autonomous in terms of animal and food mobility, called "grazing sheds". Although this approach has proven to be relevant for large-scale forage balances, it will be difficult to apply to sub-national balances, which would require detailed information on animal movements.

2.2.3 Importance of trees and shrubs in the feed ration

In a study conducted in the Sahelian zone of Burkina Faso, Sanon (2007) showed that cattle, sheep and goats spend respectively 38, 59 and 57% of their time feeding during the dry season and 72, 73 and 65% during the rainy season. During the dry season, the search for straw and leaves from trees and shrubs, fallen fruit or pods can reach 4.5% of the time for cattle, 28% for sheep and 51% for goats. Foliage supplementation (distribution of collected foliage) is also known to improve productivity and animal growth rates (Sanon et al., 2008). Browsing of woody biomass has a distinct advantage over tropical grasses in terms of its superior nutritional value (both in energy and protein content) during the dry season and constitutes an important element of the feed balance (Ouédraogo-Koné et al., 2008).

The main contributions of woody species to the subsistence of human and animal populations in the Sahelian zone have been described by Sanon et al. (2008) for West Africa, by, Ravhuhali et al. (2022) for Southern Africa, and by Gowda et al. (2019) for East Africa,. The main characteristics of browsed woody plants are their high CP and mineral content (Franzel et al., 2014). However, the high lignin content and the presence of tannins, which are antinutritional factors, potentially toxic for ruminants, may limit its consumption (Van, 2006).

However, knowledge on the seasonality and nutritional value of these species is still limited and not systematically investigated (Ouédraogo-Koné et al., 2008; Zampaligré et al., 2013). A recent study conducted in Senegal by Assouma (2016) based on field observations and excreta collection, as well as a reference document drawn up by the FAO with the support of CIRAD (FAO, unpublished) help to fill this gap.

Assouma (2016) showed that in northern Senegal tree foliage and fruit accounted for an average of 13% of livestock feed on a DM basis, but this share varied from nearly 0% in the rainy season to 40% in the hot dry season. The same author measured that the ingestion of different tree species ranged from 50 g DM per kg of $LW^{0.75}$/day to more than 80 g for leaves and fruits/pods/flowers/seeds during the cold dry and the hot dry seasons. The digestibility of the leaves ranged from 40% to over 80%, depending on the species. These values are similar to the ones obtained for fruits/pods/flowers/seeds by (Guérin, 1994).

Feed balances generally do not distinguish between the different categories of feed resources available in pastures (herbaceous and leguminous plants, tree leaves, fruits, pods, flowers and seeds) and do not take into account substitutions animals make between these different resources from one season to another. The consequence of these limitations can be a significant overestimation of intake, as shown by Assouma et al. (2018).

The same authors estimated that the tree leaf balance, calculated as the ratio between what is consumed and what is available as foliage mass, varied from 0% to 10.3% depending on the month of the year. This means that even when tree leaf browsing is at its maximum, the actual foliage intake by the animals remains modest.

2.2.4 Calibrating natural biomass and crop residues for actual use

The biomass produced during the rainy season estimated from the NDVI index can be separated in crops and rangelands, as well as herbaceous and woody plants. The actual amount of usable and accessible forage depends on assumptions made about other uses of biomass, losses, distance to water and a number of other factors (Figure 1). The lack of information to estimate the coefficients for the calibration of the available biomass into actual use constitutes a major obstacle to the establishment of accurate feed balances. De Haan et al. (2016) showed that applying the classic maximum livestock utilization rate of 30% of natural biomass from pasture in sub-Saharan drylands resulted in an average annual balance of 75% over the period 1998-2011.

This means that a systematic 25% surplus in natural vegetation should have existed during this period, when deficits did in fact occur. On the other hand, estimates made at the local scale by Diawara et al. (2018) give lower rates. These results show the need

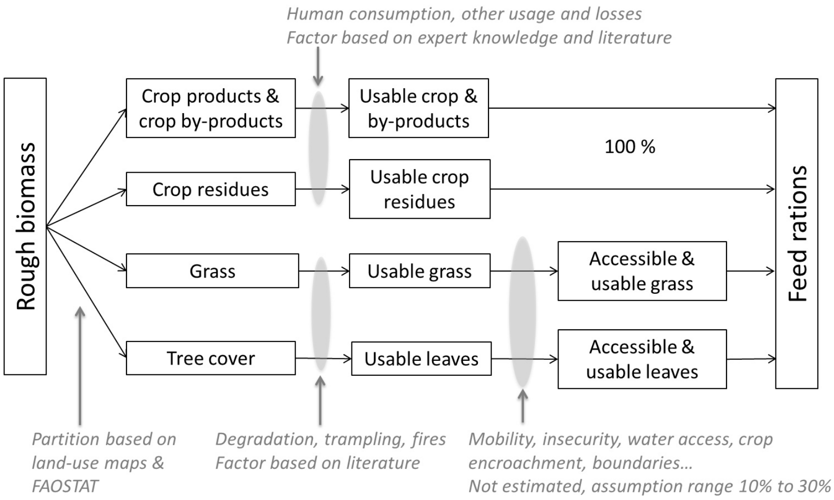

FIGURE 1
From drylands biomass to livestock feed ration (De Haan et al., 2016).

to refine these calibration factors on the basis of local observations. FAO (2018) also suggests using local factors.

Similarly, there is also a need to refine the coefficients applied to crop residues, which are often long-established default coefficients, and which have never been reviewed. These coefficients can vary at subnational level, for example farmers may return different share of crop residues to the crop field in different regions. Some crop residues may be used for construction while others may be used for fuel or animal bedding.

2.3 Method for the tool feed balance sheet

The tool we propose and describe here was developed to address the limitations identified in the previous sub-section. It is available by request to FAO or to CIRAD and it comes as an Excel file with different spreadsheets performing a number of automated calculations. After having decided at which scale the feed balance will be established (e.g. national, sub-national…), the user needs to input information about available feed resources and animals present in the geographical unit selected as a scale. The species currently covered by the tool are cattle, sheep, goats, horses, camels and donkeys, for pastoral and agro-pastoral productions systems in the Sahel. These steps and the automated calculations performed are summarized in the next sub-sections and in Figure 2.

2.3.1 Seasonal availability of feed resources

Availability of natural biomass in rangelands can be estimated from NDVI interpretation. NDVI is a relatively simple and easily available indicator for estimating biomass during the rainy season, but it is not relevant in the dry season, because the signal from dry vegetation and litter, also consumed by animals, is null. A recent review of existing indices for estimating DM during dry seasons from remote sensing information provides useful recommendations (Lo et al., 2022). This will make it possible to better monitor in real time the evolution of fodder availability during the dry season (straw, litter, stubble in the fields, burned areas).

Input information for natural biomass in the FBS correspond to total areas in ha and DM yield in kg/ha in various seasons (or degradation rates between seasons) for grass and for tree fodder. The availability is expressed in DM in kg.

Estimating the seasonal availability of crop residues and by-products can be done directly from agricultural production, which is generally quantified and monitored at sub-national scale. Input information correspond to cultivated areas for each crop, yields as well as percentage of DM and of each by-product compared to grains (e.g. bran) [see for example FAO (2018)].

Existing factors are used to calibrate available biomass as a usable and accessible resource and to estimate the share of crop residues and by-products used as animal feed, and performance parameters are used to estimate animal requirements (Hiernaux et al., 2016; FAO, 2018). National average factors that have not been revised for many years should be avoided. Instead, regular consultations with pastoral organizations and extension services, as well as case studies and consultations with stakeholders in the processing industry can help revise these parameters or establish new ones.

Parameters should also take into account the seasonality of the use of crop by-products and residues that may be stored after harvest and distributed later.

2.3.2 Nutritional value of feed resources

The nutritional value of feed resources, including grass, tree fodder, crop residues and by-products, is characterized in the FBS by their CP content and their energy content (ME expressed in Mcal/kgDM). However, the content of Digestible Proteins in the Intestine (PDI in French) proposed by the National Institute of Agronomic Research in France (INRA, 2018) is a better estimate of the amount of protein actually used by the animal and protein content is therefore expressed in kg of PDI/kg DM in the tool. Once

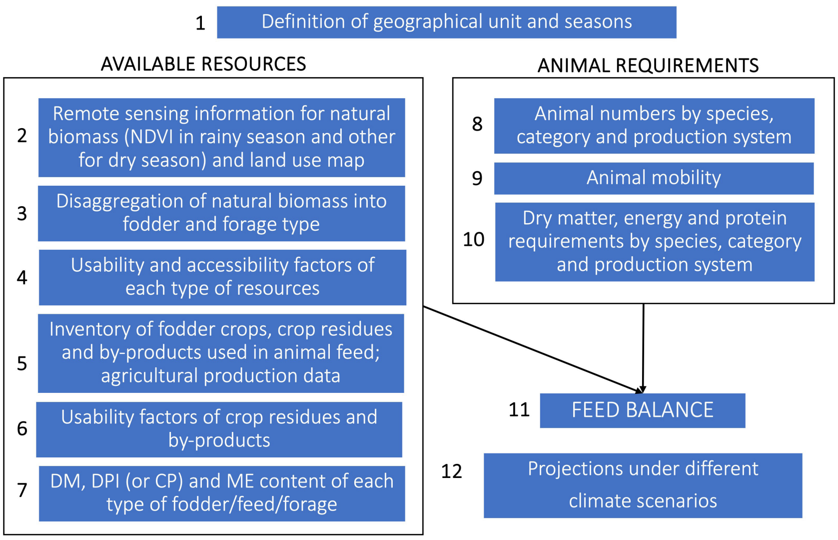

FIGURE 2
Summary of the steps to follow while using the Feed Balance Sheet.

the inventory of all types of animal feed has been established, this information can be obtained from existing international or regional reference tables such as Feedipedia (https://www.feedipedia.org/), or the Sub-Saharan Africa Feed Composition Database of ILRI (https://feedsdatabase.ilri.org/).

While a standard characterization in PDI and ME is suitable for animal feeds such as those distributed in supplementation and in stalls, the same is not true for rangeland grass and legumes, the quality of which is very variable over time and space, and further complicated by specific palatability. Specific references to the Sahel are not easily identifiable in international databases. It is therefore recommended to use the CP (or PDI) and ME content produced by national or regional institutions and agricultural research centers.

2.3.3 Animal numbers, including mobility

It is recommended to carry out regular livestock surveys in order to revise/validate the official animal numbers. A first complete and systematic census should also be carried out in order to have a reliable reference situation that can then be updated according to known and already applied methodologies, with a growth rate validated each year and taking into account the possible impacts of droughts, animal diseases etc. Livestock census data should be disaggregated between the main production systems (e.g. pastoral, agro-pastoral and peri-urban). Working with herders to collect data on the number and composition of the herd on a local and seasonal basis is also key to better estimating numbers.

Mobility is well described in various regional reports (see for example Touré et al., 2012). However, it is difficult to include it in feed balances because it depends on the scale at which it is established and it is variable from year to year. Information regarding animal mobility is mostly dispersed and available at different scales. This information must be updated to identify routes of mobility and their regular changes, including where animals are located at different times of the year.

Given the considerable impact that mobility can have on the feed balance, it is recommended to strengthen the collection of data relating to transhumance at the points of entry into the country and, more generally, of data concerning the mobility of livestock at national level. This must be done in collaboration with pastoralist organizations and can be facilitated by the use of GPS or drone technologies and spatial modeling of areas of seasonal animal concentration.

2.3.4 Animal requirements

In tropical regions, animal feed requirements are influenced by a number of factors that may differ compared to temperate climates (INRA, 2018). First, animals produce more body heat due to their physical activities of grazing and ingesting coarse feed resources. They also provide intense chewing work to enhance digestibility of poor-quality fodder. Animal needs must be estimated in ME, a common unit in animal nutrition, but also in protein (PDI) in addition to the intake capacity of DM. To do this, the numbers by animal category (age, sex and reproductive status of adult females) must be collected or estimated from surveys or modelling. The equations for estimating the needs of each category can be obtained by local studies or by meta-references such as those proposed by INRA (2018). They depend on parameters that should therefore be collected and input in the tool for each existing production system. First of all, the energy and protein requirements depend on the metabolic weight of the animals (live weight raised to the power 0.75 or $LW^{0.75}$). Requirements for growth or weight gain should be included only for the season in which animals are gaining weight and can be calculated from a daily weight gain. Pregnancy requirements depend on the stage and birth weight of the animal. They are only significant at the end of gestation (the last 3 months for cattle, for example). Lactation requirements depend on daily milk productivity. Finally, requirements for the activity/movements depend on the distances covered.

Parameters necessary to estimate the requirements consider the structure of the herd (for example, the weight of the different types of animals such as cows, heifers, young cattle, calves, ewes, lambs etc.). The other zootechnical parameters to be collected are the seasonal weight variations, the protein and fat content of the milk, the average daily milk production, the average annual weight gain for growing animals and the average daily distances walked for each season. These parameters must be collected on a regular basis (e.g. farm performance monitoring) and by type of production system.

The next sub-sections provide equations that are included in the FBS tool and that can be used in the absence of a specific reference in the country considered (INRA, 2018), based on several meta-analyses in tropical regions, reference pages and equation numbers are indicated in brackets).

2.3.4.1 Energy requirements

Energy requirements correspond to the sum of maintenance, liveweight gain, gestation, milk secreted, walking and chewing.

$$[Page\ 458]\ Maintenance\ requirements\ are\ 129.7\ and\ 150.9\ kcal\ ME/kg\ LBW^{0.75}\ respectively\ for\ small\ ruminants\ (sheep\ and\ goats)\ and\ for\ cattle$$

$$[Page\ 458]\ The\ energy\ required\ for\ a\ weight\ gain\ of\ 1g\ is\ estimated\ at\ 5.81\ Kcal\ ME,\ regardless\ of\ the\ species$$

$$[Equation\ 17.12]\ The\ energy\ requirement\ for\ gestation\ is\ 0.000695 \times LW\ at\ parturition \times exp(0.116 \times week\ of\ gestation)\ expressed\ in\ Dairy\ Forage\ Unit\ (UFL\ in\ French)$$

$$[Equation\ 17.11]\ The\ UFL\ requirement\ for\ lactation\ is\ Milk\ production \times [0.42 + [0.0053 \times (fat\ content - 40)] + [0.0032 \times (protein\ content - 31)]]$$

The equivalence 1UFL=1.7 Mcal can be used in this case. The distribution of calving between the different seasons of the year must be considered to add up the needs at the herd level for each season (for example, homogeneously distributed between the 3 seasons, or 50% occurring in the rainy season and 50% in the cold dry season).

$$[Page\ 131]\ Activity\ requirements\ are\ estimated\ with\ the\ equation\ 0.54\ cal/kg\ LBW/meter$$

$$[Page\ 458]\ Specific\ chewing\ requirements\ are\ estimated\ as\ a\ 10\,\%\ increase\ in\ maintenance\ requirements\ due\ to\ coarse\ forage$$

2.3.4.2 Protein requirements

The protein requirements of animals are expressed here principally in terms of PDI and includes requirements for maintenance, non-productive functions, gestation and milk production.

$$[Page\ 460]\ PDI\ requirements\ for\ maintenance\ are\ estimated\ with\ the\ equation\ 3.53 \pm 0.32\ g/kg\ LBW^{0.75}(regardless\ of\ species)\ and\ for\ growth\ with\ the\ equation\ 0.30\ g\ of\ Digestible\ Nitrogen\ Matter\ (or\ MAD\ in\ French)/g\ of\ Average\ Daily\ Gain\ (ADG).\ The\ rate\ of\ 16\,\%\ nitrogen\ per\ kg\ protein\ is\ used\ to\ convert\ requirements\ expressed\ in\ MAD\ to\ PDI.$$

$$[Page\ 461]\ PDI\ requirements\ for\ non-productive\ functions\ (fecal,\ urinary,\ hair\ and\ hooves\ production)\ are\ estimated,\ respectively,\ with\ the\ equation\ 3.74 \pm 0.63\ g\ g\ PDI/kg\ LBW^{0.75}\ cattle;\ 2.8 \pm 0.57\ PDI/kg\ LBW^{0.75} for\ for\ sheep,\ and\ 2.52 \pm 0.57\ g\ PDI/kg\ LBW^{0.75} for\ goats$$

$$[Equation\ 17.12]\ Protein\ requirements\ for\ gestation\ is\ 0.0448 \times LW\ at\ parturition\ x\ exp\ (0.1161 \times gestational\ week)\ /\ protein\ utilization\ efficiency.\ The\ efficiency\ of\ protein\ use\ must\ be\ estimated.\ In\ the\ absence\ of\ specific\ studies,\ an\ average\ value\ of\ 0.67\ can\ be\ used.$$

$$[Equation\ 17.19]\ Protein\ requirements\ for\ milk\ production\ depend\ on\ the\ amount\ of\ exported\ protein\ in\ milk,\ equal\ to\ the\ product\ of\ milk\ production\ times\ milk\ protein\ content:\ milk\ production\ x\ protein\ rate\ /\ milk\ efficiency\ use\ of\ proteins.$$

3 Results

The FBS tool was piloted in 6 countries in West and Central Africa (Senegal, Burkina Faso, Mali, Niger, Chad and Gambia) as part of different projects led by FAO. The results presented here are from the pilot in Chad that was carried out in 2021 by the "Direction de l'Organisation des Professionnels de l'Elevage et de la Sécurisation des Systèmes Pastoraux (DOPESSP)" as part of the FAO project "Bilans fourragers régionaux pour la résilience en zone pastorale" and the pilot in Mali that was carried out in 2022 by the "Institut d'Économie Rurale (IER)" in partnership with the "Direction Nationale des Productions et Industries Animales (DNPIA)", as part of the FAO project "Renforcer la résilience des pasteurs et agro-pasteurs au Sahel", both led by FAO with the support of CIRAD. The choice of these 2 pilots is based on the higher quality of data compared to other pilots in the region. Figure 3 shows the administrative units covered in the analysis in Chad and Mali and the input data are available in Supplementary Information. The sources for input data include national and subnational statistics of animal numbers per species, crop areas and crop yields, scientific literature on animal feeding experiments (e.g. LW, daily fodder intake, dry mater digestibility, daily milk production, average distance covered in a day…), global and

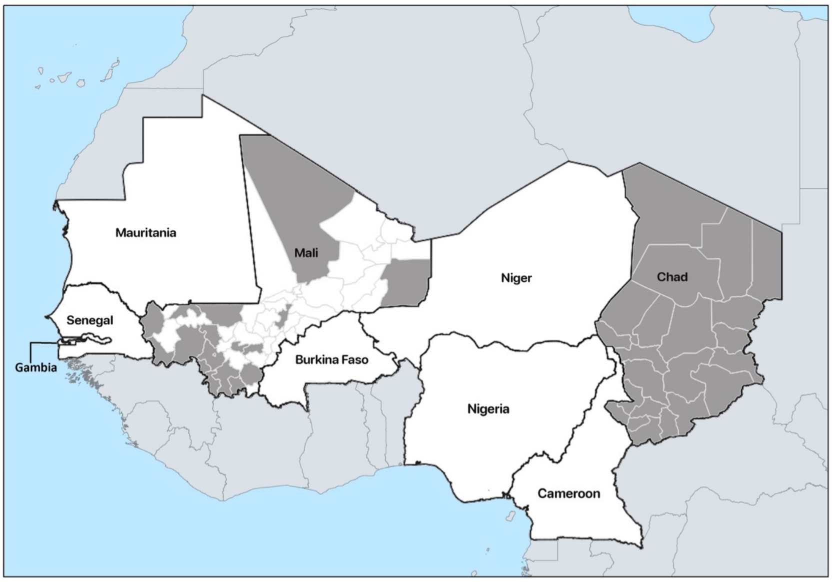

FIGURE 3
The 22 provinces (level 1 administrative units) in Chad and the 14 circles (level 2 administrative units) in Mali covered in the analysis.

regional databases on feed and fodder characteristics and expert knowledge collected during workshops in each country.

In Chad, the national averaged feed balance was estimated at 160% in DM in the rainy season, meaning that biomass covered 160% of animal requirements (Figure 4 Left). However, the balance fell to 91% and 55% respectively in the dry cold and dry hot season, showing significant deficit in DM. The balance in energy was estimated to be similar though lower (147%, 32% and 25%). The balance in protein, however, was estimated to be in deficit all year long (25%, 12% and 7%), showing a lack of protein rich feedstuff in the country. This is a particularly important limitation to the productivity of Sahelian systems, which can be addressed with supplementation of specific crop residues when possible. Results also showed a large variability of feed balances between the 22 provinces covered in the analysis (Figure 4 Right), especially in DM and energy, less so in protein. 7 provinces, essentially in the southern and less arid part of the country, were actually estimated to have an excess balance in DM all year long, but only 2 in energy and none in protein. The significant deficit estimated in the northern provinces, especially in the dry seasons, reveals the necessity for and the role of the transboundary mobility of animals. These differences between Northern and other province are the reason for the large whiskers on Figure 4 Right for dry matter and Energy in the rainy season in particular.

In Mali, the analysis covered 14 districts, or second level administrative units called circles. The limit to including more circles and to covering the whole national territory (49 circles) was the lack of capacity to monitor vegetation in the field in the 3

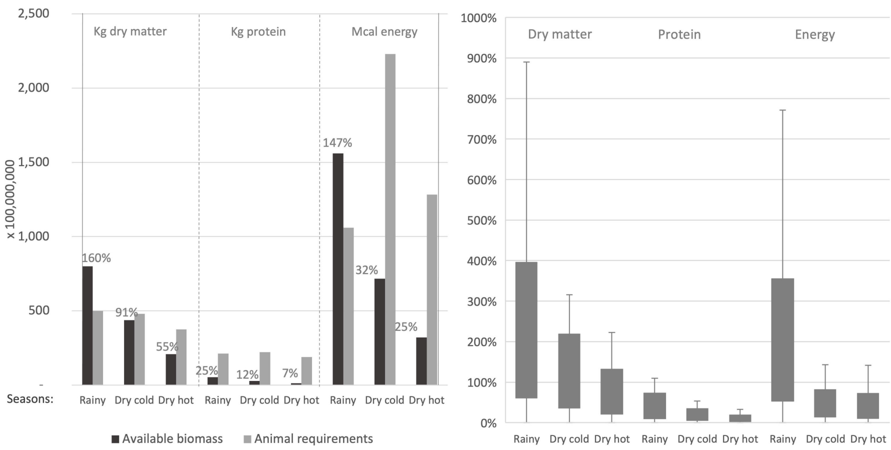

FIGURE 4
Left: feed balances in Chad in 2021 at national level in dry matter, protein and energy (share of animal requirements covered by available biomass expressed in % for each of the main seasons). Right: variability of the feed balances between the 22 provinces covered by the analysis.

different seasons in all circles, especially in the northern provinces for security reasons.

Results show that 9 of the 14 circles covered have an excess of DM all year long, and almost all of them have excess of DM in the rainy season and the cold dry season. The medians of the balances were 318%, 223% and 171% in the rainy, dry cold and dry hot seasons respectively (Figure 5). This reflects the higher number of Southern circles in the sample of the analysis, with less arid areas. Results were similar in energy with only one circle with deficit balances for all 3 seasons. However, similarly to Chad, balances showed large deficits in protein, with only 2 circles being in excess all year long and medians reaching only 83%, 61% and 49%. There is a high variability between circles around the median balance in DM and in energy, which is reflected in the length of the whiskers in Figure 5, and which can be explained by the gradient in precipitation and variability in feed resources in the country. The lower variability observed for the balance in protein can be explained by the general low protein content of all feed resources available.

4 Discussion and conclusions

The FBS tool developed by FAO and CIRAD aims to help Sahelian countries carry out advanced feed balances with improved data in order to better support herders. It is easily adaptable to other tropical regions and production systems in the world. It is intended to be used by government services in charge of establishing feed balances and of monitoring pastoral rangeland quality, and by development partners. The balances estimated with the FBS align overall with the trends reported with other methodology, such as the relative difference of biomass production estimated by CILSS (the Permanent Interstate committee for Drought Control in the Sahel) and the Réseau de prévention des crises alimentaires (RPCA) for the pastoral situation [see for example (Traoré, 2021 and 2022)]. But the FBS results provide a lot more information which is currently not captured in existing feed balances methodologies such as seasonality of feed availability and quality, better accuracy of balances with the inclusion of protein and energy in addition to DM, and better accounting of animal requirements per category of animals. It can also be used to project to impact of future climate scenarios and anticipate medium to long term adaptation strategies for the livestock sector.

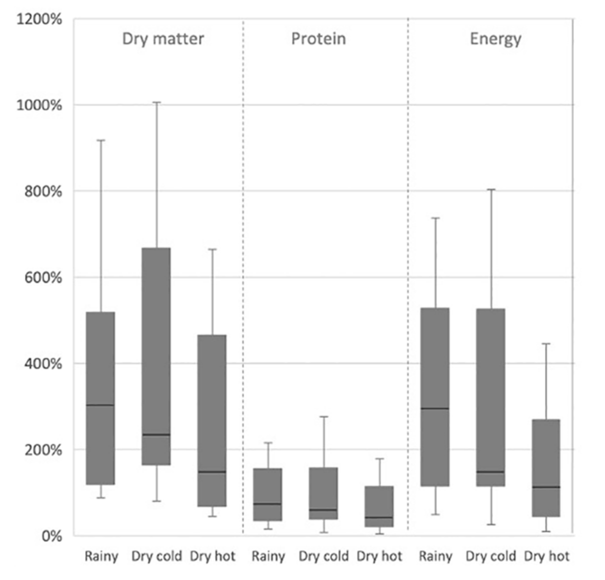

FIGURE 5
Variability of 2022 feed balances in dry matter, protein and energy, between the 14 circles (i.e. districts) in Mali covered in the analysis.

Piloting the tool in 6 countries of West and Central Africa showed that its implementation requires capacity building, in the form of training and continuous support for access to quality data sources and establishing long-term mechanisms involving different institutions, including science partners and pastoralist organizations. With adequate support, pastoralists organizations should indeed be able to use the FBS or any simple application based on it. Results obtained through the pilots in Chad and Mali carried out with support of CIRAD and the Institut d'Economie Rurale (IER) presented in this paper proved to be of better quality than the pilots in the other countries where the data used as inputs, such as the share of accessible and usable biomass or the productivity of rangelands, can be improved. For example, first results obtained from Burkina Faso with lower data quality estimated extremely large and systematic excesses in DM, energy and protein all year long, in the absence of specific data from the country on pasture productivity and use of crop residues and by-products. On the contrary, results from Chad and Mali with higher quality data presented in this paper can be used to draw the following conclusions: while DM and, to a lesser extent, energy seem to be sufficient in the southern and less arid parts of the countries to cover the animal requirements, there are almost systematic deficits in protein, including in the rainy season.

This tool can also be used in support of livestock investments, for example for quantifying the feed resources necessary to achieve a target of milk yield, or to improve GHG emission calculations at different scales, including national inventories, as enteric methane emissions are the main source of emissions from livestock production in the Sahel and are directly dependent on feed intake. While pastoral systems contribute generally little to global GHG emissions, their efficiency in feed and fodder use can be improved and their current and future impact on the climate can be reduced and access to improved feed balances can support that.

The use of the FBS tool requires input data that takes into account the specificities of each country. This includes seasonal variations of biomass availability and of animal requirements, reliable animal numbers at sub-national level and by animal category and their variations due to mobility, share of trees and shrubs in animal intake and their nutritional content and factors affecting livestock accessibility of biomass and crop residues (detailed in section 2.2.). While this means investing in long term data availability to limit uncertainty of results, the benefits of having reliable balances for planning the use of natural resources and the future of the livestock sector are significant.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can bedirected to the corresponding author.

Author contributions

AM: Writing – original draft, Writing – review & editing. MA: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work received the financial support of the French government and of the "Carbon Sequestration and greenhouse gas emissions in (agro) Sylvopastoral Ecosystems in the sahelian CILSS States" (CaSSECS) regional project funded by the European Union (European DeSIRA programme, under grant agreement No. FOOD/2019/410-169).

Acknowledgments

The authors would like to thank Alassane Ba and the Institut d'Economie Rurale in Mali, Dilla Karabeye and the Direction de l'Organisation des Professionnels de l'Elevage et de la Sécurisation des Systèmes Pastoraux in Chad, and Giuseppina Cinardi from FAO for their contributions.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fanim.2024.1354728/full#supplementary-material

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