FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Role of Cultivated Forages in Zambia

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DISCLAIMER

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Feed the Future Consortium Partners in the Feed the Future Global Supporting Seed Systems for Development activity:

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

ABC	Alliance of Bioversity International and the International Center for Tropical Agriculture
ACFDe	Annual Cultivated Forage Deficit
AFD	Annual Cattle Feed Demand
AFSR	Annual Forage Seed Requirement
ARD	Annual Roughages Demand
ARDe	Annual Roughages Deficit
BHA	Bureau of Humanitarian Assistance
BW	Body Weight
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CP	Crude Protein
CRS	Catholic Relief Services
DCP	Digestible Crude Protein
DM	Dry Matter
DMI	Dry Matter Intakes
DRC	Democratic Republic of Congo
E-SLIP	Enhanced Smallholder Livestock Investment Program
FAO	Food and Agriculture Organization
FAR	Forage Area Required
FSR	Forage Seed Required
GART	Golden Valley Agricultural Research Trust
GDP	Gross Domestic Product
GEI	Gross Energy Intakes
GHG	Greenhouse Gas
GIC	Green Innovation Center
GRZ	Government of the Republic of Zambia
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IPCC	International Panel on Climate Change
K2	Klein Karoo
ME	Metabolizable Energy
MFL	Ministry of Fisheries and Livestock
MoA	Ministry of Agriculture
MoE	Ministry of Economy
MoLF	Ministry of Livestock and Fisheries
MRA	Mixed Crop and Livestock, Rain-fed, Arid/Semi-arid
MRH	Mixed Crop and Livestock, Rain-fed, Humid/Sub-humid
MRT	Mixed Crop and Livestock, Rain-fed, Temperate/Tropical highlands
NGO	Non-governmental organization
OFID	Opec Fund for International Development

S34D	Supporting Seed Systems for Development
SCCI	Seed Control and Certification Institute
SIDA	Swedish International Cooperation Development Agency
SNV	Stichting Nederlandse Vrijwilligers
TLU	Tropical Livestock Unit
TMR	Total Mixed Ration
UN	United Nations
UNZA	University of Zambia
USAID	United States Agency for International Development
WHO	World Health Organization
ZARI	Zambia Agricultural Research Institute
ZDTP	Zambia Dairy Transformation Programme

1. INTRODUCTION

The livestock sector in Zambia has tremendous potential and capacity to improve household food security and livelihoods while contributing to the country's economic growth and has thus been identified as a targeted sector by the Zambian government (Daka, 2007; MoLF, 2021). The livestock sector is increasingly becoming an important component of the agricultural sector and the country's economy, accounting for approximately 42% of the country's agricultural GDP and for 50% of employment in rural areas (PMRC, 2020). Priority areas within the sector include improving agricultural extension services and addressing livestock health and feeding. One area which has drawn a lot of attention is the need to improve the country's natural pastoral grazing lands and adoption and cultivation of superior forage/fodder species. Feeding component costs typically account for between 70-75% of overall livestock costs and are, therefore, partially responsible for the dismal livestock performance in most sub-Saharan countries (Makkar and Beever 2013; AKLDP, 2017).

This study examines opportunities for forage and fodder seed systems to contribute to an enhanced livestock sector in Zambia. Information was collated from literature and, where information was not readily available, through the use of survey instruments. This report seeks to identify and gather more information regarding the current players in the fodder seed systems in Zambia as well as some of the various aspect associated with the fodder seed industry in the country.

1.1 Livestock sub-sector context

The current livestock performance in the country is characterized by low productivity, low domestic market, and low cattle numbers, with Zambia presenting one of the lowest cattle densities in the region at about 0.14 tropical livestock units/Ha compared to 0.63 for Kenya (World Bank, 2011). Both dairy and beef industries in Zambia present significant growth and employment opportunities. Of the 20.3 million hectares of grazing area in Zambia, only about 3 million cattle are reared (Ministry of Fisheries and Livestock, 2020). In contrast, Zimbabwe's 12.1 million hectares support 5.4 million cattle and Kenya, with virtually the same amount of grazing land as Zambia, has a cattle herd of 13.5 million. All of Zambia's agro-ecological zones are suitable for cattle, but the country's cattle stock is currently concentrated in just three provinces (**Table 1**). Cattle contribute at least 61% of the meat and 95% of the milk consumed in the country. Of the 3.7 million households in Zambia, the Southern province is second only to the Eastern province for households engaged in agricultural activities, with around 300,000 households participating in crop and fodder production (MoFL-Zambia, 2019). Additionally, the Southern province leads among the ten Zambian provinces in terms of livestock raising. While there has been a recent livestock census in Zambia (MoFL-Zambia, 2019), the publicly available statistics are estimates through 2015 as cited by the United Nations (UN) (2020) (**Table 1**).

Given the status quo, Zambia could sustain a cattle population of over 7 million – roughly double its current figure – using modern livestock practices (World Bank, 2011). As incomes increase in Zambia, it is postulated that beef and milk demand will grow significantly, thereby providing the market pull that, in turn, will trigger an increase in production. For either beef or dairy in Zambia, public and private sector efforts to strengthen the forage seed systems presents an opportunity to grow and improve the sector,, contribute to increased livestock productivity and quality of improved feeds. Opportunities also exist for reductions in methane emissions as the study will show.

Table 1. Zambia cattle population 2011-15 by provinces

Province	Cattle population				
	2011	2012	2013	2014	2015
Southern	930,111	1,629,547	1,173,606	1,394,397	1,294,580
Eastern	565,485	637,096	626,100	608,652	625,851
Central	254,644	510,515	310,193	426,101	439,660
Western	282,678	714,744	524,187	463,138	362,538
Copperbelt	28,763	53,453	40,294	40,944	276,599
Lusaka	80,666	93,491	64,170	81,767	112,326
Muchinga		133,793	83,698	121,975	79,186
North-Western	34,621	67,631	59,433	45,403	63,210
Northern	134,140	69,484	71,833	65,411	44,587
Luapula	19,123	12,354	15,427	13,909	8,136
National	2,321,231	3,922,107	2,968,941	3,261,695	3,306,673

Source: UN, 2020

Without global downturn, beef consumption has been growing at a rate of 5-7% annually, with dairy products growing close to 10% each year in Zambia. With European standards, Zambia could follow Botswana's and Namibia's example and export beef to Europe. However, current best prospects lie in supplying fresh beef to the premium markets of neighboring countries, especially as a land-linked country with seven neighbors (Angola, the Democratic Republic of Congo [DRC], Malawi, Mozambique, Namibia, Tanzania, and Zimbabwe. The dairy sector in Zambia generally underperforms as compared to its neighbors. Milk broadly comes from the traditional systems, where cows produce about two liters per day on average and, while there are some Zambian farmers that use improved production methods and that obtain around 8.2 liters per cow per day, this falls short of its neighboring country competitors (9.6, 15.1, 15.1, and 8.6 liters per cow per day for Botswana, Kenya, South Africa, and Zimbabwe, respectively). Domestic milk consumption, a key driver in providing impetus towards livestock production improvements, is low. In fact, Zambia's annual per capita milk consumption stands at a dismal 16.5–19.4 liters compared to the 200 liters recommended by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (Kawambwa et al., 2014).

In 1987, research from Kulich indicated that the most important constraints to improving livestock production in Zambia are those related to animal nutrition; despite the years that have passed this was purported, the fact remains relevant today. Because of poor forage cultivation, the use of poor-quality crop residues is a common feature of smallholder dairy production (Kawambwa et al., 2014). To reverse the situation, high-quality grasses and legumes are required. Around 70% of Zambian farmers do not grow any forage for animal productivity, while only 30% grow or purchase some forage. Consequently, during the dry season, milk production tends to drop by up to 31% (Kawambwa et al., 2014).

1.2 Zambia forage seed system

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 for increasing livestock productivity and household income through achieving higher quantity and quality of herbage, while contributing to soil improvement and higher food crop yields. A meta-analysis by Paul et al. (2020) revealed that improved forage germplasm has, on average, 2.6 times higher herbage productivity than local controls, with the most tangible benefits associated with grasses.

Zambia is relatively less engaged in forage cultivation (Fuglie et al., 2021), an area that presents opportunities for sizable improvements the country's livestock productivity (**Table 2**). This is especially so given the country's strategic plan to increase cattle population by 20% (MoFL, 2021). Kenya has up to 37 times more land under forage crop than Zambia (**Table 2**), despite Zambia's larger overall land size as compared to Kenya's (743,390 km^2 and 580,367 km^2, respectively).

Zambia largely depends on natural pastures in the low potential areas and on some cultivated forages (grasses and legumes) and crop residues in the high potential areas (Kawambwa et al., 2014). The cultivation of forages is not widespread and, where it is practiced, it often revolves around recycling seeds and/or vegetative planting materials.

Table 2. Statistics on extent of cultivated forages in developing countries

Region	Country	Derived value of forage crop production (2014-16 quantity and price) (1000 $)	Estimate of forage crop area (Ha)	Source documentation
Eastern Africa	Burundi	4,118	11,439	Gonzalez et al., 2016
Eastern Africa	Ethiopia	188,171	522,697	Gonzalez et al., 2016
Eastern Africa	Kenya	157,454	437,372	Gonzalez et al., 2016
Eastern Africa	Rwanda	9.74	27,057	Gonzalez et al., 2016
Eastern Africa	Sudan	55,800	155,000	FAO, Unpublished Statistics
Eastern Africa	Tanzania	103	287,173	Gonzalez et al., 2016
Eastern Africa	Uganda	85,674	237,984	Gonzalez et al., 2016
Southern Africa	Eswatini	370	1,029	Authors' estimate
Southern Africa	Lesotho	1,427	3,963	Authors' estimate
Southern Africa	Madagascar	5,074	14,093	Authors' estimate
Southern Africa	Malawi	617	1,715	Authors' estimate
Southern Africa	Mozambique	7,635	21,209	S. Mwendia, per. Comm.
Southern Africa	South Africa	570,600	1,585,000	FAO, Unpublished Statistics
Southern Africa	Zambia	4,248	11,801	Authors' estimate
Southern Africa	Zimbabwe	3,845	10,681	Authors' estimate

Adapted and modified from: Fuglie et al. 2021

The Zambia Agricultural Research Institute (ZARI) is broadly attributable to kickstarting the pasture and fodder industry in the country, having both provided pasture seed to government-run farms and most of the seed used by commercial farms. The Seed Control & Certification Institute (SCCI) was running forage breeding programs, especially through the Zambia Seed Company (Zamseed); however, owing to a lack of appreciation of the importance of forage production and pasture development by most small-scale livestock farmers in the country, very few smallholder farmers attached monetary value to growing herbage grasses and legumes as a source of livestock feed. The main challenges faced by the forage seed subsector during the past two decades are summarized as follows:

i) Low market demand for forage seed, especially for legumes, following market liberalization in the 1990s, during which period most private seed companies found it uneconomical to invest in forage seed production and marketing;

ii) Lack of forage expertise and skills, worsened by a 'brain-drain' of forage specialists; and

iii) Research in seed was reduced to field crop varieties and research work on forage crops had stalled.

There are five identified seed systems predominant in Zambia, which include (i) farmer-saved, (ii) NGOs and cooperatives, (iii) public-private, supported by ZARI and local seed companies, (iv) private, supported by international seed companies, and (v) private, supported by out-grower schemes for export commodities. In the informal farmer-saved system, farmers themselves multiply and exchange seed locally, both through barter and for cash. This system has no quality assurance measures for the landraces that are multiplied. In the second system, NGOs are assisting community groups or farmer cooperatives in seed multiplication and marketing. Smallholder farmers in Zambia who grow crops other than maize are nearly always acquiring seed through these two systems.

As the demand for animal products [including beef and dairy] continues to grow, hypothetically, technologies that contribute to improved cattle productivity would also emerge (Duncan et al., 2019). This is especially true for forages that take the bulk of feeding cost. Yet, from the literature reviewed from this study, there seems to be no quantified data on forage seed demand in Zambia or most other African countries, making it difficult for private sector and interested parties to gauge the outlook on forage seed businesses.

2. THE ROLE OF FORAGES IN ZAMBIA

Despite the huge potential of forage seed to contribute to enhanced livestock production, only a small handful of private companies are involved in forage seed production and marketing (e.g., Klein Karoo [K2], Hygrotech, Advanta and Afriseeds). This may be partially attributable to the scarcity of most forage seed – perennial legumes in particular – and, when such seed is available, it is expensive and therefore economically inaccessible for most smallholder farmers.

According to a baseline study/survey on the seed sector of Zambia (Miti, 2015), seed provisioning in Zambia is guided by the Plant Variety and Seeds Act (CAP 236). The Act provides for SCCI, under the Ministry of Agriculture (MoA), to enforce the Act. SCCI is also the administrator of the Plant Breeder's Rights Act (No. 18 of 2007), which aims at promoting the development of new plant varieties. The duties of SCCI are implemented through its main activities, including:

i) Variety testing, registration, and protection;

ii) Seed systems and inspections;

iii) Laboratory seed-testing; and

iv) Auditing and monitoring private laboratories that are licensed to test and certify seeds for the local market.

SCCI also trains and examines candidate inspectors, samplers, and analysts. Successful candidates are licensed to perform respective seed quality control activities. Like any other authorized seed grower, forage seed growers will be required to register with SCCI, either through an authorized seed company or a legitimate Seed Growers' Association. The seed crops are subjected to field standards which include rotation, isolation, and off types, and successful seed crops are harvested.

2.1 Methodology

The data documented in this study of the forage seed systems in Zambia was primarily obtained through phone calls, online research, and one-on-one discussions with various stakeholders. Despite the COVID-19 limitations and associated movement restrictions presented on the ability to freely collect data, this report still offers a pragmatic overview of the current forage system situation in the country.

The Alliance of Bioversity International and International Center for Tropical Agriculture (ABC CIAT), in collaboration with Catholic Relief Services (CRS), undertook a baseline study on the prevailing forage seed systems in Zambia. The aim was to provide a detailed overview of the Zambian forage seed system while identifying the gaps in the country to inform efforts towards increasing forage seed access. In addition to a desktop review, questionnaires were applied through one-on-one interviews, phone calls, and via email. Fourteen organizations/programs were selected for interviews based on their relevance in the forage seed sector (**Table 3**).

Table 3. Organizations/entities interviewed in Zambia

#	Organization	#	Organization
1	ESLIP project	6	Mochipapa Research Station
2	Green innovation Center & Consultative Group on International Agricultural Research (CGIAR)	7	Mendel University (Czech Aid)
3	Klein karoo	8	Dairy Association of Zambia
4	Afriseed	9	Seed Control and Certification Institute (SCCI)
5	Hygrotech	10	Palabana University

The collected data revealed that, although few players currently exist, there has been an increase in the number of organizations producing forage and forage seed in recent years. Due to time and logistical constraints, only those institutions (public, private, or NGO's) that are actively involved in various aspects of the sector were considered herein.

Clearly, one of the most proactive organizations regarding smallholder seed multiplication was the Enhanced Smallholder Livestock Investment Program (E-SLIP). This program is funded by the International Fund for Agricultural Development (IFAD), Opec Fund for International Development (OFID), Government of the Republic of Zambia (GRZ), and the participating communities. The lead implementing agency is the Ministry of Fisheries and Livestock (MFL) and the Department of Livestock Development manages Component 2 of the E-SLIP. Under Component 2, Livestock Production and Productivity Improvement, the program has been promoting the production of on-farm pasture production and rangeland improvements. These intervention areas serve as a means of addressing the dry season feeding challenges that farmers face every year. The project is concentrating on forage legumes e.g., Sunn hemp (*Crotalaria*), *Stylosanthes guianensis* and *Stylosanthes scabra*.

E-SLIP trained 55 small scale farmers in the fundamentals of forage seed production and the agronomical requirements necessary for establishment. The farmers were also equipped with initial seed availability and market linkages for the harvested crop. The map below shows the coverage of the seed farmers supported by E-SLIP.

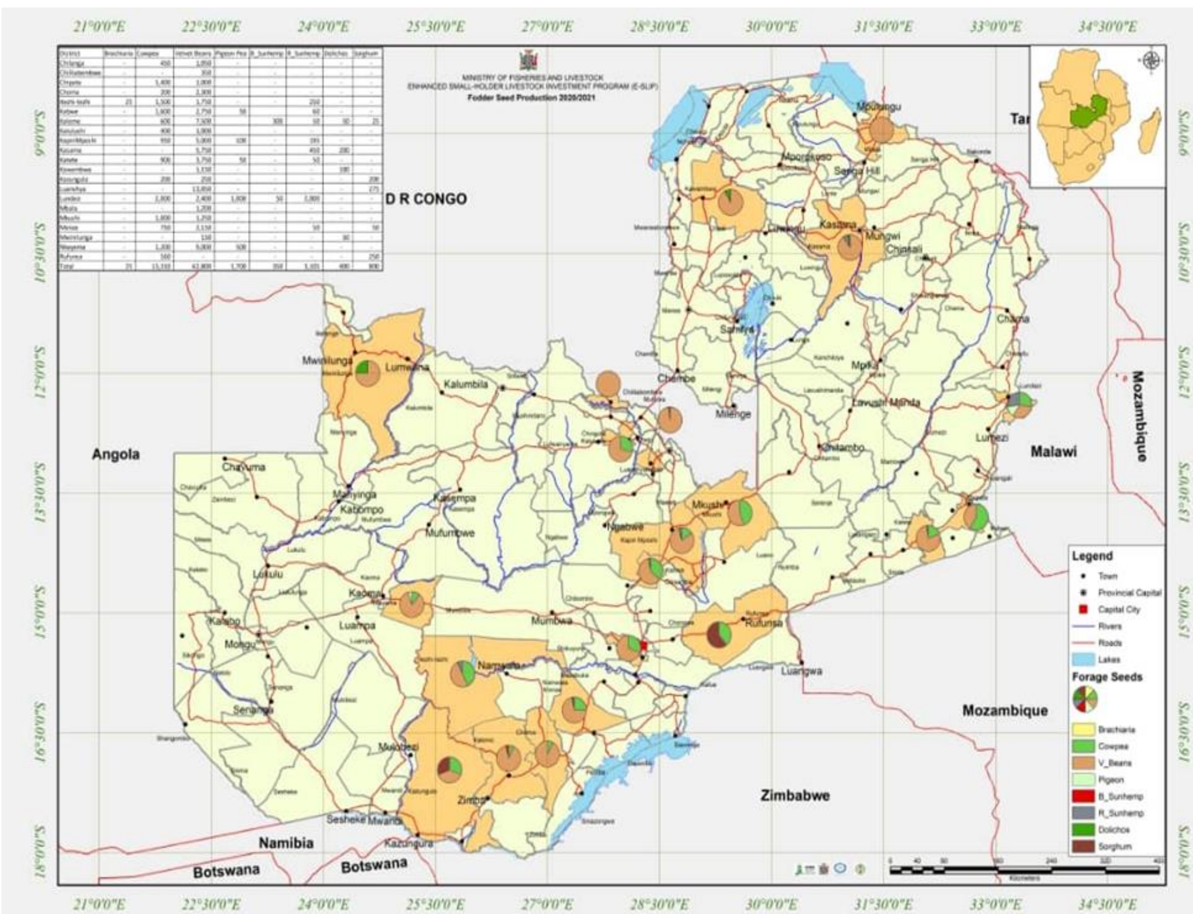

Figure 1. Distribution of E-SLIP forage seed farmers

The collaboration between Green Innovation Center-Zambia (GIC-Zambia) and CGIAR (International Livestock Research Institute [ILRI] & CIAT), working to improve forage identified a number of proposed solutions and gaps as stipulated below (**Table 4**).

Table 4. Summary of efforts in promotion of forage production as identified in project by Green Innovation Center- Zambia (GIC- Zambia) and CGIAR (ILRI & CIAT)

The problem	Proposed solutions	Status of activities	Identified gaps/challenges
Narrow and limited forages currently being utilized – Brachiaria brizantha cv Marandu, Rhodes grass (*Chloris 14now14a*) and Napier grass (*Pennisetum purpureum*) are the commonly promoted forage species, yet these might not be the most suitable fodder or pasture species for the low level of rainfall reported in this area	Identifying a range of appropriate improved, climate-resilient grazing forages and pasture management options for Southern province and developing commercial models for enhanced access to such grazing forages by dairy farmers.	-Demo plots of improved fodder established in 5 out of 7 sites. -Project to assess biomass production List of varieties include: -Brachiaria hybrid 'Cobra' -Brachiaria hybrid 'Cayman' -Brachiaria decumbens 'Basilisk' -Brachiaria brizantha 'Xaraes' -Brachiaria Hybrid decumbente Camello -Panicum maximum 'Mombasa' -Crotalaria juncea	Determine which varieties are most suitable for which areas based on altitude, rainfall pattern, and predominant soils.
Livestock producers reported inadequate access to improved forage seeds as major constraint to uptake of improved forages.	Design of commercial models for delivery of forage products.	-Feed plan models underway for 5 cooperatives to pilot commercial fodder namely Kayuni, Kalomo, Nteme, Choma and Niko cooperatives -Next steps? - The model will be complete by the end of the year, and this will give greater perspective on the actual forage and feed requirements of the farmers currently and in the next 5 years	Year-round feed availability could be cushioned by new forage varieties that are more resilient to prolonged dry spells.
While a variety of forages are stocked by seed suppliers, inadequate distribution systems, large packaging, high prices, and lack of information on available forage seed types tend to undermine wider uptake of improved forages	Identifying options for strengthening forage seeds supply systems.	Tropical seeds The private forage seed sector is actively working with other stakeholders such as GRZ, NGO's and farmers. These interactions help each party share the challenges and potentials in the sector. The company named Tropical seeds has been working in this regard with Government and was the supplier of over 7 tons of seed for the GRZ led ESLIP program. They were also the providers for the seeds currently under trial which some of which were developed and bred by CIAT	The geographic position of Zambia has shown potential to become an ideal regional hub for forage seed production. This would not only make forage seed more available locally, but also at region scale.

A survey on seed companies and programs in Zambia on dealing with forages seeds returned varied responses (Table 5) on forage types and aspects on forage seeds. Forage seed importation appeared at larger play compared to local production and 3 against 1 of the entities reported the demand for forage seed as increasing in Zambia.

Table 5. Seed companies/programs and the forage seed they are dealing with in Zambia

#	Question	Companies/programs			
		Hygrotech	E-SLIP	Klein Karoo	AfriSeed
1	Which forage seeds varieties do you deal with? List them and state packing and price (USD)	Rhodes grass, 5kg @ $72; Lucerne 5 & 25kg @ $150 & $281 respectively; 15now Kandy 5&25kg @ $15 & $65 resp, Lucerne 5 & 25kg @ $150 & $281 respectively; White Buffalo 5kg @ $ 124; Bermuda grass 1kg @ $36	Cowpea @ $3/kg; Pigeon Pea @ $3/kg; Velvet Beans @ $2.5/kg; Sun hemp @ $3/kg; Rhodes Grass @ $ 8/kg; Dolichos Lablab @ $3/kg; Panicum maximum @ $29/kg; Brachiaria @ $29/kg	Rhodes grass (1kg); Sugar graze; Lucerne(25kg); Blue Buffalo (25kg); Panicum (5kg); Lablab (10kg); Teff (15kg)	Velvet beans (2,5&10kg's)@ $7/kg; Sun hemp (2,5&10kg's)@ $3/kg; Dolichos Lablab (2,5&10kg's)@ $7/kg; Pigeon peas (2,5&10kg's)@ $7/kg; Cowpea (2,5&10kg's)@ $3/kg
2	What is the source of the seed? Imported, self-produced through out-grower scheme	Imported	Outgrowers' scheme, local suppliers and imports	Imported and self-produced	Imported, self-produced, out growers, seed companies
3	Do you notice any changes in preferences between men and women farmers regarding forage seed purchases?	Men have traditionally been in the forefront in farming activities in the past, but there is definitely a shift in the recent 10-15years. More women are rearing livestock and are buying more seed/	Women have been gradually more interested in growing seed as a business but both men and women are actively interested.	More women are now buying than the past	Mostly women prefer the cowpeas and men prefers the rest of the forage. The reason could be cowpea is multipurpose and other forage are for animal feed and soil health.
4	What are the quantities of seed you import annually?	Rhodes grass (5 Tons) 15now Kandy (5 Tons) Lucerne (5 Tons) White Buffalo (5 Tons) Bermuda grass (5 Tons) Rye grass (5 Tons) Brachiaria Marandu (5 Tons)	Brachiaria (50kg) Brachiaria cv Camello (50kg) Stylosanthes (200kg) Desmodium Herterocarpon (40kg) Ascomene Americana (45kg) Centrosema Pascuorum (300kg)	Rhodes (5 tons) Sugar graze (5 Tons) Panicum (5 Tons) lucerne (5 Tons)	N/B did not disclose importation
5	What are the quantities of seed you produce locally?	Nil	Cowpea-Basic (12 Tons) Pigeon Pea-QDS (1.7 Tons) Velvet Beans-QDS (40 Tons) Sun hemp-QDS (3 Tons) Rhodes Grass-QDS (0.05 Tons) Dolichos Lablab-QDS (0.5 Tons) Panicum Maximum-QDS	N/A	Velvet beans (100 kg) Sun hemp (100 kg) Dolichos Lablab (60 kg) Pigeon peas (50 kg) Cowpea (400 kg)
6	Is the demand for forage seed in Zambia growing, remaining the same or decreasing in the last 10 years?	Growing	Growing	Growing	Static
7	Which calendar months have the highest demand for forage seed?	Jan, Feb, Sep, Oct, Nov, Dec	Jan, Feb, Mar, Nov, Dec	Jan, Feb, Mar, Apr, Nov, Dec	Jan, Nov, Dec

8	Which calendar months have the lowest demand for forage seed?	Mar, Apr, May, Jun, Jul, Aug	The rest of the year other than mentioned above	The rest of the year other than mentioned above	The rest of the year other than mentioned above
9	What do you like most about dealing with forage seeds?	Self-marketing, People who deal in forages know what they want, the seasonality of it helps planning easier	• Environmentally friendly forage crop species • Some have dual purpose usage which includes both household and livestock usage • Legumes fix nitrogen hence minimal inputs required	1. the market is growing 2.there are not many competitors	It's a niche market
10	Which are the greatest challenges when dealing with forage seeds?	WATER AVAILABILTY- it's seasonal and any late planting is a problem in establishment, DORMANCY – The crop sometimes exhibits difficulty in growing due to dormancy, getting access to new varieties when they are released,	• Poor yield and quality • Climate change • Low quality seeds and impurities • Price fluctuations • Lack of good quality parent seed • Lack of improved varieties • Labor intensive due to demand for hand processing	1. delays in seed import permits 2. Bad seed in circulation denting image of forage seed performance	Erratic demand, lack of market specifications (standards) & poor access to EGS and new varieties
11	List IP regulations you are aware off? What is your view on these regulations?	Not privy		Not privy	1. Exclusive rights – loyalties are too high & 2. Non-exclusive rights – do not encourage research and development.
12	Do you have any forage multiplication sites?	N/A	YES. 55 Farmers spread mainly in the Southern, central, and eastern provinces but also some producers in Western and Northern Province.	Yes, in Chisamba (Central Province)	Yes
13	What are some of the challenges that you face regarding the importation of seed and certification of locally produced seed?	There are serious delays in approval of the release new varieties There are delays in the approval of permits from SCCI and ZARI	The protocols for seed certification need to be standardized and there's need for capacity building of certification staff on forage seeds production and quality requirements.	1. takes time to get permits 2. Some locally produced seed is of poor quality with poor field results	There are no quality standards set and a lack of testing protocols.
14	How do you think the challenges mentioned above can be overcome?	The country needs to breed its own varieties and have more locally grown forage crops with an established fodder seed bank.	Capacity building and strengthening the local seed production capability.	Improve certification officers understanding of the forages so that they are more informed.	Formulate standards and protocols for seed certification

N/B. Entities mentioned in ***Table 3*** *and are not deep in forage seed, mentioned in* ***Among the*** commercial farms contacted. (displayed in Table 6). most of them produce Rhodes grass seeds and to a lesser extent, velvet beans, panicum maximum and sun hemp.

Table 6

Among the commercial farms contacted. (displayed in Table 6). most of them produce Rhodes grass seeds and to a lesser extent, velvet beans, panicum maximum and sun hemp.

Table 6. List of commercial farmers producing pastures seeds by province and corresponding districts in Zambia

Province	District	Name of commercial farm	Pastures grown
Southern	Mazabuka	Syringa Farms	Rhodes grass, Rye grass
Southern	Mazabuka	Wellspring	Rhodes grass
Southern	Mazabuka	Kapinga	Rhodes grass
Southern	Mazabuka	Delta	Rhodes grass
Southern	Mazabuka	Nanga	Rhodes grass
Southern	Mazabuka	Kushya	Rhodes grass, Velvet beans
Southern	Mazabuka	Richard Nakeeye	Velvet Beans, Sun hemp
Southern	Mazabuka	Bignell	Panicum maximum
Southern	Choma	Peter Green	Rhodes Grass
Southern	Choma	Ross	Rhodes Grass
Southern	Choma	Bruce miller	Napier Grass
Central	Chisamba	Sable	Rhodes Grass
Central	Mumbwa	PSC Ranch	Rhodes Grass
Central	Mkushi	Brimagoba	Rhodes grass
Central	Mkushi	Barker	Red Sun hemp
Lusaka	Palabana	Derrick	Rhodes grass

In Zambia, there are several forage-related projects run by different partners (Table7). Most of the partners are government entities supported by different donors, while others are development-oriented non-governmental organizations also donor supported.

Table 7. Landscape partners working on forage related efforts in Zambia

Project	Donor	Implementers	Topic	Forage intervention	Location of intervention	Additional information
Dairy Project	GIZ- Through the Green Innovation Center	ABC, ILRI, MoLF	Towards climate-resilient dairy production in Southern Zambia	Started in 2020	Zambia Southern province	Project ending on 15th January 2023
E SLIP	IFAD	MoLF	The program will target key livestock systems of smallholder producers in selected provinces and districts through three main components: animal disease control, livestock production systems and program management. While national in scope, the program will place a strong focus on districts experiencing a high incidence of endemic livestock diseases, thereby reducing poverty for nearly 213,000 smallholders.	Empowering smallholders with initial forage production inputs and Training farmers in forage seed production.	Country wide	Began in 2018 and ends in August 2023
Stichting Nederlandse Vrijwilligers (SNV)	Swedish International Cooperation Development Agenc (SIDA)	SNV	Increasing climate resilience in energy agriculture systems and entrepreneurs.	Promoting the planting of fodder trees and suitable forages as a means of mitigating impacts of climate change.	Agroforestry intervention in Southern Province and Lusaka	Project started in 2020 and ending in December 2023
MENDELU	Czech Development Agency	Mendel University	Silvopastoral systems as a strategy for sustainable agriculture to increase the living standards of small-scale farmers in the Southern Province of Zambia.	Promoting the use of various forage trees and grasses together with other traditional crops to increase land use efficiency household security.	Southern Province	Started in September 2020 and ending in sept 2023
Golden Valley Agricultural Research Trust (GART)	GRZ, IFAD, USAID, SIDA, other collaborating stakeholders	GART Board	Breeding, production, and research in numerous forage species.	Knowledge dissemination to farmers regarding various forage technologies.	Based on two farms in central and Southern Provinces	Ongoing
Zambia Dairy Transformation program	Newzealand Aid	ZDTP and Prime Consultants through GRZ		Support SSF through extension, capacity building and awareness to stimulate increased productivity.	Southern, Lusaka, Central, Copperbelt and Northern Provinces	April 2017-April 2022 and extension up to July 2023
Dairy Association of Zambia	SIDA, IFAD, GRZ			Empowering farmers through knowledge, extension services in improved dairy production, Advocacy, and market linkages.	Country wide	Continuous
ZARI	GRZ	MoA		Execute research in Agricultural crops to feed into the extension branch of the Ministry in order to promote sustainable and profitable agricultural practices that improve livelihoods.	Country wide in implementation but have permanent stations in Lusaka, Central, Eastern, Northwestern, Western,	Continuous

Project	Donor	Implementers	Topic	Forage intervention	Location of intervention	Additional information
					Luapula, Northern, Copperbelt and Southern.	
SCCI	GRZ with support from various agencies such as USAID	MoA		Regulate all seed production, imports, and exports so as to satisfy all quality and phytosanitary requirements for the end user.	Country wide in operation	Continuous
UNZA	GRZ with numerous external sponsors in various sectors	MoE		Conduct training of professional agronomists to equip them with skills that are relevant to the current needs of the Agric sector.	Lusaka	Continuous
Palabana University	GRZ with numerous external sponsors in various sectors	MoLF		Train professional dairy experts in all aspects of dairy farming.	Central	Continuous
Mochipapa research	GRZ	MoLF		Conduct relevant research in livestock and forages to promote improved livestock productivity and livelihoods of SSF's.	Country wide in operation with three permanent stations in Southern, Western, Northwestern, and northern Provinces	Continuous

2.2 Types of seed systems and roles of seed industry actors

The seed industry in Zambia includes the active participation by both the private and public sectors in seed quality control and a licensing scheme. Seed systems can be either formal or informal. Formal systems generally consist of public sector research institutions (e.g., ZARI), public and private sector agencies producing and marketing seed, and organizations responsible for seed certification and quantity control (e.g., SCCI).

The formal sector seed supply system in Zambia operates along two models:

i) Public sector model (variety testing and research): Researchers improve and develop breeder seed through a public research institution to multiply on research stations or through contract seed-growers. All activities, including seed cleaning, processing, quality control and marketing are conducted by government-supported research and/or donor-funded research grants and development organizations like the GART.

ii) Private sector model: Private seed companies, to which smallholder farmers are linked, play an important role in seed multiplication and marketing. Researchers from the public sector provide breeder seed (released varieties) to private seed companies to be multiplied into parent and commercial seed (certified seed). Forage seed production, processing, and marketing is done by private companies and/or farmer cooperatives.

2.3 Active Fodder Seed Companies

There are six major companies (Table 8) that are currently either producing, distributing, or both. Here is an outline of each of these companies, their contacts, and what types of forage seeds they are handling. Some of the information may not be conclusive as we respect the right of reservation to information as each company's policy dictates.

It would be important to note that some small-scale farmers dotted around the country were also trained in forage seed production through a project entitled E-SLIP.

Table 8. Seed companies and their phone contacts

S/n	Seed source	Contact (+260)
1	Advanta	977324688
2	Afriseed	211 847 735 / 950 847735
3	Agriserve	960349577 / 969767272
4	E-SLIP Forage Seed Growers	CIAT
5	Hygrotech	977 545 534
6	Klein Karoo	977762111 / 975732172

1. Advanta

Advanta Seed has been supplying and selling seeds through Klein Karoo over the past 5 years, but the company intends to start selling forage sorghum as Advanta Seed. The seeds that are being traded include:

- Nutrifeed
- Sugargraze

2. Afriseed

Afriseed is a company that has been trading cereals and legumes for human consumption. In the recent past, the company has incorporated the production of forage legumes as a protein source to address the dry season challenges that farmers face in Zambia. The main clients who buy seeds from the company are smallholder and medium-scale farmers. The company has recently reported increased seed sales due to heightened interest from emerging farmers. The company reports that demand currently outstrips supply. Among the legumes being sold are:

- Dolichos lablab
- Velvet beans
- Cowpea

Due to the increased demand for forage legumes, the company has focused on capacity building their staff in pasture production of both legumes and grasses. The company has focused their effort establishing demonstration plot of different pastures and legumes as a way of building the pasture section. The company focuses on such pastures as:

- Rhodes grass
- Siratro
- Desmodium
- Stylosanthes
- Bana grass

3. Agriserve

The company has seen an expanded interest in brachiaria and Rhodes grass from farmers. This trend was observed in 2019, but this did not translate into sales; however, an uptick in sales did occur in 2020. Their clientele base primarily consists of commercial farmers who buy in large volumes, with a small percentage being smallholder farmers. Among the notable varieties that Agriserve sells are:

- Brachiaria Marandu
- Brachiaria Piata
- Brachiaria Ruziziensis
- Panicum Mombaca
- Panicum Zuri

Agriserve has branches in Lusaka and Chisamba.

4. E-SLIP forage seed growers

Through E-SLIP, the Ministry of Fisheries trained 55 farmers in seed production principles. The 55 seed growers are smallholder farmers located in 22 districts across 9 provinces and are comprised of 35 males, 20 females, and 1 youth. The seed growers were trained on a contract-based buyback system. The objective of training the 55 seed growers was to make forage seeds available, accessible, and affordable to smallholder farmers across the country.

The contract buyback system has been implemented over three seasons to present, during which time there has been an increase in production from one season to another. This concept has led to the creation of 55 rural fodder seed banks.

At the institutional level, two livestock breeding centers – namely, Chipompo in Northern province and Mukulaikwa in Central province – produce forage seeds.

5. Hygrotech

More information is yet to be collected from this company. However, their representatives indicated that they were marketing the following varieties:

- Kikuyu grass
- Panicum maximum

- Stylosanthes scabra cv seca
- Stylosanthes hamata V8
- Lucerne
- Red clover
- Forage sorghum (cow candy, sugar graze)

6. Klein Karoo

Klein Karoo was established in 2011 and is one of the biggest companies supplying pasture seeds to farmers. They have a very strong demonstration center in Chisamba, which has been a pioneer of demonstrating pasture production to smallholder farmers. A number of organizations and individual farmers have been trained at their demonstration center in Chisamba. Among the notable pasture varieties the company sells are:

- Rhodes grass
- Panicum Maximum
- White Buffalo
- Blue Buffalo cv Molopo
- Blue Buffalo cv Gayanda
- Kikuyu
- Love weeping grass
- Velvet beans
- Sunnhemp
- Sugar graze
- Pigeon pea
- Cowpea
- Dolichos lablab
- Nutrifeed
- Lucerne

Klein Karoo has branches in Chisamaba and Lusaka (Makeni and Mungwi road) that supply seed to both commercial and small-scale farmers across the country.

7. Livestock Services

Livestock Services Cooperative Society is a nonprofit organization established by the Zambian farming community in 1991. Its aim is to become the leading livestock & agricultural cooperative in Africa through the provision of quality products at the most competitive prices. This organization is the largest retailer and wholesaler of livestock products in the country (Table 9). They stock different types of seed depending on market demand and seed availability.

Table 9. Current fodder seed market prices

Average Market Prices For Pasture Seeds			
S/N	Item	Package Size (Kg)	Price (Zmw)/Package
Grasses			
1	Kikuyu	1	2000
2	Brachiaria	5	2000
3	Panicum Maximum	5	1800
4	Rhodes Grass	5	1500
5	Weeping love grass	1	180

Average Market Prices For Pasture Seeds			
S/N	Item	Package Size (Kg)	Price (Zmw)/Package
6	Teff Grass	1	60
7	Blue Buffalo	1	350
Legumes			
1	Velvet Beans	1	42
2	Lablab	1	85
3	Pigeon Pea	1	42
4	Cowpea	1	42
5	Lucerne	5	2,300
6	Stylosanthes	5	2,200
Forage sorghums			
1	Nutrifeed	1	300
2	Sugargraze	1	160

2.4 Discussion

From our study, it was obvious that the majority of livestock farmers (majority being small scale) do not readily have access to quality forage seed, nor do they have sufficient knowledge on the establishment of improved pastures. The seed and the agronomical and economical information that move in tandem were available only for the minority commercial sector. The challenges facing the forage seed system in Zambia can be looked at from four main parameters: production, distribution, seed regulation and adoption.

i) Production
- No national forage seed breeding institution is functional to establish the most ideal forage species for specific areas.
- Inadequate knowledge of fodder establishment (farmers and extension officers).
- Poor irrigation infrastructure as a back-up to the impacts of climate change.
- Low accessibility to quality seed.

ii) Regulation
- Insufficient knowledge from seed control authorities on the modalities that determine the quality of forage seed. There has historically been a focus on food crop seeds; thus, there is a need for sensitization.
- Due to the above point, the process of importing quality seed is very rigorous and often very time-consuming.
- Informal seed sales are the norm and, as such, the quality of seed is not certain. This often leads to poor performance of the forages.

iii) Distribution
- Most of the seed suppliers are retail outfits situated along the rail line. As such, rural livestock farmers do not have access to the few seed suppliers in the country.
- The high cost of packaging equipment and material often compromises the quality of packaging that, in turn, reduces the seed viability by the time of planting.

iv) Adoption
- Many farmers utilize local grass (such as hyparrhenia) for dry season feeding despite the low nutritional quality of the hay.
- The high cost of certified seed makes it unaffordable to many farmers.

2.5 Opportunities

There are a number of opportunities for the development and scaling up of the forage seed system in Zambia, some of which include:

- Increasing demand for forage seed. There is a huge demand for forage seed, as evidenced by the inability of the seed suppliers to meet local market demand, especially for grasses (Rhodes grass, Brachiaria and Panicum maximum) and, increasingly, for legumes as well.
- Zambia currently has one of the best milk prices in the region (USD 0.50 – 0.60/ Lt). This price has made farmers realize that sustaining milk production throughout the year is more profitable than most other farming ventures. As such, there is more willingness for the uptake of improved pasture practices.
- The government has enacted deliberate policies to ensure that the livestock sector is highly prioritized. One example is the creation of a directorate office for rangeland and pasture development at the Ministry of Livestock and Fisheries.
- Cattle disease control efforts have led to increases in livestock numbers, thus creating demand for improved rangelands.
- The climate in Zambia is ideal for the establishment of most tropical forages.
- The geographical position of Zambia is strategic as a forage seed producing hub that can supply the sub-Saharan region and beyond.

2.6 Key takeaways

This study shows that the forage seed system in the country is still in its infancy. There is a need for the formal sector to play a much bigger role in the development of the sector to meet the growing demand for forage seed. There is also a need to have a holistic forage/fodder training component in extension staff curriculum to have a stronger knowledge base concerning fodder establishment. Strengthening research in the selection and breeding of relevant fodder species, along with upgrading existing research centers, is imperative to reduce the knowledge gap.

Forage seed should also be integrated in the Farmers Input Support program, which is a government-subsidized, agro-support program. By so doing, a clear database of forage seed consumers would be established for easy monitoring of seed quality and forage crop performance. Specially designated agro-dealers and community groups would be used to ensure that forage seed reaches the end-users at the correct time. Rural shops, groceries, '*tumtembas*' and veterinary drug retail outlets are promising channels for disseminating information about the availability of forage seed to customers. This would greatly improve the distribution channels and ensure that the most ideal forage species are distributed specific to the area within and outside Zambia.

3. POTENTIAL ANNUAL FORAGE SEED REQUIREMENT AND FORAGE SPECIES FOR PROSPECTIVE BUSINESS IN ZAMBIA

3.1 Selection of representative forage species

In order to choose forage species for viable forage businesses in Zambia, the following criteria was used:

i) *Species that are used to some extent in Zambia*: While the use of released and registered forage varieties in Zambia was considered, we did not identify a catalogue of released forage varieties in the country as for food crops (e.g., maize). We considered the possible introduction of newer forage materials from outside, as they may be more beneficial in terms of biomass yield and nutritional value.

ii) *Nutrient requirements*: Keeping livestock nutrient requirements such as metabolizable energy (ME) and crude protein (CP) in consideration, we focused on three forage grasses containing moderate protein and energy levels (Panicum, Rhodes, Brachiaria) and three legume forages rich in protein and moderate in energy (Lablab, Cowpea, Stylosanthes).

iii) *Local adaptation*: Forages should be adapted to Zambian ecologies, especially where rain-fed production is possible or in areas where irrigation could be employed.

iv) *Livestock maintenance and growth*: The forages selected produce relatively high biomass yields that are also of good quality and digestibility, thereby making available the desired nutrients for maintenance, growth, production, and reproduction of animals.

Based on reconnaissance survey and literature, we selected Rhodes grass (*Chloris gayana*), *Panicum maximum,* Cowpea (*Vigna unguiculata*), Lablab (*Lablab purpureus*) and Stylo (*Stylosanthes guianensis*). Keeping in mind possible forage introduction into Zambia, we also included *Brachiaria* hybrid, e.g., 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. We extracted biophysical suitability criteria and associated thresholds for these forages' from the **Tropical Forages tool** and confirmed this information using forage experts in ABC and ILRI (**Table 10**). Following the methodology documented in Notenbaert et al. (2018) and using ABC's **land-targeting tools**, suitability maps were produced for current as well as future climate conditions (**Annex 1**). Selected forages come with different agronomic traits and dry matter yield potential (Table 11).

The different forage crops exhibit different ranges of suitability. Together, they provide options for growing forages across large areas of Zambia, though with a general trend of higher suitability in the highlands, due to their more favorable underlying agro-climatic conditions. In comparison with legumes, the suitability of the grasses generally extends further into the drier areas, with Rhodes grass being more adaptable than *Brachiaria* Mulato II and *Panicum maximum* being the most demanding grass in terms of agro-ecological conditions. In addition, climate change is projected to impact legumes more than grasses.

Climate smart properties, pests and diseases

Forages have various attributes that contribute to ecosystem health and services. They tend to grow relatively well in sub-humid to semi-arid areas, with excellent water use efficiency and a deep rooting system that contributes to soil carbon through turnover (Ludlow et al., 1985; Skerman and Riveros, 1990; Guenni et al., 2002). Brachiaria species through brachialactone compounds contribute to nitrification inhibition, thereby minimizing nitrate (NO_3) and nitrous oxide (N_2O) emissions, both of which have significant environmental consequences (Subbarao et al., 2009). Additionally, the use of more nutritious forages leads to low greenhouse gas emission per unit animal product (milk, meat).

Panicum and Rhodes grasses do not exhibit major diseases and pests of economic importance in the region; however, lablab and cowpea are often affected by fungal rusts associated with moist conditions (Dey et al., 2022). *Stylosanthes* is affected by anthracnose and head blight. The former causes "tar spots" on leaves and stems and ultimately kills susceptible varieties. The best control is selection of resistant varieties. *Brachiaria* hybrids are attacked by spidermites. Spidermites appear mostly during dry weather, but because the spidermites are phobic to wet conditions, they disappear during rains.

Gender contribution

From smallholder farmers' perspectives, the forage value chain provides engagement opportunities at the various nodes. At the production node, the involvement of women, men, or youth in seed/planting materials production, seedlings, and hay is possible. Moreover, all these activities provide opportunities for small businesses involvement (Mwangi and Onyango, 2019). The on-farm cultivation of forages can reduce the overall workload associated with livestock, as less feed must be collected from roadsides and other communal areas. At the household level, these forages are beneficial in increasing milk and meat production, including in small ruminants, thereby contributing to household income and, potentially, nutrition. To make sure women benefit from this increased income, considerations include:

i) Making seeds/planting material accessible to women, as women often lack access to the formal seed system;

ii) Ensuring the forages are also easy to handle (upright growth, soft); and

iii) Exploring and transforming some gender norms, roles, and decision-making power so that women do not increase their workload while losing control over income generated from livestock production.

Table 10. Forage types and thresholds used for the suitability analysis

Forage	Common name	Type	Temperature (°C)		Precipitation (mm)		Length of Growing Season		Elevation (m)		Soil pH		Soil Organic Carbon (mg/ha)	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Brachiaria	Mulato II Hybrid	Perennial grass	15	35	700	2615	24	52	0	1800	4.6	8	10	1000
Chloris gayana	Rhodes grass	Perennial grass	5	50	310	4030	24	52	0	2400	4.5	10	20	1000
Lablab purpureus	Lablab	Annual legume	3	30	500	3000	11	52	0	2000	4.5	7.5	10	1000
Stylosanthes guianensis	Stylo	Weak perennial legume grass	19	27	700	5000	11	52	1000	2000	4.0	8.3	20	1000
Vigna unguiculata	Cowpea	Annual legume	25	35	650	1100	10	16	0	1500	4	7	20	1000
Panicum maximum	Panicum	Perennial grass	15	30	1100	2500	24	52	0	2000	5	8	10	1000

Table 11. Selected forage species for the study and their agronomic attributes

Forage	Seed rate (kg/ha)	Days to first cut (perennials)	Days to regrowth cutting (perennials)	Days to cutting after sowing (annuals)	Potential yield (t/ha/year)
Panicum	3	75-90	30-45	–	20
Rhodes grass	3	90-150	60	–	15
Stylo	4	–	–	95	10
Lablab	20	–	–	90	8
Cowpea	20	–	–	70-90	8
Brachiaria-Mulato II	8	90	30-45	–	17

– implies not applicable

3.2 Estimation of the forage seed requirement in Zambia

The feed balance data for Zambia is unavailable. Therefore, the following approach was adopted to estimate forage seed requirement in Zambia. Livestock population (Cattle, sheep, goats) were converted to tropical livestock units (TLU, equivalent to 250 kg lwt). The TLU was used to estimate the annual dry matter (DM) requirement at 3% live body weight. Due to a lack of national forage deficit, we estimated this from a recent farmers survey (Mwilima et al., 2021; Mulindi et al., 2021; Mwansa et al., 2021; Mulindi et al., 2021b) that was taken in the Southern province of Zambia.

- ⇨ Annual Cattle Feed Demand (cattle, sheep, goats) - AFD (Roughages and concentrates)
- ⇨ Annual Roughages Demand - ARD (70% of AFD) (feed in developing countries, including Zambia, is generally comprised of 70% roughage and 30% supplementation)
  Annual Roughages Deficit - ARDe (29.14% of ARD) (Mwilima et al., 2021; Mulindi et al., 2021; Mwansa et al., 2021; Mulindi et al., 2021b). The deficit prevails with all roughages considered (natural pastures, cultivated forages, and crop residues) i.e., the Basal diet
- ⇨ Annual Cultivated Forage Deficit – ACFDe (33% of ARDe to account for recommended cultivated forage inclusion in roughage for sustainable food production systems; see next paragraph)
- ⇨ AFD = 8,094,787.5 tons (computed from TLU)
- ⇨ ARD = 8,094,787.5 *0.70 = 5,666,351.25 tons
- ⇨ ARDe = 5,666,351.25 * 0.2914 = 1,651,505.1 tons
- ⇨ ACFDe = 1,651,505.1*0.33 = 544,996.68 tons

As cultivated forages are for supplementation, we scaled back estimations at 33% of the deficit of the basal diet (roughages are 70% of the diet). We have taken this level of the 33% replacement of roughages with cultivated forages, keeping food system sustainability in mind because the land used for the cultivation of forages has potential competition with the food grain crops. A cultivated forages level of 33% of the roughage total is the minimum required to elicit a good animal production response under developing country scenarios, provided the concentrate feeds (30% of the diet) has a good protein level. Also, for the sustainability of food systems, it is prudent that the concentrate portion of the diet is comprised of components (e.g., agro-processing by-products) that do not compete with human food and that the rest of the roughages (aside from cultivated forages) are comprised of crop residues, tree leaves, and pasture biomass, among other human non-edible biomass.

Key assumptions

- Inclusion of cultivated forages at 33% of the roughage in livestock ration to cater for sustainable food systems as farmers grow other crops.
- The seed system is functioning for each of the forage types and, therefore, enough seed is available and 100% adoption to cover the DM deficit.
- Forage seed supply and demand pull is growing with stable policy support.
- The selected forages are adopted to the extent of 20% for grasses and 10% for legumes at the annual rate of 10% each.

Many farmers prefer to cultivate perennial forages, which occupy the allocated piece of land without having to replant seasonally e.g., *Panicum maximum*, *Brachiaria* hybrid and *Chloris gayana* for grasses. However, some farmers prefer annual forages that would allow growing other crops thereafter. For this reason, we incorporated an annual forages grass (*Lablab purpureus, Vigna unguiculata and Stylosanthes guianensis*).

Adoption rate

Adoption would happen simultaneously for the various forage species over the span of several years. According to Schiek et al. (2018), forage adoption in eastern African countries varies depending on the area, with humid and sub-humid areas standing a higher chance of adoption. Using an economic surplus model, the study using showed that the adoption rate in (i) the mixed crop and livestock, rain-fed, arid/semi-arid (MRA); (ii) mixed crop and livestock, rain-fed, humid/sub-humid (MRH); and (iii) mixed crop and livestock, rain-fed, temperate/tropical highlands (MRT) zones of Ethiopia have higher potential than the much drier lowlands. From the study, the high potential zones MRA, MRT, MRH come with adoption likelihood of 2, 3, and 4, respectively, on a scale of 1-5, where 1 = not at all likely, and 5 = very likely. Later, a score of two was assigned 25% likelihood, based on the figures in Uganda wherein the same scale of 1-5 was used. We take a conservative figure of 20% for grasses and 10% for the legumes for the extent of adoption as cited by Dey et al (2022). The legumes are difficult to grow and maintain and hence their adoption likelihood is expected to be lower. If the entire cultivated forage deficit for one year is to be met by these six forages, a total of ≈383 tons of forage seed would be required in the first year (**Table 12.** Forage seed required for selected forages). However, their adoption rate would differ and, taking an average annual adoption rate of 10%, the quantity of seed required for the first, second, and third year would be 38.3, 67.7, and 97.1 tons, respectively (**Table 13**). As such, at any level of adoption, a reasonable quantity of seeds would be qrequired.

Table 12. Forage seed required for selected forages

Common name	Seed rate (kg/ha)	Potential DM yield (tons/ha/yr)	Forage Area Required (FAR) (ha)	Forage Seed Required (FSR) for meeting the deficit by one of the selected forages (tons)
Panicum	3	20	27,250	81.7
Rhodes grass	3	15	36,333	109
Stylosanthes guianensis	4	10	54,500	218
Lablab	20	8	68,125	1,362
Cowpea	20	8	68,125	1,362
Mulato II	8	17	32,059	256

Table 13. Annual forage seed requirement (AFSR) in tons

Forages	AFSR forages grown simultaneously deficit[a]	Annual FSR for the first 10 years[b] (tons)									
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Panicum	16.34	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Rhodes grass	21.8	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Stylosanthes guianensis	21.8	2.2	4.4	6.6	8.8	11	13.2	15.4	17.6	19.8	22
Lablab	136.2	13.6	27.2	40.8	54.4	68	81.6	95.2	108.8	122.4	136
Cowpea	136.2	13.6	27.2	40.8	54.4	68	81.6	95.2	108.8	122.4	136
Brachiaria	51.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Regeneration seed[c] (perennials)	-	-	-	-	-	-	-	-	8.9	8.9	8.9
TOTAL	**383.54**	**38.3**	**67.7**	**97.1**	**126.5**	**155.9**	**185.3**	**214.7**	**253**	**282.4**	**311.8**

[a], when 100% of annual cultivated forage deficit met in the first year by growing simultaneously the four grasses @ 20% each and two legumes; [b], 10% increase per annum (a life span of 10 years was taken for the perennial grasses); [c], for the three perennial grasses

Seed replacement rate

For the perennial forages, once the strand is established, it could stay for long time before replanting. Specifically, a grass strand of the perennial grasses considered here could produce for 8 to 10 years with good management. Keeping the forages weed-free and top dressing with nitrogenous fertilizers annually are key for the longevity of the perennial forages; this management practice is often where the producers fail, necessitating a fresh planting. While the establishment is possible from seeds or vegetatively using splits, the splits are bulky, which increases the labor cost, especially if the land size is extensive. Legumes fix atmospheric nitrogen, but the addition of phosphorus – especially at planting – bolsters their performance. The forages remain productive while providing quality feed. Annual forages, on the other hand, require a fresh planting once harvested. In most of Eastern Africa, rainfall is bimodal and planting annual forages twice in a year is therefore possible.

With the given proposition, awareness creation for the need of forage cultivation, feed planning, and budgeting, coupled with capacity development of farmers, are some of the key requisites for forage seed uptake. The development and adoption of forage business cases with financial margins could precipitate the uptake of forage cultivation with knock-on effects on forage seed demand, which in turn would contribute to increased livestock productivity in Zambia.

3.3 Key takeaways

To address low livestock productivity in Zambia, the cultivation of improved forages is important to provide key nutrients for the animal performance. While multiple reasons exist for low forage cultivation in Zambia, availability and access of forage seeds is one of the major concerns pointing on the need for functional forage seed system. The forages we propose here – namely, *Panicum maximum*, *Brachiaria-* Mulato II and *Chloris gayana* (grasses), *Lablab purpureus*, *Vigna unguiculata and Stylosanthes guianensis* (legumes) – are not only productive and nutritious under good management but are adaptable and do well under irrigation. The outlooks for the seed requirement for the above forages for the first four and ten years are approximately 126 and 311 tons, respectively. These figures should stimulate livestock improvement planning in Zambia with focus on boosting forage value chain actors. Livestock market pull exists in Zambia, especially for the commercial feedlots, quarantine stations, and commercial-oriented dairy. These are potential triggers for forages adoption, with knock-on effects on forage seed demand and, eventually, to improved livestock productivity in Zambia.

4. NUTRITIONAL, ECONOMIC, AND ENVIRONMENTAL ASSESSMENTS OF CULTIVATED FORAGES

4.1 Nutritional evaluation

The nutrient composition of the selected cultivated forages is given in **Table 14**. Based on the CP contents, lablab, cowpea, and *Stylosanthes* can be considered as high-quality fodders, while *Panicum maximum*, *Chloris gayana*, and *Brachiaria* can be categorized as medium quality fodders.

Table 14. Nutrient composition of the selected cultivated forages

Cultivated forages	CP (% in DM)	ME (MJ/kg DM)
Panicum maximum (e.g., Mombasa)	7.2	8.4
Chloris gayana	9.0	8.5
Stylosanthes guiyanensis	14.0	8.0
Lablab	18.4	9.2
Cowpea	18.1	9.8
Brachiaria (hybrid)	9.2	8.0

Source: www.feedipedia.org

Here we assess the potential of cultivated forages in meeting the nutrient requirements of fattening and dairy animals and of animals during the drought period.

Using the medium quality forages, *Panicum maximum* (e.g., Mombasa), *Chloris gayana*, and *Brachiaria*, a diet containing only 9% CP and 8.4 MJ/kg DM can be prepared. A proper mixing of the medium and high-quality forages would enable formation of a diet containing 10% CP and around 8.5 MJ/kg dDM. During the pellet, block, or cube formation, 6% of molasses is generally added as a binder. Molasses is rich in ME (10.4 MJ/kg liquid bases) and 6% addition of molasses would enhance the ME of these grass pellets. The addition of a small amount of grains (ME is between 13.0 and 13.5 MJ/kg) or distillers grains (ME is between 13.0 and 14.0 MJ/kg) could also be added as a binder and ME enhancer of the pellets. From the six forages listed in this section, a diet containing 9.3 MJ/kg of ME and 10% CP on a DM basis is possible, and a substantial part (*ca* 70%) of the diet would be composed of these forages. We have shown earlier (Dey et al., 2022) that this diet (10% CP and 9.3 MJ/kg of ME) is able to meet daily growth rate of the animals, from 0.5 kg to 1.3 kg. Our survey and the literature show that the growth rate of animals that are fattened for beef production in Zambia under different production systems (extensive and intensive) ranges from 0.5 kg to 1.3 kg.

In Zambia, the feedlot farmers do not buy prepared mash feed or concentrate feed from feed manufacturers for use as a supplement with hay or straws. The reason for this is that they find the cost of these prepared feeds prohibitive. The feedlot farmers buy individual components and prepare the feed on-farm. For adoption of the cultivated forage-based total mixed ration (TMR) by feedlot farmers, its cost must be substantially lower than the cost of the feed they prepare on-farm themselves by buying individual feed ingredients and mixing them. These aspects are discussed in the **4.2 Economic** analysis.

For achieving daily growth rates from 0.5 to 1 kg, different amounts of the forage-based diet would need to be fed which, according to our analysis (Dey et al., 2022), varied from 2.5 to 3.0% of body weight. Generally, animals upper limit of intake is approximately 3.5% of the body weight. In the crop-livestock mixed systems, farmers could have hay or straw from their own fields, and these are at no-cost to the farmers. In such a situation, the farmer can reduce the cost of feeding by reducing the amount of cultivated forage-based diet, and meeting energy and protein requirements from locally stored hay and/or straw; however, these feed resources are low in nutritive value (CP value of 4.5-6% and ME of 5-7 MJ/kg). In such a situation, the reduction in ME and CP because of decreased cultivated forage-based diet can be compensated by hay or straw so that the diet (forage-based plus hay or straw) intake does not exceed 3.5% of the body weight. Such an approach would decrease the cost of fattening in the crop-livestock mixed systems. It may be noted that, in feedlot animals, an intake of up to 4.66% of the body weight has been recorded (Gebremariam, 2019).

This study also showed that a feed intake of 4.61% of the body weight of a diet containing 6.1% CP (6 kg hay containing 5.5% CP and 4 kg maize containing 7.1% CP) supported an average daily body gain of 1.3 kg of fattening bulls, from an initial body weight of 220 kg to a final slaughter weight of 339 kg. The cultivated forage-based diet of 9.3 MJ/kg ME and 10% CP would also be able to sustain a daily body gain of 1.3 kg, albeit at intake at around 4% of the animal body weight.

From the DM yields of the *Panicum* forages, it could be surmised that a 500 ha farm would be able to fatten around 10,000 adult animals in one year. On average, approximately one ton of *Panicum* forage is required to fatten one animal in one cycle of 100-120 days (Dey et al., 2022). The number of animals that can be fattened in one cycle (3 cycles in one year) would be around 3,000 animals.

Dey et al. (2022) also showed that increases in daily average growth rate from 0.5 to 0.75 kg increased the feed use efficiency by almost 50%. The slower the gain in body weight, the more feed is required per unit body weight gain. Feed is an expensive input, and feed production is very energy demanding. The more fossil energy is needed, the higher the amount of greenhouse gas emissions. Therefore, an increase in average daily body weight gain would decrease cost of feed as well as greenhouse gas emission per unit of meat production. Furthermore, lesser the feed consumed, lesser is the methane production from the rumen of animals. This translates to an overall 'win-win' scenario, with more economic meat production and decreased greenhouse gas emissions. Increases in the daily growth rate could be achieved through (i) an increase in the genetic potential of animals and (ii) feeding a balanced diet. The government should address these issues in policy formulation. The use of a total mixed ration, for example, in the form of a cultivated forage-based pellets, is an attractive proposition towards meeting this goal. It enables easy delivery of a balanced ration to the animals. A number of approaches can be devised to achieve this, but these are beyond the scope of this study and hence not discussed. Certainly, the above options need to go hand-in-hand with improvements in animal health and other farming practices, including proper housing and free availability of drinking water.

In conclusion, diets containing a substantial portion of cultivated forages can support fattening of animals in Zambia. Feeding such diets would substantially decrease the cost of fattening, increase the farmers' profitability, and contribute towards greening of the livestock sector, as illustrated in the **4.2 Economic** analysis section.

Dairy animals

For dairy animals, a forage-based diet of 9.3 MJ/kg ME and CP of 10% was able to meet both ME and CP requirement for only 2 liters of milk production/day. For higher production (> 2 and ≤ 10 liters/day), a supplementation of protein-rich ingredients such as oilseed cakes (around 7% of the diet) would be required (Dey et al., 2022).

A better-quality diet (CP of 14% and ME of 9.3 MJ/kg) can be prepared by mixing the selected cultivated forage-containing diet (**Table 14**). Also, depending on the forages selected – especially those categorized above as medium quality forages – oilseed cakes (as protein source) and maize, by-product from starch products, wheat, or cassava meal (as energy sources) would need to be added to achieve a diet containing 14% CP and 9.3 MJ/kg. Taking a cut-off limit for animal intake of 4% of body weight, this diet would be able to meet nutrient requirements to yield: 15 liters of milk/day from animal of 300 kg and 350 body weights; up to 20 liters/day from animals of 400 kg and 450 kg body weights; and up to 25 liters of milk/day from animals of body weight 500 kg (Dey et al., 2022).

To illustrate further, the use of fresh cultivated forages at lower levels (around 25% of the diet) in a situation where cultivated forages are not available in abundance, diets using lablab (one among the high-quality forages) are given in **Table 15**. Also, ME and CP requirements to yield daily milk of 20 liters and 25 liters from animals with body weights of 450, 500, and 550 kg are given in Table 16. Likewise, the use of *Panicum* (one among the medium quality forages) at varying levels in fresh form along with other commonly available feed resources can meet the nutrient requirements of animals to obtain daily up to 25 liters of milk (data not shown).

Table 15. ME and digestible crude protein (DCP) requirements of dairy animals

Body weight (kg)	Milk yield (kg/day)	ME requirement (MJ/day)	DCP requirement (kg/day)
450	20	153	1.307
	25	179	1.572
500	20	157	1.327
	25	183	1.592
550	20	161	1.346
	25	187	1.612

ME requirement of maintenance = 0.48(BW)*$^{0.75}$
ME requirement of milk = 5.3 MJ/kg (fat of milk 4.3% and protein 3%; See Annex 1)
g DCP requirement of maintenance = 2.5(BW)*$^{0.75}$
*g DCP requirement per liter of milk = 85*0.625*
(For DCP requirement calculation, 62.5 % CP digestibility of feed has been taken)

Table 16. Feeding requirements for animals of different weights and milk yielding capacities

Ingredients	Fresh weight (kg)	Dry weight (kg)	ME content (MJ)	DCP content (kg)
Animal body weight 450 kg, yielding daily 20 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	7.3	6.6	85.8	0.462
Wheat bran	3.3	3	30.3	0.39
		13.6	**152.9**	**1.344**
Intake of this diet would be 3% of the body weight, and percent Lablab in DM is around 29%.				
Animal body weight 450 kg, yielding daily 25 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	8.4	7.6	98.8	0.532
Wheat bran	4.8	4.3	43.43	0.559
		15.9	**179.03**	**1.583**
Intake of this diet would be 3.5% of the body weight, and percent Lablab in DM is around 25%.				
Animal body weight 500 kg, yielding daily 20 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	7.9	7.1	92.3	0.497
Wheat bran	3.0	2.7	27.27	0.351
		13.8	**156.37**	**1.34**
Intake of this diet would be 2.8% of the body weight, and percent Lablab in DM is around 29%.				
Animal body weight 500 kg, yielding daily 25 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	8.9	8	104	0.56
Wheat bran	4.7	4.2	42.42	0.546
		16.2	**183.22**	**1.598**
Intake of this diet would be 3.2% of the body weight, and percent Lablab in DM is around 25%.				
Animal body weight 550 kg, yielding daily 20 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	8.4	7.6	98.8	0.532
Wheat bran	2.8	2.5	25.25	0.325
Total		**14.1**	**160.85**	**1.349**
Intake of this diet would be 2.6% of the body weight, and percent Lablab in DM is around 29%.				
Animal body weight 550 kg, yielding daily 25 liters of milk				
Lablab	16	4	36.8	0.492
Maize grains	9.2	8.25	107.25	0.5775
Wheat bran	4.7	4.2	42.42	0.546
Total		**16.45**	**186.47**	**1.6155**
Intake of this diet would be 3% of the body weight, and percent Lablab in DM is around 25%.				

These results illustrate that balanced diets can be prepared using cultivated forages and other locally available feed ingredients for a wide range of milk production from animals of varying body weights.

Feeding during drought

The main aim of feeding during emergencies is to meet only the maintenance requirements from the feed. Nutritional analyses of a forage-based diet of ME of 9.3 MJ/kg and CP of 10% showed that this diet, at an intake of < 2% of body weight, meets the maintenance requirement of animals (Dey et al., 2022).

Total mixed ration (TMR) versus feeding as individual components

The feed prepared by feedlot and dairy farmers is generally imbalanced, and a substantial amount of the feed gets wasted by animals (since animal can chose the good quality feed ingredients and leave the poor ones untouched), while this is not possible when a TMR is fed. The use of TMR reduces wastage, and it allows for the feeding of a balanced diet. The use of TMR also has other advantages; for example, the nutrients are released in a synchronized manner in the rumen, leading to higher feed nutrient utilization and higher feed use efficiency. In addition, this would decrease methane (a greenhouse gas) from ruminants. The overall impact of feeding forage-based TMR would be more animal source food from less feed and, since feed production is resource demanding in terms of energy and water use, the use of forage-based TMR would result in reduced greenhouse gas emissions. In addition, feeding a TMR takes less time than that required for mixing individual ingredients and then feeding them. In most situations in developing countries, the feeding is done by women. The saved time can be used for other productive activities (e.g., tending to children's education, nutrition, and health). All these offer gains from economic, environment, and social perspectives – a triple win as envisaged in three-dimensional definition of sustainability (Makkar, 2016).

Key takeaways

Key takeaways from the above presented three subsections are as follows:

i) A forage-based feed containing 10% CP and 9.3 MJ/kg of ME, which could be formed from the forages identified for cultivation, would be able to support daily growth rates up to 1.3 kg of feedlot animals and other animals fattened for meat production. A large component of this diet (*ca* 70%) would be composed of the identified forages. This diet would also be able to support daily milk yield of 2 liters. This feed is also suitable for supporting animals during droughts.

ii) For cows producing daily milk of > 2 < 10 liters/day, the supplementation of any locally available oilseed cake at a low level (< 7% of diet) would be required to the diet containing 10% CP and 9.3 MJ/kg of ME.

iii) For high-yielding animals giving daily milk > 15 liters, a better-quality diet of 14% CP and 9.3 MJ/kg of ME could be formed by mixing non-legume and legume forages identified in this study. This diet, supplemented by a small amount of energy-rich ingredients such as maize grains (< 10% of the diet), would be able to support the daily milk yield of 25 liters. Should there be reduced availability of cultivated forages, the supplementation of energy- and protein-containing ingredients would be able to support feedlot animals growing daily up to 1.5 kg body weight, and dairy animals giving daily 25 liters of milk.

iv) If the feed is densified as pellets or blocks, it would offer advantages such as decreases in (i) transport and storage costs; (ii) feeding time, thus empowering women while reducing labor costs (because women generally feed the animals); and feed wastage and, as a result, increases in feed use efficiency, livestock productivity, and of natural resource use, and reductions in greenhouse gas emissions. The introduction of this innovative technology has the potential to generate employment, better integrate youth, and provide triple gains – higher profitability, social gains, and environment benefits.

4.2 Economic analysis

As is evident from the previous section, the feeds based on *ca* 70% forages would be able to meet the nutrient requirements of beef animals that have daily body weight gain of up to 1.3 kg, and of dairy animals yielding daily milk of up to 25 liters. This section assesses the economic feasibility of the cultivated forage-based pellets/blocks for feeding to different types of animals and under different situations including normal and drought situations.

Cost of production of cultivated forages vis-à-vis conventional feed ingredients

Methodology

The total DM production and cost of production of the five identified forages assessed is taken from 1**7.**. For assessing the cost of the conventional feed ingredients, sources were contacted and an average of the two values for each ingredient has been used. The selling prices of hay and concentrate feed used as a supplement were collected from feed dealers. The source of CP and ME data is from literature including databases (see www.feedipedia.org). The cost of production of the cultivated forages and the conventional feed ingredients were compared on per kg CP and per 1000 MJ for ME bases. All costs are presented in USD.

Results

Table 17. Cost of production of cultivated forages on the bases of DM, CP and ME

Cultivated forages	Cost of production (USD/ton DM)	CP (kg/ton)	ME (MJ/ton)	Cost (USD)/kg CP)	Cost (USD)/10³MJ of ME
Panicum maximum	8.55	72	8400	0.12	1.02
Chloris gayana	11.35	90	8500	0.13	1.34
Stylosanthes guiyanensis	45.87	140	8000	0.33	5.73
Lablab	53.13	184	9200	0.29	5.78
Cowpea	53.13	181	9800	0.29	5.42
Brachiaria (hybrid)	10.11	92	8000	0.11	1.26

The cost of production (USD) per ton DM varied from 8.55 for *Panicum* to 53.13 each for lablab and cowpea. Based on the CP contents, lablab, cowpea and *Stylosanthes* can be classified as high-quality fodders, while other three are medium-quality fodders. Costs per unit of CP and ME supply of the medium-quality forages are lower than that of the high-quality forages, which could be attributed to higher biomass production (1.5 to 2.5 folds; **Table 12)** and lower cost of production (almost five-fold) of medium-quality forages than the high-quality forages (**8**).

Among oilseed cakes, the cost (USD) per kg of CP varied from 0.66 for sunflower cake to 1.04 for soymeal. Grains are used as energy source and wheat brans for mainly energy source but are also have substantial amount of protein. On per unit CP and ME bases, brans are much better than grains (**Table 18**).

Table 18. A comparative evaluation of costs of cultivated forages and conventional feed ingredients on the bases of DM, CP and ME

Cultivated forages	CP (kg/ton)	ME (MJ/ton)	Cost (USD)/kg CP)	Cost (USD)/MJ ME)x10³
Cultivated forages (range)	72-184	8000-9800	**0.11 – 0.33 (0.17-0.50)**	**1.02 – 5.78 (1.53-8.67)**
Oilseed cakes				
Soymeal	530	10500	1.04	52.57
Sunflower cake	279	10900	0.66	17.0
Oilseed cakes (range)	279-530	10500-11900	**0.66-1.04**	**17.0-52.57**
Grains				
Wheat	126	13100	4.33	41.68
Maize	80	13600	2.74	16.10

Cultivated forages	CP (kg/ton)	ME (MJ/ton)	Cost (USD)/kg CP)	Cost (USD)/MJ ME)x10³
Grains (range)	80-126	13100-13600	**2.74-4.33**	**16.10-41.68**
Brans				
Wheat bran	160	11300	1.28	18.05
Maize bran	119	11000	1.50	16.18
Brans (range)	119-160	11000-13100	**1.28-1.50**	**16.18-18.05**
Commercial feeds				
Dairy concentrate	240	13000	2.45	45.15
Total mixed diet, dairy	140	11000	2.21	28.09
Total mixed diet, feedlot	NA	NA	NA	NA
Commercial feed (range)	140-240	11000-13000	**2.21-2.45**	**28.09-45.15**
Roughages				
Wheat straw	NS	NS	NS	NS
Rice straw	NS	NS	NS	NS
Maize stover	39	6900	0.28	1.59
Hay	80	7000	1.72	14.71
Maize silage	80	10500	0.21	1.63
Roughages (range)	39-80	7000-10500	**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%.

Cultivated forages have lower ME contents than the categories of feed listed in the table except in the roughage category, but the 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 supplied by the cultivated forages to the animals is much lower: CP costs are lower by 3-6, 11-26, and 5-12 fold than oilseed cakes, grains, and bran, respectively. Likewise, per unit of ME supply is also much lower when using cultivated forages by: 9-17, 7-16, and 3-16 fold than oilseed cakes, grains, and bran, respectively (these values get lowered by a factor of 1.5 in the scenario of 50% profit). Similar results were obtained for Ethiopia. The cost per unit of nutrient supply from cultivated forages was substantially lower than those from the other commonly used feed ingredients (Dey et al., 2022). These results suggest that meeting animal nutrient requirements would be much lower using cultivated forages. Cultivated forages can replace substantial amounts of concentrates in the diet, resulting in decreased cost of the diet and increased farmers' profits.

Opportunity cost of production of cultivated forages

The opportunity cost of cultivating forages against key crops grown in Zambia is presented in **Table 19** and **Table 20**. 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 with *Stylosanthes guianensis*, lablab, and cowpea. For cash-deprived farmers, it would be easier to cultivate forages and generate good profits, as the return-on-investment is higher for the forage crops.

Table 19. Profit/ha from cultivated forages

Cultivated forage	Cost of production (USD/t DM)	Selling price (USD/t DM)*	Profit (USD/t DM)	Yield DM t/ha	Profit, USD/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

**Selling price of cultivated forages was based on the current selling price of hay in Zambia (120 USD/t). Panicum 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 20. Cost of production per ton, market price, yield/ha and profit per hectare of some cash crops

Crop	Production cost (USD/ton)	Average yield (ton/ha)	Average market price (USD/ton)	Profit/ha (USD)
Maize (commercial)	250	10	235	-150
Maize (smallholder)	199	2.8	235	131
Wheat	294	8.5	420	1071
Soybean	428	3.5	588	560
Sunflower	342	1.52	400	88
Cotton	721	1.5	925	306
Cassava	755	5.8	1624	5040

Economics of cultivate forage-based pellet/block production

The costs of cultivation, densification to form pellets, and diet formation have been considered in the economic evaluation.

Methodology

With the aim to understand the viability and practicability of turning cultivated forages into compacted forms e.g., pellets/cubes/leaf meals/blocks, a questionnaire was developed to learn from the experiences in India, Mexico, Tunisia, and Kenya. Given the vast distances between areas of forage production and consumer regions in Zambia, and the cost involved in densification, we examined whether it is economically sound to use densified, cultivated, forage-based diets in feedlots, in dairying (especially in dry season), and in fodder banks (especially during emergencies). Therefore, it was considered important to generate information concerning the costs of transport and densification.

The costs of production of cultivated forages have been taken from **Table 17**. The transport cost, as collected from feed millers in Zambia, was 12 USD/ton/100 km; and the cost of densification is presented below. It has been taken from our earlier study (Dey et al., 2022).

- Cost of the densification machine, with all accessories, is from 80K to 110K USD for a production capacity of 20 tons per 8-hour (8-h) shift. This production capacity is considered appropriate for a business model based on 400 to 600 ha forage cultivation.
  An investment of approx. 100K USD is needed for the machinery required for densification.
- Cost of maintenance per year was taken as 3500 USD based on the information collected from the countries. This translates to 3500/6000 = 0.58 USD/ton (taking 300 working days in a year and 8-h shift per day; production of 20 tons/8-h shift).
- The running cost per ton was taken as an average of those listed by the respondents, which was 16.35 USD.
- Depreciation cost by taking life of machinery to be 20 years = 100000/120000= 0.83 USD/ton (running at 6000 ton/year). The working life of machinery was reported to be 18 years, 20 years, and 25 years in the case studies from the countries. Here we have taken working life to be 20 years.

A total cost of 0.58 + 16.35 + 0.83 = 17.76 USD/ton considers the running, maintenance, and depreciation costs of the machinery. The running cost includes the cost of additives such as molasses, minerals, and vitamins. For economic evaluation, a running cost of USD 18/ton was taken. Since the cost of labor and electricity in Zambia is of the same order as the average in these countries, a running cost of USD 18/ton was also taken for Zambia.

Results

Cost of diets without densification

In the previous section on nutritional feasibility, two types of feeds – Feed-A containing 10% CP and 9.3 MJ/kg ME, and Feed-B containing 14% CP and 9.3 MJ/kg of ME – have been 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 mixed 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 and this will also be an additional provider of ME, and its cost has been included in the running cost/ton as presented in previous section). The cost of such a feed, at the production site, can be taken as 16.4 USD/ton. However, if sunflower cake – which as the cheapest per unit cost of CP among the cakes taken (see **Table 18**) – as a CP source is added in absence of lablab or cowpea (8% of sunflower cake would need to be added), the cost of the feed would be 25 USD/ton. This also shows that 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 ratio with either lablab or cowpea. Both lablab and cowpea production costs are the same (53.13 USD/ton). The cost of Feed-B at the production site is expected to be (10*1 + 53.13*1.3)/2.3 = 34.38 USD/ton. However, its ME content is calculated to be 9 MJ/kg. The 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 USD/ton and 35 USD/ton for Feed-A and Feed-B at the production site (slightly on the higher side of the calculated value) for further economic analysis. These costs are without densification as pellets, and the pellets are comprised of all forages (no addition of oilseed cakes). It may be noted that the 500 ha should have cultivation of both grasses and legumes.

For further analysis, the cost of production at the production site taken are USD17/ton for Feed-A and 35 USD/ton for Feed-B.

Costs of densification and diets

A wide range of forages are cultivated, both under irrigation and rain-fed conditions. Feeds in the densified form, as blocks or pellets, are used in locations as far as 1500 km from their production sites in a number of countries. In India, over 70% of the grown forages are used in the fresh form. In Tunisia, the use of fresh forage is only 30%, while the use of hay is up to 50%. Forages are as broadly used as pastures (90%) in Mexico. In the countries surveyed, forages generally not converted to pellets and blocks at present. However, all respondents saw a high potential of these new products to be used as animal feed. The adoption rate [of forage to pellet conversion] 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). Increases in the use of the technology would create new job opportunities for youth and women.

The cost of pelleting or block formation is 18 USD/ton (see **Methodology** section). At the production site (sites of cultivated forage production and forage densification are very close to each other), the cost of production of cultivated forage-based pellets/blocks is expected to be 17 + 18 = 35 USD/ton for Feed-A and 35 + 18 = 53 USD/ton for Feed-B. If these are sold at a 50% profit margin, the selling price could be 53 USD/ton and 80 USD/ton, respectively. If the densified feeds are transported to other regions, the cost of transport needs to be accounted for, which is 12 USD/ton/100 km in Zambia, as per our survey. This assumes that the market is within a maximum radius of 500 km. The cost of feed, without any profit, turns out to be 35 + 60 = 95 USD/ton and 53 + 60 = 113 USD/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 USD/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 would be further reduced at a rate of about 12 USD/ton/100 km for the cost of transport. The costs per unit of nutrients (CP and ME) for densified feeds are given in **Table 21**. These costs are much lower than those of conventional feed resources, 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 USD/ton.

The cost of cultivated forages at the site of production (without densification) ranges from 8.6 to 53 USD/ton, and these cultivated forages are of much higher quality than hay. *Panicum*, which is produced at a cost of 8.6 USD/ton, has higher CP and ME (7.2% and 8.4 MJ/kg) than hay. This provides substantial leverage for 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 USD/ton, respectively, after a 50% profit) than hay. Hay alone cannot be used for fattening or dairy animals, while Feed-A and Feed-B can be used. The cost per unit nutrients (CP and ME) of Feed-A and Feed-B (**Table 21**) is also lower when compared with the conventional feed ingredients (**Table 18**).

Table 21. Costs per unit of nutrients of the densified feeds (prices have been adjusted for 50% profit)

Feeds	Cost (USD/kg CP)	Cost (USD/MJ ME)x10³
Feed-A, production site	(53/100) = **0.53**	(53/9300)*1000 = **5.70**
Feed-A, 500 km away from production site	(143/100) = **1.43**	(143/9300)*1000 = **15.38**
Feed-B, production site	(80/140) = **0.57**	(80/9300)*1000 = **8.60**
Feed-B, 500 km away from production site	(170/140) = **1.21**	(170/9300)*1000 = **18.28**

Pros and cons of the densification

Forages in loose form have low bulk density and hence are difficult to handle, transport, and store. Densification technologies provide opportunities to increase the bulk density manifold. The use of densified feeds has been shown to have several benefits for animals, livestock owners, and the environment (**Table 22**).

Table 22. Benefits of the densification of feed

Productivity and monetary benefits	Less wastage, higher animal productivity, ease of feeding, smaller storage space requirement, lower transport cost, and non-selection of feed ingredients by animals and, as a result, better utilization of poorer quality ingredients, less time required for feeding, prevention of fire, which could result on storage of forages in loose form, and long shelf life.
Women- and youth-related benefits	Currently, women are involved in forage harvesting, collection, drying, feeding, and dissemination of the technology. Feeding of pellets and blocks takes less time, which is attractive to both the youth and women. The innovative nature of the technology is attractive for youth. Both youth and women have role in running of the densified plants. Increased use of thetechnology would create new employment opportunities. In addition, enhancing skills to produce formulations, operate and maintain the machines and run the densified forage production as a small business would attract youth in this innovative technology. It is also expected to decrease the migration of youth which is of particular importance during the COVID-19 situation.

However, a number of constraints were also identified through our previous studies (Dey et al., 2022). There is irregular production of the densified forages as pellets or blocks, mainly due to restricted supply of raw materials and improper matching capacity of the densification machines with the availability of the raw materials. Farmers are well-familiarized with the use of fresh green forages or as hay and, hence, the introduction of forage-based pellets as feed is a challenge. In addition, there would be competition with the concentrate-based pellets available in the market. However, this constraint can be overcome if the quality of the forage-based pellets is high and costs are lower than the concentrate-based pellets, which is the case as evident from our analysis. Another challenge listed was the high cost of the machinery, which an individual farmer cannot afford; however, the machinery can be used by a group of farmers or by a private entrepreneur on the lines of a feed miller company. The high initial cost of the machinery, difficulty in getting finance to start the business, and farmers' lack of knowledge surrounding the use of improved feeds are other constraints. Furthermore, the higher cost of pellets than that of hay bales could discourage potential users, and other locally available feed resources (even though of lower quality) compete with the pellets. Outreach efforts including demonstration of the increased animal productivity and economic benefits to the farmers on using cultivated forage-based pellets/blocks would enhance adoption of the technology. Some other challenges are that the use of forage pellets is a new concept and extensive marketing efforts would be required. Besides, there is a confusion between the forage-based pellet and the dairy meal, both in the minds of farmers and the market, because the former is taken to mean dairy meal. Actually, the former (pelleted diet) is a complete diet and the latter (dairy meal) is a supplement and other feed ingredients need to be added to the latter to form a complete diet. Awareness creation among farmers and market players is required.

Cost of feeds for maintenance during drought periods: hay versus densified feed

For animals weighing 250 to 300 kg, daily consumption of the cultivated forage-based pellets/blocks for meeting the maintenance nutrient requirements of animals (Feed-A: CP of 10% and ME of 9.3 MJ/kg) is presented in **Table 23**. Hay (ME of 7 MJ/kg and CP of 6%) is generally used in the drought areas; the daily consumption of this hay required for meeting the maintenance nutrient requirements of these animals is also shown in **Table 23**. Taking the costs of these feeds for use during drought, daily savings of USD 0.20 and USD 0.23 (average 0.215 USD) per animal could be realized. In a dry spell of 100 days, saving per animal turns out to be 21.5 USD, or for 1000 animals a saving of 21500 USD, if the cultivated forage-based pellets/blocks are sold at 50% profit. Although we have the cost of Feed-A at sites 500 km away from the site of densification, we could not calculate the savings because the cost of hay at sites 500 km away from the site of hay production is unavailable. If the hay is to be transported 500 km, the cost of transport of hay/ton would be higher than that of Feed-A because the latter is densified. In such a scenario, the savings would thus be even greater.

Table 23. 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, USD	kg daily hay required for maintenance[1]	Daily cost of hay, USD	Saving per day, USD
250	3.58	0.29	4.76	0.49	0.20
300	4.11	0.33	5.46	0.56	0.23

Source: Dey et al. (2022); cost of hay in Zambia varies from 103 to 143 USD/ton (here the former has been taken)

Cost of feeds for feedlots using densified feed

For the feedlot animals, the use of Feed-A has been proposed and evaluated under three scenarios: (i) 1 kg/day growth rate; (ii) 0.75 kg/day growth rate; and (iii) 0.5 kg/day growth rate. This feed meets the nutritional requirements, as illustrated in the Nutrition evaluation section. To fatten animals from initial body weight of 250 kg to the slaughter weight of 350 kg at different growth rate, the feed required is presented in **Table 24**.

Table 24. Feed-A requirement for fattening and their costs[1]

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

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

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. The costs of feed for one animal for these three scenarios are 63.6, 76.9, and 115.4 USD, respectively. The cost per kg of daily body weight gain comes to 0.64, 0.77, and 1.15 USD when daily body weight gain is 1, 0.75, and 0.50 kg respectively. Certainly, it would be cheaper to produce meat from

[1] Cost of Feed-A at 500 km away from the production site (80 USD/ton) has been taken

animals of good genetic potential (for example those growing at 1 kg/day) than those from animals of poor genetic potential (for example 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 cost per unit of ingredients from the densified cultivated forages is 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 made an attempt to calculate 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 USD/ton and of wheat bran as 204 USD/ton, the diet cost per kg of daily body weight gain comes to 0.618 + 0.816 = 1.43 USD. This is almost 2-fold higher than the cost of a diet based on cultivated forage-based pellets (0.64 USD/kg body weight gain; Scenario 1 above). In addition, the use of densified cultivate forage-based by the feedlot farmers offer several other benefits, which have been discussed in **Table 22**.

Cost of feed for dairy animals using densified feed

From animals weighing 350 kg, a daily Feed-A amount of 5.32 kg can support daily milk yield of 2 liters (Dey et al., 2022), giving feed cost per liter milk to be 0.213 USD respectively (taking cost of feed to be 80 USD/ton 500 km away from the densification site). This cost will be 0.140 USD per liter at the site of densification. Both the costs include a profit of 50%.

Table 25. The ME and 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 USD
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 USD/ton) has been taken; cost of sunflower cake taken is 184 USD/ton

For obtaining daily milk of 10 liters from animals weighing 250, 300 and 350 kg, daily amounts of Feed-A and sunflower cake required are given in **Table 25**. Taking the cost of Feed-A at a site 500 km away from the production site and the market price of sunflower cake (184 USD/ton), the daily feed cost per liter milk comes to 0.085, 0.088, and 0.091 USD from animals weighing 250, 300, and 350 kg, respectively, for an average of 0.088 USD/liter. This cost of milk production is almost 2.4-fold lower than that of cows giving 2 liters of milk per day, as presented in the previous paragraph. This situation is similar to that for the beef producing animals. The higher the daily milk production by an animal, lower would be the cost per kg of milk production because higher proportion of the feed (and of feed cost) goes for maintenance cow's body function giving lower milk. Also, the cost of milk production would be higher from animals of higher body weight, having 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 USD/liter, and the market price is 0.64 USD/liter. The cost of feed forms approximately 14% of 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. The use of cultivated forage based would lower the cost of milk production, giving higher profit to the dairy farmers.

For dairy animals, Feed-B containing 14% CP and 9.3 MJ/kg of ME has also been evaluated (see **4.1 Nutritional** evaluation section). Feeding a diet formed by mixing Feed-B along with a small amount of maize (or any other energy source) as a supplement would be able to meet nutrient requirements of cows to yield (i) 15 liters of milk/day from animal of 300 kg and 350 body weights; (ii) up to 20 liters/day from animals of 400 kg and 450 kg body weight; and (iii) up to 25 liters of milk/day from animals of body weight 500 kg.

Table 26. Feed cost of dairy cows yielding ≥15 kg milk per day

Weight of animals (kg)	kg Milk yield/ day	kg Feed-B required*	Supplement required (maize), kg/day*	Cost of feed, USD/day (close to production site)	Cost of feed, USD/day (500 km away from production site)	Cost of feed/liter milk (close to production site), USD	Cost of feed/liter milk (500 km away from production site), USD
300	15	11.2	0.79	1.85	2.08	0.124	0.138
350	15	11.4	0.89	1.90	2.13	0.127	0.142
400	20	14.7	0.90	2.40	2.70	0.120	0.135
450	20	14.9	1.0	2.45	2.75	0.123	0.138
500	25	18.2	1.0	2.95	3.31	0.118	0.133

**Source: Dey et al. (2022)*

Taking the cost of Feed-B at production site (150 USD/ton) and at 500 km away from the production site (170 USD/ton) and market selling price of maize (219 USD/ton), the calculated daily feed cost and cost of feed per liter of milk are given in **Table 26**. This translates to an average feed cost/liter milk of (i) 0.12 USD at the site of production of pelleted diet (Feed-B) and (ii) 0.14 USD at sites 500 km away from the site of production. As stated above, the cost of milk production/liter in Zambia is 0.41 USD and it is sold in the market at 0.64 USD per liter.

Cost of feed with and without fresh cultivated forage (lablab)

The cultivated forages in the fresh form are used for feeding dairy animals. The costs of feeding dairy animals using diets containing fresh cultivated forage was calculated. These costs were compared with diets that do not have fresh cultivated forage. An example is illustrated wherein lablab was a part of the diets fed to dairy animals of body weight 450, 500, and 550 kg, all giving 20 liters of milk daily. The diet was formulated that meets the nutrient requirements (ME & DCP) and then the costs were calculated using the costs of ingredients in Zambia. The results are shown in **Table 27** and **Table 28**.

Table 27. Feed ingredient requirements and cost of the diet containing cultivated forage (lablab)

Feed ingredients	Daily feed ingredients to meet nutrient requirement (kg DM)*	Cost of ingredients, USD	Total cost of diet, USD	Cost of diet in USD/liter of milk
Animal body weight 450 kg, daily milk production 20 liters				
Lablab	4	0.318**	2.375	0.119
Maize grains	6.6	1.4454		
Wheat bran	3	0.612		
Animal body weight 500 kg, daily milk production 20 liters				
Lablab	4	0.318*	2.424	0.121
Maize grains	7.1	1.5549		
Wheat bran	2.7	0.5508		
Animal body weight 550 kg, daily milk production 20 liters				
Lablab	4	0.318	2.494	0.125

Maize grains	7.6	1.8396		
Wheat bran	2.5	0.51		

**Meets nutrient requirements for maintenance and 20 liters of milk production; ** Cost of lablab adjusted for 50% profit*

Table 28. Feed ingredient requirements and cost of the diet free of cultivated forage

Feed ingredients	Daily feed ingredients to meet nutrient requirement (kg DM)*	Cost of ingredients, USD	Total cost of diet, USD	Cost of diet in USD/liter of milk
Animal body weight 450 kg, daily milk production 20 liters				
Sunflower	2	0.37	2.59	0.130
Maize grains	5	1.095		
Wheat bran	4	0.816		
Hay	3	0.309		
Animal body weight 500 kg, daily milk production 20 liters				
Sunflower	1.5	0.278	2.70	0.135
Maize grains	4.5	0.986		
Wheat bran	4.5	0.918		
Hay	5	0.515		
Animal body weight 550 kg, daily milk production 20 liters				
Sunflower	1.5	0.278	2.86	0.143
Maize grains	5	1.095		
Wheat bran	4.5	0.918		
Hay	5.5	0.567		

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

The feed-cost per liter of milk production increased with increases in body weight for diets with or without cultivated forages. The feed cost of milk production was lower for diets containing cultivated forages. Substituting cultivated forages for oilseed cakes (sunflower cake) by decreasing the feed cost of milk production.

Key takeaways

i) The costs per unit of nutrients (CP & ME) supplied to animals from the cultivated forages are much lower than those from the conventional feed ingredients, including hay and concentrate feed ingredients. Furthermore, the per unit nutrient costs of Feed-A and Feed-B prepared using the cultivated forages mainly for fattening and dairy animals, respectively, are also lower than most conventionally used feed ingredients. Meeting the nutrient requirements of animals at any physiological stage would be much cheaper if they were fed diets based on the cultivated forages.

ii) The cost of daily feed prepared from the cultivated forages for fattening an animal in the feedlot would be around 50% lower than of the feed prepared using currently used feed ingredients. The costs per kg of daily body weight gain are 0.64, 0.77, and 1.15 USD 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.

iii) The average feed cost per liter of milk is 0.12 USD at the site of production of pelleted diet (Feed-B) and is 0.14 USD at sites 500 km away from the site of production. The cost of production of milk/liter in Zambia is 0.41 USD. Milk is sold in the market at 0.64 USD per liter. The feed costs (0.12 and 0.14 USD/liter) form 29 and 34% of the cost of milk production. Generally, the feed cost comprises between 50 and 70% of the total cost of milk production. For dairy animals, the cost of feed could be substantially reduced, and profit increased, by using cultivated forage-based diets. In addition, the use of densified cultivate forage-based feeds offers several other environmental and social benefits.

iv) If the cultivated forage-based pellets/blocks are used in place of hay, a saving of 21500 USD for maintaining 1000 animals during a drought period of 100 days can be realized.

v) The feed cost per liter of milk production increased with increase in animal body weight for diets with or without cultivated forages. It is economical to produce milk from cows having low body weight. The feed-cost of milk production was lower on feeding diets containing cultivated forages. Substitution of oilseed cake (sunflower cake) by cultivated forage decreased the feed-cost of milk production.

vi) Reductions in the cost of feeding animals in the drought areas to dairy and feedlot animals offers ample opportunities for the business units involved in the forage cultivation and their pelleting and to the farmers to generate profit. Providing cultivated forage-based feeds at a cost lower than that of other feeds would enhance adoption and applicability of these novel feeds.

4.3 Environmental impact evaluation

The bulk of livestock-related greenhouse gas (GHG) emissions originate from four main categories of processes: enteric fermentation, manure management, feed production, and energy consumption along livestock supply chains. Enteric fermentation (the digestive process in which sugars are broken down into simpler molecules for absorption into the bloodstream) is the largest source of emissions in cattle production. Worldwide, emissions from enteric fermentation amount to 1.1 gigatons CO_2 equivalents, representing 46% and 43% of the total emissions in dairy and beef supply chains, respectively.

In this study, we calculate the reduction in methane emissions from enteric fermentation due to an increased use of cultivated forages as animal feed in Zambia. Thereafter, the cost of carbon pegged by the current United States administration was taken to monetize these GHG emission mitigation gains as an illustration and to provide a benchmark for comparisons with other animal feeds. Secondly, the already existing 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.

Methodology

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

Step 1: Estimate daily ME and CP requirements of animals: Using nutrient requirement values for maintenance, growth, and milk production, 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

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. EntericFermCH_4 Lactation (kg) = GEI305d × Ym/100/55.65.

b. EntericFermCH_4 Growth (kg) = GEIx × Ym/100/55.65

Ym, the methane conversion factor, set to 6.3 (as per the (IPCC) 2019 guidelines).

Step 4: Calculate CH_4 emission intensity (i.e., the CH4 emissions per unit of milk or meat)

a. Dairy: CH_4 emission intensity (kg CH_4/L milk) = EntericFermCH_4 Lactation in kg/Lactation milk yield in liters

b. Beef: CH_4 emission intensity (kg CH_4/kg body weight gain) = EntericFermCH_4 Growth in kg/kg weight gain in x days

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

a. DMIi = DMI * fractioni

b. LR = ∑DMIi/ Yieldi

DMIi, the DM intake of feed ingredient i (kg).

fractioni, the fraction of the animal diet constituted of feed ingredient i.

Yieldi, the yield of the crop from which feed ingredient i is produced (kg/ha).

Table 29 presents the yields of crops used for preparing feeds.

We calculated the enteric CH_4 emission and land requirements for three cases – feedlot animals, dairy animals, and for animals during the drought period.

Table 29. The yields of the crops used for feed production

Feed ingredient/Feed	Associated crop	Yield (ton DM/ha)
Sunflower	Food crop	1.5
Sunflower cake (58% of seeds)	Co-product	0.87 (allocation by weight)
Maize	Maize, smallholder system	3
Wheat	Food crop	8.5
Wheat bran (12% of grain)	Co-product	1.1 (allocation by weight)
Wheat bran	By-product	0
Hay	Native grass	4
Lablab or cowpea	Cultivated legume	8
Panicum, Rhodes or Brachiaria	Cultivated forage	20, 15, 17 respectively
Feed-A	Panicum, Rhodes or Brachiaria + 12% Lablab/cowpea	16
Feed-B	Panicum, Rhodes or Brachiaria + 30% Lablab/cowpea	14

Social costs were calculated using the social cost of methane pegged by the U.S. government (Chemnick, 2021). 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.

Feedlot animals

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 increase 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, it takes 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) for a total weight gain of 90 kg in 120 days.

Animal during droughts and dairy animals

For the animals experiencing drought conditions, we provide estimates for two types of feed – Feed-A (cultivated forage-based diet) and hay. The dairy animals, with body weights between 300 and 500 kg, are assumed to produce between 15 and 20 liters of milk per day. The animals during drought were assumed to weigh between 250 and 500 kg. Enteric methane emissions from feeding the cultivated forage based diets and the conventional diets for dairy animals were calculated using the diets presented in **Table 27** and **Table 28**.

Results

The potential environmental co-benefits in terms reduction in enteric methane and land required for feedlot animals, animals during drought, and dairy animals are presented below.

Feedlot animals

Use of cultivated forages could significantly reduce 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 reductions in land requirements were 45% and 33% in Scenario 1 and 2, respectively. The use of cultivated forage-based diets 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 (Chemnick, 2021) as $1500 per ton, the methane abatement value ranges from $165 to $240 per ton of body weight gain in the fattening animals (Dey et al., 2022).

We also compared enteric methane emission from a concentrate-based diet and a cultivated forage-based diet (Feed-A), both giving daily body weight gain of one kg. The feed required to fatten one animal from 250 kg to 350 kg body weight in 100 days is given in **Table 30**. The environmental gain of using cultivated forage-based diets in place of a diet containing a mix of wheat bran and hay is 21.93 tons of methane for fattening 10 thousand animals. The monetized benefit of the social costs is $64,227.

Table 30. 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	--	--

Source: [1]*Dey et al. (2022);* [2]*Gebremariam (2019)*

Using land use and yield data (**Table 29**), the calculated land required is 0.05 ha (0.795/16) for Feed-A, and 0.51 ha (0.6/4+0.4/1.1) for the conventional diet. But the land required reduces to 0.150 ha (0.6/4) for the conventional diet when the land required for wheat bran is omitted if we consider that wheat bran is a by-product of wheat, and no land is required per se to produce it. The use of a cultivated forage-based diet reduced land use by 90% and 67%, respectively. In absolute terms, the former scenario would save 0.46 ha of land and the latter 0.1 ha of land for fattening one animal. For fattening 10,000 animals the land savings would equate to 4,600 ha and 1,000 ha, respectively. The latter value would be acceptable by most because wheat is not grown to produce wheat bran and hence it is a by-product and not a co-product. Less land is required for fattening animals fed on cultivated forage-based diets.

Draught animals

During draughts, the diets should meet the maintenance requirement. **Table 31** gives the amounts of Feed-A and hay that meet the maintenance requirement. This table also shows enteric methane production for maintaining 1,000 animals for a draught period of 100 days, the social cost of reduced methane emitted as a result of using Feed-A, and the land requirement.

Table 31. Daily feed requirement for maintenance of animals and their costs

Weight of animal (kg)	kg daily Feed-A required per animal for maintenance[1]	kg enteric CH_4 emitted in 100 days fed Feed-A (a)	kg daily hay required per animal for maintenance[1]	kg enteric CH_4 emitted in 100 days fed hay diet (b)	Environmental gain on using Feed-A, kg CH_4/100 day/animal (b-a)	Environmental gain on using Feed-A in 100 days for 100 thousand animals, tons CH_4 (b-a)
250	3.58	7.48	4.76	9.94	2.46	246
300	4.11	8.58	5.46	11.40	2.82	282

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

For maintaining an animal of 250 kg body weight, the abatement of methane is 246 tons for one-hundred thousand animals, having a social cost of $3.69 million. These figures for 300 kg body weight are 282 tons and $4.23 million.

Using land use and yield data (**Table 29**), the calculated land for feeding one-hundred thousand animals of 250 kg body weight for 100 days of drought period is 2,240 ha (35,800/16) for Feed-A, and 11,900 ha (47,600/4) for the hay. These values for animals of 350 kg body weight are 2,569 ha versus 13,650 ha, respectively.

The above results suggest that the use of cultivated forage-based diet has substantial environmental and social gains and substantially reduced the land requirement.

Dairy animals

Enteric methane emissions on feeding the cultivated forage based diets and the conventional diets, along with the environmental gains of using cultivated forage based diets and their social costs are presented in **Table 32** and **Table 33**. The diets used have been taken from **Table 27** and **Table 28**.

Daily total abatement of enteric methane using cultivated forage-based diet ranges from 0.4 to 2.5 tons per one million liters production daily (**Table 32**). Higher environmental gains are obtained for animals of higher body weight. The social costs of the reduction in enteric methane ranges from $600 to $3,750 depending on the body weight of the animal for the daily production of one million liters of milk. Annual social gains from the production of one million liters of milk would range from $0.22 million to $1.37 million.

Table 32. 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)	Daily CH_4 abatement, ton per one ton milk, (b-a)
BW 450 kg, 20 liters milk	13.6	0.284	14.20	0.40
BW 500 kg, 20 liters milk	13.8	0.288	14.4	1.8
BW 500 kg, 20 liters milk	14.1	0.295	14.7	2.5

*BW, Body weight; * Taken from **Table 27**; ** Meets nutrient requirements for maintenance and 20 liters of milk production*

Table 33. 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)
BW 450 kg, 20 liters milk	14.0	0.292	14.6
BW 500 kg, 20 liters milk	15.5	0.324	16.2
BW 500 kg, 20 liters milk	16.5	0.345	17.2

*BW, Body weight; * Taken from **Table 28**; ** Meets nutrient requirements for maintenance and 20 liters of milk production*

There is a reduction of 38.6% of the land requirement for production of 1 million liters of milk using cultivated forage-based diets as opposed to conventional diets. That is, more land will be available for food/cash crop production or the conservation of forests or other natural ecosystems. This, along with reductions in enteric methane, illustrates the benefits of using cultivated forage-based diets.

CONCLUSIONS

Animal feed has the largest share of input costs (up to 70%) in the livestock sector. 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 not only 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 high-quality forage seed for cultivation to 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-folds lower for CP and 16-folds lower for ME 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/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 for maintaining 1000 animals during drought period of 100 days can be realized. Reductions in the cost of feeding dairy and feedlot animals, and to animals in drought periods, offer ample opportunities for the business units involved in the forage cultivation and their pelleting and for 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 adoption of cultivated forages in the livestock sector. Substantial environmental gains through abatement of greenhouse gases could be obtained using cultivated forage-based rations. Forage-based feeding presents a triple-win – economic, social, and environmental gains – and is one of the true promising climate-smart feeding interventions.

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ANNEX 1

Quality attributes of the selected forage species

Forage type	Crude protein (% DM)	Crude fibre (% DM)	Neutral Detergent Fibre (% DM)	Acid Detergent Fibre (% DM)	Lignin (% DM)	In vitro organic matter digestibility (%)	Organic Matter Digestibility (%)	Metabolizable Energy, MJ/kg DM	DM as fed (%)
Panicum maximum	11.2 ± 4.3 (n=2396)	37.3 ± 3.7 (n=2218)	72.3±6.5 n=245	43.4 ± 5.4 n=178	6.1 ± 1 n = 177	65	59.2 ± 6.5 n = 50	8.0	22.7 ± 7.4 (n=1835
Rhodes grass (Chloris gayana[2])	9.0 ± 2.8 (n=262), [9.6-12.4][9], [9.8][10]	36.9 ± 3.9 (n=235)	75.0 ± 3.4 (n=28), [65.0-67.0][9], [62.7][10]	43.0 ± 3.3 (n=22)	6.0 ± 1.7 (n=12)	--	60.4 ± 7.5 (n=18), [65][10]	8.5, 9.01	24.9 ± 6.2 (n=197)
Stylosanthes guianensis (Avena sativa)	14 ± 3.4 (n=1079),	31.2 ± 4.2 (n=1065)	49.6 ± 8.5 (n=25),	38.1 ± 6.8 (n=42), [37.0-	8.7 ± 1.7 (n=31)	--	56.6± 5.5 (n=10)	8.0	27 ± 8 (n=962)
Lablab purpureus)[4]	18.4 ± 3.1 (n=92)	28.2 ± 3.1 (n=59), [23.7][12]	44.6 ± 4.3 (n=49), [25.3] [12]	32 ±4.7 (n=62), [12.2][12]	7.2 ±1.8 (n=21), [4.4][12]	--	67	9.2	22.1 ± 7.3 (n=23)
Cowpea (Vigna unguiculata)[5]	18.1 ± 2.8 (n=24), [17.3][13]	24.1 ± 6.1 (n=18)	38.6 ± 6.6 (n=13), [43.3][13]	27.1 ± 6.8 (n=14), [34.2][13]	4.6 ± 1.4 (n=5), [6]13	[67.1][13]	71.2	9.8, [10.1][13]	20.9 + 5.6 (n=9)
Brachiaria - hybrid	(10-17)[14]	31.4	68.1	37.2	5.1	67.2 -71.4	55.2	7.3 -9.1	
Alfalfa[6]	20.6 ± 3.4 (n=1832)	26.7 ± 4.1 (n=1187)	39.3 ± 6.3 (n=1305)	30.9 ± 5.0 (n=1451)	7.6 ± 1.8 (n=1224)	--	68.5 ± 5.5 (n=112)	9.4	19.9 ± 3.1 (n=1277)
Mixed natural grass hay in Ethiopia[7]	[6.4]	--	[73.2]		[7.5]	[57.2]	--	--	--

[1]Feedipedia: https://www.feedipedia.org/node/480
[2]Feedipedia: https://www.feedipedia.org/node/500
[3]Feedipedia: https://www.feedipedia.org/node/12192
[4]Feedipedia: https://www.feedipedia.org/node/233
[5]Feedipedia: https://www.feedipedia.org/node/275
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