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Forage Seed Systems to Close the Ruminant Feed Deficit in Eastern Africa

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Abstract: This study examines key challenges and opportunities for improving ruminant productivity in East Africa, with a focus on enhancing access to forage seeds critical for livestock systems in Ethiopia, Tanzania, Kenya, Uganda, Rwanda, and Burundi. Despite high potential for increased livestock production, the region faces a significant feed deficit—nearly 40% of annual feed demand remains unmet—due to the limited availability and affordability of forage seeds. The research identifies a critical gap in quality seed access, with many farmers relying on outdated materials. We propose the promotion of recently improved forage varieties and local seed production as a solution to reduce dependence on costly imports and enhance adoption. Our analysis suggests that bridging the forage deficit would require the cultivation of 2 million hectares and the involvement of 1.5 million farmers, highlighting the scale of intervention needed. Additionally, the regional forage seed market presents an economic opportunity, potentially valued at USD 877 million over the next decade, underlining the importance of government policies, the development of seed systems, and market incentives. The study concludes with recommendations for fostering seed production, improving seed distribution, and addressing socio-economic barriers to ensure widespread adoption and enhance livestock productivity in the region.

Keywords: cultivated forages; feed deficit; food security; market potential; ruminants; seed systems

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1. Introduction

Livestock farming is essential in Africa, where most producers are small-scale farmers who rely on their animals for income, nutrition, insurance, and savings [1–3]. The continent is projected to experience a significant rise in demand for animal-sourced foods (ASFs), with milk consumption expected to increase from 30 L to 64 L per capita annually by 2050 and meat consumption from 14 kg to 26 kg [4–7]. In East Africa, livestock supports millions of livelihoods by providing food, income, and employment [8], and the region counts on Africa's largest cattle herd and is the main exporter of cattle on the continent [9].

When it comes to feeding these large numbers of livestock, mixed feed baskets are the main source of animal nutrition and feed makes up approximately 60–70% of the overall production costs [10,11]. The literature is abundant with information on the limitations in the quality and quantity of livestock feed, its impact on animal productivity in Africa, and the influence of climate change on feed production [12,13]. This issue has persisted for several decades and remains prevalent across most sub-Saharan African countries. Despite the existence of technologies, such as adapted forages, that could potentially address these gaps and positively impact rural livelihoods (e.g., through higher animal productivity, employment generation, and income diversification), the intentional cultivation of forages has lagged [14–16]. Furthermore, business models for seed distribution that could stimulate market demand for quality cultivated forages and increase technology access are underdeveloped and lead to high shares of labor-intense vegetative propagation through splits [14,17].

Mixed farming and pastoral systems, both of which strongly rely on ruminants, are widespread but lack strategies to bridge feed deficits, leading to animal losses in severe cases, a situation strongly aggravated by climate change. Notably, forage cultivation is limited in mixed systems [18], and pastoral areas depend on natural grasses without large-scale conservation efforts for the dry seasons. In some countries, like Rwanda, livestock populations continue to grow despite these challenges, adding pressure to the production systems [19].

To put the low levels of cultivation into perspective, Ethiopia, Tanzania, Kenya, Uganda, Rwanda, and Burundi together have a cultivated forage area of about 1.5 million hectares, compared to Colombia's 8.9 million hectares, which is 5.8 times higher despite eastern Africa having significantly more agricultural land compared to Colombia (273 million vs. 42.7 million hectares) [18]. The reasons for low forage cultivation are diverse and include limited land availability due to competition with food crops, lack of seeds and planting materials [14], high seed prices and unwillingness to pay for improved forage seeds [14,19], adverse weather conditions, lack of skills and technology [10,14,18,20] and other socio-cultural factors.

Addressing these key bottlenecks is essential. For instance, integrating forages into mixed systems at a maximum rate of 33% could support sustainable food production [21]. In addition, mitigation strategies are urgently needed to address adverse climatic conditions and contribute to greenhouse gas (GHG) emission reduction. Cultivated forages can help in carbon sequestration, reduce methane emissions per unit of animal product, and in general, sustainably increase meat and milk productivity [12,22–25]. Some forages, like certain *Urochloa* species, possess biological nitrification inhibition (BNI) properties that reduce nitrate denitrification to nitrous oxide, a potent GHG [26]. Cultivated forages can alleviate land pressure by boosting productivity per hectare, thereby helping to prevent the encroachment of agricultural expansion into vital ecosystems like forests and protected areas [27,28]. In addition to their mitigation potential, improved forages also enhance system adaptation to adverse climatic conditions, such as severe droughts or waterlogging, thereby increasing resilience [29–31].

The shortage of forage seeds and limited access to them could be addressed through local seed production initiatives. This would lower seed costs compared to imports, making them more affordable for farmers and reducing their reluctance to invest in them [19]. For example, *Urochloa* seeds cost USD 40–50 per kilo in Kenya [14] compared to about USD 15–30 in Latin America, where most of the seeds are being produced. A conducive policy environment that fosters access to forage seeds through efficient variety registration processes is key for further seed sector development and stronger private seed sector involvement [14]. Local seed production business models can also boost income generation and diversification, thereby improving the livelihoods of people in rural areas and contributing to reducing the migration of youth to cities [32].

Against this background, this article aims at providing evidence for improving access to forage seeds for ruminant systems in several East African countries, specifically Ethiopia, Tanzania, Kenya, Uganda, Rwanda, and Burundi. Drawing on the existing literature, we address the following research questions:

(i) What are the key government plans in the region to support the livestock sector, and how do these plans incorporate the use of forage seeds?
(ii) What is the current gap in cultivated forage dry matter in the region, and how much seed is needed to close this deficit?
(iii) How much land and how many farmers are needed to successfully implement the adoption of forage cultivation at scale?
(iv) Can vegetative propagation (using plant splits) effectively replace seed-based cultivation to address the forage deficit?
(v) What is the economic value of the forage seed market, and how much economic benefit could be generated by increasing forage crop production over time?

(vi) What steps are necessary to establish a functional regional forage seed system to ensure widespread adoption of improved forage varieties?

We begin by examining the governmental priorities for the livestock sector in the studied countries to identify future goals and needs. Next, we calculate the annual feed demand for ruminant livestock and the existing feed deficit. Following this, we select two forage grasses—*Urochloa* hybrids and *Megathyrsus maximus*—and two forage legumes—*Lablab purpureus* and *Vigna unguiculata* (cowpea)—chosen for their adaptability to the predominantly tropical agroclimatic conditions of these countries, their provision of essential nutrients for ruminants, and the availability of their seeds. *Urochloa* and *Megathyrsus* genera have undergone significant forage improvement through selection and breeding, an area where progress has lagged in Africa compared to food crops. International private companies have taken up seed multiplication, making seeds available globally [33,34]. *Lablab purpureus* and *Vigna unguiculata*, which are well adapted to relatively dry regions, have also benefited from substantial improvement efforts by international researchers and are widely recognized and utilized by farmers in Africa [35,36]. We then calculate the quantity of forage seeds needed to bridge the estimated feed deficit. Afterward, we estimate the land area required to cultivate these forages, the number of farmers needed for adoption, the economic value of this potential forage seed market, and the value that forage crop adoption could generate over a 10-year period. Finally, we outline the steps necessary to develop a functional forage seed system to support widespread adoption.

This study is highly significant for several key reasons. First, it addresses the role of livestock farming as a cornerstone of rural livelihoods in East Africa, where millions of small-scale farmers depend on ruminants for income, nutrition, and savings. As the demand for animal-sourced foods (ASFs) is projected to rise by 2050, the study provides crucial insights into how the livestock sector can meet future food security needs and support regional economic growth. Second, the study tackles the persistent feed deficit that hinders livestock productivity, emphasizing the need for increased forage cultivation to improve feed quality and availability. This is vital to meet the growing demand for milk and meat. The study also highlights the environmental impact of cultivated forages, which can help reduce greenhouse gas emissions, sequester carbon, and enhance climate resilience, aligning with global sustainability goals. Furthermore, by focusing on the economic potential of the forage seed market, the research demonstrates opportunities for rural economic growth, job creation, and reduced urban migration. The study's examination of governmental plans and regional integration underscores the need for coordinated policies to drive sustainable forage adoption. Finally, it addresses critical knowledge gaps, providing essential insights for future agricultural investments and policy decisions in East Africa.

This article is structured as follows: Section two highlights the materials and methods applied in each section, Section three provides a combined results and discussion section in which we answer the research questions, and Section four provides concluding remarks and recommendations.

2. Materials and Methods

We utilized the Google Scholar search engine to identify the relevant literature aligned with our objectives. The search focused on various subtopics of interest, including livestock development, livestock populations, dry matter deficits, forage seed systems, and trade blocs. For selecting forages to illustrate forage seed systems, we employed the Tropical Forages Selection Tool [37] to choose adaptable forages and assess their agronomic attributes. Each subtopic search returned over 200 articles, and the synthesis ultimately relied on 85 articles, which are included in the reference list.

As shown in Figure 1, we first examined the most recent governmental plans, such as Livestock Master Plans, across the six countries under analysis. Using qualitative content analysis, we summarized these plans, highlighting key aspects relevant to future development.

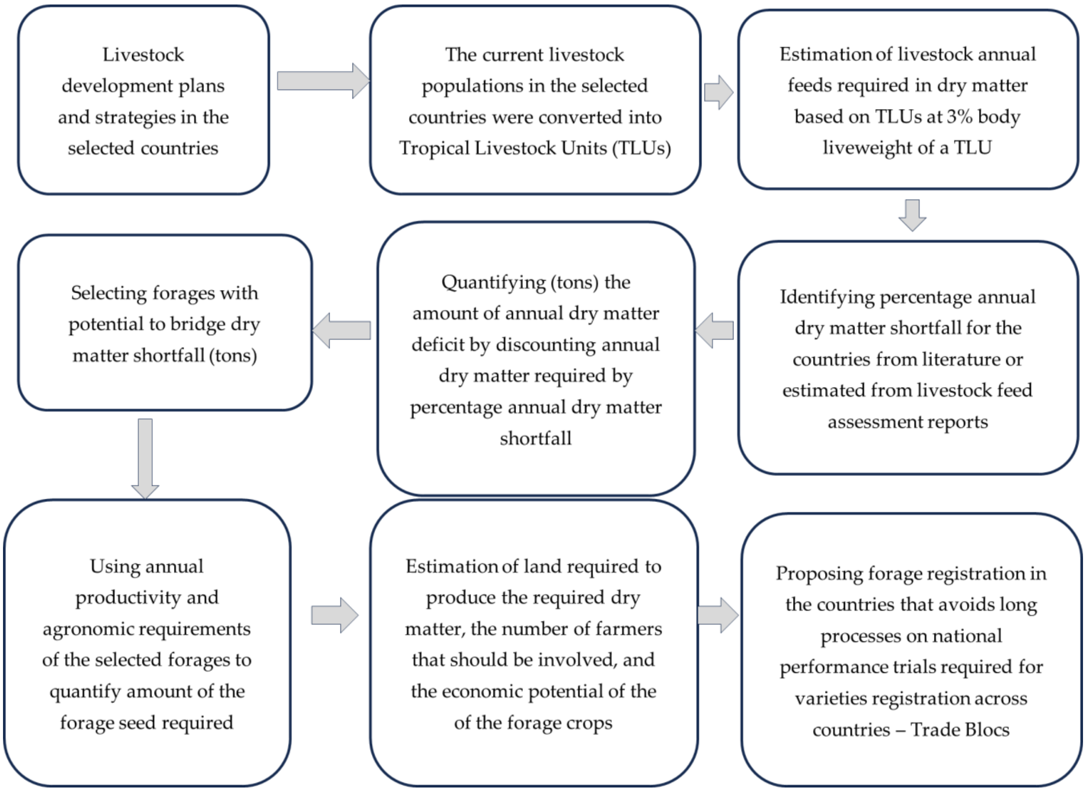

Figure 1. Overview of the key steps for literature search applied in the study.

Second, we reviewed recent the scientific and gray literature to gather data on total ruminant populations (including cattle, sheep, and goats), converted this to TLUs according to Jahnke [38], and subsequently used this to calculate annual feed demand and annual feed deficit (see Table 4). This process included estimating dry matter consumption per TLU and extrapolating these values to the total number of TLUs in each country. We applied the nutritional guideline that ruminants consume up to a maximum of 3% of their body weight [39]. This approach followed the methodology outlined by Dey et al. [21], and we estimated the portion of the annual feed deficit that could be addressed by the selected forage grasses and legumes (referred to as the annual cultivated forage deficit) for each country using the following equation:

$$ACF_{\mathrm{Def}} = AFD\ RS\ CFS \quad (1)$$

where ACF_{Def} is the annual cultivated forage deficit per country in tons of dry matter (tons Dry Matter/year) and AFD is the total annual feed deficit per country in tons of dry matter (tons Dry Matter/year). RS is the share of roughages of the total diet, which is estimated to be 70% (30% concentrates) [21,40]. CFS is the share of RS accounting for recommended cultivated forage inclusion and is 33% [21].

Third and prior to estimating the amount of forage seeds needed to bridge the projected feed deficits, we selected two forage grasses and two forage legumes that (i) are adaptable to the (largely tropical) agroclimatic conditions of the countries, (ii) supply key nutrients required by ruminants, i.e., metabolizable energy and crude protein, and (iii) have seed availability in the region, either through the private seed sector or other sources (e.g., informal seed system, development projects, governmental programs). The selected grass species are *Urochloa* hybrids and *Megathyrsus maximus*, and the selected legume species are *Lablab purpureus* and *Vigna unguiculata* (cowpea), both of which, in some cases, are used for human food and can also perform well in relatively marginal areas. Their attributes, such as growth type, seed rate, days to first cut, days to regrowth cutting, days to cutting after sowing, and potential yields, were extracted from Dey et al. [21].

Fourth, we estimated the amount of forage seeds required for the four selected species to address the identified ACF_{Def}. For this purpose, we calculated different scenarios:

- Scenario 1: Where 100% of the identified ACF_{Def} is covered in the first year by simultaneously planting the two grass species at 35% each and the two legume species at 15% each. This scenario considers a 10-year evaluation horizon, the annual seed requirements for reseeding the legumes, and regeneration seed for the grasses for the last 3 years at 100%.
- Scenario 2: Where 10% of the identified ACF_{Def} is covered in the first year by simultaneously planting the two grass species at 35% each and the two legume species at 15% each. We projected a 10% annual increase in covering the ACF_{Def} and a lifespan of 7 years for the perennial grasses [41]. For the two longer-term perennial grasses (*Megathyrsus maximus*, *Urochloa* hybrids), we included annual regeneration seed in the calculation after year 7 at 100%. The projected horizon for our calculations is 10 years.

The following equations were estimated for Scenario 1:

$$AFSR = AFSR_U + AFSR_M + AFSR_L + AFSR_V \tag{2}$$

where $AFSR$ is the annual forage seed requirement of a country (in tons), $AFSR_{\mathrm{U}}$ is the annual forage seed requirement for *Urochloa* hybrids (in tons), $AFSR_{\mathrm{M}}$ is the annual forage seed requirement for *Megathyrsus maximus* (in tons), $AFSR_{\mathrm{L}}$ is the annual forage seed requirement for *Lablab purpureus* (in tons), and $AFSR_{\mathrm{V}}$ is the annual forage seed requirement for *Vigna unguiculata* (in tons).

$$AFSR_U = AFSR_{UG} + AFSR_{URS} = \left(\frac{(ACFDef\ U_{\mathrm{area}})}{U_{\mathrm{yield}}} U_{\mathrm{SR}}\right) + \left(\frac{(ACFDef\ U_{\mathrm{area}})}{U_{\mathrm{yield}}} U_{\mathrm{SR}} \frac{RS}{EH}\right) \tag{3}$$

$$AFSR_M = AFSR_{MG} + AFSR_{MRS} = \left(\frac{(ACFDef\ M_{\mathrm{area}})}{M_{\mathrm{yield}}} M_{\mathrm{SR}}\right) + \left(\frac{(ACFDef\ M_{\mathrm{area}})}{M_{\mathrm{yield}}} M_{\mathrm{SR}} \frac{RS}{EH}\right) \tag{4}$$

$$AFSR_L = \left(\frac{(ACFDef\ L_{\mathrm{area}})}{L_{\mathrm{yield}}} L_{\mathrm{SR}}\right) EH \tag{5}$$

$$AFSR_V = \left(\frac{(ACFDef\ V_{\mathrm{area}})}{V_{\mathrm{yield}}} V_{\mathrm{SR}}\right) EH \tag{6}$$

where $AFSR_{UG}$ is the general annual forage seed requirement for *Urochloa* hybrids, $AFSR_{URS}$ is the forage seed requirement for *Urochloa* hybrids for regeneration purposes, $AFSR_{MG}$ is the general annual forage seed requirement for *Megathyrsus maximus*, $AFSR_{MRS}$ is the forage seed requirement for *Megathyrsus maximus* for regeneration purposes, ACF_{Def} is the total annual cultivated forage deficit of a country (in t), U_{area} is the share of area that could be covered with *Urochloa* hybrids (35%), U_{SR} is the *Urochloa* hybrid seed rate (in t ha^{-1}), U_{yield} is the *Urochloa* hybrid yield (in t ha^{-1}), M_{area} is the share of area that could be covered with *Megathyrsus maximus* (35%), M_{SR} is the *Megathyrsus maximus* seed rate (in t ha^{-1}), M_{yield} is the *Megathyrsus maximus* yield (in t ha^{-1}), L_{area} is the share of area that could be covered with *Lablab purpureus* (15%), L_{SR} is the *Lablab purpureus* seed rate (in t ha^{-1}), L_{yield} is the *Lablab purpureus* yield (in t ha^{-1}), V_{area} is the share of area that could be covered with *Vigna unguiculata* (15%), V_{SR} is the *Vigna unguiculata* seed rate (in t ha^{-1}), V_{yield} is the *Vigna unguiculata* yield (in t ha^{-1}), RS is the number of years in which regeneration seed is being used (3 years), and EH is the evaluation horizon (10 years).

For Scenario 2, we broke down $AFSR_U$ and $AFSR_M$ by year by multiplying $AFSR_{UG}$ and $AFSR_{UG}$ by 10% to reflect the projected adoption rate and their perennial character. For the inclusion of regeneration seed, for the years 8, 9, and 10, we divided $AFSR_{URS}$ and $AFSR_{URS}$ by RS and added the respective values to the $AFSR_{UG}$ and $AFSR_{UG}$ for years 8, 9, and 10. To reflect the annual seeding of the selected legumes, we divided $AFSR_L$ and $AFSR_V$ by EH and then multiplied it by the respective year of analysis.

Fifth, we estimated the amount of land that would be required for the adoption of the suggested cultivated forages as well as the number of farmers that would be needed. For this, we estimated the following equations:

$$LR = \frac{FSR_{\mathrm{U}}}{U_{\mathrm{SR}}} + \frac{FSR_{\mathrm{M}}}{M_{\mathrm{SR}}} + \frac{FSR_{\mathrm{L}}}{L_{\mathrm{SR}}} + \frac{FSR_{\mathrm{L}}}{V_{\mathrm{SR}}} \quad (7)$$

$$FR = \frac{LR}{AFS} \quad (8)$$

where LR is the amount of land required in the adoption process (in ha); FSR_{U}, FSR_{M}, FSR_{L}, and FSR_{V} are the total forage seed requirements (in tons) for *Urochloa* hybrids, *Megathyrsus maximus*, *Lablab purpureus*, and *Vigna unguiculata*; U_{SR}, M_{SR}, L_{SR}, and V_{SR} are the seed rates (in tons ha^{-1}) for *Urochloa* hybrids, *Megathyrsus maximus*, *Lablab purpureus*, and *Vigna unguiculata*; FR is the total number farmers needed in the adoption process; and AFS is the average farm size (in hectares) per country.

Sixth, we estimated both the total and annual economic values of the cultivated forage seed market, applying two scenarios. For Scenario 1, we used current seed prices to reflect the current situation. For Scenario 2, we applied seed prices reduced by 25% to reflect a scenario in which (a) some of the seed is produced locally and (b) economies of scale apply due to higher seed purchases. The following equation was calculated:

$$EV = FSR_{\mathrm{U}}\mathrm{P_U} + FSR_{\mathrm{M}}\mathrm{P_M} + FSR_{\mathrm{L}}\mathrm{P_L} + FSR_{\mathrm{V}}\mathrm{P_V} \quad (9)$$

where EV is the economic value of the forage seed market in USD, and $\mathrm{P_U}$, $\mathrm{P_M}$, $\mathrm{P_L}$, $\mathrm{P_V}$ are the average seed prices (in 2023 USD) for *Urochloa* hybrids, *Megathyrsus maximus*, *Lablab purpureus*, and *Vigna unguiculata*.

Seventh, we estimated the potential cultivated forage value in 2015 USD according to the method described by Fuglie et al. [18]. We applied a forage price equivalent to 18% of the global maize price (as leading feed grain). The global average maize price was taken from the FAO for 2014–2016 (USD 201 t^{-1}) and the resulting average forage price was USD 36 per ton dry matter (in 2015 USD). For this, we estimated the following equation:

$$FCV = \left(\left(LR_{\mathrm{U}}\, U_{\mathrm{yield}}\right) + \left(LR_{\mathrm{M}}\, M_{\mathrm{yield}}\right) + \left(LR_{\mathrm{L}}\, L_{\mathrm{yield}}\right) + \left(LR_{\mathrm{V}}\, V_{\mathrm{yield}}\right)\right) + p\, EH \quad (10)$$

where FCV refers to the cultivated forage crop value (in 2015 USD); LR_{U}, LR_{M}, LR_{L}, LR_{V} to the estimated area to be cultivated with *Urochloa* hybrids, *Megathyrsus maximus*, *Lablab purpureus*, and *Vigna unguiculata* (ha); U_{yield}, M_{yield}, L_{yield}, V_{yield} to the forage dry matter yield for *Urochloa* hybrids, *Megathyrsus maximus*, *Lablab purpureus*, and *Vigna unguiculata* (t ha^{-1} y^{-1}); and p to the average forage price per ton of dry matter (in 2015 USD).

Table 1 provides an overview of the data used for each variable and some general characteristics of the forage species; Table 2 provides an overview of the applied seed prices.

Table 1. Data used for each variable and some characteristics of the forage species.

Characteristic	Forage			
	Urochloa hybrid	***Megathyrsus maximus***	***Lablab purpureus***	***Vigna unguiculata***
Share of forage deficit to cover (%)	35	35	15	15
Seed rate (t ha^{-1})	0.008	0.003	0.02	0.02
Yield (dry matter t ha^{-1})	17	20	8	8
Growth type	Perennial	Perennial	Annual	Annual
Days to first cut	90	75–90	n.a.	n.a.
Days to regrowth cutting	30–45	30–45	n.a.	n.a.
Days to cutting after sowing	n.a.	n.a.	90	70–90
Lifespan (years)	8	8	1	1
Adoption rate (%)	10	10	10	10
Regeneration seed	100% after year 7	100% after year 7	n.a.	n.a.

Source: based on [21].

Table 2. Seed prices for the studied forage grasses and legumes.

Country	*Urochloa hybrids* (cv. Mulato II) Current Price (USD t^{-1})	*Urochloa hybrids* (cv. Mulato II) Reduced Price ** (USD t^{-1})	*Megathyrsus maximus* (cv. Mombasa) Current Price (USD t^{-1})	*Megathyrsus maximus* (cv. Mombasa) Reduced Price ** (USD t^{-1})	*Lablab purpureus* Current Price (USD t^{-1})	*Lablab purpureus* Reduced Price ** (USD t^{-1})	*Vigna unguiculata* Current Price (USD t^{-1})	*Vigna unguiculata* Reduced Price ** (USD t^{-1})
Ethiopia	50,460	37,845	48,670	36,503	6245 *	4684 *	9426	7070
Tanzania	50,460	37,845	48,670	36,503	6245 *	4684 *	4378	3284
Kenya	43,660	32,745	48,670	36,503	2291	1718	1975	1481
Uganda	50,460	37,845	48,670	36,503	10,199	7649	1485	1113
Rwanda	50,460	37,845	48,670	36,503	6245 *	4684 *	4442	3332
Burundi	50,460	37,845	48,670	36,503	6245 *	4684 *	2719	2040

Notes: all prices in 2023 USD; * no price available, the average price was built for Kenya and Uganda and applied to the countries with no information on prices; ** price reduced by 25% to reflect a scenario in which (a) some of the seed is produced locally and (b) economies of scale apply due to higher seed purchases. Sources: [42–52].

3. Results and Discussion

3.1. Governmental Plans for the Livestock Sector in the Studied Countries

Table 3 summarizes the governmental plans for the livestock sector in the studied countries. It highlights that governments in the region aim to increase the sector's contribution to their Gross Domestic Products, while emphasizing the need for sustainably boosting livestock productivity with a commercial focus and prioritizing environmental stewardship in some cases. Likewise, emphasis is put on the role of feeding improvements to reach the planned aims, which corresponds to the strong contribution of feed to the overall production cost [10,11] and its enormous potential for climate change mitigation and adaptation [25]. Governments in the studied countries are increasingly prioritizing the use of forages in their livestock policies, recognizing their critical role in improving livestock productivity and sustainability. Through policies that promote forage cultivation, seed system development, and farmer training, these countries are addressing the persistent challenges of feed shortages and low livestock productivity. The emphasis on forages is a clear indication that sustainable livestock development in East Africa depends on improved feed resources, with far-reaching implications for food security, rural livelihoods, and economic growth.

Table 3. Governmental plans for the livestock sector.

Country	Focus and Aspirations
Ethiopia	The Ethiopian government plans to quadruple milk production by 2031 by enhancing the productivity of dairy cows and goats. This goal is a key focus of the government's ten-year strategic plan for the dairy sector. The plan aims to address significant challenges related to genetics, technology, feeding, health, marketing of inputs and outputs, value addition, product quality, and consumer safety [53]. Ethiopia's Livestock Master Plan [54] emphasizes the importance of forages in improving livestock productivity. The plan addresses forage shortages, particularly during dry periods, by promoting the cultivation of improved forage varieties and better pasture management. The government supports research and development of high-yielding forage crops and the integration of forage production into mixed farming systems. Additionally, there are efforts to enhance the dissemination of forage technologies and improve farmers' access to quality seeds. By prioritizing forages, Ethiopia aims to boost livestock productivity and support the livelihoods of pastoral and agro-pastoral communities.
Tanzania	By 2025, the livestock sector is expected to be largely commercial, modern, and sustainable, leveraging improved and highly productive livestock to ensure food security, boost household and national income, and support environmental conservation [55]. Both Tanzania's National Livestock Policy [55] and Livestock Sector Transformation Plan [56] prioritize the development and use of forages to modernize the livestock sector. The policy emphasizes the need for improved forage resources and sustainable feed management practices. The government promotes the cultivation of high-quality forage crops and supports research on forage technologies. Additionally, there are initiatives to enhance the availability of forage seeds and improve pasture management. By focusing on forages, Tanzania seeks to address feed scarcity, increase livestock productivity, and contribute to the overall development of the sector.

Table 3. *Cont.*

Country	Focus and Aspirations
Kenya	Kenya's Livestock Policy [57] aims to harness livestock resources to enhance food and nutrition security and improve livelihoods while protecting the environment. This objective will be met through several measures, including improved management of livestock, feed, and rangeland resources, as well as promoting social inclusion and environmental resilience. Interventions in livestock nutrition, feeds, and feeding will involve various measures focused on roughage and concentrate feed resources. These measures will ensure the availability of adequate forage resources by enhancing the productivity and utilization of diverse roughage materials. Forages are thus a key component in improving livestock productivity and sustainability. The plan advocates for the development of improved forage varieties and the adoption of better forage management practices. The government supports the cultivation of forage crops, the use of high-quality feed supplements, and the establishment of forage banks to ensure availability during dry periods. Furthermore, there are initiatives to educate farmers on effective forage management through extension services. By prioritizing forages, Kenya aims to enhance livestock performance and support pastoral and agro-pastoral livelihoods.
Uganda	Uganda's National Animal Feeds Policy [58] aims to address challenges in the livestock sector by improving the quality, availability, and affordability of animal feeds. This policy, first introduced in 2005, aligns with Uganda's broader agricultural development strategy, particularly its Plan for the Modernization of Agriculture. The policy seeks to ensure optimal use of local feed resources, which would improve livestock productivity and increase the supply of animal products. The recent Animal Feeds Act [59] builds on this policy by introducing more stringent regulations for the production, sale, and transportation of animal feeds. It mandates licensing for all stakeholders involved in these activities and seeks to control the quality of animal feeds by regulating imports and exports. The Act also includes provisions for penalties for non-compliance, especially in cases involving counterfeit or low-quality feeds, which have been problematic in the sector. Additionally, inspectors will be empowered to ensure that feeds meet safety and nutritional standards. This policy and its legislative updates are expected to enhance Uganda's livestock productivity by improving feed quality, reducing animal diseases linked to poor nutrition, and ultimately supporting the country's growing livestock sector. Uganda's Livestock Sector Prioritization under the Agriculture Sector Strategic Plan (ASSP) [60] recognizes the role of forages in enhancing livestock productivity. The plan includes strategies to boost forage production through the development of improved forage varieties and the promotion of sustainable forage management practices. The government supports research and development in forage technologies and encourages private sector involvement in forage production. Additionally, efforts are made to improve the distribution of forage seeds and enhance farmers' knowledge of forage cultivation. By prioritizing forages, Uganda aims to address feed shortages and support smallholder farmers.
Rwanda	Rwanda's 5th Strategic Plan for Agricultural Transformation (PSTA5) highlights the crucial role of the livestock sector in the country's economic growth and development from 2024 to 2030. The Rwandan government has established several targets for the sector, including boosting milk production from 785 million liters in 2018 to 1.5 billion liters by 2024 and expanding the national herd size from 1.5 million to 2.5 million [61]. Rwanda's National Livestock Policy and Livestock Master Plan [62] emphasize the importance of forages in increasing livestock productivity and sustainability. The plans focus on improving forage resources and management practices, including the cultivation of high-quality forage crops and the development of forage technologies. The government also supports integrated approaches that combine forage production with other agricultural activities to maximize resource use. By prioritizing forages, Rwanda aims to enhance livestock performance and contribute to food security and rural development.
Burundi	Burundi's National Plan for Development [63] focuses on enhancing productivity, encouraging private sector investment, and strengthening the capabilities of public and private institutions. Burundi's National Agricultural Investment Plan [64] places a strong emphasis on increasing livestock productivity through improved feeding systems, including the use of cultivated forages. The plan highlights the need for expanding forage cultivation to reduce the country's dependence on natural pastures, which are often overgrazed and degraded.

3.2. Annual Ruminant Feed Demand, Feed Deficit, and Cultivated Forage Deficit in the Region

The annual ruminant feed demand is determined by the total ruminant population of a country, the equivalent number of Tropical Livestock Units (TLUs), and the animals' requirements for body maintenance, growth, production, and reproduction. The annual feed deficit is calculated as the difference between annual feed demand and the available feed resources. Table 4 presents these indicators for the six countries studied, showing a total regional annual feed demand of 353 million tons of dry matter and a significant regional annual feed deficit of nearly 40% of this amount, which equates to 136 million tons of dry matter.

Table 4. Annual feed demand, feed deficit, and cultivated forage deficit in the selected countries.

Country	Ruminant Population (Heads)	Tropical Livestock Units (TLUs)	Dry Matter Deficit (%)	Annual Feed Demand (Dry Matter t y^{-1})	Annual Feed Deficit (Dry Matter t y^{-1})	Annual Cultivated Forage Deficit (Dry Matter t y^{-1})
Ethiopia	156,968,403	64,524,901	21.6	176,636,918	38,153,574	8,813,476
Tanzania	66,900,000	27,030,000	72.3	73,994,625	53,498,114	12,358,064
Kenya	69,481,459	23,455,031	60	64,208,147	38,524,888	8,899,249
Uganda	32,461,107	12,126,138	13	33,195,304	4,315,389	996,855
Rwanda	4,758,591	1,199,288	42	3,283,051	1,378,881	318,522
Burundi	2,673,929	621,212	35	1,755,316	614,361	141,917

Notes: Ruminants include cattle, sheep, and goats. 1 TLU = 250 kg; Sources: [65–69].

This situation is concerning because ruminants, particularly cattle, are vital for food security, combating hunger and poverty, and supporting the livelihoods of millions in the region [70]. Additionally, dryland cattle holders, who typically have a limited number of Tropical Livestock Units (TLUs) per capita, are highly vulnerable to external shocks like climate change [71]. Such shocks can rapidly threaten their livelihoods and exacerbate the regional feed deficit.

In the region, farms often lack adequate land for grazing, leading to widespread reliance on cut-and-carry forages and stall feeding [24]. Forage is generally scarce and of low quality, a problem that intensifies during dry seasons and is further aggravated by climate change, thus impacting food security over time [12,13]. This issue has been notably evident in 2022 in Kenya, Ethiopia, and Somalia [72]. Table 4 also indicates that the regional annual cultivated forage deficit exceeds 31 million tons of dry matter, with Tanzania, Kenya, and Ethiopia having the highest deficits.

This scenario underscores the urgent need to address the forage gap to enhance regional food security and reduce poverty. One potential solution is to increase the availability and accessibility of forage seeds, particularly as demand currently exceeds supply [14]. The following section will estimate the forage seed requirements for the studied countries to address the cultivated forage deficit.

3.3. Annual Forage Seed Requirements for Bridging the Regional Cultivated Forage Deficit

According to Table 5, for Scenario 1, which assumes a 100% adoption rate, the regional Annual Forage Seed Requirement (AFSR) for the adoption year would be 22,612 tons. This figure does not account for the additional forage seeds needed for annual legume replacement or regeneration seeds for perennial forage grasses. Including these additional requirements, the total regional Forage Seed Requirement (FSR) for Scenario 1 amounts to 166,543 tons over a 10-year period. The highest seed requirements would be in Tanzania (8863 tons in the adoption year; 65,280 tons over 10 years), followed by Kenya (6383 tons; 47,009 tons), Ethiopia (6321 tons; 46,556 tons), Uganda (715 tons; 5266 tons), Rwanda (228 tons; 1683 tons), and Burundi (102 tons; 750 tons). However, this scenario appears highly unrealistic given the current low seed availability in the region, high seed prices, and the generally underdeveloped seed systems [14,16,20,21,70,73,74].

Scenario 2 offers a more realistic estimate by applying a 10% adoption rate, which would allow the cultivated forage deficit to be gradually addressed over 10 years. Under this scenario, the total regional FSR would be 95,605 tons. The distribution of this requirement is as follows: Tanzania would need 37,474 tons, Kenya 26,986 tons, Ethiopia 26,726 tons, Uganda 3023 tons, Rwanda 966 tons, and Burundi 430 tons. The Annual Forage Seed Requirement (AFSR) for the adoption year totals 2261 tons at the regional level. Although this is still a significant amount, it is more manageable compared to the 22,612 tons required under Scenario 1, considering the current limitations in the seed sector.

Table 5. Estimated annual forage seed requirement to bridge the roughage dry matter gap in Ethiopia, Tanzania, Kenya, Uganda, Rwanda, and Burundi using selected forages.

Country	Forages	Scenario 1: 100% Adoption Rate, AFSR (t/y1)/FSR (t/10y)	Scenario 2: 10% Adoption Rate, AFSR for 10 Years (t)										
			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	FSR (t/10y)
Ethiopia	*Megathyrsus maximus*	463/463	46	46	46	46	46	46	46	46	46	46	463
	Urochloa hybrids	1452/1452	145	145	145	145	145	145	145	145	145	145	1452
	Vigna unguiculata	2203/22,030	220	441	661	881	1102	1322	1542	1763	1983	2	12,119
	Lablab purpureus	2203/22,030	220	441	661	881	1102	1322	1542	1763	1983	2	12,119
	Regeneration seed *M. maximus*	0/139	-	-	-	-	-	-	-	46	46	46	139
	Regeneration seed *Urochloa* hybrids	0/436	-	-	-	-	-	-	-	145	145	145	436
	Total	6321/46,556	632	1073	1514	1954	2395	2836	3276	3908	4349	4790	26,726
Tanzania	*Megathyrsus maximus*	649/649	65	65	65	65	65	65	65	65	65	65	649
	Urochloa hybrids	2035/2035	204	204	204	204	204	204	204	204	204	204	2035
	Vigna unguiculata	3090/30,900	309	618	927	1236	1545	1854	2163	2472	2781	3090	3090
	Lablab purpureus	3090/30,900	309	618	927	1236	1545	1854	2163	2472	2781	3090	3090
	Regeneration seed *M. maximus*	0/195	-	-	-	-	-	-	-	65	65	65	195
	Regeneration seed *Urochloa* hybrids	0/611	-	-	-	-	-	-	-	204	204	204	611
	Total	8863/65,280	886	1504	2122	2740	3358	3976	4594	5480	6098	6716	37,474
Kenya	*Megathyrsus maximus*	467/467	47	47	47	47	47	47	47	47	47	47	467
	Urochloa hybrids	1466/1466	147	147	147	147	147	147	147	147	147	147	1466
	Vigna unguiculata	2225/22,250	223	445	667	890	1112	1335	1557	1780	2002	2225	12,236
	Lablab purpureus	2225/22,250	223	445	667	890	1112	1335	1557	1780	2002	2225	12,236
	Regeneration seed *M. maximus*	0/140	-	-	-	-	-	-	-	47	47	47	140
	Regeneration seed *Urochloa* hybrids	0/440	-	-	-	-	-	-	-	147	147	147	440
	Total	6383/47,009	638	1083	1528	1973	2418	2863	3308	3946	4391	4836	26,986

Table 5. *Cont.*

Country	Forages	Scenario 1: 100% Adoption Rate, AFSR (t/y1)/FSR (t/10y)	Scenario 2: 10% Adoption Rate, AFSR for 10 Years (t)										
			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	FSR (t/10y)
Uganda	*Megathyrsus maximus*	52/52	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	52
	Urochloa hybrids	164/164	16	16	16	16	16	16	16	16	16	16	164
	Vigna unguiculata	249/2490	25	50	75	100	125	150	174	199	224	249	1371
	Lablab purpureus	249/2490	25	50	75	100	125	150	174	199	224	249	1371
	Regeneration seed *M. maximus*	0/16	-	-	-	-	-	-	-	5.2	5.2	5.2	16
	Regeneration seed *Urochloa* hybrids	0/49	-	-	-	-	-	-	-	16	16	16	49
	Total	715/5266	72	121	171	221	271	321	371	442	492	542	3023
Rwanda	*Megathyrsus maximus*	17/17	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	17
	Urochloa hybrids	53/53	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	53
	Vigna unguiculata	80/800	8	16	24	32	40	48	56	64	72	80	438
	Lablab purpureus	80/800	8	16	24	32	40	48	56	64	72	80	438
	Regeneration seed *M. maximus*	0/6	-	-	-	-	-	-	-	2	2	2	5
	Regeneration seed *Urochloa* hybrids	0/15	-	-	-	-	-	-	-	5	5	5	16
	Total	228/1683	23	39	55	71	87	103	118	141	157	173	966
Burundi	*Megathyrsus maximus*	7/7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	7
	Urochloa hybrids	23/23	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	23
	Vigna unguiculata	36/360	4	7	11	14	18	21	25	28	32	36	195
	Lablab purpureus	36/360	4	7	11	14	18	21	25	28	32	36	195
	Regeneration seed *M. maximus*	0/2	-	-	-	-	-	-	-	0.7	0.7	0.7	2
	Regeneration seed *Urochloa* hybrids	0/7	-	-	-	-	-	-	-	2.3	2.3	2.3	7
	Total	102/750	10	17	24	32	39	46	53	63	70	77	430
Grand Total		22,612/166,543	2261	3838	5414	6990	8566	10,143	11,720	13,981	15,557	17,134	95,605

Notes: AFSR: Annual Forage Seed Requirement; FSR: Forage Seed Requirement.

3.4. Land and Farmers Required in the Forage Adoption Process

As shown in Table 6, addressing the cultivated forage deficit in the region would require nearly 2 million hectares of land across the six countries, with the majority needed in Tanzania (779,648 hectares), Kenya (561,438 hectares), and Ethiopia (556,027 hectares). Although a gradual adoption scenario with a 10% adoption rate would not require all this land at once, the annual land requirement would still be around 200,000 hectares.

Table 6. Land required for the cultivation of forages to close the forage deficit in the region.

Forage	Ethiopia (ha)	Tanzania (ha)	Kenya (ha)	Uganda (ha)	Rwanda (ha)	Burundi (ha)	Total (ha)
Megathyrsus maximus	154,236	216,266	155,737	17,445	5574	2484	551,741
Urochloa hybrids	181,454	254,431	183,220	20,523	6558	2922	649,108
Vigna unguiculata	110,168	154,476	111,241	12,461	3982	1774	394,101
Lablab purpureus	110,168	154,476	111,241	12,461	3982	1774	394,101
Total (ha)	556,027	779,648	561,438	62,890	20,095	8953	1,989,051

Notes: Based on [21], the following seed rates were applied: *Megathyrsus maximus* 3 kg/ha; *Urochloa* hybrids 8 kg/ha; *Vigna unguiculata* and *Lablab purpureus* 20 kg/ha.

Given the production pressures faced by farmers in the region, the strong competition for land between livestock farming and crop production [75–77], and the increasing impacts of climate change, this target might be ambitious. Burkart [78] highlights this challenge by noting that *Urochloa* hybrid adoption in Africa between 2005 and 2023 covered only 30,141 hectares, including vegetative propagation. Additionally, while some authors like Flórez et al., Junca Paredes et al., and Burkart [14,70,79] describe the forage seed market in the region as emerging with significant potential, Creemers and Opinya [17] characterize the Ugandan forage seed market as small.

Based on average farm sizes in the studied countries, our analysis indicates that closing the forage deficit would require the participation of approximately 1.5 million farmers, with the majority located in Kenya (652,835), Tanzania (412,512), and Ethiopia (397,162) (see Table 7). In a gradual adoption scenario with a 10% adoption rate, this would translate to over 150,000 farmers annually adopting the recommended forage technologies.

Reaching this number of adopters may be challenging due to several factors. Farmers are typically risk-averse, forage seeds are expensive and often difficult to access, willingness to pay is low, and there is limited technical assistance for technology adoption [14,19,74]. For example, *Urochloa* hybrids were adopted by approximately 65,000 farmers in Africa between 2005 and 2023, including vegetative propagation [78]. Furthermore, Ahumuza et al. and Dey [15,16] reported low adoption rates for forage seeds in Uganda and Ethiopia, respectively. The African Seed Access Index highlights that forage seeds are notably absent from focus areas, which are predominantly centered on food crops like maize [80]. Flórez et al. [14] noted a strong demand for improved forage seeds in East Africa but limited access, mainly due to availability and high prices. In Ethiopia, Tekalign [74] identified an underdeveloped and informal forage seed system unable to meet the growing demand, while Creemers et al. [73] reported limited seed availability in Kenya. Similarly, Ahumuza et al. [15] emphasized the need for improved seed dissemination in Uganda. These observations align with our findings, indicating that while there is significant demand for cultivated forage seeds, issues of accessibility (price and availability) are major barriers to higher adoption rates.

Table 7. Estimated number of farmers required to be involved in the adoption process.

Country	Average Farm Size (ha)	Number of Farms (Total)	Number of Farms (Annual, 10% Adoption Rate)
Ethiopia	1.4	397,162	39,716
Tanzania	1.89	412,512	41,251
Kenya	0.86	652,835	65,284
Uganda	1.51	41,649	4165
Rwanda	0.72	27,910	2791
Burundi	0.5	17,907	1791
Total		1,549,974	154,998

Note: For this analysis, we estimated that each farm is led by a single farmer. Sources: Average farm sizes were consulted from the Family Farming Knowledge Platform of FAO [81] for Ethiopia, Tanzania, Kenya, and Uganda; for Rwanda, we used Ngango and Hong [82]; and for Burundi, we used information provided by the Ministry of Agriculture and Livestock Burundi [83].

3.5. The Role of Vegetative Propagation in the Forage Adoption Process

Not all cultivated forages on farmers' fields come from purchased seed. In sub-Saharan Africa, it is common for farmers to sell, purchase, or distribute vegetative material in the form of splits, largely due to high seed prices and limited seed availability [14]. A conservative estimate for the split-to-seed ratio in the study region is 3:1, meaning that for every plant sown from purchased seed, three additional plants are propagated vegetatively (S. Mwendia, P. Karimi, M. Peters, personal communication). This highlights the significant role of vegetative propagation in the current adoption of cultivated forages. Burkart [78] also noted that over 22,000 hectares of the total 30,000 hectares of *Urochloa* hybrid adoption in Africa by 2023 were derived from vegetative material.

However, vegetative propagation has its drawbacks. It requires substantial labor and often involves additional transportation, especially when converting large areas with splits, which significantly increases costs. For example, Tiley [84,85] reported that cultivating a single hectare of *Cenchrus purpureus* (Napier grass), an example that could apply to *Megathyrsus maximus* and *Urochloa* hybrids, with vegetative material required 20,000 splits. This material weighs about 10 tons (transportation cost), must be sourced from an area of 1000 m^2 (land requirement), and involves approximately 445–1000 man-hours for sourcing, transportation, and planting (labor cost). For large-scale adoption, such as the 2 million hectares proposed, relying solely on vegetative propagation seems impractical. Instead, the primary source of planting material should be seeds, with vegetative propagation serving as a supplementary method to support the adoption process.

3.6. Estimated Value of the Regional Forage Seed Market and Potential Forage Crop Value Generation

The development of seed systems largely depends on the willingness of seed companies, particularly when aiming for large-scale adoption. These companies seek to maximize profits and thus require economic incentives to enter a market. Additionally, markets must be of a sufficient size to be profitable.

Table 8 provides an overview of the estimated forage seed market value for the studied countries. The data indicate that the regional seed market holds significant potential, even with a conservative adoption rate of 10%. At current seed prices, this market is valued at approximately USD 877 million over 10 years. Even if seed prices were reduced by 25%, the market value would remain substantial at around USD 658 million.

Table 9 details the estimated value of cultivated forages that could be generated over 10 years. At the regional level, this value ranges from USD 5.6 billion to USD 10.2 billion, depending on the adoption rate. This equates to annual values of between USD 560 million and USD 1.02 billion. Tanzania, Kenya, and Ethiopia are expected to contribute the highest values. The two grass species being analyzed account for the largest share of the total estimated values.

Table 8. Estimated seed market value for the selected countries.

Country	Scenario	Seed Market Value (in Millions 2023 USD)				
		Megathyrsus maximus *****	***Urochloa*** **hybrids ***	***Vigna unguiculata***	***Lablab purpureus***	**Total**
Ethiopia	1a/1b	29.28/21.96	95.22/71.42	207.69/155.77	137.60/103.20	469.79/352.34
	2a/2b	29.28/21.96	95.22/71.42	114.23/85.67	75.68/56.76	314.41/235.81
Tanzania	1a/1b	41.05/30.79	133.52/100.14	135.26/101.45	192.94/144.70	502.78/377.08
	2a/2b	41.05/30.79	133.52/100.14	74.40/55.80	106.12/79.59	355.08/266.31
Kenya	1a/1b	29.56/22.17	83.19/62.40	43.94/32.95	50.96/38.22	207.66/155.74
	2a/2b	29.56/22.17	83.19/62.40	24.16/18.12	28.03/21.02	164.95/123.71
Uganda	1a/1b	3.31/2.48	10.77/8.08	3.70/2.77	25.42/19.06	43.20/32.40
	2a/2b	3.31/2.48	10.77/8.08	2.03/1.53	13.98/10.48	30.10/22.57
Rwanda	1a/1b	1.06/0.79	3.44/2.58	3.54/2.65	4.97/3.73	13.01/9.76
	2a/2b	1.06/0.79	3.44/2.58	1.95/1.46	2.74/2.05	9.18/6.89
Burundi	1a/1b	0.47/0.35	1.53/1.15	0.96/0.72	2.22/1.66	5.19/3.89
	2a/2b	0.47/0.35	1.53/1.15	0.53/0.40	1.22/0.91	3.75/2.82
Total	1a/1b	104.73/78.55	327.68/245.76	395.09/296.32	414.11/310.58	1241.62/931.21
	2a/2b	104.73/78.55	327.68/245.76	217.30/162.98	227.76/170.82	877.47/658.11

Notes: Scenario 1a: 100% adoption rate, 10-year evaluation horizon, current seed prices; Scenario 1b: 100% adoption rate, 10-year evaluation horizon, seed prices reduced by 25%; Scenario 2a: 10% adoption rate, 10-year evaluation horizon, current seed prices; Scenario 2b: 10% adoption rate, 10-year evaluation horizon, seed prices reduced by 25%. * Regeneration seed included.

Table 9. Estimated cultivated forage crop value for the selected countries.

Country	Scenario	Estimated Cultivated Forage Crop Value (in Millions 2015 USD)				
		Megathyrsus maximus *****	***Urochloa*** **Hybrids ***	***Vigna unguiculata***	***Lablab purpureus***	**Total**
Ethiopia	1/2	1110/611	1110/611	317/175	317/175	2856/1571
Tanzania	1/2	1557/856	1557/856	445/245	445/245	4004/2202
Kenya	1/2	1121/617	1121/617	320/167	320/167	2883/1586
Uganda	1/2	126/69	126/69	36/20	36/20	323/178
Rwanda	1/2	40/22	40/22	11/6	11/6	103/57
Burundi	1/2	18/10	18/10	5/3	5/3	46/25
Total	1/2	3972/2185	3972/2185	1134/616	1134/616	10,215/5619

Notes: Scenario 1: 100% adoption rate, 10-year evaluation horizon; Scenario 2: 10% adoption rate, 10-year evaluation horizon. * Regeneration seed included.

The potential forage crop value would make a substantial contribution to the estimated USD 63 billion annual value of cultivated forage crops in the developing world, as reported by Fuglie et al. [18]. Specifically, for *Urochloa* hybrids, the potential annual forage crop value in the studied region would be between USD 219 million and USD 397 million. This would also significantly add to the estimated annual forage crop value of USD 1.14 billion for *Urochloa* hybrids already adopted in the global tropics [78].

3.7. Developing the Forage Seed Market and Ensuring Forage Adoption

A recent position paper by the Intergovernmental Authority on Development [86], which includes eight member states—Djibouti, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Uganda, and Eritrea—emphasizes the need to focus on forage seed value chain development and demand creation, given the region's large livestock population and the livelihoods tied to livestock. This recognition highlights the critical importance of ensuring forage seed availability. One key aspect is the registration of forage varieties in individual countries, which is essential to encourage private sector involvement and to tap into the region's market potential. However, registering forage varieties can be a time-consuming process, often involving significant bureaucracy [10,14,17,20,21,73,87].

A more efficient approach would involve leveraging regional trade blocs to expedite the registration process. For instance, under COMESA (Common Market for Eastern and Southern Africa), a variety registered in two member countries can be accepted in a third member country without undergoing lengthy and resource-intensive national performance trials [88]. Extending this approach to other trade blocs, such as the East African Community (EAC), IGAD, or the Southern African Development Community (SADC), could present a significant opportunity for the easier movement of developed forage varieties across borders. Given the overlapping memberships of many countries in these trade blocs, such harmonization would facilitate smoother regional trade and agricultural integration. Table 10 gives an overview of the membership of several African countries in regional trade blocs.

Table 10. Membership of African countries in the regional trade blocs COMESA, IGAD, EAC, SADC.

Country	**COMESA**	**IGAD**	**EAC**	**SADC**	**Total Memberships**
Angola				■	1
Botswana				■	1
Burundi	■		■		2
Comoros	■			■	2
Djibouti	■	■			2
Democratic Republic of Congo	■		■	■	3
Egypt	■				1
Eritrea	■	■			2
Eswatini	■			■	2
Ethiopia	■	■			2
Kenya	■	■	■		3
Lesotho				■	1
Libya	■				1
Madagascar	■			■	2
Malawi	■			■	2
Mauritius	■			■	2
Mozambique				■	1
Namibia				■	1
Rwanda	■		■		2
Seychelles	■			■	2
Somalia	■	■	■		3
South Africa				■	1
South Sudan		■	■		2
Sudan	■	■			2
Tanzania			■	■	2
Tunisia	■				1
Uganda	■	■	■		3
Zambia	■			■	2
Zimbabwe	■			■	2
Total member countries	21	8	8	16	

Note: Shaded cells indicate membership.

To lower seed costs, boosting production within the continent and targeting regional markets is a promising strategy. This involves identifying the most suitable locations for such production. For some forage species, achieving synchronized flowering and seed setting requires longer photoperiods [89]. Classical examples used in this study include the genera *Urochloa* and *Megathyrsus*, which require longer photoperiods that are more achievable at locations further from the equator, either to the north or south [89]. Zambia has been suggested as a suitable location due to its longer day lengths and strong ties to regional trade blocs like COMESA and SADC [40], which together encompass 37 member countries, providing enhanced market linkages. Additionally, Zambia's well-established seed production sector, particularly for maize, a staple food in the region, and the involvement of numerous private companies in its production and marketing [90] make it a strategic choice. The relatively low human population densities in these countries, compared to many other African nations, indicate that land availability for seed production may not be a limiting factor. However, establishing forage seed production and processing facilities would require significant capital investment from private sector entities. Such entities could potentially mitigate these costs by partnering with and contracting farmers who are already engaged in forage seed production, as suggested by Mwendia et al. [40].

Once seeds are registered in a country, establishing effective distribution logistics is crucial, which remains a challenge in the current forage seed system [14,17]. Distribution models involving seed companies and producer associations could address issues related to bulk seed purchases, distribution in rural areas, and providing essential information for successful technology adoption. Livestock producers in the region often lack knowledge about forage cultivation [10,14,18,20], which can lead to poor adoption outcomes and technology rejection. Collaboration on technical assistance and extension among stakeholders—such as seed companies, public entities, NGOs, and producer associations—could bridge this knowledge gap and support effective technology adoption.

However, establishing a functional seed system alone will not guarantee widespread adoption of cultivated forages. Existing modest adoption rates are influenced by a complex interplay of social, economic, political, cultural, and environmental factors, including risk aversion, labor availability, access to inputs and credit, land tenure, regulatory frameworks, market dynamics, and gender dynamics. Addressing these complexities requires a comprehensive strategy that considers the multifaceted influences on adoption, which is essential for designing effective approaches to promote the large-scale use of forage innovations.

3.8. Environmental Impacts of Improved Forage Seed Adoption

Numerous studies highlight the critical impact of improved forages in sustainably increasing productivity in both meat and milk production, which translates to higher incomes for livestock producers [12,22–24,91–93]. Additionally, these forages exhibit greater resilience to extreme weather events, such as droughts and waterlogging, contributing to climate adaptation, especially in silvo-pastoral and agroforestry systems [29–31]. Notably, species like *Urochloa* have shown effectiveness in boosting milk production, enhancing animal welfare, improving nutrition, reducing soil erosion, and optimizing water use [23,24,94]. The adoption of improved forages also supports mitigation by generating higher biomass yields, which reduces the land area required for cultivation and livestock feeding, enabling more land to be dedicated to afforestation, conservation, crop production, or infrastructure [27,28]. Furthermore, improved forages help decrease methane emissions from ruminants and facilitate biological nitrification inhibition and carbon sequestration [91,95,96]. In Africa, several studies identify both economic and environmental benefits from the use of improved forages [21,23,24,97–100], suggesting that the adoption of these forages could lead to substantial environmental benefits and advance the United Nations Sustainable Development Goals (SDGs) on both the environment and livelihoods, i.e., No Poverty (UN-SDG 1), Zero Hunger (UN-SDG 2), Sustainable Cities and Communities (UN-SDG 11), Responsible Consumption and Production (UN-SDG 12), Climate Action (UN-SDG 13), and Life on Land (UN-SDG 15) [101].

4. Conclusions and Recommendations

The livestock sector across East Africa is recognized as a key contributor to economic growth and rural livelihoods, with governments in the region focusing on improving productivity and sustainability through various initiatives and policies. These efforts increasingly prioritize the use of forages due to their potential to enhance livestock production and mitigate environmental impacts. However, the region faces significant challenges, notably the vast feed and cultivated forage deficits, which threaten food security and economic stability.

Efforts to close the feed gap reveal that over 40% of feed demand remains unmet, exacerbated by climate change and limited land availability, especially in smallholder farming systems. This critical shortage underscores the urgency of increasing forage cultivation and seed availability, although the current seed systems are underdeveloped and lack accessibility—resulting in limited seed availability and high prices.

Closing the cultivated forage feed gap over 10 years seems to be an ambitious endeavor since challenges related to land requirements, farmer participation, and access to inputs persist. Vegetative propagation remains a supplementary but costly method, emphasizing the need for a robust seed system to scale up forage adoption.

Despite these significant hurdles, the forage seed market holds considerable economic potential, with an estimated seed value of up to USD 877 million over 10 years at a slow adoption rate of 10%, which could lead to significant economic gains in terms of forage crop values. To realize this potential, governments and private entities must work together to improve seed systems, lower costs, and streamline registration processes, particularly by leveraging regional trade blocs.

For widespread adoption, addressing socio-economic barriers, including risk aversion, access to credit, and gender dynamics, will be crucial. A comprehensive, multi-stakeholder approach is necessary to build an inclusive and sustainable forage seed market that supports the region's livestock sector, food security, and rural development goals.

From this, we propose the following recommendations:

- Enhance feed and forage policy integration: Governments should enhance the integration of feed and forage policies with broader livestock sector strategies. This includes aligning forage production initiatives with overall livestock productivity and environmental sustainability goals. They should also emphasize the adoption of sustainable forage management practices to improve feed quality and availability. Likewise, policies that balance economic, environmental, and social objectives in forage production should be developed.
- Address feed and forage deficits: Strategies to significantly boost the availability of forage seeds should be developed. This could involve supporting seed production initiatives, reducing seed prices, and improving seed distribution channels. Investments in research to develop high-yielding and climate-resilient forage varieties is essential. Collaboration with international research organizations can help accelerate the development of suitable forage crops for the region.
- Improve seed systems and distribution: Regional trade blocs such as COMESA and EAC should be used to streamline the registration and movement of forage varieties across borders. This can reduce bureaucratic delays and enhance seed accessibility. Efficient seed distribution models that involve seed companies and producer associations should be developed to improve access to seeds in rural areas. Logistics and supply chain solutions to ensure timely delivery of forage seeds should be established.
- Support of farmers and land use: Comprehensive training and extension services to farmers on forage cultivation and management are essential. This should include practical advice on the use of forage technologies and addressing common challenges in forage production. Innovative land management practices should be explored to maximize the use of available land for forage cultivation. Policies that mitigate competition between livestock and crop production and promote sustainable land use planning should be developed.

- Enhance market incentives: Economic incentives for seed companies to enter and invest in the forage seed market should be created. This could involve subsidies, tax breaks, or public–private partnerships to support the development of the seed industry. The forage seed value chain should be developed by encouraging private sector involvement, improving market infrastructure, and fostering demand creation for forage crops.
- Address adoption barriers: Barriers related to high seed prices and limited seed availability should be addressed. This could involve subsidies or financial support mechanisms (e.g., credits) for farmers adopting improved forage varieties. Likewise, social, economic, and environmental factors that influence adoption rates must be addressed, e.g., through developing targeted interventions to overcome risk aversion, labor constraints, and other barriers to successful technology adoption.
- Monitor and evaluate adoption: Robust monitoring and evaluation systems to track progress in forage adoption, seed distribution, and impact on livestock productivity should be established. Data derived from such systems can be used to refine strategies and make evidence-based adjustments to policies and programs.

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