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REVIEW

Unexploited economic and environmental benefits from cultivated forages in Zambia

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Abstract

Livestock production is critical for improved food and nutrition security, sustainability of ecosystems, and resilience. Zambia, like many countries in sub-Saharan Africa, aspires to increase livestock's contribution to the Gross Domestic Product and generate economic opportunities. Global environmental change, however, and the potential of ruminant production to exacerbate it, requires the implementation of innovative and pragmatic technologies for mitigation of and adaptation to the adverse effects of environmental change. Feeding of quality cultivated forages is one of the improved options to address such challenges, especially with dismal cultivation in the country. Cultivated forages provide multiple benefits including an increase in livestock productivity and soil health and reduced greenhouse gas emission intensity. In this study, the seed requirement of promising forage crops to offset the current ruminant roughage gap is estimated. The nutritional and economic benefits of including forages in beef and dairy rations, and associated projected greenhouse gas abatement, are presented. Consequently, the study proposes contextualized business models in Zambia based on both demand-pull factors and supply-push technologies. Zambia is land-linked with eight neighboring countries, and a member of both the Southern African Development Community and the Common Market for Eastern and Southern Africa trade blocks. Therefore, Zambia could produce forage seeds for domestic use as well as the regional market. In addition, it can be a hub for feed production for drier neighboring countries and locations with good livestock production, thereby benefiting the whole region.

Keywords: cultivated forages, cost-benefit analysis, ruminant nutrition, greenhouse gas abatement, seed systems

Introduction

The Zambian Government identified the agricultural sector as a priority to drive the economy for national development in its 7th National Development Plan (MNDP, 2017). Around 92% of the rural workforce and over 67% of the country's labor force are directly or indirectly linked with the sector (Mulemba, 2009; ZEF *et al*., 2017). The country is endowed with a ruminant population of approximately 2.6 million cattle, 580,000 goats, and 65,000 sheep. More than 85% of these animals are in the traditional smallholder sector, where there is a marked potential to increase livestock production. The dairy sector has been earmarked as a key sector to spur development through job creation and improvement in human nutrition. In 2017, approximately 21% of the European Union's (EU) agri-food exports to Zambia were made up of milk powders and whey (EU, 2018). This provides a scope to increase domestic production in the country. The sector has potential for commercialization that could lead to an increase in contribution to Gross Domestic Product (GDP) (Cheelo, 2019). The government has had a strategic plan to increase the cattle population by 20% by 2020–2021 (Ministry of Fisheries and Livestock-Zambia, 2021). Unfortunately, current government efforts to improve the productivity of animals are being hampered by several constraints, of which inadequate animal nutrition tops the list. In the dry season, available forages and crop residues are usually in short supply and often of poor quality, characterized by low concentrations of energy, protein, and other nutrients (minerals and vitamins). The Zambian National Livestock Development Policy 2021 envisages promotion of appropriate forage conservation and utilization technologies (Ministry of Fisheries and Livestock-Zambia, 2021). Increased livestock productivity needs to address animal nutrition, which is the most critical; and when addressed, positive changes are realized within

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a shorter time. The use of quality cultivated forages primarily to feed ruminant livestock is key to the endeavor. Concomitantly, forages contribute to the mitigation of global environmental change. This happens through soil erosion control, roots that decompose and contribute to soil organic carbon. Some forage lines desirably inhibit nitrification thereby more nitrate (NO_3) becomes available for plant uptake, and nitrous oxide is diminished, which otherwise is a highly potent gas that contributes to global warming (Villegas *et al*., 2020). In addition, ruminant livestock, through enteric fermentation, produce methane gas that contributes to global warming. Feeding of quality forages reduces the emission intensity of methane i.e., decreases methane production per unit of animal product, meat or milk. Indeed, the forages have an important role to mitigate climate change, as envisaged in the Government's plans. For example, the Zambia National Adaptation Programme of Action (NAPA) prioritizes improved environmental health and adaptation of land use practices, livestock included, to cope with the climate change mediated global warming (UNDP, 2023).

Zambia is strategic as a regional hub for trade including livestock and related value chains. The membership in two trade entities, SADC (Southern African Development Community) and COMESA (Common Market for Eastern and Southern Africa), coupled with having eight neighboring countries (Angola, Botswana, Democratic Republic of Congo, Malawi, Mozambique, Namibia, Tanzania, and Zimbabwe) presents potential market-pull for forage seeds, forages, live animals, and livestock products. Indeed, some trade already exists and could be strengthened, including of forage and livestock value chain products. For example, Zambia exports molasses often used in animal feeds to the tune of >74,000 tonnes (WITS, 2019).

The forage seed system in Zambia is weak leading to low forage cultivation (Fuglie *et al*., 2021). Conversely, strengthening the forage seed system presents an opportunity to grow and improve the sector and contribute to increased livestock productivity in the country. Currently, there is increased interest, and some entities are engaging in forage seed and forage production (Sikaceya and Mwendia, 2023). Largely, five seed systems exist in Zambia: (i) farmer-saved, (ii) non-governmental Organizations and cooperatives, (iii) public-private supported by local seed companies, (iv) private supported by international seed companies, and (v) private supported by out-grower schemes (USAID, 2016). Specifically, on forage seeds, the government-implemented and donor-funded project – Enhanced Smallholder Livestock Investment Program (E-SLIP) – is most noticeable. It has a national outlook, engaging farmers in forage seed production, especially legumes – *Crotalaria juncea, Stylosanthes guianensis,* and *Stylosanthes scabra*. Along the forage seed value chain, there is a need to increase forage seed supply to support cultivation of quality forages at scale, so that it will be possible to supply a variety of output markets that include dairy hubs, feedlots, livestock quarantine stations and the drought-prone forage-shortage areas (Fig. 1). Forages can be used either fresh or conserved as silage, hay, or pellets (Dey *et al*., 2022). While silage has high water content and is thus not efficient in transportation, hay and pellets are condensed/densified with pellets being more efficient in terms of cost of transportation and having a longer shelf-life (Dey *et al*., 2022). The next section discusses the concept of an integrated forage value chain, followed by the methodology used in the study, The integrated forage value chain is illustrated in Fig. 1.

Based on an estimation of forage seed requirement and economic and environmental benefit calculations, this study investigates the appropriate business models for forage seed multiplication, forage crop production and densification in Zambia.

Review methodology

The review employed a hybrid approach whereby keywords were searched using Google Scholar, and from forage and feed databases namely the Feedipedia and Tropicalforages tool. The information was complemented by rapid interviews to meet specific required information in Zambia's context. These applied to costs of conventional feed ingredients through phone calls to feed manufacturers, transport cost data from reaching Zambian Transporters Association, selling prices of cash crops by reaching to farmers and short visits and discussions with implementers of Enhanced Smallholder Livestock Investment Program (E-SLIP) project in Zambia on forage seed production.

Methodology

Conceptually, the work was done following the steps as shown in Fig. 2 which in the end allowed informed business model propositions in Zambia, after taking into consideration the inferences obtained from the steps 1 through 6.

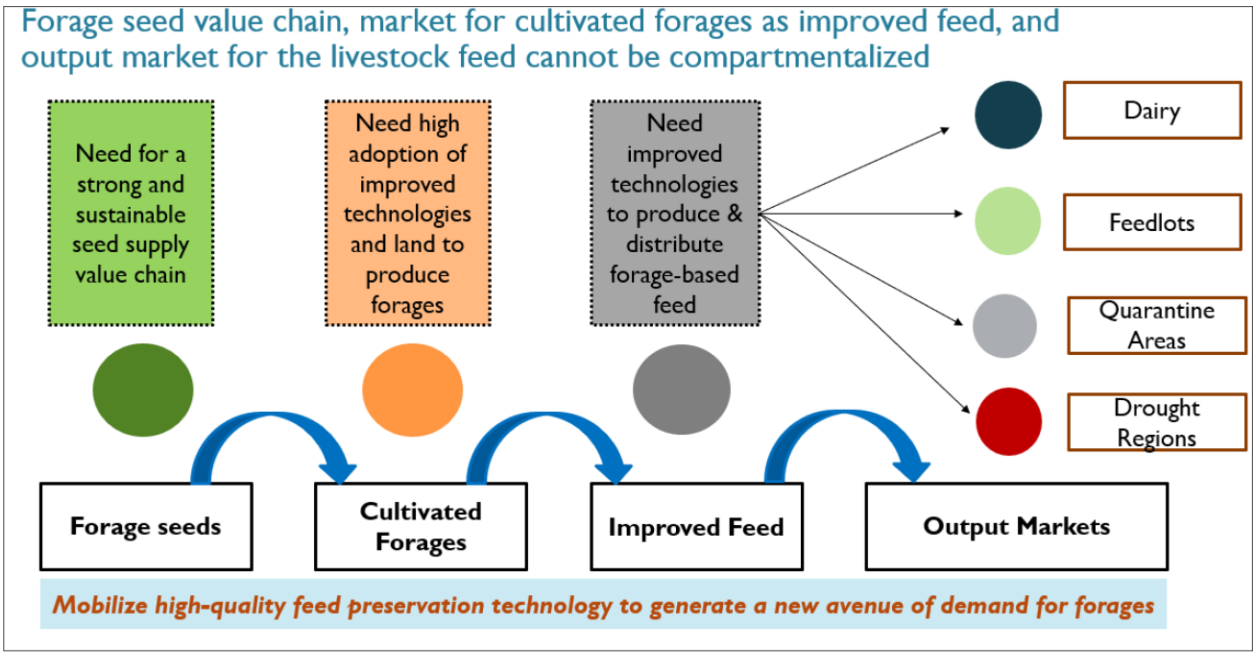

Fig. 1. Adapted from Dey *et al.* (2022) conceptual framework of forage seed and forages linked to markets.

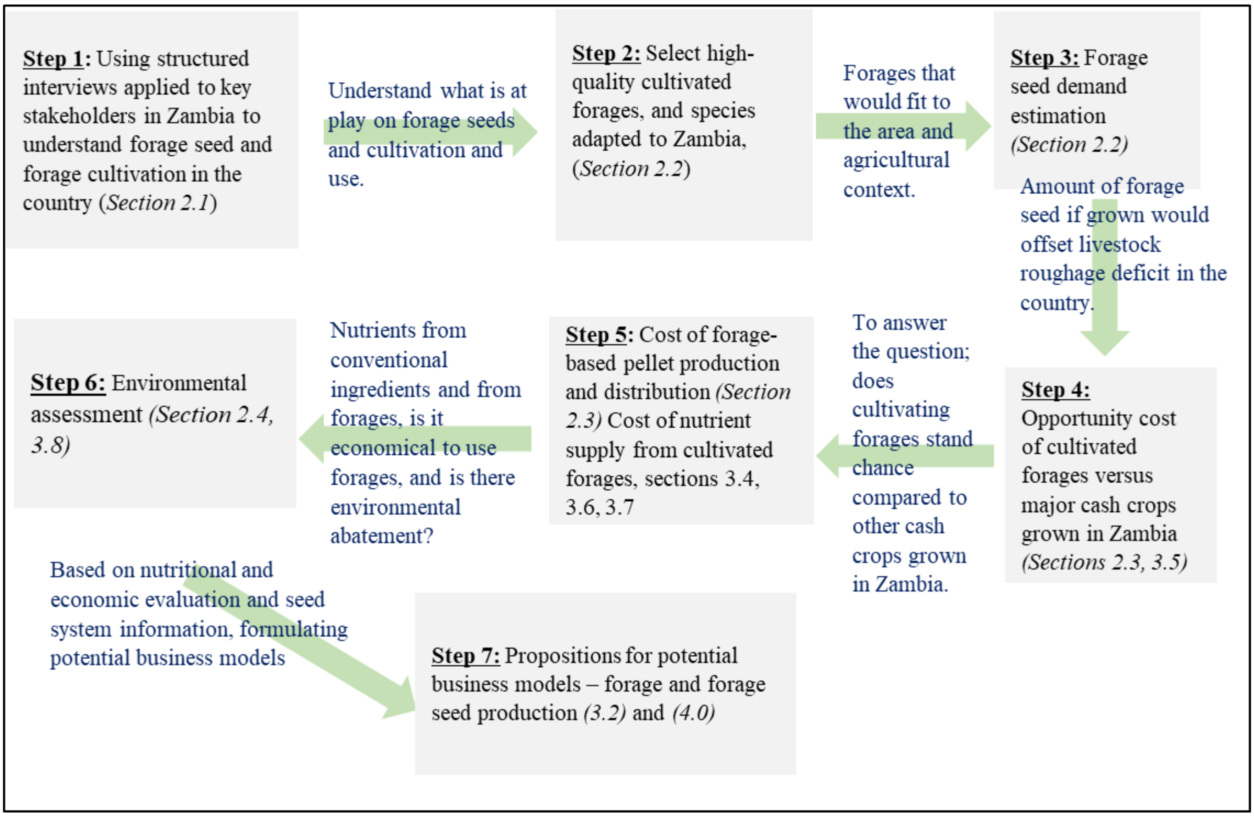

Fig. 2. Overview of the key steps employed in the study in Zambia.

DATA COLLECTION

Survey instruments were developed and implemented through either one-on-one interviews and phone calls, or emails in which the tools were shared followed by a follow-up call, Specifically, two survey instruments were applied: (i) forage seed survey and (ii) economic and nutrition survey. The forage seed survey tool captured forage seed types, trade, and entities involved in Zambia. Phone contacts from various enterprises in Zambia supplemented information on the cost of the forage seeds/kg, cost of land preparation (Ploughing, harrowing), weeding, mowing/harvesting grass/legume per hectare basis. The economic and nutrition instrument returned the location of dairy enterprises and feedlots as well as feed densification where applicable. It also provided information on the availability of forage seeds, the costs of livestock feedstuffs, and the cost associated with the production of other cash crops grown in Zambia. For conventional feed ingredients, sources were contacted and averages of at least two values for each ingredient used. The selling prices of hay and concentrate feed used as a supplement were collected from feed dealers. The cost of transportation was gathered through phone call to Truck Drivers Association of Zambia. Desktop reviews via various search engines complemented information including livestock density and locations, government strategies, livestock roughage deficit and source of crude protein, and metabolizable energy data is from literature including the Feedipedia database (INRAE CIRAD and FAO, 2022). In addition to the structured surveys, information on current forage landscape was gathered through discussions with implementation partners, national and local governments, and private sector entities. Geospatial data on their locations, transport information, and local intelligence was used to arrive at contextual business model propositions for Zambia. In sequence, the partnership landscape came first, and survey instruments were applied, followed by information gathering through contacting, forage seed demand estimation, economic analyses and business model propositions.

FORAGE SEED DEMAND

Identification of feasible forage cultivation areas – It was guided by review of cattle distribution in the country (Cheelo, 2019). Administrative regions with a high concentration of livestock were assumed to be demand sinks, i.e., providing a market pull. The areas adjacent to the demand sinks with favorable climates for forage cultivation were taken as possible cultivation areas including forage seed production. Largely, the southern province is involved in maize and sugarcane production in addition to cattle rearing (ZEF *et al*., 2017; Cheelo, 2019).

Selection of cultivated forages. Cultivated forages include a variety of annual and perennial grasses, herbaceous and dual-purpose legumes, and multipurpose trees and shrubs. They have been promoted throughout sub-Saharan Africa (SSA) for increasing livestock productivity and household income through achieving year-round higher quantity and quality of herbage, while contributing to soil improvement and higher food crop yields. For choosing forage species for viable forage businesses in Zambia, we considered the following.

(i) Species that are to some extent already grown and used in Zambia – we started off by considering released and registered forage varieties in Zambia. As released varieties were biased toward food crops, especially maize, we also proposed the introduction of newer forage materials that have undergone initial adaptation trials in Zambia.
(ii) Nutrient and biomass yield: Forage nutrients mainly metabolizable energy (ME) and crude protein (CP) were considered. The forages selected produce high biomass yields that are also of good quality and digestibility.
(iii) Local adaptation: Adaptability to Zambian ecologies, mainly rainfed and under irrigation production.

Based on the above criteria, a field visit and literature search, we selected Rhodes grass (*Chloris gayana*), Guinea grass

(*Panicum maximum,* now *Megathyrsus maximus),* Cowpea (*Vigna unguiculata*), Lablab (*Lablab purpureus*), and Stylo (*Stylosanthes spp*). For possible forage introduction into Zambia, we also included *Brachiaria* (now *Urochloa*) hybrids such as Mulato II, because of its good quality and potential for high biomass yield and recent importation into Zambia by the Green Innovation dairy value chain development project in the southern province.

Forage seed demand estimation. The approach for estimating forage seed demand was the same as described earlier (USAID, 2016). It was based on the ruminant population and associated feed requirements against available feeds (Mulindi *et al*., 2021; Mwilima *et al*., 2021). The prevailing dry matter gap/deficit was converted to a quantity of seed using selected forage legumes and grasses with high yield and quality potential to bridge the gap.

ECONOMIC EVALUATION

Forage production cost and cost per nutrient – For economic analysis, the cost of production of the selected forages was first sought as described above. The cost of production of the cultivated forages and the market price of conventional feed ingredients were compared on per kg crude protein (CP) and per 1000 Mega Joules (MJ) for metabolizable energy (ME) bases. All costs were presented in US dollars.

The opportunity cost of the forages against commonly grown crops in the areas (maize, wheat, soybean, sunflower, cotton, cassava) was compared by calculating profits of each crop. The yield data was obtained from literature and the selling prices from the farmers. The nutritional analysis used forage quality data from the Feedipedia database (INRAE CIRAD and FAO, 2022), while Feed-A and Feed-B used the cost of the ingredients in Zambian market.

Cost of forage-based pellet production and distribution. To evaluate the economics of forage-based pellet productions, lessons from India, Mexico, Tunisia, and Kenya were taken into consideration as described by Dey *et al*. (2022). The elements considered in the calculation of the cost of densification, as taken from our earlier study (Dey *et al*., 2022), are presented below:

a. The cost of the densification machine with all accessories is between 80,000 and 110,000 US$ for a production capacity of 20 tonnes per 8-h shift. This production capacity is considered appropriate for a business model based on 400–600 ha forage cultivation. As such, an investment of ≈100K US$ is required on the machinery required for densification.
b. The cost of maintenance per year was taken as 3500 US$ based on the information collected from the countries (India, Mexico, Tunisia, and Kenya). This translates to 3500/6000 = 0.58 US$/ton (taking 300 working days in a year and 8-h shift per day; production of 20 tonnes/8-h shift).
c. The running cost per ton was taken as an average of those listed by the respondents, which was 16.35 US$. The running cost includes the cost of additives such as molasses, minerals, and vitamins.
d. Depreciation cost by taking life of the machinery to be 20 years and a capacity of running at 6000 tonnes/year = 100,000/120,000= 0.83 US$/ton. The working life of machinery was reported to be 18, 25, and 20 years in the case studies from the countries. Here we have taken working life to 20 years.

A total cost of 0.58 + 16.35 + 0.83 = 17.76 US$/ton considers the running, maintenance, and depreciation costs of the machinery. We rounded this number to 18 US$/ton and used it for economic analysis. Given the vast distances between areas of forage production and consumer regions in Zambia, we also determined the cost of transportation. The aim was to examine whether it is economically sound to use densified cultivated forage-based diets in feedlots and in dairying, especially in the dry season in places far off from the forage production and densification site. Forage densification site and forage production site were considered in proximity. The transport cost was collected from Feed Millers in Zambia, and estimated to be 12 US$/tonnes/100 km.

ENVIRONMENTAL ASSESSMENT

Methane abatement, its monetization. For the assessment of environmental benefits, we first calculated the reduction in enteric methane emissions due to the increased use of cultivated forages as animal feed. Monetization of methane abatement was calculated using the social cost of methane pegged by the United States government (Gavrilova *et al*., 2019). The monetized benefits of abatement values per 1000 kg of body weight gain in the fattening sector, and for 1 million liters of milk production in the dairy sector were calculated.

The methane emissions associated with the enteric fermentation of the animals fed on the different diets were estimated using the following steps:

Step 1: Estimate daily metabolizable energy (ME) and crude protein (CP) requirements of animals: Using nutrient requirement values for maintenance, growth, and milk production, the daily ME and CP requirements of animals were calculated.

Step 2: Estimate daily intakes of dry matter (DMI) and gross energy (GEI)

a. Daily DMI (kg) of feed was calculated using ME and CP contents of feeds under study that meets the daily ME and CP requirements of animals.
b. Daily GEI (MJ) = Daily DMI (kg) × 18.45 (18.45 is the factor as per International Panel on Climate Change (IPCC)) 2019 guidelines (Odero-Waitituh, 2017).
c. GEI for one lactation of 305 days in MJ (GEI305d) = Daily GEI × 305.
d. GEI for a growth period of x days in MJ (GEIx) = Daily GEI × x.

Step 3: Calculate CH_4 emissions from enteric fermentation.

a. Enteric Ferm CH_4 lactation (kg) = GEI305d × Ym/100/55.65.
b. Enteric Ferm CH_4 growth (kg) = GEIx × Ym/100/55.65 Ym, the methane conversion factor, set to 6.3 (as per the (IPCC) 2019 guidelines) (Odero-Waitituh, 2017).

Step 4: Calculate CH_4 emission intensity (i.e., the CH_4 emissions per unit of milk or meat)

a. Dairy: CH_4 emission intensity (kg CH_4/L milk) = Enteric Ferm CH_4 lactation in kg/lactation milk yield in liters.
b. Beef: CH_4 emission intensity (kg CH_4/kg body weight gain) = Enteric Ferm CH_4 growth in kg/kg weight gain in x days.

Land use – The competition for land between crop and livestock production in Zambia is expected to persist as demand for income, food, fuel, and feed continues to rise. Therefore, the reduction in the amount of land that is required to grow the animal feed ingredients due to the increased use of cultivated forages therein was calculated.

The number of hectares needed to grow the feed ingredients was calculated as follows:

$$DMI_i = DMI * fraction_i$$

$$LR = \sum DMI_i / Yield_i$$

DMI: total dry matter intake (kg);
DMI_i: the dry matter intake of feed ingredient i (kg);
$fraction_i$: the fraction of the animal diet constituted of feed ingredient i;
$Yield_i$: the yield of the crop from which feed ingredient i is produced (kg/ha);
LR: the land required to grow the animal feed ingredients (ha).

Scenarios considered – For the feedlot animals, we compared the CH_4 emissions and land requirements associated with three distinct growth scenarios. The baseline scenario represents a typical scenario whereby animals gain on average 0.5 kg weight/day and take 180 days to gain from 260 kg to the selling weight of 350 kg. In Scenario 1, the livestock producers take full advantage of the improved forage-based feeding and by increasing daily weight gain to 1 kg/day, taking 100 days to fatten a 250-kg animal to the required 350 kg. In Scenario 2, animals grow at a rate of 0.75 kg/day (an intermediate scenario) in which a total weight gain of 90 kg is accomplished in 120 days. For the animals during drought, we provide estimates for two types of feed: (a) Feed-A (cultivated forage-based diet), and (b) hay. The animals during drought were assumed to weigh between 250 and 500 kg. For assessment of methane abatement and land use for dairy animals, animals with body weights between 300 and 500 kg, producing between 15 and 20 liters of milk per day were taken.

Results

FORAGE SEED REQUIREMENT

Estimation of forage seed required in Zambia for the six selected forages is 398.6 tonnes for the six forage types selected. It ranged from 19.1 tonnes for *Megathyrsus maximus* to 136.2 tonnes for *Lablab purpureus* and *Vigna unguiculata* (Table 1). As it is not possible to have the required seeds adopted by farmers in 1 year, we spread the required seed amount incrementally over 10-year period (Table 2) which is more realistic.

POTENTIAL FORAGE PRODUCTION AREAS

Areas in proximity to the dairy hubs and feedlots are preferable. However, the areas should also have a sufficient length of growing period (Fig. 3). The areas shaded in light-green color in the southern part of Zambia could support forage production including seed production.

NUTRITIONAL ASSESSMENT OF FORAGE-BASED DIETS

Two types of feed were considered under nutritional evaluation as described by Dey *et al*. (2022). Feed-A contains 10% CP and 9.3 MJ of ME/kg, and Feed-B contains 14% CP and 9.3 MJ of ME/kg. Feed-A was found to meet the nutritional requirements of fattening animals, low-to-moderate milk-yielding dairy cows and cattle during drought period. For fattening daily weight gain (kg) of 0.5 to 1 was considered and for milk production 2 l/day. Feed-B can meet the requirements for high-milk-yielding dairy cows i.e., 15 l or more/day (Dey *et al*., 2022).

Table 1. Selected forages estimated seed requirement based allocated land and corresponding seed rates.

Forage	Seed rate (kg/ha)	Proportion allocation to each forage[a]	dry matter allocation (kg)[b]	Potential dry matter yield (tonnes/ha/yr)	Forage area required (FAR) (ha)	Forage Seed required (FSR) for meeting the deficit-selected forages (tonnes)
Megathyrsus maximus	3	0.23	127,165.9	20	6,358	19.1
Chloris gayana	3	0.23	127,165.9	15	8,478	25.4
Stylosanthes guianensis	4	0.1	54,499.7	10	5,450	21.8
Lablab purpureus	20	0.1	54,499.7	8	6,812	136.2
Vigna unguiculata	20	0.1	54,499.7	8	6,812	136.2
Urochloa hybrid Mulato II	8	0.23	127,165.9	17	7,480	59.8
Total						398.6

[a]Land allocation based at 70% for the grasses and 30% for the legumes corresponding to proportionate as recommended when feeding to ruminants.
[b]Amount of dry matter expected from the respective forage species after land allocation.

Table 2. Selected forages and their estimated annual seed requirements spread over 10 years period.

Forages	AFSR forages grown simultaneously deficit[a]	Annual FSR for the first 10 years[b] (tonnes)									
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Megathyrsus maximus	19.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Chloris gayana	25.4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Stylosanthes guianensis	21.8	2.2	4.4	6.5	8.7	10.9	13.1	15.3	17.4	19.6	21.8
Lablab purpureus	136.2	13.6	27.2	40.9	54.5	68.1	81.7	95.4	109	122.6	136.2
Vigna unguiculata	136.2	13.6	27.2	40.9	54.5	68.1	81.7	95.4	109	122.6	136.2
Urochloa hybrid Mulato II	59.8	6	6	6	6	6	6	6	6	6	6
Regeneration seed [c] (perennials)	—	—	—	—	—	—	—	—	10.4	10.4	10.4
TOTAL	398.6	39.9	69.3	98.7	128.2	157.6	187	216.4	256.3	285.7	315.2

[a]When 100% of the annual cultivated forage deficit met in the first year by growing simultaneously the three grasses @ 23.3% each and three legumes @ at 10%.
[b]10% increase per annum (a life span of 10 years was taken for the perennial grasses).
[c]For the three perennial grasses. AFSR-Annual forage seed requirement.

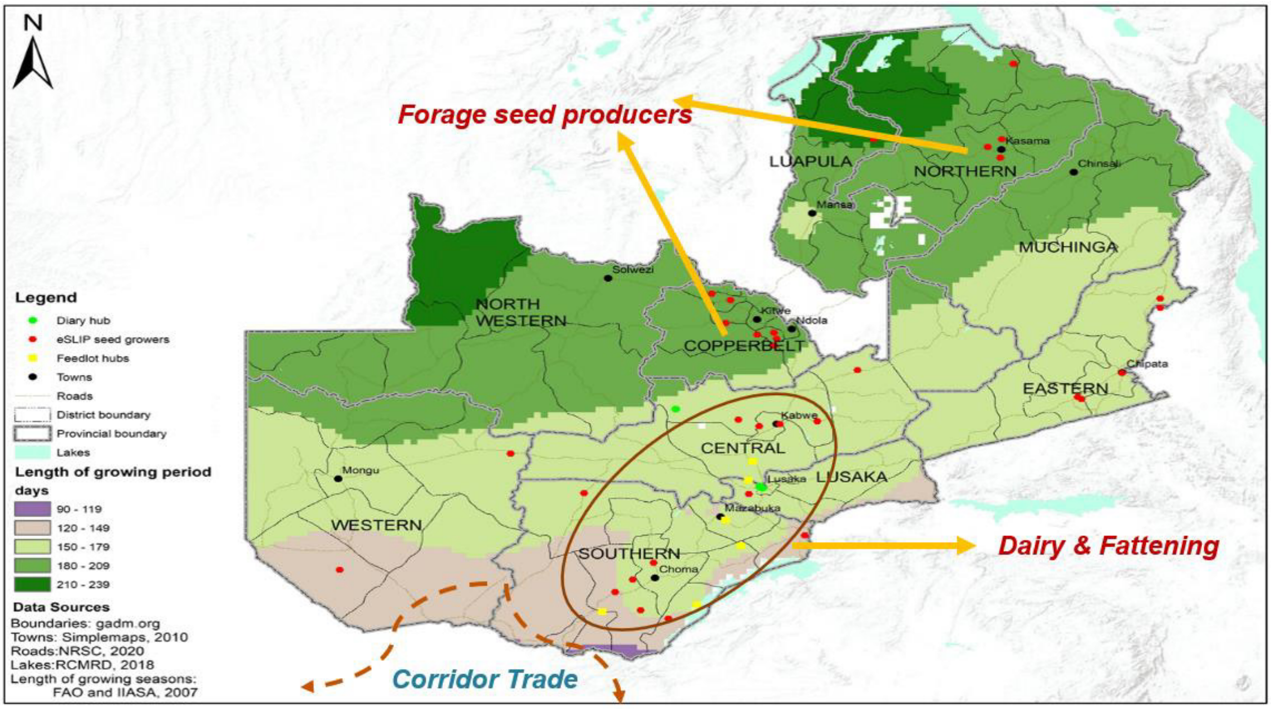

Fig. 3. Dairy hub, feedlots, forage seed producers (E-SLIP project), and the length of growing period (days) in Zambia.

ECONOMIC ANALYSIS

Cost per unit of nutrient supply from cultivated forages.

The cost of feed nutrients varied greatly (Table 3). For cultivated forages ranges were 0.17–0.50 US$ per kg CP and 1.53–8.67 USD per 1000 MJ of ME. Similar values for oilseed cakes were 0.66–1.04 CP and 17.0–52.57 for the energy, while for grains were 2.74–4.33 for CP and 16.10–41.68 for the energy. Grains are used as an energy source, and wheat brans for main energy sources but these also have substantial amounts of protein. On cost per unit CP and ME bases, brans were much better than grains. The cost per unit of nutrients for cultivated forages was the lowest.

OPPORTUNITY COST

The opportunity cost of cultivating forages against key crops grown in Zambia is presented in Table 4. Cassava production generated substantially higher profit than the cultivated forages. However, for the other cash crops, forages have higher returns except for wheat when compared to *Stylosanthes guianensis*, Lablab and Cowpea. For cash-deprived farmers, it would be easier to cultivate forages and generate good profit. The rate of return on investment is higher for the forage crops.

COSTS OF FEED-A AND FEED-B WITHOUT DENSIFICATION

Above we reported results on the cultivated forages as harvested. Here we present data on the Feeds (Feed-A and Feed-B) prepared using the cultivated forages.

For understanding the costs of diets with and without densification, the cost of Feed-A containing 10% CP and 9.3 MJ/kg ME, and Feed-B containing 14% CP and 9.3 MJ/kg of ME were evaluated. Using the nutritional quality data and the cost of production of the identified forages, Feed-A can be prepared either exclusively or by a mix of cultivated forage such as *Panicum*, *Brachiaria* or Rhodes grasses with a small amount (around 12% of Lablab or cowpea). This will increase its CP to 10% and ME to 9.3 MJ/kg (it may be noted that 6–8% molasses is used as a binder during pelleting, and this will also be an additional provider of ME). The cost of such a feed, at the production site, can be taken as 16.4 US$/ton. However, if sunflower cake as a CP source is added (Table 4) in the absence of Lablab or cowpea (8% of sunflower cake would need to be added), the cost of the feed would be 25 US$/ton. This also shows that the replacement of oilseed cakes with cultivated forages decreases the cost of feeding animals. For Feed-B, because of higher CP content, *Panicum*, *Brachiaria* or Rhodes would need to be mixed in 1:1.3 ratios with either lablab or cowpea. Both lablab and cowpea production costs are the same (53.13 US$/ton). The cost of Feed-B at the production site is expected to be (10*1 + 53.13*1.3)/2.3 = 34.38 US$/ton. However, its ME content was calculated to be 9 MJ/kg. On addition of 6–8% of molasses while pelleting would increase its ME to 9.3 MJ/kg. To keep some margin, we have taken costs of 17 US$/ton and 35 US$/ton for Feed-A and Feed-B at the production site.

COSTS OF FEED-A AND FEED-B AFTER DENSIFICATION

Densification entails the compaction of feeds into pellets. Costs presented earlier are without densification. The cost of pelleting is 18 US$/ton (see Methodology). At the production site (sites of cultivated forage production and forage densification should be very close to each other) cost of production of cultivated forage-based pellets is expected as: Feed-A, 17 + 18 = 35 US$/ton and Feed-B, 35 + 18 = 53 US$/ton. If these are sold at 50% profit margin, the selling price could be 53 US$/ton and 80 US$/ton respectively. If the densified feeds are transported to other regions, the cost of transport needs to be accounted for, which on average is 12 US$/ton/100 km in Zambia, as per our survey. If we take the market to be within a radius of a maximum of 500 km. The cost of feed, without any profit, turns out to be 35 + 60 = 95 US$/ton and 53 + 60 = 113 US$/ton for Feed-A and Feed-B respectively at sites 500 km away from the cultivation and densification site. Taking a 50% profit margin, the selling price could be around 150 US$/ton and 170 US$/ton for Feed-A and Feed-B respectively. If the cultivated forage-based diets are used at places < 500 km from the site of densification, the selling price could be further reduced (reduction of about 12 US$/ton/100 km; the cost of transport). The costs per unit of nutrients (CP and ME) for densified feeds, Feed-A and Feed-B are given in Table 5. These costs are much lower than those of conventional feed resources,

Table 3. A comparative evaluation of costs of cultivated forages and the market price of conventional feed ingredients on the bases of dry matter (DM), crude protein (CP) and metabolizable energy (ME).

Feed type	CP (kg/ton)	ME (MJ/ton)	Cost (US$)/kg CP)	Cost (US$)/MJ ME) x10^3
Cultivated forages (range)	72–184	8,000–9,800	0.11–0.33 (0.17–0.50)	1.02–5.78 (1.53–8.67)
Oilseed cakes				
Soymeal	530	10,500	1.04	52.57
Sunflower cake	279	10,900	0.66	17.0
Oilseed cakes (range)	279–530	10,500–11,900	0.66–1.04	17.0–52.57
Grains				
Wheat	126	13,100	4.33	41.68
Maize	80	13,600	2.74	16.10
Grains (range)	80–126	13,100–13,600	2.74–4.33	16.10–41.68
Brans				
Wheat bran	160	11,300	1.28	18.05
Maize bran	119	11,000	1.50	16.18
Brans (range)	119–160	11,000–13,100	1.28–1.50	16.18–18.05
Commercial feeds				
Dairy concentrate	240	13,000	2.45	45.15
Feedlot concentrate				
Total mixed diet, dairy	140	11,000	2.21	28.09
Total mixed diet, feedlot	NA	NA	NA	NA
Commercial feed (range)	140–240	11,000–13,000	2.21–2.45	28.09–45.15
Roughages				
Wheat straw	NS	NS	NS	NS
Rice straw	NS	NS	NS	NS
Maize stover	39	6,900	0.28	1.59
Hay	80	7,000	1.72	14.71
Maize silage	80	10,500	0.21	1.63
Roughages (range)	39–80	7,000–10,500	0.21–1.72	1.59–14.71

NA – could not be made available; NS not sold – grazed in situ or used as a mulch.

For cultivated forage, the values in parenthesis are for the scenario if sold at a profit of 50%.

suggesting lower costs of fattening and milk production using these densified feeds as well. It may be noted that hay of much lower quality (CP and ME around 6% and 7 MJ/kg) is being sold in Zambia at 103 US$/ton.

The cost of cultivated forages at the site of production (without densification) ranges from 8.6 to 53 US$/ton, and these cultivated forages are of much higher quality than hay. Panicum, which is produced at a cost of 8.6 US$/ton, has higher CP and ME (7.2% and 8.4 MJ/kg) than hay. This provides a substantial leverage of generating profit, if used as a fresh forage. Even after densification, Feed-A and Feed-B are of lower cost at the site of production (53 and 80 US$/ton respectively after a 50% profit) than hay.

Densified diets for the drought

For animals weighing 250–300 kg, daily consumption of the cultivated forage-based pellets/blocks (Feed-A): CP of 10% and ME of 9.3 MJ/kg) for meeting the maintenance nutrient requirements of animals is presented in Table 6. Hay (ME of 7 MJ/kg and CP of 6%) is generally used in drought areas, and daily consumption of this hay required for meeting the maintenance nutrient requirements of these animals is also shown in Table 6. Taking the costs of these feeds for use during drought, daily savings of US$ 0.20 and US$ 0.23 (average 0.215 US$) per animal could be realized. In a dry spell of 100 days, savings per animal turn out to be 21.5 US$, or for 1000 animals a saving of 21,500 US$, if the cultivated forage-based pellets/blocks are sold at 50% profit.

Densified diets for the dairy animals

To understand the cost of feed for dairy animals using densified feed, we took animals weighing 350 kg. A daily Feed-A amount of 5.32 kg can support daily milk yield of 2 l (USAID, 2016), giving feed cost per liter milk as 0.213 US$ at sites 500 km away from the densification site (taking cost of feed to be 80 US$/ton 500 km

Table 4. A Comparison of profit/ha (USD) for selected forages and real profit for selected cash crops grown in Zambia.

Cultivated forage	Cost of production (US$/t DM)	Selling price (US$/t DM)*	Profit (US$/t DM)	Yield DM t/ha	Profit, US$/ha
Panicum	8.6	100	91.4	20	1828
Rhodes grass	11.4	100	88.6	15	1329
Stylosanthes guianensis	45.9	120	74.1	10	741
Lablab	53.1	120	66.9	8	535
Cowpea	53.1	120	66.9	8	535
Mulato II	10.1	120	109.9	17	1868
Cash crop	Production cost (US$/t)	Average market price (US$/t)		Average yield (t/ha)	Profit US$/ha
Maize (small holder)	199	235	—	2.8	131
Wheat	294	420	—	8.5	1071
Soybean	428	588	—	3.5	560
Sunflower	342	400	—	1.52	88
Cotton	721	925	—	1.5	306
Cassava	755	1624	—	5.8	5040

*Selling price of cultivated forages was based on the current selling price of hay in Zambia (120 US$/t). Guinea and Rhodes selling cost was considered slightly lower than hay, although these are of higher nutritional quality than hay. The data on cash crops was collected from the farmers in Zambia.

Table 5. Costs per unit of nutrients of the densified feeds (prices have been adjusted for 50% profit).

Feed	Cost (US$/kg CP)	Cost (US$/MJ ME) x$10^3$
Feed-A, production site	(53/100) = 0.53	(53/9.3) = 5.70
Feed-A, 500 km away from production site	(80/100) = 0.80	(80/9.3) = 8.60
Feed-B, production site	(150/140) = 1.07	(150/9.3) = 16.13
Feed-B, 500 km away from production site	(170/140) = 1.21	(170/9.3) = 18.28

Table 6. Daily feed requirement for maintenance of animals and their costs

Weight of animal (kg)	kg daily Feed-A required for maintenance[1]	Daily cost of Feed-A, US$	kg daily hay required for maintenance[1]	Daily cost of hay, US$	Saving per day, US$
250	3.58	0.29	4.76	0.49	0.20
300	4.11	0.33	5.46	0.56	0.23

[1]Source: USAID (2016) cost of hay in Zambia varies from 103 to 143 US$/ton (here the former has been taken).

away from the densification site). The cost will be 0.140 US$ per liter at the site of densification, and in both cases, the costs include a profit of 50%.

Obtaining daily milk of 10 l from animals weighing 250, 300, and 350 kg, daily amounts of Feed-A and sunflower cake required are given in Table 7. Taking the cost of Feed-A at a site 500 km away from the production site and the market price of sunflower cake (184 US$/ton), the daily feed cost per liter of milk gets to 0.085, 0.088, and 0.091 US$ from animals weighing 250, 300, and 350 kg respectively (average 0.088 US$/liter). This cost of milk production is almost 2.4-fold lower than that of cows giving 2 l of milk per day, as presented in the previous paragraph. This situation is like that for the beef-producing animals (see below). The higher the daily milk production by an animal, the lower the cost per kg of milk production because a higher proportion of the feed (and of feed cost) goes to maintaining cow's body functions giving less milk. Also, the cost of milk production would be higher for animals of higher body weight, having the same daily milk production. The feed cost per kg of milk production will be lower in places nearer to the production site of cultivated forage-based densified feeds. It is worth noting that the cost of milk production in Zambia with conventional feed resources is 0.41 US$/liter and the market price is 0.64 US$/liter, based on our survey. The cost of feed therefore accounts for ≈14% of the market price and 21% of the cost of milk production. It is considered that 50–70% of the cost of milk production is the feed cost (Odero-Waitituh, 2017) and the use of cultivated forage based would lower the cost of milk production, giving higher profit to the dairy farmers.

Densified diets for fattening

The total feed required is 961 kg for the total fattening period of 120 days when the animals are growing at a daily growth rate of 0.75 kg; and the feed required is 1443 kg for the fattening period of 180 days at a daily growth rate of 0.50 kg (USAID, 2016). The costs of feed for one animal for these three scenarios are 63.6, 76.9, and 115.4 US$, respectively (Table 8). The cost per kg of daily body weight gain comes to 0.64, 0.77, and 1.15 US$ when daily body weight gain is 1, 0.75 and 0.50 kg, respectively. Certainly, it would be cheaper to produce meat from animals of good genetic potential (e.g., those growing at 1 kg/day) than those from animals of poor genetic potential (e.g., those growing at 0.5 kg/day). In these calculations, the cost of feed at a site 500 km away from the production site (adjusted for 50% profit) has been taken, and if the feedlots are located nearer than 500 km, the cost of production would be lower than these values. Currently, we do not have cost of the feed that feedlot farmers prepare on-farm from the individual ingredients, but since the costs per unit of nutrients from the densified cultivated forages were substantially lower than those from the conventional concentrate ingredients and hay used by the feedlot farmers, it is safe to conclude that the cost of fattening animals would be much lower using the densified cultivated forage-based feeds. We calculated the cost of feed using Treatment 2 data reported in Gebremariam (2019) in which a daily growth rate of 1 kg was obtained in *Bos indicus* bulls when fed a daily diet containing 6 kg of hay and 4 kg of wheat bran. By taking the Zambian cost of hay as 103 US$/ton and of wheat bran as 204 US$/ton, the cost of diet per kg of daily body weight gain comes to 0.618 + 0.816 = 1.43 US$. This is almost 2-fold higher than the cost of diet based on cultivated forage-based pellets (0.64 US$/kg body weight gain; Scenario 1 above). In addition, the use of densified cultivate forage-based by the feedlot farmers offers several other benefits, which have been discussed in Table 5. (Cost of Feed-A at 500 km away from the production site (80 US$/ton) has been taken.)

ENVIRONMENTAL BENEFITS

Feeding of cultivated forage could significantly reduce enteric methane emissions. The environmental gain as kg methane emission/kg of body weight gain during the fattening period decreased by 48% and 33%, while the reduction in land requirement was 45% and 33% in Scenarios 1 and 2, respectively (in Scenario 1, the livestock producers take full advantage of the improved forage-based feeding to realize higher genetic potential of animals and obtained average daily body weight gain of 1 kg, taking 100 days to fatten a 250-kg animal to the required 350 kg; and in Scenario 2, animals grow at a rate of 0.75 kg/day [an intermediate scenario] in which a total weight gain of 90 kg is accomplished in 120 days). The use of cultivated forage-based diet decreased the carbon footprint and land required for fattening. Using the social cost of carbon (as CO_2) put forth by the current US administration at $1500 per ton (Chemnick, 2021), the monetized value of the methane abatement ranges between $165 and $240 per ton of body weight gain in the fattening animals.

We also compared enteric methane emission from a concentrate-based diet and a cultivated forage-based diet (Feed-A) in fattening animals, both giving daily body weight gain of 1 kg. The feed required to fatten one animal, from 250 kg to 350 kg body weight in 100 days is given in Table 9. The environmental gain by using cultivated forage-based diets in place of the diet containing a mix of wheat bran and hay is 21.93 tonnes of methane for fattening of 10 thousand animals. The monetized benefit taking the social costs is $64,227.

For dairy animals, enteric methane emission on feeding the cultivated forage-based diets and the conventional diets, environmental gains

Table 7. The metabolizable energy (ME) and crude protein (CP) requirements of animals, and the amount of forage-based diet needed.

Body weight (kg)	Milk production liters/day	Total ME (maintenance + milk production) / day, MJ	kg/day of the feed of 9.3 MJ ME/kg required to meet the ME requirement	g Total CP (maintenance + milk production) required/ day(x)	g CP in feed containing 10% CP(y)	kg Sunflower cake as supplement (279 g CP/kg sunflower cake)	Cost of feed (Feed-A + sunflower cake) in US$
250	10	83.18	8.94	1101.5	894.4	0.743	0.852
300	10	87.60	9.42	1138.3	941.9	0.703	0.883
350	10	91.84	9.88	1173.7	987.5	0.667	0.913

Cost of Feed-A at 500 km away from the site of densification (80 US$/ton) has been taken; cost of sunflower cake taken is 184 US$/ton.

Table 8. Feed-A requirement for fattening and their costs.

Daily growth rate (kg)	Fattening period (day)1	Total feed required for fattening (kg)1	Feed cost for the fattening period (US$)
1.0	100	795	63.6
0.75	120	961	76.9
0.5	180	1443	115.4

[1]Source: Dey *et al*. (2022).

Table 9. Environmental gains (kg methane) on replacing a conventional diet with cultivated forage-based diet.

Daily growth rate, kg	Fattening period, days	Total feed required for fattening (kg)	Enteric CH_4 for the fattening period, kg	Environment gain for one fattening period (one animal), kg CH_4	Environmental gain for 10,000 fattening animals, ton CH_4
1.0	100	795[1] (Feed-A)	16.61	4.28	42.8
1.0	100	1000 kg (400 kg wheat bran + 600 kg hay)[2] – A conventional diet	20.89	—	—

[1]Source: Dey *et al*. (2022).
[2]Source: Odero-Waitituh (2017).

on using the cultivated forage-based diets and their social costs are presented in Tables 10 and 11. Daily total abatement of enteric methane on using cultivated forage-based diet ranges from 0.4 to 2.5 tonnes per one million liters of milk production daily (Table 10). Higher environmental gains are obtained for animals of higher body weight. The social costs of the reduction in enteric methane range from $600 to $3750, depending on the body weight of the dairy animal for producing one million liters of milk. Annual social gains from the production of 1 million liters of milk would range from $0.22 million to $1.37 million.

Discussion

The objective of this study was to assess the feasibility of using cultivated quality forages to meet gaps in livestock feed in Zambia. Results show compelling evidence of the economic and environmental benefits of using cultivated forages in Zambia. Quality cultivated forages come with greater herbage productivity, especially for grasses, by a factor of 2.6 (Paul *et al*., 2020). While cultivated forages have lower ME contents than the concentrates, crude protein (CP) content in some cultivated forages could be comparable or even higher than those in grains and their bran. Important to note is that the cost of energy and protein supply to the animals through the cultivated forages is much lower: CP lower by 3–6, 11–26, and 5–12 fold than oilseed cakes, grains, and brans respectively. Likewise, the cost per unit of ME supply is also much lower when using cultivated forages, i.e., 9–17, 7–16, and 3–16-fold lower than for oilseed cakes, grains, and brans respectively (these values get lowered by a factor of 1.5 in the scenario of 50% profit). Similar results were obtained for Ethiopia, where cost per unit of nutrient supply from cultivated forages was substantially lower than those from other feed ingredients commonly used (Dey *et al*., 2022). These results suggest that meeting the nutrient requirements of dairy and fattening animals would be much lower when using cultivated forages. Cultivated forages can replace substantial amounts of concentrates in the diet, resulting in decrease in the cost of the diet and increase in profit for the farmers.

While forage cultivation is currently minimal in Zambia (Fuglie *et al*., 2021), any effort to increase cultivation warrants bolstered forage seed availability. Given the context, two complementary business models present the realistic opportunity to increase livestock productivity while conserving the environment. One, strengthen and scale-up forage seed production in Zambia; and two, increase cultivated forage production (for use either as fresh forage or densified feed) to supply high-quality animal feed for both domestic and regional markets.

Figure 3 shows the location of dairy hubs, feedlots, forage seed producers and the length of the growing period in days in Zambia. Seed production could potentially be leveraged on the E-SLIP forage seed producers (Fig. 3), which have acquired technical knowledge and skills dealing with forage seeds. Expanding the scale of these producers and increasing their numbers will result in increased seed for forages under consideration including new technologies such as grass species and hybrids under the *Urochloa* and *Megathyrsus* genera. This could happen under forward contracting arrangements with seed companies in the country to first meet the domestic potential demand of the ≈ 398.6 tonnes (see Tables 1 and 2) and then increase seed production as the regional market grows. A similar model on forage seed production has been found to work in Thailand and Laos (Hare, 2014), where farmers are contracted to produce forage seeds for companies. However, producing certified seeds and maintaining quality should be targeted, as this would be key for the regional market and beyond. Certified seed production, however, needs to rely on early generation seeds from reputable sources. As such, the key to success lies in establishing strong connections and partnerships with both public and private entities in Zambia. The Zambia Agricultural Research Institute (ZARI), University of Zambia and Seed Control and Certification Institute (SCCI), and private companies like Zamseeds and Tropical Seeds are some good examples. These entities could provide high-quality early generation seeds.

Forage seeds are dense and can be transported efficiently in a cost-effective manner to different parts of the country and to the neighboring countries. Given that the E-SLIP project seed producers in Zambia are already producing forage seeds, especially of legumes, the domestic network could be leveraged for efforts to increase forage seed production including grasses. It should be noted that for some forages, seed production should not be close to the equator as these forages require longer daylengths

Table 10. Enteric methane emission on feeding cultivated forage-based diets*.

Animal body weight and daily milk production	Amount of daily cultivated-forage-based feed fed to meet nutrient requirement (kg DM)**	Daily enteric CH_4, kg/20 liters milk	Daily enteric CH_4, ton/one million liters milk (a)
BW 450 kg, 20 liters milk	13.6	0.284	14.20
BW 500 kg, 20 liters milk	13.8	0.288	14.4
BW 500 kg, 20 liters milk	14.1	0.295	14.7

BW: Body weight.

*Taken from Table 1 in the supplementary.

**Meets nutrient requirements for maintenance and 20 liters of milk production.

Table 11. Enteric methane emission on feeding conventional diets*.

Animal body weight and daily milk production	Amount of daily conventional feed fed to meet nutrient requirement (kg DM)**	Daily enteric CH_4, kg/20 liters milk	Daily enteric CH_4, ton/1 million liters milk (b)	Daily CH_4 abatement, ton per one ton milk, (b-a)
BW 450 kg, 20 liters milk	14.0	0.292	14.6	0.40
BW 500 kg, 20 liters milk	15.5	0.324	16.2	1.8
BW 500 kg, 20 liters milk	16.5	0.345	17.2	2.5

BW: body weight.

*Taken from Table 2 in the supplementary.

**Meets nutrient requirements for maintenance and 20 liters of milk production.

than possible close to the equator where day and nights are of similar duration. Specifically, forage grasses like *Urochloa* spp (Hare *et al*., 2015) return greater seed yields in areas that are away from the equator, which is key for commercial seed production, otherwise low yields lead to high prices in quest to cover costs incurred (FIGMDP-19 technical paper, 2019). Zambia, located at 13.1339°S, thus presents a compelling opportunity as a forage seed production hub in the region.

In relation to the second business model, forage production and densification would be most suitable in the areas with favorable length of growing period as indicated in light green color on the map (Fig. 3). The aim would be to engage commercial forage producers in areas with a length of growing period of at least 150 days. As seen in the map (Fig. 3), these areas are located in and around Mumbwa, Mazabuka, Monze, and Choma. The areas are within proximity of the feedlots and dairy hubs, which desirably reduces the cost of transportation. Increased forage production and its use without densification by small dairy farmers is thus a first promising option in this region. In line with the experiences in Thailand (FIGMDP-19 technical paper, 2019), in this model, a relatively progressive farmer is identified in a region near to the small-scale dairy farmers that grows good quality cultivated forages in 2–5 ha of land as a cash crop and supplies green forage at doorsteps of land-constrained and resource-limiting small scale dairy farmers. Such farmers buy green native forages of low quality from the market or cut them from the roadsides. The provision of good quality cultivated forages to small farmers increases milk production, and in dry season helps to sustain milk production. According to the economical assessment on densification and transportation, supplying forage-based pellets to other areas of Zambia and developing their regional supply offers promising business opportunities worth piloting. In this case, the producers will focus on forage production that is sold to the densification unit, and densification units can be imported from e.g., Germany, India or China. Alternatively, a large cultivation area and forage plantation could be owned by private owner(s) or cooperatives, that may run the densification unit. The forages would then be densified, and in addition to increased efficiency on transport, would provide longer shelf life, and facilitate feed budgeting/planning at the feedlots or dairy hubs.

For densification, a cultivation area of 500 ha has been considered in this study. It may be noted that the 500-ha should have cultivation of both grasses and legumes. As the former is easier and cheaper to cultivate, a ratio of around 80% grasses and 20% legumes may be considered. Feeds in the densified form, as pellets, are used in locations as far as 1500 km from their production sites in several countries. For example, in India over 70% of the grown forages are used in the fresh form, while in Tunisia the use as fresh forage is only 30% while their use as hay is to the extent of 50%. The use of forages is largely (90%) as pastures in Mexico. Currently, their conversion to pellets and blocks is very little in the countries surveyed. However, all respondents appreciated the high potential of these new products to be used as animal feed. The adoption rate varies from 5% in Mexico to 20–40% in India. Youth and women find the innovative nature of the technology attractive (Dey *et al*., 2022) as they are involved in livestock activities, and potential businesses on forage and forage seeds value chains. Increase in the use of the technology would create new job opportunities for youth and women.

The proposed forage and forage seed production sites could tap into the trade corridor that connects Zambia to neighboring countries, especially, Zimbabwe, Botswana, Mozambique, and Namibia. Pelleted forages and forage seeds could be transported by road and/or railway line, especially with a railway extension under consideration connecting Zambia with the region.

The use of cultivated forages clearly presents plausible abatement of methane and a decrease in methane emission intensity. As we have shown here the abatement of enteric methane on using cultivated forage-based diet ranges from 0.4 to 2.5 tonnes per 1 million liters of milk production daily, with higher environmental gains obtained for animals of higher body weight. Annually, social gains from the production of 1 million liters of milk would range from $0.22 to $1.37 million. Fattening ten thousand animals for 100 days returns 42.8 tonnes methane environmental gain (Table 9). Likewise, during 100 days of drought, hundred thousand animals accrue environmental gain (tons CH_4) of 246 and 282 for animals weighing 250 and 300 kg (Taken from Table 3 in the supplementary). As such, the use of cultivated forages fit well within Zambia plans toward addressing climate change, where improving livestock is envisaged (UNDP, 2011). Equally, it is in line with Zambia's Ministry of Fisheries and Livestock Policy to increase livestock productivity while creating jobs along the value chains (Ministry of Fisheries and Livestock-Zambia, 2021).

Conclusions

Animal feed represents the largest share of input costs (up to 70%) in the livestock sector (Chemnick, 2021). Thus, if this share could be brought down while holding nutrient level at its highest requirement, the profit per unit of livestock product would increase. This would bring economic benefits to livestock value chain actors, especially smallholder farmers, but also increase the availability of affordable animal-source foods. This study shows the feasibility of doing so for Zambia, by adopting and using high-quality cultivated forages. To do so, Zambia would need access to high-quality forage seed so that increased forage cultivation can help bridge the gap between requirement and availability of good quality feeds, especially in the dry season.

Costs of nutrients from cultivated forages are up to 26-fold lower for crude protein and 16-fold lower for metabolizable energy than those from the conventional feed resources. Consequently, the cost of daily feed/ration, prepared from cultivated forages, for fattening an animal in the feedlot would be around 50% lower than of the feed prepared using currently used feed ingredients. Equally, the feed costs (0.12 and 0.14 US$/liter) form 29 and 34% the cost of milk production. The cost of milk production can be reduced by 50% on using cultivated forages and profit increased by using cultivated forage-based diets. If the cultivated forage-based pellets/blocks are used in place of hay, a saving of 21,500 US$ for maintaining 1000 animals during a drought period of 100 days can be realized. Reduction in the cost of feeding dairy and feedlot animals, and to animals in the drought periods offers ample opportunities for the business units involved in the forage cultivation and their pelleting, and for the farmers to generate profit.

Given that millions of animals are fattened, and billions of liters of milk are produced in Zambia, the figures on reduction in enteric methane represent significant opportunities for climate change mitigation and must be taken into consideration while estimating benefits from the adoption of cultivated forages in the livestock sector. Substantial environmental gains through the abatement of greenhouse gases could be obtained using cultivated forage-based rations. The forage-based feeding presents a triple-win: economic, social as well as environmental gains, and is one of the true promising climate-smart feeding interventions.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS CONTRIBUTION

Dr Solomon Mwendia led the forage seed estimation and choice of forages considered in this study and drafting the paper. Dr Bhramar Dey led the overall conceptualization, design, and execution of the study, especially the development of the data-driven business model propositions while the rest of the authors supported the design and execution of the study. Ms An Notenbaert conducted the spatial analyses. Dr Harinder Makkar led the nutritional and economic analyses and supported the environmental impact of cultivated forages and forage seed estimation studies. Mr Ngoma conducted all field-level surveys in Zambia. He also provided valuable local context and input to the forage seed system discussions. Dr Michael Peters led the forage seed system component of the work and provided valuable inputs for the nutrition and economic analyses and forage seed estimation.

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