Working paper- Literature review on Potential options for livestock feed improvement in Malawi

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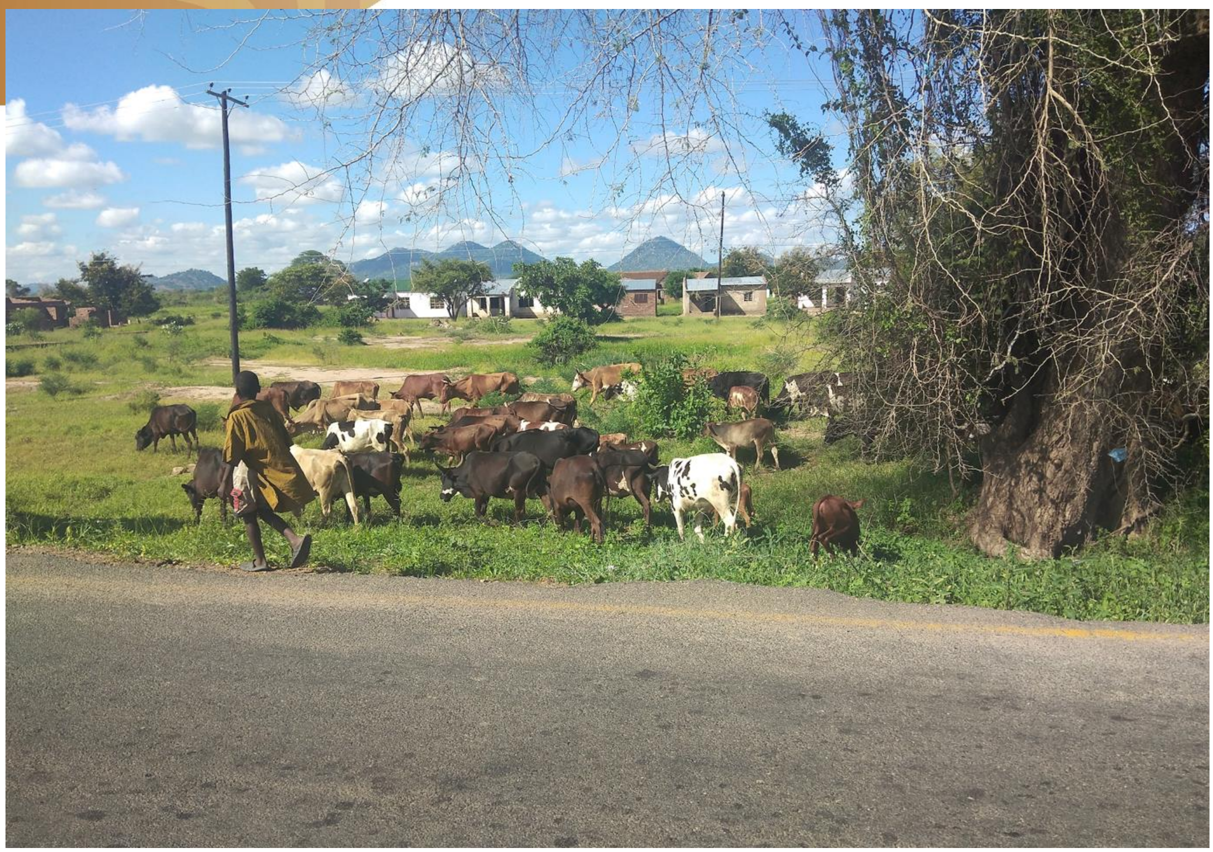

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

Contents

Abbreviations and acronyms

ADMARC	Agricultural Development and Marketing Corporation
AEDOs	Agricultural Extension Development Officers
AEZs	Agroecological Zones
APES	Agricultural Census Production Survey
ASF	Animal-Source Foods
CEAs	Community-Based Extension Agents
CIMMYT	International Maize and Wheat Improvement Centre
CP	Crude Protein
DM	Dry Matter
FGD	Focused Group Discussion
FISP	Farm Input Subsidy Programme
g CP DM/ d	Gram's crude protein per day (Dry matter basis)
g/ kg	Grams per kilogram
GDP	Gross Domestic Product
GHG	Greenhouse gas
IPC	Integrated Food Security Phase Classification
MFS	Mixed Farming Systems
MJ/ kg	Megajoules per kilogram
NDF	Neutral detergent fibre
NGO	Non-Governmental Organisations
R & D	Research and Development
SDG	Sustainable Development Goal
SI-MFS	Sustainable Intensification of Mixed Farming Systems
SSA	Sub-Saharan Africa

Executive summary

Smallholder farmers in Malawi are confronted with many challenges, encompassing both biophysical and socioeconomic aspects, which negatively impact their livelihoods. Unfortunately, these challenges are often addressed in fragmented approaches, lacking a holistic perspective, that prioritises isolated components and dimensions of their livelihoods. Instead of prioritising the improvement of nutrient content in forages and grains, crucial for both quantity and quality of protein, interventions tend to overlook this aspect. Consequently, food security remains compromised, exacerbating issues related to hidden hunger. This study was designed to explore opportunities in the contrasting communities within the Mangochi district, characterised by aridity, with the higher potential (semi-arid) sites of Kasungu where CIMMYT implements activities under Mixed Farming Systems initiatives. The study assessed various forage options within the framework of sustainable intensification aimed at enhancing livelihoods across diverse landscapes in Malawi, highlighting opportunities for maximising synergistic benefits and minimising potential trade-offs.

The first activity was a comprehensive literature review, delineating the array of feed/ forage resources available for smallholder farmers. The review further evaluated the challenges and opportunities inherent in their pursuit of optimal animal productivity. In Malawi, smallholder farmers benefit from a rich assortment of feed resources for their livestock, primarily relying on local sources such as natural rangeland pastures, which serve as the primary source of their feed inventory. The main challenge of rangeland pastures is the decline in biomass and quality, particularly in the dry season. Although a minority, predominantly dairy farmers, leverage improved forages like Napier and Rhodes grass through the cut-and-carry system, the prevalence of such practices remains limited. Following harvest, cereal and legume crop residues emerge as crucial supplementary feeds during this period. The dominant crop residues are maize stover and bran, and groundnut haulms. Regrettably, there's a notable oversight regarding alternative sources of energy- and protein-rich feeds, such as small cereal grains, cassava, legumes (including fodder trees/ shrubs and herbaceous forages), insect-based meals, and hydroponic fodder. Notably, fodder derived from ligneous trees and shrubs presents a promising solution to address feed shortages during the dry season, boasting high protein content, a critical nutrient deficit during this period. Commercial feeds and supplements are prevalent among large-scale livestock farmers, as the adoption among smallholders is constrained primarily by prohibitive costs.

The second activity was to identify the potential sources of feed improvement for livestock aligned to the different agroecological regions. Key informant interviews (KII) were carried out in Kasungu (n = 26) and Mangochi (n = 11), complemented by six focused group discussions (FGDs), with three conducted in each district. Additionally, chemical profiles of forages were analysed in both districts, with 11 samples from each. The KII showed that maize-based farming is the dominant agricultural practice in the surveyed districts, followed by crop-livestock mixed farming. Livestock breed preferences varied between districts; however, local breeds were prevalent in both districts. Across the two districts, 57% of the respondents in Kasungu reported that farmers use supplements, whilst in Mangochi, it was 43%. Maize bran (100%) and stover (92%) were reported as the main energy supplements, with groundnut the dominant protein supplement in both districts, reported by close to two-thirds of the KIIs.

During the FGDs, farmers highlighted numerous obstacles, including challenges with agricultural inputs (i.e., seeds and fertiliser), worsened by climate change impacts such as delayed rainfall onset and increased pest and disease prevalence. In addition to diseases and pest prevalence, feed shortages during the dry season were a major factor influencing the reduction in animal production. Despite feed and diseases being primary limitations to animal production among smallholder farmers, it was the financial constraints that wield the greatest influence as farmers could not afford supplementary feed or the cost of purchasing veterinary medicines. Despite these challenges, there's optimism about adopting Sustainable Intensification practices, as farmers acknowledge its potential to enhance productivity and optimise resource utilisation even after the project phases out, reflecting hope for increased yields and household incomes. Leucaena leucocephala had the greatest crude protein content (35.3%) across the two districts. Snot apple tree (Azanza garckeana) leaves and Bambusa balcooa were second and third in terms of CP content in Kasungu after L. leucocephala at 23.2% and 22.2%, respectively. In Mangochi, the greatest CP content was in the order of Moringa oleifera (25%), Khaya nyasica (22.1%) and cassava (Manihot esculenta) leaves (21.4%). Based on the relative feed value, snot apple leaves and giant milkweed (Calotropis procera) ranked the highest in Kasungu and Mangochi at 112 and 108, respectively.

The third objective was to propose options for impact pathways for crop-livestock-based poverty escape for the Kasungu and Mangochi districts. Despite the myriad of challenges in achieving the goals of SI-MFS, adopting the practices can yield benefits such as increased productivity, enhanced resilience, and improved livelihoods for rural farmers. In land-limited areas like Mangochi, introducing non-conventional crops can boost productivity and address food insecurity, while integrating small stock rearing with crop production could potentially optimise land use and reduce reliance on external inputs. Smallholder farmers in both districts can sustainably manage their livestock feed resources through innovative strategies like utilising tree/ shrub and herbaceous legume foliage for both nutritious feed and enhanced soil fertility. Supporting smallholder farmers to use local resources for feed, coupled with training in livestock management, particularly, feed formulation (e.g., Pearson square method) could enhance the feed quality and improve animal nutrition and production. Preservation of feed resources (e.g. haymaking) and proper preparation techniques (i.e., chopping or grinding crop residues) to improve feed intake, digestibility and animal productivity is recommended.

To improve the adoption of some of these technologies, capacity building for achieving change needs to occur throughout the continuum from youth through in-service learning for professionals in research, extension, and other private and public sectors, as well as institutional capacity building. Successful implementation of these technologies will require a revitalised and efficient extension service, including community-based agents and farmer-to-farmer programs, which are crucial in disseminating knowledge and facilitating the adoption of sustainable practices. In addition, integrated marketing and value-addition initiative programs can also enhance market access and farmer incomes, contributing to a holistic approach to addressing the complex challenges faced by smallholder farmers in these communities.

General Introduction

In developing countries, agriculture serves as the source of income and sustenance, for most of the populace. It contributes to 4.3% of the GDP with figures reaching up to 30% in some of the developing nations as reported by the World Bank (World Bank, 2023). To achieve the Development Goal of eradicating hunger, there is a need for a 60% increase in food production within the agricultural sector to meet a projected surge in demand of almost 70% according to Pawlak and Kołodziejczak (2020). This goal poses challenges for smallholder rural farmers who face issues like climate-related disruptions, governance shortcomings and ineffective public services (Guo et al., 2020; Stevens and Madani, 2016). The situation is crucial for women involved in farming activities since they contribute over 45% of the world's food production but have limited ownership over land (<15% of farmland;Wudil et al., 2022). To address the rising food demands farmers must consider expanding their land area or enhancing productivity within existing boundaries through intensification methods.

In countries like Malawi, it is crucial to ensure food production since smallholder farmers play a crucial role in the food supply chain (FAO, IFAD, UNICEF, 2019) on small farm sizes (<2 hectares; Giller et al., 2021; Samberg et al., 2016). The Integrated Food Security Phase Classification report indicates that 15% of the population is facing food insecurity (IPC, 2023), worsened by frequent droughts and floods over the past decade (Bhatti et al., 2021; McCarthy et al., 2021). To address these challenges, it is important to focus on intensification practices that aim to increase productivity while minimising environmental impact and resource depletion (Haggar et al., 2021). By implementing strategies like diversified cropping systems (Szymczak et al., 2020), agroforestry (Vanlauwe et al., 2015), integrated soil fertility management (Vanlauwe et al., 2015) and crop-livestock integration (Sekaran et al., 2021), smallholder farmers can improve their resilience to extreme climatic conditions, like droughts and floods. However, Ayantunde et al. (2020) note that despite the advantages of intensification, its widespread adoption has been limited due to factors such as climate change inadequate use of resources, insecure land ownership and a lack of uptake of technologies that enhance productivity.

Sub-Saharan Africa stands out as a significant global focal point for issues such as soil degradation, nutrient depletion, water resource scarcity and contamination, and biodiversity loss attributed to climate-induced shocks (McCarthy et al., 2021). This is why Oyewole (2022) suggests that smallholder farmers can enhance their competitiveness in the market by focusing on long-term productivity and maximising resource efficiency while also ensuring resilience and ecosystem services. Improving soil health is crucial for the sustainability of smallholder farming systems as it presents a productivity challenge. Therefore, integrating practices for managing soil fertility becomes essential for achieving Sustainable Intensification of Mixed Farming Systems (SI-MFS) due to its potential to increase crop yields by, up to 20% of their capacity (Ayantunde et al., 2020; Giller et al., 2021; Van Ittersum et al., 2016; Vanlauwe et al., 2015). Van Ittersum et al. (2016) argue that "If intensification is not successful and massive cropland land expansion is to be avoided, SSA will depend much more on imports of cereals than it does today."

Therefore, the implementation and adoption of SI-MFS as a mechanism to ensure food security is a matter of urgency.

Smallholder farmers are also keepers of livestock, and feed gaps in terms of quality and biomass yield are also a major factor that affects their production and livelihood. Poor soil quality not only affects crop yield but also has a negative impact on feed availability, particularly after crop harvest as crop residues form the basis of the supplemental feed for animals (Rusinamhodzi et al., 2015). In SI-MFS, the intricate interplay between soils, forages, human nutrition, and livelihoods is essential. Thus, by optimising these interactions, sustainable intensification not only bolsters agricultural productivity but also promotes human well-being and economic resilience within mixed farming systems. Therefore, the overall scope and objective of this consultancy were to interrogate the interactions of soils, forages, nutrition, and livelihoods across different landscapes in Malawi to identify opportunities to maximise synergies and minimise trade-offs. This was accomplished by undertaking the following activities: 1) conducting an exhaustive literature review on viable options for enhancing livestock feed in Malawi, 2) conducting a thorough analysis of potential sources for improving livestock feed tailored to various agroecological regions, and 3) devising impact pathways for crop-livestock based poverty alleviation in diverse regions of Malawi.

Potential options for livestock feed improvement in Malawi

Summary

Smallholder farmers are crucial to the livestock sector in Malawi, but a limited supply of quality feeds impedes the development of this sector. Diverse forages (annual and perennial grasses, herbaceous and dual-purpose legumes, and multipurpose trees and shrubs) and feeds (commercial and crop residues) are available but the cost of bought-in commercial feeds severely constrains the exploitation of this opportunity. Therefore, farmers rely on low-quality rangeland pastures as the main feed source for their animals with crop residues used opportunistically during times of feed scarcity. Crop residues, while abundant in the dry season, are often nutrient-deficient for optimal livestock growth and reproduction. Additionally, competition for resources between crops and livestock is adding more stress to the feed resources base. To overcome these challenges and attain sustainable intensification, optimising feeding practices alongside the cultivation of improved forages form the foundation for enhancing livestock productivity and improving food and nutrition security. Emphasising the cultivation of high-yielding and drought-resistant forages, promoting sustainable land management practices and investing in small-scale processing facilities can enhance the nutritional quality and availability of feed. Additionally, exploring novel feed sources, such as insect-based protein and hydroponics, offers potential avenues for diversification in future. To improve the adoption of these feed technologies, participatory technology development involving all stakeholders is key. Leveraging accessible and affordable feed resources tailored to local conditions, smallholder farmers can improve the viability and sustainability of their livestock enterprises, thereby enhancing food security and rural livelihoods.

Introduction

Malawi's economy is largely driven by agriculture, with nearly 80% of the population employed in this sector (Bhatti et al., 2021). Like many developing countries that rely on rain-fed agriculture, the country is susceptible to external shocks, particularly climate-related (i.e., droughts and floods). The country endured serious and atypical sequential droughts and floods between 2015 and 2019, which had devastating socio-economic effects both at household and national levels (Bhatti et al., 2021). The floods of 2015 resulted in a 54% reduction in maize yield (McCarthy et al., 2021), which is the main crop grown by most of the smallholder farmers. This exemplifies the risks associated with relying on a solitary crop for a nation's food security. It is, therefore, important to consider adopting alternative agricultural practices that guarantee sustainable food production and mitigate the risks associated with crop failure. Crop diversification and livestock farming offer reliable alternatives (Thornton and Herrero, 2015) in a complementary rather than substitutive or competitive manner.

Livestock are an essential component within African farming systems as an important pathway to escape poverty for rural households through the provision of financial insurance but also encompasses cultural and social aspects and supplies dietary protein (Bhatti et al., 2021). However, the scarcity of land in Malawi

(Giller et al., 2021; Samberg et al., 2016) often side-line livestock farming in favour of crops such as maize at the expense of the establishment of improved pastures (Kumwenda and Ngwira, 2003). Overall, livestock farming is vital for sustainable development, and poverty reduction, and promotes the well-being of resource-limited rural communities. The productivity of livestock in sub-Saharan Africa (SSA) including Malawi is low compared to other developing nations, and this is due to a myriad of factors, primarily inadequate nutrition, disease incidences and poor management (FAO, 2022). The seasonal feed gap has been cited as one of the greatest challenges among smallholder farmers, which is further compounded by the exorbitant cost of commercial feeds/ supplements (Baltenweck et al., 2020; Safaloah and Chapotera, 2007; Thornton and Herrero, 2015).

Rangelands, browse and non-food biomass from crop residues are the main feed resources for livestock for smallholder livestock farmers (FAO, 2022; Lamega et al., 2021). These feed resources are characterised by a low nutrient density, especially during the cool-dry season (Chingala et al., 2019a; Dzowela et al., 1990; Lamega et al., 2021) and research has shown that most on-farm mixed daily rations do not supply adequate nutrients required for reproduction, growth and production (Safaloah and Chapotera, 2007). Programmes (Addy and Thomas, 1977a; Bhatti et al., 2020; Chingala et al., 2019a; Dzowela et al., 1990; Kumwenda, 1999) aimed at delivering 'high-quality' feed options for improved livestock performance and product quality for smallholder farmers have been conducted, but the adoption rates have been low due to a combination of economic, social, and educational factors (Baltenweck et al., 2020; Kumwenda and Ngwira, 2003). It is an undeniable fact that providing high-quality feed is an imperative step towards higher livestock productivity. Livestock are sometimes designated as a buffer against climate-related shocks that can potentially decimate crop yields (Thornton and Herrero, 2015). Investment in livestock nutrition, therefore, fortifies this position and could lead to an increase in cropping systems' resilience. The purpose of this review is to provide an up-to-date overview of Malawi's livestock feed base, with a focus on the available feed resources that smallholder farmers can utilise and an evaluation of the challenges and prospects they encounter in their quest to achieve optimal animal productivity within mixed farming systems.

Livestock distribution in Malawi

Malawi can be classified into three agroecological zones (AEZs; Fig. 2.1): the Lower Shire Valley, the Lakeshore plains and the Upper Shire Valley, and the mid-altitude plateau with the highlands (i.e., high-altitude plateau and hilly areas) sometimes considered as the fourth category (CIAT-World Bank, 2018; FAO, 2022). This classification is based on various biophysical characteristics which include climate, vegetation, hydrography and relief. Understanding AEZs is important for livestock production because different zones influence the availability and quality of forage and disease prevalence, thereby shaping breeding choices and management practices (Lamega et al., 2021). In Malawi, most of the indigenous livestock breeds are found countrywide with exotic breeds concentrated in certain parts of the country (FAO, 2022). In terms of numbers, chickens account for the greatest proportion at 88.6% (160 156 726), including local ecotypes (Dwarf, Frizzle and others), broilers (Ross), layers (White Leghorn and Cobb 500) and the dual Black Australop (Fig. 2.2a) (Commercial Agriculture for Smallholders and Agribusiness, 2020; FAO, 2022). Goats are the second most dominant livestock species (5.5%; 10 028 678), followed by pigs (4.6%; 8 383 086), cattle (1.0%; 1 867 034) and sheep (0.2%; 351 458) (Fig. 2.2b) (FAOSTAT, 2024). However, farmers also farm rabbits, guinea fowls, turkeys, guinea pigs, doves and ducks but on a smaller scale (Banda et al., 2021; FAO, 2022).

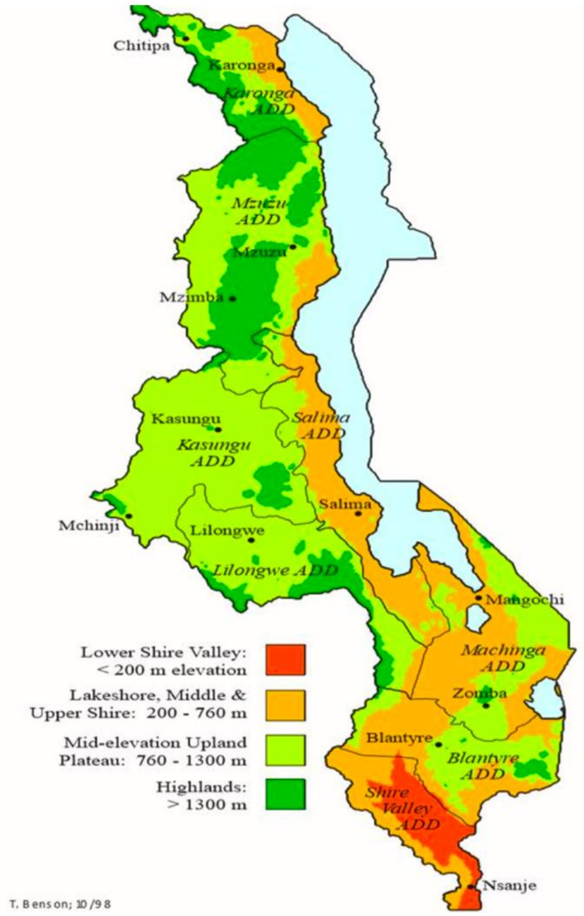

Figure 0.1 Agro-ecological zones of Malawi. Source: (CIAT-World Bank, 2018)

The Malawian small East African goat is the dominant species with a few Boer goats, and some introduced dairy breeds (i.e., Saanen) are also available (FAO, 2022; Msalya et al., 2020). Local sheep breeds dominate the Malawian landscape with the presence of Dorper in some estates (FAO, 2022). Pig breeds include indigenous local pigs and some exotics (i.e., Landrace, Large White and Tristar) (FAO, 2022). The *Bos indicus* (Malawian Zebu and Boran), *B. taurus indicus* (Brahman, Bonsmara Beef Master, Brangus and Santa Gertrudis), Brahman crosses, Boran crosses and non-descript breeds are the beef cattle found in Malawi with the indigenous Zebu constituting over 98% of cattle (FAO, 2022;

Mapiye et al., 2019; Nyamushamba et al., 2017). Dairy cattle breeds comprise less than 6% of the cattle population in Malawi with the Holstein-Friesian and Jersey as the main exotics whilst 77% of these are hybrids between exotics and local breeds (Banda et al., 2012; FAO, 2022). According to FAO (2022), small stocks are mostly reared by female-headed households, whilst cattle are kept in 10 of the 18 livelihood zones by households who are “wealthy”. It is an unfortunate reality that, despite women being the ones who usually acquire livestock through market or inheritance, men still tend to exert control within the confines of marriage (Djurfeldt et al., 2018).

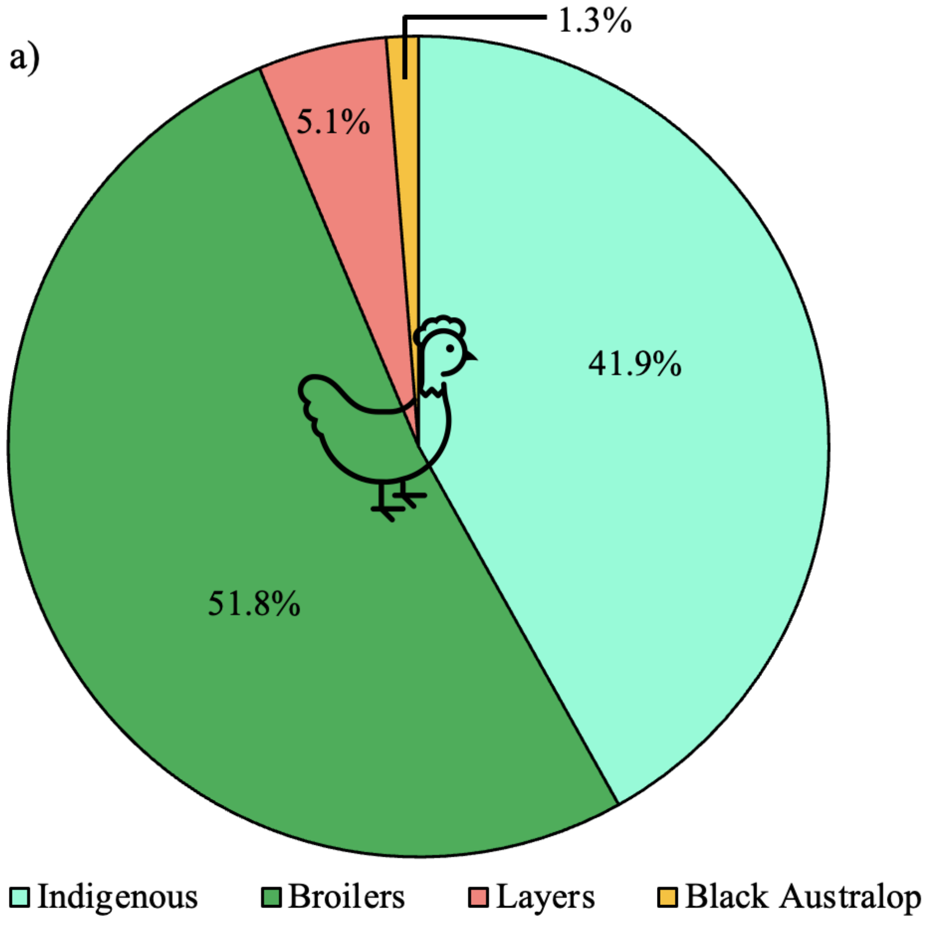

Figure 0.2 Proportion of a) chickens and b) pigs, goats, sheep and cattle in Malawi.

Current livestock feed practices in Malawi

Malawi can be classified into three agroecological zones (AEZs; Fig. 2.1): the Lower Shire Valley, the Lakeshore plains and the Upper Shire Valley, and the mid-altitude plateau with the highlands (i.e., high-altitude plateau and hilly areas) sometimes considered as the fourth category (CIAT-World Bank, 2018; FAO, 2022). This classification is based on various biophysical characteristics which include climate, vegetation, hydrography and relief. Understanding AEZs is important for livestock production because different zones influence the availability and quality of forage and disease prevalence, thereby shaping breeding choices and management practices (Lamega et al., 2021). In Malawi, most of the indigenous livestock breeds are found countrywide with exotic breeds concentrated in certain parts of the country (FAO, 2022). In terms of numbers, chickens account for the greatest proportion at 88.6% (160 156 726), including local ecotypes (Dwarf, Frizzle and others), broilers (Ross), layers (White Leghorn and Cobb 500) and the dual Black Australop (Fig. 2.2a) (Commercial Agriculture for Smallholders and Agribusiness, 2020; FAO, 2022). Goats are the second most dominant livestock species (5.5%; 10 028 678), followed by pigs (4.6%; 8 383 086), cattle (1.0%; 1 867 034) and sheep (0.2%; 351 458) (Fig. 2.2b) (FAOSTAT, 2024). However, farmers also farm rabbits, guinea fowls, turkeys, guinea pigs, doves and ducks but on a smaller scale (Banda et al., 2021; FAO, 2022).

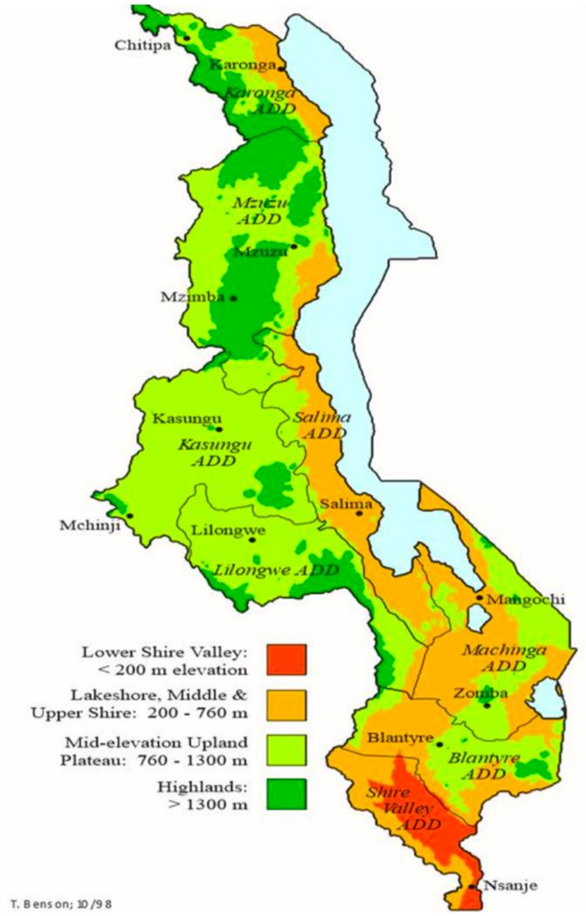

Figure 0.3 Agro-ecological zones of Malawi. Source: (CIAT-World Bank, 2018)

The Malawian small East African goat is the dominant species with a few Boer goats, and some introduced dairy breeds (i.e., Saanen) are also available (FAO, 2022; Msalya et al., 2020). Local sheep breeds dominate the Malawian landscape with the presence of Dorper in some estates (FAO, 2022). Pig breeds include indigenous

Feed Resources Used by Smallholder Livestock Farmers

According to Reynolds (2006), livestock grazing in Malawi is restricted to the *dambos* (i.e., wetlands) and roadsides (Fig. 2.3) in the central and some parts of the southern regions, whilst open woodlands and forests are used for grazing in the northern region and the Upper Shire Valley areas. The prevalence of worms and liver flukes in wetlands during the rainy season restricts farmers to hill and roadside grazing to prevent encroachment into arable land (Bhatti et al., 2020; Nanganga and Safalaoh, 2020). However, with the increasing population in Malawi, rangelands, which serve as the primary source of nutrition for ruminants are shrinking as farmers are migrating into traditional grazing areas (Bhatti et al., 2020).

Figure 0.4 Cattle in Mpanganjira (Mangochi district) grazing along the road.

The livestock sector in Malawi is dominated by the low-input free-range system of feeding for both non-ruminants (poultry and pigs) and ruminants (cattle, sheep and goats), where there is little to no supplementary feeding, minimal housing provisions, and limited animal health services (FAO, 2022). For example, over 90% of beef (Chingala et al., 2019a) and all small ruminants (FAO, 2022) are raised on communal rangelands. This feed base results in poor animal performance emanating from the decline in biomass and nitrogen content coupled with fibre increasing. A study by Dzowela et al. (1990) demonstrated this phenomenon using pure Rhodes grass (*Chloris gayana* cv. Boma) in Malawi where the crude protein (CP) content declined by 58% and neutral detergent fibre (NDF) increased by 9.2% between January and May 1982/3. This resulted in a 34.1% decrease in the *in vitro* dry matter (true) digestibility (Dzowela et al., 1990). The consequences are greater with the progression of the dry season. Similar observations have been reported by other authors in southern Africa (Kumwenda and Ngwira, 2003; Lamega et al., 2021; Mphinyane et al., 2015; Omphile et al., 2005). Overall, the decline in nutritional quality results in reduced nutrient digestibility and utilisation efficiency, higher methane emissions, and poor reproduction and growth performances (Bhatti et al., 2020; Chingala et al., 2019a; Wolf et al., 2021). Apart from rangelands, smallholder farmers, particularly dairy also rely on improved pastures.

A small proportion of smallholder dairy farmers practice zero-grazing where animals are pen-fed using improved fodder but the majority use crop residues

(Addy and Thomas, 1977a, 1977b; Kumwenda and Ngwira, 2003; Reynolds, 2006). Napier (*Pennisetum purpureum*) grass and *C. gayana* are two of the main grasses that are utilised in the 'cut and carry' system by smallholder dairy farmers (Banda et al., 2012). Napier grass is highly favoured due to its ability to produce a significant amount of biomass and it has a quick regrowth. It is also well-suited for areas with low rainfall as it can tolerate drought and does not undergo seasonal dormancy (Paul et al., 2020). Many farmers, dairy included, make use of crop residues as supplementary feed for the livestock and to a lesser extent agro by-products.

Maize stover, *madeya* (i.e., maize bran), groundnut (*Arachis hypogaea*) haulms and other crop by-products are often utilised by farmers as they are readily available after harvest. These are normally provided to cattle grazing on rangelands since goats are generally tethered by the roadside (Addy and Thomas, 1977b; FAO, 2022; Reynolds, 2006). These feed resources contribute to the animals' diet, offering both energy and fibre but may not be able to meet the specific dietary requirements for optimal growth and production, let alone maintenance. Some smallholder farmers also incorporate agro-industrial by-products in their production systems, for example, brewers' spent grains and oilseed cakes from soybean or sunflower processing. These can enhance and potentially address protein deficiencies due to their high CP content (Safaloah and Chapotera, 2007). However, the availability and affordability of such by-products are influenced by market dynamics and external factors and are not easily accessible to smallholder farmers.

Some researchers (Chagunda et al., 2016; Chingala et al., 2019a, 2019b) have also investigated the potential of forage tree legumes/ shrubs due to their high CP, minerals and vitamins. Fodder trees/ shrubs improve smallholders' livestock productivity, and increase environmental resilience, incomes and subsequently livelihoods (Chakeredza et al., 2007; Franzel et al., 2014). Sustainable management practices, improved forage varieties, and targeted nutritional interventions are essential to enhance the overall efficiency of feed utilisation among smallholder livestock farmers in Malawi.

Impact of livestock on the environment

Animal-source foods (ASF) such as milk, meat and eggs play a role in ensuring the food and nutrition security of millions of individuals by contributing around 17% of calorie intake and 33% of protein consumption, respectively (Rojas-Downing et al., 2017). In Africa, the livestock population accounts for one-third of the livestock population (Balehegn et al., 2021), with a projected rise in demand for ASF driven by factors like population growth, rising incomes and urbanisation. Despite the benefits that livestock offer (Bhatti et al., 2021), there are environmental drawbacks associated with livestock farming. Climate change triggered by increased greenhouse gas emissions from livestock and land degradation due to activities like overgrazing and deforestation for pasture development are factors negatively impacting the environment because of animal agriculture. Studies suggest that 14.5% of greenhouse gas emissions can be attributed to the livestock industry (Dopelt et al., 2019; Rojas-Downing et al., 2017; Thornton and Herrero, 2015).

According to Balehegn et al. (2021), dairy cattle in Africa are responsible for around 10% of methane emissions while nearly half of the rangelands in Sub-Saharan Africa suffer from degradation due to overgrazing. The emissions from cattle particularly rank as the largest greenhouse gas source following the feed production industry as highlighted by Thornton and Herrero (2015). Livestock production not only contributes to environmental damage (e.g., climate change) but is also affected by it (i.e., "impact on quality of feed crop and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity") (Rojas-Downing et al., 2017). Feed quality plays a significant role in in the production of enteric emissions, particularly difficult-to-digest lignocellulosic components of feed (Thornton and Herrero, 2015). Therefore, optimising feed quality and formulation (Balehegn et al., 2022) is essential in enhancing livestock productivity while minimising the negative environmental impact of livestock.

Nutrient profiles of feed resources available for livestock farmers in Malawi

Livestock farmers in Malawi rely on a diverse range of feed resources to meet the nutritional requirements of animals. Yet, there is usually a mismatch between the nutrients in feed and the animal's requirements. This imbalance can be attributed to several factors with a lack of farmer knowledge regarding optimal animal nutrition contributing significantly to this imbalance (Herrero et al., 2009). Generally, smallholder farmers are not cognisant of the appropriate composition of feed and the specific nutritional needs of their livestock, either based on animal species, breed, age or physiological status. The lack of awareness regarding the nutritional quality of feed and animal requirements is further compounded by feed scarcity and seasonal variability.

Proper nutrition is key to the success of any livestock operation, regardless of the production system. Yet, the variance in the nutrient profiles of the feed resources (Table 2.1) available to Malawian smallholder livestock farmers presents both challenges and opportunities for farmers striving to optimise animal nutrition and subsequent productivity. As such, it is important to be aware of these differences to capitalise on the opportunities available to optimise animal nutrition. Natural pastures or crop residues often provide a mix of grasses and fodder legumes, offering a fair balance of protein and fibre (Chingala et al., 2019a; Dzowela et al., 1990; Fulkerson et al., 2007). However, their nutritional content can be highly dependent on the type of feed, seasonal changes and climate conditions (Fulkerson et al., 2007), and grasses generally have lower CP and higher fibre content than legume pastures (Table 2.1). Forage legumes such as Hyacinth bean (*Lablab purpureus*), stylo (*Stylosanthes guianensis*) and silverleaf desmodium (*Desmodium uncinatum*) are well-adapted to areas of high temperature and low precipitation, therefore, and their higher CP content (Baloyi et al., 2001; Jingura et al., 2001; Mupangwa et al., 1997), can be used in the cut-and-carry system or alternative in the wet season when yields are at maximum, conserved to be fed as supplements in the dry season.

Maize is the most cultivated food crop in Malawi, but despite its higher energy content, smallholder farmers prioritise it for direct human consumption over livestock feed. Consequently, maize residues (i.e., stover and bran) are thus commonly used as the main energy source by livestock farmers in Malawi but tend to be low in CP (Table 2.1) and require supplementation if production is to be optimised. Agro-industrial by-products and oilseed cakes can serve as valuable protein supplements (Table 2.1), while improved pastures offer a more controlled and nutrient-rich option if properly managed (FAO, 2022). However, as stated earlier, the availability and affordability of agro-industrial by-products influence their use by farmers. Foliage from tree/shrub legumes can reduce the nutrient gap between demand and availability of green fodder owing to their high contents of CP, soluble carbohydrates, minerals and vitamins (Chakeredza et al., 2007; Chingala et al., 2019a; Franzel et al., 2014). However, the elevated levels of secondary metabolites/ phytochemicals (e.g., proanthocyanidins) (Hove et al., 2001), which are anti-nutritional require careful planning when formulating livestock diets. Feeding *Acacia angustissima* (now known as *Acaciella angustissima*), *Calliandra calothyrsus* and *Leucaena leucocephala* as supplements to rangeland pasture hay resulted in superior nutrient intake and retained nitrogen than rangeland pasture hay alone (Hove et al., 2001). Striking the right balance and understanding the nutritional composition of these feed resources is key for livestock farmers to enhance animal health, growth, and overall productivity in the dynamic agricultural landscapes of SSA.

Elevating Livestock Sustainability: Exploring Untapped Climate-Smart Feed Resources

In the quest for sustainable and diversified livestock nutrition, exploring the untapped potential of underutilised crops emerges as a promising avenue, offering a unique opportunity to enhance feed efficiency, resilience, and environmental stewardship in livestock production systems. These alternative feed resources should be integrated into the existing smallholder livestock production systems to complement the existing feed resources, without substitution or competition for land and/ or other resources. Therefore, incorporating crops that have food and feed value in mixed farming systems can significantly enhance animal productivity and efficiency and the livelihoods of poverty-stricken farmers.

Table 0.1: Chemical profiles of potential feed resources available for use by smallholder livestock farmers in Malawi

Class	Feed resource	Composition (g/ kg DM)									
		Crude protein	Ether extract	Organic matter	Crude fibre	Neutral detergent fibre	Acid detergent fibre	Acid detergent lignin	Metabolisable energy (MJ/ kg)	Gross energy (MJ/ kg)	References
Grasses	Palisade grass (*Brachiaria brizantha*)	25.0 - 158	12.0 - 33.0	880	276 - 409	579 - 780	311 - 394	30.0 - 56.0	6.60 - 8.10	18.2	a
	Rhodes grass (*Chloris gayana*)	44.0 - 101	6.10 - 13.2	987 - 994	282 - 434	731 - 732	359 - 476	27.0 - 77.0	8.10 - 8.50	18.3	a
	Napier grass (*Pennisetum purpureum*)	28.0 - 227	10.0 - 38.0	749 - 961	255 - 432	541 - 799	295 - 529	27.0 - 91.0	7.90 - 8.20	18.9	a
	Guinea grass (*Megathyrsus maximus*)	32.0 - 214	8.00 - 38.0	818 - 93.9	277 - 469	541 - 802	282 - 498	33.0 - 88.0	7.70 - 8.00	18.1	a
Cereal grains	Maize (*Zea mays*)	74.0 – 124	31.0 - 57.0	981 - 986	16.0 - 38.0	96.0 - 153	23 – 37.0	2.00 – 12.0	13.6	18.6	a, b
	Sorghum (*Sorghum bicolor*)	81.0 - 143	24.0 – 44.0	944 – 987	17.0 – 46.0	78.0 - 147	27.0 - 71.0	3.00 – 29.0	13.3 – 13.5	18.6 – 19.7	a, b
	Pearl millet (*Pennisetum glaucum*)	114 - 116	40.0 - 54.3	967	64.0 - 115	152	84.2	20.0	13.2	-	c, d
	Maize bran	113	47	955	86	393	106	17	12.4	19.1	a, b
Cereal residues	Maize stover	6.00	12.0 - 22.0	855 - 960	210 - 374	476 - 913	288 - 586	37.0 - 121	8.40	15.5 - 18.2	a, e
	Sorghum stover	45.3 - 74.1	-	884 - 912	-	703 - 729	462 - 484	62.5 - 84.3	5.01 - 7.04	-	f
Roots, tubers and their by-products	Cassava (*Manihot esculenta*) pulp dried	23	7	996	173	369	186	39	-	17.6	b
	Cassava (*M. esculenta*) peels	20.0 - 93.7	2.80 - 34.1	920 - 978	40.4 - 310	158 - 235	156 - 186	40.0 - 121	7.70	10.0 - 17.7	a, b, g
	Cassava (*M. esculenta*) leaf meal	177 - 251	60.0 - 127	839 - 926	66.4	313 - 662	225 - 546	86.0 - 293	3.30 - 4.30	13.7 - 21.3	g, h, i
	Sweet potato (*Ipomoea batatas*) vines	82.0 - 242	25.0 - 104	847 - 992	119 - 303	298 - 516	199- 406	45.0 -118	8.80	17.6 – 18.3	a, h
Legume by-products	Soybean oil seed cake (whole seed extruded)	402	205	944	63	134	78	10	16.6	23.3	b
Legume forages	Cowpeas (*Vigna unguiculata*)	147 - 272	16.3 - 42.2	880 - 970	111 - 359	379 - 663	208 - 419	60 - 206	9.80	18.6 - 19.1	a, h, k, l
	Pigeon pea (*Cajanus cajan*)	217	60.6	951	372 – 629	545	362	176	9.60	19.7 - 22.5	a, h
	Velvet beans (*Mucuna pruriens*)	165 - 228	9 - 53	898 - 933	142 – 366	499 - 603	342 - 435	109 - 112	9.70	18.6 - 19.1	a, h, l
	Hyacinth bean (*Lablab purpureus*)	165 - 195	17.0 – 39.0	884 - 939	220 – 361	320 - 468	229 - 376	50 - 86	9.20	18.2	a, l
	Silverleaf desmodium (*Desmodium uncinatum*)	115 – 208	11.0 – 37.0	826 – 993	248 – 413	344 – 681	227 – 514	48	7.40	18.6	a
	Stylo (*Stylosanthes guianensis*)	62.0 – 217	12.0 – 42.0	961 – 953	208 – 415	350 – 618	256 – 512	55.0 – 108	8.00	18.2 – 21.4	a
Legume residues	Soybean hulls	95.0 – 186	6.00 – 50.0	941 – 956	312 – 453	516 – 740	369 – 548	70.0 – 44.0	11.5	18.2	a

	Sunflower hulls and screenings	47.0 – 111	25.0 – 98.0	943 – 969	333 – 593	465 – 851	534 – 665	129 – 309	8.10	20.2	a
	Sunflower forage and residues	78.0 – 166	15.0 – 32.0	831 – 905	189 – 328	347 – 449	298 – 426	85.0 – 107	8.90	151 – 176	a
	Groundnut (*Arachis hypogaea*) haulms	119 - 136	18.6 - 27.0	907 - 919	-	387	320	57.5	-	16.9	a, l, m
	Bambara groundnut (*Vigna subterranea*) haulms	71.0 – 162	-	800 – 960	227 – 288	379 – 717	328 – 634	-	6.50	17.2	a
Tree foliage	*Leucaena leucoephala*	142 - 279	47.0 - 59.0	894 - 927	125 – 297	275 - 461	168 - 338	60.0 - 75.7	11.0	18.7 - 20.5	a, h, l, m, n
	Gliricidia sepium	160 - 263	46.0 - 100	882 - 972	144 – 284	296 - 656	250 - 357	80.0 - 107	9.45 - 9.67	17.3	a, e; l, p, q; r
	Calliandra calothyrsus	119 - 250	25	860 - 950	153 – 498	284 - 534	162 - 342	93 - 150	10.4	19.1	a, l, r, s

[a] - (INRAE-CIRAD-AFZ and FAO, 2022), [b] - (INRAE-CIRAD-AFZ, 2021); [c] - (Batonon-Alavo et al., 2016); [d] - (Mehri et al., 2010); [e] - (Aregheore and Perera, 2004); [f] - (Singh et al., 2017); [g] - (Jiwuba et al., 2021); [h] - (Kambashi et al., 2014); i - (Korir et al., 2020); [j] - (Oni et al., 2010); [k] - (Anele et al., 2010); [l] - (Castro-Montoya and Dickhoefer, 2020); [m] - (Singh et al., 2012); [n] - (Stifkens et al., 2022); [o] - (Hove et al., 2001); [p] - (Anele et al., 2009); [q] - (Ash, 1990); [r] - (Merkel et al., 1999); s - (Salawu et al., 1999).

Energy-rich Livestock Feed Sources

Small Cereal Grains

Sorghum (*Sorghum bicolor*) (Beretta et al., 2021; Savadogo et al., 2000; Selle et al., 2010) and pearl millet (*Pennisetum glaucum*) (Safalaoh and Kavala, 2020) are valuable alternatives to maize feeds for all classes of livestock (Kambashi et al., 2014). These are drought-tolerant and resilient crops, particularly for smallholder farmers facing challenges such as water scarcity and unpredictable weather conditions. For instance, when sorghum dry distillers' grains plus soluble (a by-product of alcohol production) were fed to Hereford steers, up to 450 g/ kg, no differences were observed regarding feed intake, growth performance and carcass traits (Beretta et al., 2021). Similarly, the addition of pearl millet up to 200 g/ kg had neutral effects on the body and carcass weights, and nutrient digestibility when compared to maize, albeit the former having poorer feed efficiencies (Safalaoh and Kavala, 2020). This highlights the potential of these energy-dense feeds as an alternative feed to maize.

The challenge with some of these climate-smart feed ingredients, especially sorghum, is the presence of antinutrient factors (e.g., kafirin, phytate and condensed tannin), which might negatively affect nutrient intake and digestibility and subsequently productivity, particularly when included in poultry diets (Selle et al., 2010). However, simple processing methods such as sun-drying have been shown to reduce the levels of these antinutrient factors (Dzowela et al., 1995; Mupangwa et al., 1997). Furthermore, when formulating diets with antinutrient factors, caution should be taken to include the feeds at levels which do not compromise nutrient intake and digestibility. These small cereal grain species are adaptable to diverse agroecological zones enabling their cultivation in marginal lands, further expanding the resource base for smallholders. Moreover, these grains are cost-effective and can be integrated into existing farming systems seamlessly. As climate change continues to impact traditional feed sources, the utilisation of sorghum and pearl millet not only enhances the resilience of livestock production but also contributes to sustainable agricultural practices for small-scale farmers.

Plant Tuber and By-Products

Another alternative that is gaining popularity in Malawi is Cassava (*Manihot esculentum*). Cassava roots and their by-products (i.e., bagasse) have significant quantities of carbohydrates and fibre (Bizzuti et al., 2021; Chagunda et al., 2016; Saraiva et al., 2020). Currently, its use is limited to ruminants because of the nutrient imbalances and presence of hydrogen cyanide, which can be toxic to poultry and pigs, although the latter can be reduced by processing (e.g., sun drying) (Bakare et al., 2021). The other advantage of cassava is its adaptability to harsh environments (drought-tolerant, grows well in acidic and poor nutrient soils), therefore, providing feed security for herds in arid and semiarid regions (Bizzuti et al., 2021; Saraiva et al., 2020). Considering the adverse impact of climate change on traditional feed sources, some of these non-conventional energy sources will not only provide food for humans but likely improve livestock production while promoting sustainable agricultural practices.

Protein-rich Livestock Feed Sources

Legume Grains

Farmers in Malawi also grow cowpeas (*Vigna unguiculata*) and chickpeas (*Cicer arietinum* L.), in addition to common beans (*Phaseolus vulgaris*) and soybeans (*Glycine max*). Cowpeas, chickpeas and their by-products are currently underutilised as livestock feed, yet they present an alternative to soybean in animal nutrition due to their high crude protein with an exceptionally balanced amino acid profile, mineral and vitamin contents (Phiri et al., 2023). Observations by Anele et al. (2011) with commercial cowpea haulms revealed superior microbial mass and lesser methane emissions than the improved cowpea haulms in ruminant diets. In addition, cowpea haulms had a greater digestibility coefficient than sorghum stover (0.70 vs 0.47) and required almost half the organic matter required to meet energy requirements for maintenance in sheep (Savodogo et al., 2000). Additionally, these pulses are not only nutrient-rich, but are resilient, hardy and well-adapted to diverse climates, making them a suitable alternative to resource-constrained farmers in marginal environments. Apart from providing food for human consumption and being a potential feed source, they improve soil fertility through nitrogen fixation and, therefore, contribute to environmental stability. Accordingly, this reduces the farmers' dependence on expensive fertilizers and commercial feeds, thereby reducing the agricultural financial burden for farmers. By harnessing the benefits of underutilised legumes, smallholder farmers can enhance the efficiency and sustainability of their animals.

Leaf Meals

Apart from the tuber/ roots, cassava leaves are richer in protein (250 – 290 g/ kg) than the roots with an amino acid profile comparable to soybean (Chagunda et al., 2016). A study by Korir et al. (2020) showed that zebu heifers fed supplemented with cassava leaf meal had superior weight gains than those on the basal diets (i.e., *Brachiaria mulatto* II or mixed range grass). Sweet potatoes (*Ipomoea batatas*) are also grown by smallholder farmers in Malawi, and the leaves and vines can potentially be used as animal feed whilst the tuber as a source of human food (Nkosi and Meeske, 2010; Zhang et al., 2022). Sweet potato vines have a moderate to high protein content (160 – 230 g/ kg) and judicious fibre (260 g/ kg) (Gakige et al., 2020). They have been added to goat (Megersa et al., 2012) and pig (Zhang et al., 2022) diets, either fresh or in the form of silage, respectively. In both cases, there was an improvement in feed intake and growth performance, indicating the potential of sweet potato vines as an alternative feed supplement in livestock diets.

Fodder from ligneous plants (i.e., leguminous trees and shrubs) has always played a significant role in the nutrition of domestic animals among many rural households in many developing nations (Chakeredza et al., 2007; Kambashi et al., 2014). The nutritional value of fodder from multipurpose legume tree species is often superior to herbaceous plants and is available throughout the year, which can satisfy the dry season protein gap. Nutrient profiles of some of the most common multipurpose legume tree species in southern Africa by Chakeredza et al. (2007) showed that the foliage contained an average of 232 grams of crude protein per kilogram of feed but ranged from 125 g/ kg to as high as 384 g/ kg. In addition to the high protein content, fodder from multipurpose legume tree species is endowed with secondary phytochemicals such as condensed tannins, which have antioxidant, antimicrobial and anthelmintic properties. The positive effects of these phytochemicals on animals include improved fertility and growth, healthier and superior product quality (i.e., milk, meat and wool production) and lower methane emissions (Mueller-Harvey et al., 2019).

The failure of smallholder farmers to adopt appropriate feeding strategies for multipurpose legume tree species foliage has resulted in missed opportunities to improve animal productivity. Appropriate feeding strategies, for example, combining tree/ shrub fodder with poor quality feeds (e.g., rangeland grass, crop residues) is an effective solution to this challenge and improves their yields and profitability. Apart from their exploitation *in situ* as feed for ruminants, these ligneous plants have environmental and socio-economic benefits (Fig. 2.4) to rural communities (Chagunda et al., 2016; Chakeredza et al., 2007; Franzel et al., 2014). Therefore, multipurpose legume tree species not only improve livestock productivity but enhance the sustainable livelihoods of resource-poor smallholder farmers who have limited land and financial resources.

Insect-Based Proteins as Novel Feeds for Livestock

The cultivation of insects is gaining traction as a sustainable alternative to the current challenges (e.g., deforestation, land degradation, water pollution) posed by the present food and feed systems (Chia et al., 2019; Mulumpwa, 2018; Tanga and Kababu, 2023; van Huis and Oonincx, 2017). There are several benefits associated with insect farming; for example, their production uses less land and water, emits fewer greenhouse gases, and can transform low-value organic by-products (e.g., crop leftovers) into high-quality feed (van Huis and Oonincx, 2017). This is of great significance in Malawi where most of the country's smallholder farmers cultivate on less than one hectare of rainfed land with much of the land devoted to maize production. The business of insect rearing for animal feed is still in its infancy globally, and its success will depend on the willingness of farmers and feed manufacturing companies to adopt this new technology.

A study in Kenya's Kiambu County by Okello et al. (2021) showed that over 90% of the farmers interviewed were ready and willing to use insect-based feed in poultry production. The uptake of insect cultivation still is suboptimal because of low acceptability among farmers and feed millers, safety concerns and lack of legislation governing the industry (Chia et al., 2019; Tanga and Kababu, 2023). Mulumpwa (2018) notes that partnership between government, industry and academia is essential to address some of the challenges that are currently faced with the acceptability, adoption and upscaling of insect-based businesses. Education is prudent to increase farmers' technical knowledge of the nutritional and ecological benefits of insect meals in animal feeds and the overall market potential opportunities (Chia et al., 2020). The potential of insect farmers among smallholder farmers is immense as it would increase the supply of animal feed protein and enhance the sustainability and resilience of livestock production systems, particularly in regions where access to conventional protein sources is limited.

Maximising Returns through Agroforestry-Crop-Livestock Integration for Smallholder Farmers

The amalgamation of crops and livestock creates a synergistic rapport, where dung from livestock aids as a valuable organic fertiliser for crops, while crop residues provide 'nutritious' feed for the animals (McDonald et al., 2019). This mutualistic approach not only maximises land use efficiency but also minimises waste, creating a closed-loop system that promotes sustainability within the same agricultural landscape. The integration of multipurpose legume tree species into the crop-livestock mixed farming systems, not only provides valuable timber and non-timber forest products but also contributes to soil fertility, water conservation, and biodiversity enhancement (Fig. 2.4). Consequently, smallholder farmers in resource-limited settings can leverage the synergies between these three components to improve agricultural productivity and create greater revenue from multiple sources, whilst enhancing environmental sustainability. Research in Kenya (Nyaata et al., 2002) revealed a synergistic relationship between *C. calothyrsus* intercropped with Napier grass (*P. purpureum*) and dairy production. By fostering a harmonious coexistence between agriculture and forestry, this approach promotes long-term sustainability and represents a holistic solution for the challenges faced by smallholder farmers in managing their land.

The agroforestry-crop-livestock system is undeniably advantageous as represents a holistic and adaptive strategy for smallholders for farmers by diversifying risks (e.g., crop failure or livestock diseases), utilise labour efficiently, recycling waste, adding value to crops and crop products, thereby ensuring a more stable livelihood of farmers in the face of economic uncertainties. Agroforestry activities are often gender-differentiated with men interested in commercial purposes of trees, yet women are more inclined to the subsistence nature (i.e., source of food and feed, cooking fuel, soil amendment). Overall, women and girls in developing countries collect the majority of fuelwood, fodder, medicinal products and fruits from forests, and may have to walk for several hours, often in insecure conditions.

It is important to recognise that these duties demand significant amounts of time and can severely limit opportunities to pursue education or engage in activities that promote capacity-building and income generation (Wan et al., 2011). Therefore, the presence of tree/ shrub legumes offers opportunities to reduce their workload by providing on-farm resources for firewood, livestock fodder and materials for traditional crafts, thereby alleviating time burdens and enabling women to participate more actively in community decision-making processes (Okorio et al., 2004). However, these benefits should be managed well as conflicts and/ or competition for land, labour and other resources among these enterprises could arise (Rusinamhodzi et al., 2015). In general, smallholder farming systems benefit significantly from cultivating MPTs, as they promote economic stability, gender equity, and environmental resilience, ultimately empowering rural communities.

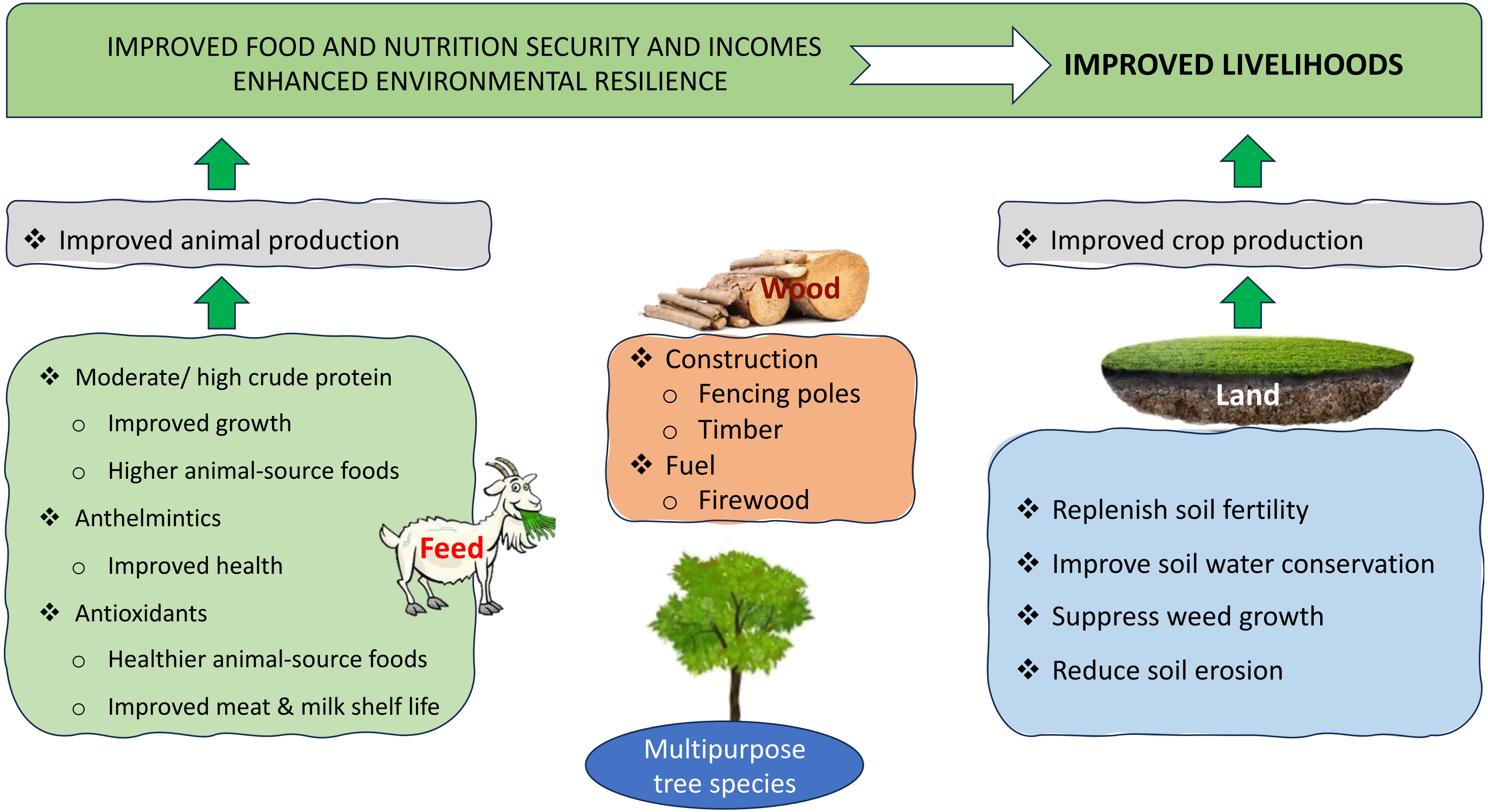

Figure 0.5 Socio-economic and environmental benefits of multipurpose tree species in smallholder mixed farming systems

Unraveling the Constraints Faced by Smallholder Livestock Farmers in Accessing Quality Feed

A combination of several socio-economic and environmental factors hinders smallholders in Malawi from attaining optimal outputs from livestock production (Banda et al., 2012; Chagunda et al., 2016; Tebug et al., 2012). Chiefly among these challenges is the diminishing farm sizes (Muyanga et al., 2020). This has resulted in most smallholder farmers prioritising maize production, which is vital to the food security of Malawi. Maize is by far the most widely grown crop in Malawi accounting for close to 80% of the cultivated land, this is equivalent to 59% of the country's land (Stevens and Madani, 2016). Due to the scarcity of arable land, farmers are less likely to allocate a significant portion of it for pasture unless it yields a higher economic return compared to crop production (Kumwenda and Ngwira, 2003).

Linked to this is the inadequate financial resources, which impede farmers' ability to invest in high-quality feeds and/ or supplements, veterinary medications, and construction of proper infrastructure for livestock. For instance, in well-run livestock enterprises, feed costs can account for between 50 and 70% of the total production costs (Duncan et al., 2023). This is beyond the reach of most resource-limited smallholder farmers in Malawi. In Malawi, the agreement between the Ministry of Trade and the poultry industry in 2020 did very little to dampen the cost of feed (FAO, 2022). The challenge with feed costs is that besides the cost of feed ingredients, there are other external factors (i.e., transport and import costs, poor infrastructure), which add to the cost of producing the final product. A review by Chingala et al. (2017) noted that high-income farmers' perceptions of decreasing rangeland biomass were lower than those of low-income farmers in Malawi indicating that greater financial resources to acquire resources required to improve rangeland for beef production. In addition, to feed costs, a lack of comprehensive knowledge and awareness of the significance of high-quality feed for livestock metabolism (Baur et al., 2017) also affects feed utilisation and/ or availability as farmers will not prioritise technologies like planting improved pastures or use of multipurpose legume tree species fodder.

Climate change is dampening all efforts that have been developed in terms of feed interventions. It affects changes in feed resources (i.e., availability, quality, and distribution, both temporal and spatial) (Thornton et al., 2009) but disparities in mean climate variables (temperature, precipitation) and their variability not only affect the feed base resources but water availability required for growth of both plants and animals and also negatively impact the animal's health and production (Godde et al., 2021; Herrero et al., 2013). These impacts are severe in sub-Saharan Africa, where crops and livestock rely heavily on rain-fed agricultural land for their livelihoods. Some of the factors mentioned above that have a significant effect on feed availability are made worse by the lack of knowledge among farmers and limited access/ inefficiencies in extension services (Phiri et al., 2019a). These two factors play a critical role in weakening the resilience of agricultural systems, among smallholder farmers, especially in livestock feed availability. Due to limited access to information and resources, smallholders in particular marginalised lands may struggle to adopt modern, sustainable farming practices. Furthermore, funding and research are not sometimes aligned with the needs of farmers in sub-Saharan Africa, resulting in agricultural technologies being imposed that do not apply to the region (Nhantumbo et al., 2016; Rusere et al., 2019), and often limiting the farmers' capacity to continue with innovations after service providers have pulled out (Chowa et al., 2013). Given the complexity of livestock (and in most cases crop-livestock) systems in developing countries, a mix of technological, policy and institutional innovations will be required (Thornton et al., 2009).

Feed interventions to improve livestock production under smallholder settings

A livestock feed intervention program is aimed at changing the existing practices to provide superior quality feed, to increase animal productivity. Accordingly, Balehegn et al. (2020) proposed areas of technological solutions that must be implemented for a successful feed intervention program. These are 1) feed productivity improvement, 2) feed quality enhancement, 3) feed quality maintenance or preservation and 4) feed formulation techniques. These will be discussed in detail and the context of smallholder livestock farmers in a country like Malawi.

Feed Productivity Improvement

Implementation of sustainable agricultural practices, such as agroforestry (Franzel et al., 2014) and cover cropping (Jingura et al., 2001; Mapiye et al., 2006) within existing land holdings could assist in diversifying crop yields and providing additional biomass for livestock consumption. The augmentation of the rangeland pastures and crop residues with fodder from perennial trees/ shrubs legumes is vital for improving feed availability/ biomass production, especially with the scarcity of land among communal farmers and the increasing water stress (i.e., drought). The challenges of water scarcity can be addressed through the adoption of efficient water management practices (e.g., rainwater harvesting, water recycling or even small-scale irrigation) (Oweis and Hachum, 2006; Rahaman et al., 2019), which could play a significant role in sustaining vegetation growth. Collaborative efforts with the government (e.g., agricultural extension services) and other stakeholders [e.g. non-governmental organisations (NGO) and private sector players] to facilitate the dissemination of knowledge and the adoption of modern technologies in these communities are crucial if farmers are to adopt of some these strategies. The adoption of tropical forage technologies among smallholder communities is low in the region because of factors such as lack of awareness and knowledge, low support and investment from national and local authorities, lack of available, accessible and affordable forage seed and planting material, and lack of market linkages for inputs and outputs (Balehegn et al., 2022; Paul et al., 2020). In addition, the exploration of novel feed resources such as insect farming (Tanga et al., 2021) and hydroponic fodder (Mekonnen et al., 2019; Ndaru et al., 2020) production could further supplement traditional feed options.

Feed Quality Enhancement

The enhancement of the nutritional value, palatability, intake, and digestibility of low-quality feeds is critical for improving animal productivity. This can be achieved by supplementing rangeland pasture with locally available fodder legumes, which are rich in nitrogen, vitamins and minerals (Chagunda et al., 2016; Franzel et al., 2014). This must be coupled with proper forage management (i.e., harvesting when forages are at maximum nutrient density followed by long-term conservation). This could then be augmented with good feed practices, for example, providing the supplement in homemade feed trough when animals are kraaled to reduce feed wastage (Monkwe et al., 2023). Feed efficiency utilisation must entail chopping or grinding the feed before offering the animals as this not only improves intake but also increases its digestibility (Duguma and Janssens, 2021; Duncan et al., 2023) and subsequent performance of animals. However, farmers must be capacitated with the techniques for the ultimate well-being and productivity of their livestock. Depending on the scale of implementation, small-scale mechanisation equipment (e.g., chopper and bailing wooden boxes) (Balehegn et al., 2022; Duguma and Janssens, 2021) may improve the on-farm processing and output of the feed.

Feed Quality Maintenance or Preservation

To ensure the well-being of livestock in communal areas, feeding feeds of the highest nutritional quality is crucial, especially during off-seasons when natural forage is scarce. Preservation of feeds when they are at their optimum biomass becomes a linchpin for community resilience, in areas where livestock production plays a crucial role in the livelihoods of farmers. Preservation techniques such as silage or hay play a vital role in extending the availability of nutrient-rich feeds (Balehegn et al., 2022; Hove et al., 2001; Nkosi and Meeske, 2010). This proactive approach not only ensures the health of livestock but also contributes to the overall economic stability of these communities.

Feed Formulation Techniques

Simple feed formulation techniques, such as the Pearson square, Microsoft Excel spreadsheet, and mobile or computer applications (e.g., PC Dairy and Feed Formulator MOF-DairyEdition) enable farmers to formulate effective rations based on locally available feed resources (Balehegn et al., 2020; Chakeredza et al., 2008; Irungu et al., 2015). It is well known that many communal farmers have limited resources (e.g., mobile phones, and internet access), both in terms of finances and technical expertise (Mapiye et al., 2021). They can, however, collaborate with their extension officials in using straightforward feed formulation methods that will assist the farmers in optimising the best out of the available local feed resources or using nutrient values from literature. Agricultural extension systems are, therefore, vital to addressing the challenges that are faced by farmers in marginalised communities. Training of extension officials will avail innovation in the smallholder farming sector through the exchange of knowledge, technologies and skills on production (Warburton et al., 2011) Incorporation of locally available, such as crop residues and by-products, communal farmers can create cost-effective and nutritionally balanced feeds (Chakeredza et al., 2008). Furthermore, simple feed formulation empowers farmers to adapt to varying environmental conditions and feed availability, making their livestock operations more resilient. Ultimately, the accessibility and ease of implementing these techniques enable communal farmers to improve the efficiency of their livestock production, contributing to food security and livelihoods in these communities.

Barriers impeding adoption of feed improvement by smallholder farmers

Livestock farmers in many developing countries, such as Malawi, face multifaceted challenges that hinder them from adopting modern agricultural technologies, including feed improvement strategies. These include limited access to financial or technical resources, low education levels, and inadequate support from extension workers (Rodriguez et al., 2008). One way to improve the nutrition of communal livestock is to augment existing feeds with commercial supplements. Regrettably, most rural farmers in Malawi live below the poverty line (CIAT-World Bank, 2018), and cannot afford the prohibitive cost of commercial feed (Chakeredza et al., 2008). To ensure that they have access to affordable and sustainable animal feed, farmers could opt for locally available resources, such as fodder from legumes (Chakeredza et al., 2007; Franzel et al., 2014). Unfortunately, the unavailability of quality seeds (Nhundu et al., 2023), lack of investment and the shortage of skills often hamper the ability to incorporate these legumes into their feed systems (Chakeredza et al., 2008; Sekaran et al., 2021). In cases where seeds are available, limited access to credit exacerbates the farmers' ability to purchase them. Furthermore, long-established and routine feed practices, such as the use of rangeland pastures and crop residues may contribute to resistance or reluctance to change traditional practices (Antwi-Agyei and Stringer, 2021), overlooking the potential advantages of other alternatives.

Farmers face significant obstacles due to their insufficient technical knowledge and inadequate training (Chakeredza et al., 2007; Rodriguez et al., 2008), which often result in a lack of awareness about the benefits and proper implementation of improved feed options. The success of farmers depends heavily on their access to knowledgeable and well-trained extension workers. Unfortunately, this access is often hindered by a lack of adequate training, an overwhelming extension-to-farmer ratio (i.e., up to 3000 to 1) and insufficient transportation networks (Antwi-Agyei and Stringer, 2021; Lee et al., 2023; van den Berg et al., 2020), further impeding the transference of innovative feed strategies. Such obstacles not only prevent farmers from receiving the crucial support they need but can also have a devastating impact on their livelihoods. Moreover, the lack of storage facilities contributes to post-harvest losses (Boote et al., 2022; Duguma and Janssens, 2021), reducing the incentive for farmers to invest in feed improvement. According to Curry et al. (2021), the low adoption rates of technology and innovation cannot simply be blamed on education levels, access to information, or financial and/ or technical resources. Rather, it is how these new technologies and innovations are introduced and presented to target communities (Nhantumbo et al., 2016). The authors (Curry et al., 2021; Nhantumbo et al., 2016) note that these technologies are often incompatible with indigenous values, habits, socio-cultural institutions, and traditional farming practices, therefore, making it difficult for farmers to adopt new methods of farming. Addressing these challenges will require comprehensive strategies that encompass not only technical solutions but also socioeconomic empowerment initiatives to support smallholder farmers in embracing innovations for livestock feed enhancement.

Prospects and Recommendations

The increasing demand for livestock products in sub-Saharan Africa will require transformative steps in the livestock feed sector, particularly, in the communal areas where livestock are fed opportunistically with feeds that are immediately available (Duncan et al., 2023). It will be important to adopt a multipronged approach that tackles diverse aspects of the entire feed value chain (production, management, and utilisation) across various domains, which would warrant that the smallholder farmers have access to improved-quality feed that would improve animal productivity, and subsequently their livelihoods. Most importantly, investing in Research and Development (R&D) tailored to the specific needs and constraints of communal farming can yield innovative solutions. However, past R&D concerning animal nutrition in communal areas have concentrated on a limited number of available feeds in mixed systems, rather than looking at the systems level of development and promotion of all livestock feed resources (Lenné and Thomas, 2006). Development of nutrition programs must be designed to match the diverse livestock nutrient demands at different times in the production cycle, based on the availability and strategic use of all feed resources in mixed farming systems (Lenné and Thomas, 2006). These programs should, however, improve the entire feed sector value chain. Otherwise, a system that provides only technical information without addressing smallholders' market access and bargaining power is bound to fail (Kebebe, 2019).

Capacity-building initiatives, for both farmers and extension officers, play a crucial role in empowering the farmer with the knowledge and skills (Antwi-Agyei and Stringer, 2021; Chowa et al., 2013; Zerssa et al., 2021) necessary to adopt modern farming techniques and utilise improved feed options. With the challenges faced by extension workers in most developing nations (Chowa et al., 2013; Kebebe, 2019; Phiri et al., 2019a), the Lead-Farmer approach (i.e., farmer-to-farmer extension) training should be intensified as it would assist in the dissemination of the required information/ technologies to local farmers (van den Berg et al., 2020). The effectiveness of such programs should be with all the relevant stakeholders through fostering public-private partnerships and local communities. However, investments in infrastructure (e.g., rural roads, milling machines, storage facilities) are key as they improve access to essential resources, reduce post-harvest losses, increase market connectivity (Duguma and Janssens, 2021; Jellason et al., 2021) and enhance overall agricultural productivity.

By integrating climate-smart practices, engaging local communities, and implementing robust monitoring and evaluation mechanisms (Shikuku et al., 2017; Zerssa et al., 2021), Malawi can embark on a transformative journey towards enhancing feed improvement options and fostering sustainable agricultural development for communal farmers. Furthermore, policy support from the government is indispensable in creating an enabling environment for agricultural development. Policies that incentivise sustainable farming practices, promote market access for smallholder farmers, and provide financial support for infrastructure projects (Chowa et al., 2013; Mafirakurewa et al., 2023; Markelova and Mwangi, 2010) can catalyse positive change in the communal farming sector. Overall, by pursuing these prospects and recommendations, stakeholders can contribute to sustainable livestock development and poverty alleviation in communal farming communities.

Conclusion

Livestock is important for smallholder farmers in Malawi but lags crops. The main challenge is the feed shortages affected by food-feed nexus consumption, poor nutrition, which is seasonal and the shortage of land, which favours food crops at the expense of cultivated pastures. Crop residues form an integral component of the livestock feed base, particularly, during the dry season. However, their nutrient quality often fails to meet animal demands for reproduction and growth. The utilisation of agro-industrial by-products presents multiple opportunities to enhance agricultural productivity. However, availability constraints have made it challenging for smallholder farmers to access these resources.

Furthermore, there is currently a lack of attention given to alternative sources of energy- and protein-rich feeds such as small cereal grains, cassava, legumes (tree/shrub fodder trees and forages), insect-based meals, and hydroponic fodder. By embracing these alternative options, we can reduce our dependence on rangelands. To improve animal productivity and enhance the livelihoods of poor communal farmers in Malawi, interventions must prioritise utilising alternative feed resources.

References

Addy, B.L., Thomas, D., 1977a. Intensive fattening of beef cattle by stall feeding on the Lilongwe plain, Malawi III. Comparative productivity of Malawi zebu and Friesian x Malawi zebu steers. Trop Anim Health Prod 9, 197–202.

Addy, B.L., Thomas, D., 1977b. Intensive fattening of beef cattle by stall feeding on the Lilongwe plain, Malawi II. Utilisation of crop residues, crop by-products and leucaena. Trop Anim Health Prod 9, 191–196.

Africa RISING, 2014. Sustainable intensification of crop-livestock mixed farming systems in the Guinea/Sudan Savanna Zone of West Africa Africa.

Alonso, S., Dominguez-Salas, P., Grace, D., 2019. The role of livestock products for nutrition in the first 1,000 days of life. Animal Frontiers 9, 24–31.

Anele, U.Y., Arigbede, O.M., Südekum, K.H., Ike, K.A., Oni, A.O., Olanite, J.A., Amole, G.A., Dele, P.A., Jolaosho, A.O., 2010. Effects of processed cowpea (Vigna unguiculata L. Walp) haulms as a feed supplement on voluntary intake, utilization and blood profile of West African dwarf sheep fed a basal diet of Pennisetum purpureum in the dry season. Anim Feed Sci Technol 159, 10–17. https://doi.org/10.1016/j.anifeedsci.2010.05.004

Anele, U.Y., Arigbede, O.M., Südekum, K.H., Oni, A.O., Jolaosho, A.O., Olanite, J.A., Adeosun, A.I., Dele, P.A., Ike, K.A., Akinola, O.B., 2009. Seasonal chemical composition, in vitro fermentation and in sacco dry matter degradation of four indigenous multipurpose tree species in Nigeria. Anim Feed Sci Technol 154, 47–57. https://doi.org/10.1016/j.anifeedsci.2009.07.007

Anele, U.Y., Südekum, K.H., Hummel, J., Arigbede, O.M., Oni, A.O., Olanite, J.A., Böttger, C., Ojo, V.O., Jolaosho, A.O., 2011. Chemical characterization, in vitro dry matter and ruminal crude protein degradability and microbial protein synthesis of some cowpea (Vigna unguiculata L. Walp) haulm varieties. Anim Feed Sci Technol 163, 161–169. https://doi.org/10.1016/j.anifeedsci.2010.11.005

Anseeuw, W., Jayne, T., Kachule, R., Kotsopoulos, J., 2016. The quiet rise of medium-scale farms in Malawi. Land (Basel) 5, 19. https://doi.org/10.3390/land5030019

Antwi-Agyei, P., Stringer, L.C., 2021. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. Clim Risk Manag 32, 100304. https://doi.org/10.1016/j.crm.2021.100304

Aregheore, E.M., Perera, D., 2004. Effects of Erythrina variegata, Gliricidia sepium and Leucaena leucocephala on dry matter intake and nutrient digestibility of maize stover, before and after spraying with molasses. Anim Feed Sci Technol 111, 191–201. https://doi.org/10.1016/j.anifeedsci.2003.06.001

Ash, A.J., 1990. The effect of supplementation with leaves from the leguminous trees Sesbania grandiflora, Albizia chinensis and Gliricidia sepium on intake and digestibility of guinea grass hay by goats. Anim Feed Sci Technol 28, 225–232.

Ayantunde, A.A., Oluwatosin, B.O., Yameogo, V., van Wijk, M., 2020. Perceived benefits, constraints and determinants of sustainable intensification of mixed crop and livestock systems in the Sahelian zone of Burkina Faso. Int J Agric Sustain 18, 84–98. https://doi.org/10.1080/14735903.2019.1698494

Bakare, A.G., Zindove, T.J., Iji, P.A., Stamatopoulos, K., Cowieson, A.J., 2021. A review of limitations to using cassava meal in poultry diets and the potential role of exogenous microbial enzymes. Trop Anim Health Prod. https://doi.org/10.1007/s11250-021-02853-6

Balehegn, M., Ayantunde, A., Amole, T., Njarui, D., Nkosi, B.D., Müller, F.L., Meeske, R., Tjelele, T.J., Malebana, I.M., Madibela, O.R., Boitumelo, W.S., Lukuyu, B., Weseh, A., Minani, E., Adesogan, A.T., 2022. Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. Agron J 114, 75–99. https://doi.org/10.1002/agj2.20954

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A.A., Issa, S., Karimou, M., Zampaligré, N., André, K., Gnanda, I., Varijakshapanicker, P., Kebreab, E., Dubeux, J., Boote, K., Minta, M., Feyissa, F., Adesogan, A.T., 2020. Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. Glob Food Sec 26, 100372. https://doi.org/10.1016/j.gfs.2020.100372

Balehegn, M., Kebreab, E., Tolera, A., Hunt, S., Erickson, P., Crane, T.A., Adesogan, A.T., 2021. Livestock sustainability research in Africa with a focus on the environment. Animal Frontiers. https://doi.org/10.1093/af/vfab034

Baloyi, J.J., Ngongoni, N.T., Topps, J.H., Acamovic, T., Hamudikuwanda, H., 2001. Condensed tannin and saponin content of Vigna unguiculata (L.) Walp, Desmodium uncinatum, Stylosanthes guianensis and Stylosanthes scabra grown in Zimbabwe. Trop Anim Health Prod 33, 57–66.

Baltenweck, I., Cherney, D., Duncan, A., Eldermire, E., Lwoga, E.T., Labarta, R., Rao, E.J.O., Staal, S., Teufel, N., 2020. A scoping review of feed interventions and livelihoods of small-scale livestock keepers. Nat Plants 6, 1242–1249. https://doi.org/10.1038/s41477-020-00786-w

Banda, L.J., Chiumia, D., Gondwe, T.N., Gondwe, S.R., 2021. Smallholder dairy farming contributes to household resilience, food, and nutrition security besides income in rural households. Animal Frontiers 11, 41–46. https://doi.org/10.1093/af/vfab009

Banda, L.J., Kamwanja, L.A., Chagunda, M.L.G., Ashworth, C.J., Roberts, D.J., 2012. Status of dairy cow management and fertility in smallholder farms in Malawi. Trop Anim Health Prod. https://doi.org/10.1007/s11250-011-9972-4

Banda, L.J., Tanganyika, J., 2021. Livestock provide more than food in smallholder production systems of developing countries. Animal Frontiers 11, 7–14. https://doi.org/10.1093/af/vfab001

Batonon-Alavo, D.I., Bastianelli, D., Lescoat, P., Weber, G.M., Umar Faruk, M., 2016. Simultaneous inclusion of sorghum and cottonseed meal or millet in broiler diets: Effects on performance and nutrient digestibility. Animal 10, 1118–1128. https://doi.org/10.1017/S1751731116000033

Baur, I., Tabin, L., Banda, M.L., Chiumia, D., Lips, M., 2017. Improving dairy production in Malawi: a literature review. Trop Anim Health Prod 49, 251–258. https://doi.org/10.1007/s11250-016-1184-5

Benke, K., Tomkins, B., 2017. Future food-production systems: vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy 13, 13–26. https://doi.org/10.1080/15487733.2017.1394054

Beretta, V., Simeone, A., Franco, J., Bentancur, O., Novac, M., Panizza, V., Rodríguez, M.V., 2021. Using sorghum dry distillers' grains plus solubles in sorghum-based finishing diets: feed utilization, cattle performance and carcass traits. Anim Feed Sci Technol 271, 114731. https://doi.org/10.1016/j.anifeedsci.2020.114731

Bhatti, M.A., Chanza, W., Kamwanja, L.A., Chikomola, S., Chipandula, M., Chikaonda, A., Jansen, D.C., Klevar, S., Klem, T.B., Stokstad, M., Reksen O., 2020. Effect of Dry Season Supplement Feeding of Malawi Zebu Cows on Reproductive Performance, Lactation and Weight Gain in Calves, in: Singh Bal Ram and Safalaoh, A. and A.N.A. and E.L.O. and S.B.K. and L.R. (Ed.), Climate Impacts on Agricultural and Natural Resource Sustainability in Africa. Springer International Publishing, Cham, pp. 239–248. https://doi.org/10.1007/978-3-030-37537-9_14

Bhatti, M.A., Godfrey, S.S., Ip, R.H.L., Kachiwala, C., Hovdhaugen, H., Banda, L.J., Limuwa, M., Wynn, P.C., Ådnøy, T., Eik, L.O., 2021. Diversity of sources of income for smallholder farming communities in Malawi: Importance for improved livelihood. Sustainability (Switzerland) 13. https://doi.org/10.3390/su13179599

Bizzuti, B.E., Faria, L.A., Costa, W.S., Lima, P.M.T., Ovani, V.S., Krüger, A.M., Louvandini, H., Abdalla, A.L., 2021. Potential use of cassava by-product as ruminant feed. Trop Anim Health Prod 53, 108. https://doi.org/10.1007/s11250-021-02555-z

Boote, K.J., Adesogan, A.T., Balehegn, M., Duncan, A., Muir, J.P., Dubeux, J.C.B., Rios, E.F., 2022. Fodder development in sub-Saharan Africa: An introduction. Agron J 114, 1–7. https://doi.org/10.1002/agj2.20924

Branca, G., Cacchiarelli, L., Haug, R., Sorrentino, A., 2022. Promoting sustainable change of smallholders' agriculture in Africa: Policy and institutional implications from a socio-economic cross-country comparative analysis. J Clean Prod 358. https://doi.org/10.1016/j.jclepro.2022.131949

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual Res Psychol 3, 77–101. https://doi.org/10.1191/1478088706qp063oa

Bruce, M.C., Macheso, A., Kelly-Hope, L.A., Nkhoma, S., McConnachie, A., Molyneux, M.E., 2008. Effect of transmission setting and mixed species infections on clinical measures of malaria in Malawi. PLoS One 3, e2775. https://doi.org/10.1371/journal.pone.0002775

Cairns, J.E., Chamberlin, J., Rutsaert, P., Voss, R.C., Ndhlela, T., Magorokosho, C., 2021. Challenges for sustainable maize production of smallholder farmers in sub-Saharan Africa. J Cereal Sci 101, 103274. https://doi.org/10.1016/j.jcs.2021.103274

Cardoso-Gutierrez, E., Aranda-Aguirre, E., Robles-Jimenez, L.E., Castelán-Ortega, O.A., Chay-Canul, A.J., Foggi, G., Angeles-Hernandez, J.C., Vargas-Bello-Pérez, E., González-Ronquillo, M., 2021. Effect of tannins from tropical plants on methane production from ruminants: A systematic review. Vet Anim Sci. https://doi.org/10.1016/j.vas.2021.100214

Castellanos-Navarrete, A., Tittonell, P., Rufino, M.C., Giller, K.E., 2015. Feeding, crop residue and manure management for integrated soil fertility management - A case study from Kenya. Agric Syst 134, 24–35. https://doi.org/10.1016/j.agsy.2014.03.001

Castro-Montoya, J.M., Dickhoefer, U., 2020. The nutritional value of tropical legume forages fed to ruminants as affected by their growth habit and fed form: A systematic review. Anim Feed Sci Technol. https://doi.org/10.1016/j.anifeedsci.2020.114641

Chagunda, M.G.G., Mwangwela, A., Mumba, C., Dos Anjos, F., Kawonga, B.S., Hopkins, R., Chiwona-Kartun, L., 2016. Assessing and managing intensification in smallholder dairy systems for food and nutrition security in Sub-Saharan Africa. Reg Environ Change 16, 2257–2267. https://doi.org/10.1007/s10113-015-0829-7

Chakeredza, S., Akinnifesi, F.K., Ajayi, C., Sileshi, G., Mngomba, S., Gondwe, F.M.T., 2008. A simple method of formulating least-cost diets for smallholder dairy production in sub-Saharan Africa. Afr J Biotechnol 7, 2925–2933.

Chakeredza, S., Hove, L., Akinnifesi, F.K., Franzel, S., Ajayi, O.C., Sileshi, G., 2007. Managing fodder trees as a solution to human-livestock food conflicts and their contribution to income generation for smallholder farmers in southern Africa. Nat Resour Forum 31, 286–296. https://doi.org/10.1111/j.1477-8947.2007.00160.x

Chakoma, I., Manyawu, G., Gwiriri, L.C., Moyo, S., Dube, S., Imbayarwo-Chikosi, V.E., Halimani, T.E., Chakoma, C., Maasdorp, B.V., Buwu, V., 2016. Promoting the use of home-mixed supplements as alternatives to commercial supplements in smallholder beef production systems in the subhumid region of Zimbabwe. Afr J Range Forage Sci 33, 165–171. https://doi.org/10.2989/10220119.2016.1207706

Chia, S.Y., Macharia, J., Diiro, G.M., Kassie, M., Ekesi, S., van Loon, J.J.A., Dicke, M., Tanga, C.M., 2020. Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. PLoS One 15, e0230552. https://doi.org/10.1371/journal.pone.0230552

Chia, S.Y., Tanga, C.M., van Loon, J.J.A., Dicke, M., 2019. Insects for sustainable animal feed: inclusive business models involving smallholder farmers. Curr Opin Environ Sustain 41, 23–30. https://doi.org/10.1016/j.cosust.2019.09.003

Chimonyo, V.G.P., Mabhaudhi, T., Muthoni, F., Chavula, G., 2023. Context assessment for mixed farming systems in Malawi.

Chingala, G., Mapiye, C., Raffrenato, E., Hoffman, L., Dzama, K., 2017. Determinants of smallholder farmers' perceptions of impact of climate change on beef production in Malawi. Clim Change 142, 129–141. https://doi.org/10.1007/s10584-017-1924-1

Chingala, G., Raffrenato, E., Dzama, K., Hoffman, L.C., Mapiye, C., 2019a. Intake, digestibility, rumen protein synthesis, and growth performance of Malawi Zebu steers fed diets containing rangeland-based protein sources. Trop Anim Health Prod 51, 199–204. https://doi.org/10.1007/s11250-018-1676-6

Chingala, G., Raffrenato, E., Dzama, K., Hoffman, L.C., Mapiye, C., 2019b. Carcass and meat quality attributes of Malawi Zebu steers fed Vachellia polyacantha leaves or Adansonia digitata seed as alternative protein sources to Glycine max. S Afr J Anim Sci 49, 396–402. https://doi.org/10.4314/sajas.v49i2.18

Chowa, C., Garforth, C., Cardey, S., 2013. Farmer Experience of Pluralistic Agricultural Extension, Malawi. Journal of Agricultural Education and Extension 19, 147–166. https://doi.org/10.1080/1389224X.2012.735620

CIAT-World Bank, 2018. Climate-Smart Agriculture in Malawi. CSA Country Profiles for Africa Series. . Washington.

Commercial Agriculture for Smallholders and Agribusiness, 2020. Poultry Sector Strategy – Malawi.

Creswell, J.W., Creswell, J.D., 2023. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 6th ed. SAGE Publications, Inc., California 91320.

Curry, G.N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E., Nailina, R., 2021. Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. J Rural Stud 88, 422–431. https://doi.org/10.1016/j.jrurstud.2021.07.022

Danso-Abbeam, G., Dagunga, G., Ehiakpor, D.S., Ogundeji, A.A., Setsoafia, E.D., Awuni, J.A., 2021. Crop–livestock diversification in the mixed farming systems: implication on food security in Northern Ghana. Agric Food Secur 10, 35. https://doi.org/10.1186/s40066-021-00319-4

Descheemaeker, K., Amede, T., Haileslassie, A., 2010. Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. Agric Water Manag 97, 579–586. https://doi.org/10.1016/j.agwat.2009.11.012

Devendra, C., 2001. Small ruminants: Imperatives for productivity enhancement improved livelihoods and rural growth - A review. Asian-Australas J Anim Sci 14, 1483–1496. https://doi.org/10.5713/ajas.2001.1483

Dhehibi, B., Fouzai, A., Frija, A., Adhim, M.A., M'hamed, H.C., Ouerghemmi, H., Rekik, M., 2023. Assessing complementary synergies for integrated crop–livestock systems under conservation agriculture in Tunisian dryland farming systems. Front Sustain Food Syst 6, 1022213.

Djurfeldt, A.A., Hillbom, E., Mulwafu, W.O., Mvula, P., Djurfeldt, G., 2018. "The family farms together, the decisions, however are made by the man" —Matrilineal land tenure systems, welfare and decision making in rural Malawi. Land use policy 70, 601–610. https://doi.org/10.1016/j.landusepol.2017.10.048

Dopelt, K., Radon, P., Davidovitch, N., 2019. Environmental effects of the livestock industry: The relationship between knowledge, attitudes, and behavior among students in Israel. Int J Environ Res Public Health 16, 1359. https://doi.org/10.3390/ijerph16081359

Duguma, B., Janssens, G.P.J., 2021. Assessment of livestock feed resources and coping strategies with dry season feed scarcity in mixed crop–livestock farming systems around the gilgel gibe catchment, southwest ethiopia. Sustainability (Switzerland) 13, 10713. https://doi.org/10.3390/su131910713

Duguma, B., Janssens, G.P.J., 2016. Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. Springerplus 5, 717. https://doi.org/10.1186/s40064-016-2417-9

Duncan, A.J., Lukuyu, B., Mutoni, G., Lema, Z., Fraval, S., 2023. Supporting participatory livestock feed improvement using the Feed Assessment Tool (FEAST). Agron Sustain Dev 43, 34. https://doi.org/10.1007/s13593-023-00886-9

Dzowela, B.H., Hove, L., Maasdorp, B. V., Mafongoya, P.L., 1997. Recent work on the establishment, production and utilization of multipurpose trees as a feed resource in Zimbabwe. Anim Feed Sci Technol 69, 1–15. https://doi.org/10.1016/S0377-8401(97)81618-5

Dzowela, B.H., Hove, L., Mafongoya, P.L., 1995. Effects of drying method on chemical composition and in vitro digestibility of multipurpose tree and shrub fodders. Tropical Grasslands 29, 263–269.

Dzowela, B.H., Kumwenda, L., Msiska, H.D.C., Hodges, E.M., Gray, R.C., 1990. Seasonal trends in forage dry matter production of some Improved pastures and animal performance in relation to chemical composition in Malawi. Anim Feed Sci Technol 28, 255–266.

Evitayani, L., Warly, A., Fariani, A., Ichinohe, T., Fujihara, T., 2004. Seasonal changes in nutritive value of some grass species in west Sumatra, Indonesia. Asian-Australas J Anim Sci 17, 1663–1668.

FAO, 2022. Livestock sector report – A review of the livestock sector in Malawi in 2021, Livestock sector report. FAO. https://doi.org/10.4060/cc1073en

FAO, 2021. Synergies and trade-offs in climate-smart agriculture: An approach to systematic assessment, Synergies and trade-offs in climate-smart agriculture. FAO. https://doi.org/https://doi.org/10.4060/cb5243en

FAO, IFAD, UNICEF, W. and W., 2019. The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns. Food and Agriculture Organization of the United Nations, Rome, Italy, Italy. https://doi.org/10.1109/JSTARS.2014.2300145

FAOSTAT, 2024. Crops and livestock products [WWW Document]. URL https://www.fao.org/faostat/en/#data/QCL (accessed 2.11.24).

Fish, L., Mashau, A.C., Moeaha, M.J., Nembulani, M.T., 2015. Identification guide to grasses of southern Africa. An identification manual with keys, descriptors and distributions, Strelitzia 36. ed. South African National Biodiversity Institute, Pretoria.

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., Wambugu, C., 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Curr Opin Environ Sustain. https://doi.org/10.1016/j.cosust.2013.11.008

Fulkerson, W.J., Neal, J.S., Clark, C.F., Horadagoda, A., Nandra, K.S., Barchia, I., 2007. Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. Livest Sci 107, 253–264. https://doi.org/10.1016/j.livsci.2006.09.029

Gakige, J.K., Gachuri, C., Butterbach-Bahl, K., Goopy, J.P., 2020. Sweet potato (Ipomoea batatas) vine silage: A cost-effective supplement for milk production in smallholder dairy-farming systems of East Africa? Anim Prod Sci 60, 1087–1094. https://doi.org/10.1071/AN18743

Giller, K.E., Delaune, T., Silva, J.V., van Wijk, M., Hammond, J., Descheemaeker, K., van de Ven, G., Schut, A.G.T., Taulya, G., Chikowo, R., Andersson, J.A., 2021. Small farms and development in sub-Saharan Africa: Farming for food, for income or for lack of better options? Food Secur 13, 1431–1454. https://doi.org/10.1007/s12571-021-01209-0

Godde, C.M., Mason-D’Croz, D., Mayberry, D.E., Thornton, P.K., Herrero, M., 2021. Impacts of climate change on the livestock food supply chain, a review of the evidence. Glob Food Sec 28, 100488. https://doi.org/10.1016/j.gfs.2020.100488

Grace, D., Songe, M., Knight-Jones, T., 2015. Impact of neglected diseases on animal productivity and public health in Africa, in: 21st Conference of the OIE Regional Commission for Africa. Rabat, Morocco.

Guo, Q., Ola, O., Benjamin, E.O., 2020. Determinants of the adoption of sustainable intensification in southern african farming systems: A meta-analysis. Sustainability (Switzerland) 12. https://doi.org/10.3390/SU12083276

Haggar, J., Nelson, V., Lamboll, R., Rodenburg, J., 2021. Understanding and informing decisions on Sustainable Agricultural Intensification in Sub-Saharan Africa. Int J Agric Sustain 19, 349–358. https://doi.org/10.1080/14735903.2020.1818483

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., Rufino, M.C., 2013. The roles of livestock in developing countries. Animal 7, 3–18. https://doi.org/10.1017/S1751731112001954

Herrero, M., Thornton, P.K., Gerber, P., Reid, R.S., 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Curr Opin Environ Sustain 1, 111–120. https://doi.org/10.1016/j.cosust.2009.10.003

Hewett, E.W., 2012. High-value horticulture in developing countries: Barriers and opportunities. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. https://doi.org/10.1079/PAVSNNR20127054

Hove, L., Topps, J.H., Sibanda, S., Ndlovu, L.R., 2001. Nutrient intake and utilisation by goats fed dried leaves of the shrub legumes Acacia angustissima, Calliandra calothyrsus and Leucaena leucocephala as supplements to native pasture hay. Anim Feed Sci Technol 91, 95–106.

INRAE-CIRAD-AFZ, 2021. INRAE-CIRAD-AFZ Feed tables Composition and nutritive values of feeds for cattle, sheep, goats, pigs, poultry, rabbits, horses and salmonids [WWW Document].

INRAE-CIRAD-AFZ and FAO, 2022. Feedipedia - Animal Feed Resources Information System [WWW Document].

IPC, 2023. IPC acute food insecurity analysis.

Irungu, K.R.G., Mbugua, D., Muia, J., 2015. Information and Communication Technologies (ICTs) Attract Youth into Profitable Agriculture in Kenya. East Afri Agric For J 81, 24–33. https://doi.org/10.1080/00128325.2015.1040645

Jayasinghe, P., Ramilan, T., Donaghy, D.J., Pembleton, K.G., Barber, D.G., 2022. Comparison of nutritive values of tropical pasture species grown in different environments, and implications for livestock methane production: A Meta-analysis. Animals 12, 1806. https://doi.org/10.3390/ani12141806

Jellason, N.P., Robinson, E.J.Z., Ogbaga, C.C., 2021. Agriculture 4.0: Is sub-Saharan Africa ready? Applied Sciences (Switzerland) 11. https://doi.org/10.3390/app11125750

Jingura, R.M., Sibanda, S., Hamudikuwanda, H., 2001. Yield and nutritive value of tropical forage legumes grown in semi-arid parts of Zimbabwe. Tropical Grasslands 35, 168–174.

Jiwuba, P.C., Jiwuba, L.C., Ogbuewu, I.P., Mbajiorgu, C.A., 2021. Enhancement values of cassava by-product diets on production and haemato-biochemical indices of sheep and goats: a review. Trop Anim Health Prod 53, 207. https://doi.org/10.1007/s11250-021-02656-9/Published

Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H., Bindelle, J., 2014. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. Anim Feed Sci Technol 191, 47–56. https://doi.org/10.1016/j.anifeedsci.2014.01.012

Kaumbata, W., Banda, L., Mészáros, G., Gondwe, T., Woodward-Greene, M.J., Rosen, B.D., Van Tassell, C.P., Sölkner, J., Wurzinger, M., 2020. Tangible and intangible benefits of local goats rearing in smallholder farms in Malawi. Small Ruminant Research 187, 106095. https://doi.org/10.1016/j.smallrumres.2020.106095

Kebebe, E., 2019. Bridging technology adoption gaps in livestock sector in Ethiopia: A innovation system perspective. Technol Soc 57, 30–37. https://doi.org/10.1016/j.techsoc.2018.12.002

Kessy, R.F., Ochieng, J., Afari-Sefa, V., Chagomoka, T., Nenguwo, N., 2019. Solar-dried traditional African vegetables in rural Tanzania: awareness, perceptions, and factors affecting purchase decisions. Econ Bot 72, 367–379. https://doi.org/10.1007/s12231-018

Kita, S.M., 2017. “Government Doesn’t Have the Muscle”: State, NGOs, Local Politics, and Disaster Risk Governance in Malawi. Risk Hazards Crisis Public Policy 8, 244–267. https://doi.org/10.1002/rhc3.12118

Komarek, A.M., Koo, J., Haile, B., Msangi, S., Azzarri, C., 2018. Trade-offs and synergies between yield, labor, profit, and risk in Malawian maize-based cropping systems. Agron Sustain Dev 38, 32. https://doi.org/10.1007/s13593-018-0506-6

Korir, B.K., Wanyoike, M.M.M., Kuria, J.K.N., Mwangi, D.M., Muge, E.K., 2020. Cassava leaves and azolla as crude protein supplement feed to east african short horned Zebu Heifers. Afr J Agric Res 16, 1458–1463. https://doi.org/10.5897/ajar2020.15061

Krueger, R.A., Casey, M.A., 2014. Focus Groups: A Practical Guide for Applied Research, 5th ed. SAGE Publications, Inc., Thousand Oaks, California 91320.

Kumbuyo, C.P., Yasuda, H., Kitamura, Y., Shimizu, K., 2014. Fluctuation of rainfall time series in Malawi: An analysis of selected areas. Geofizika 31, 13–28. https://doi.org/10.15233/gfz.2014.31.1

Kumwenda, M., Ngwira, A., 2003. Forage demand and constraints to adoption of forage technologies by livestock keepers in Malawi. Tropical Grasslands 37, 274–278.

Kumwenda, M.S.L., 1999. Strategic dry season supplementation of traditionally managed animals in Northern Malawi: Current practices and proposed strategies for the future, in: Animal Traction Network for Eastern and Southern Africa. Printed on behalf of the Animal Traction Network for Eastern and Southern Africa by Mills Lotho, pp. 142–145.

Lamega, S.A., Komainda, M., Hoffmann, M.P., Ayisi, K.K., Odhiambo, J.J.O., Isselstein, J., 2021. It depends on the rain: Smallholder farmers' perceptions on the seasonality of feed gaps and how it affects livestock in semi-arid and arid regions in Southern Africa. Clim Risk Manag 34, 100362. https://doi.org/10.1016/j.crm.2021.100362

Lee, H.B., McNamara, P.E., Ho, H., 2023. Road accessibility and agricultural extension services in Malawi. Agric Food Secur 12, 3. https://doi.org/10.1186/s40066-023-00410-y

Lenné, J.M., Thomas, D., 2006. Integrating crop-livestock research and development in Sub-Saharan Africa Option, imperative or impossible? Outlook Agric 35, 167–175.

Mafirakurewa, T., Mushunje, A., Zantsi, S., 2023. Factors Influencing Smallholder Farmers' Decisions to Participate in Loan-Based Farming in Mutare District, Zimbabwe-A Double-Hurdle Model Approach. Agriculture 13, 2225. https://doi.org/10.3390/agriculture

Mango, N., Makate, C., Lundy, M., Siziba, S., Nyikahadzoi, K., Fatunbi, A.O., 2017. Collective market participation for improved income among smallholder farming households: a case of Balaka Innovation Platform in Malawi. Afr Crop Sci J 25, 97. https://doi.org/10.4314/acsj.v25i1.8s

Maonga, B.B., Mgomezulu, W.R., 2020. Analysis of maize market integration in Malawi: are government influenced ADMARC prices transmitted to retail markets? Agricultural Economics Review 21, 61–74.

Mapiye, C., Chikwanha, O.C., Chimonyo, M., Dzama, K., 2019. Strategies for sustainable use of indigenous cattle genetic resources in Southern Africa. Diversity (Basel) 11, 214. https://doi.org/10.3390/d11110214

Mapiye, C., Mupangwa, J.F., Mugabe, P.H., Chikumba, N., Poshiwa, X., Foti, F., 2006. A review of forage legume research for rangeland improvement in Zimbabwe. Tropical Grasslands 40, 145–149.

Mapiye, O., Makombe, G., Molotsi, A., Dzama, K., Mapiye, C., 2021. Towards a revolutionized agricultural extension system for the sustainability of smallholder livestock production in developing countries: The potential role of icts. Sustainability (Switzerland) 13, 5868. https://doi.org/10.3390/su13115868

Markelova, H., Mwangi, E., 2010. Collective Action for Smallholder Market Access: Evidence and Implications for Africa. Review Policy Research 27, 621–640.

Matita, M., Chiwaula, L., Chirwa, E.W., Mazalale, J., Walls, H., 2022. Subsidizing improved legume seeds for increased household dietary diversity: Evidence from Malawi's Farm Input Subsidy Programme with implications for addressing malnutrition in all its forms. Food Policy 113. https://doi.org/10.1016/j.foodpol.2022.102309

McCarthy, N., Kilic, T., Brubaker, J., Murray, S., De La Fuente, A., 2021. Droughts and floods in Malawi: Impacts on crop production and the performance of sustainable land management practices under weather extremes. Environ Dev Econ 26, 432–449. https://doi.org/10.1017/S1355770X20000455

McDonald, C.K., MacLeod, N.D., Lisson, S., Corfield, J.P., 2019. The Integrated Analysis Tool (IAT) – A model for the evaluation of crop-livestock and socio-economic interventions in smallholder farming systems. Agric Syst 176, 102659. https://doi.org/10.1016/j.agsy.2019.102659

Mcdonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., Wilkinson, R.G., 2011. Animal nutrition. Pearson, Harlow, England.

Megersa, T., Urge, M., Nurfeta, A., 2012. Effects of feeding sweet potato (Ipomoea batatas) vines as a supplement on feed intake, growth performance, digestibility and carcass characteristics of Sidama goats fed a basal diet of natural grass hay. Trop Anim Health Prod 45, 593–601. https://doi.org/10.1007/s11250-012-0264-4

Mehri, M., Pourreza, J., Sadeghi, G., 2010. Replacing maize with pearl millet in laying hens' diets. Trop Anim Health Prod 42, 439–444. https://doi.org/10.1007/s11250-009-9440-6

Mekonnen, E., Mekuriaw, Y., Tegegne, F., Asmare, B., 2019. Evaluation of fodder biomass yield of hydroponically-grown barley and oats and the effects on intake, digestibility and weight gain of Washera sheep when fed as a supplement to a basal diet of natural pasture hay in Ethiopia. Tropical Grasslands-Forrajes Tropicales 7, 519–526. https://doi.org/10.17138/TGFT(7)519-526

Merkel, R.C., Pond, K.R., Burns, J.C., Fisher, D.S., 1999. Intake, digestibility and nitrogen utilization of three tropical tree legumes II. As protein supplements. Anim Feed Sci Technol 82, 107–120.

Moahid, M., Maharjan, K.L., 2020. Factors affecting farmers' access to formal and informal credit: Evidence from rural Afghanistan. Sustainability (Switzerland) 12, 1268. https://doi.org/10.3390/su12031268

Monkwe, T.R., Gxasheka, M., Gunya, B., 2023. Identification of the feed supplements commonly utilised by communal beef cattle farmers during the dry season at Ga-Matlala, Limpopo province. Pastoralism 13, 10. https://doi.org/10.1186/s13570-023-00272-w

Mphinyane, W.N., Tacheba, G., Makore, J., 2015. Seasonal diet preference of cattle, sheep and goats grazing on the communal grazing rangeland in the Central District of Botswana. Afr J Agric Res 10, 2791–2803. https://doi.org/10.5897/AJAR2014.9157

Msalya, G., Nziku, Z.C., Gondwe T., Kifaro, G.C., Eik, L.O., Ådnøy, T., 2020. The Need for Farmer Support and Record Keeping to Enhance Sustainable Dairy Goat Breeding in Tanzania and Malawi, in: Singh Bal Ram and Safalaoh, A. and A.N.A. and E.L.O. and S.B.K. and L.R. (Ed.), Climate Impacts on Agricultural and Natural Resource

Sustainability in Africa. Springer International Publishing, Cham, pp. 287–299. https://doi.org/10.1007/978-3-030-37537-9_17

Mthi, S., Rust, J.M., Washaya, S., Washaya, D.D., Morgenthal, T.L., Sondzaba, B., 2021. Seasonal variation in nutritive value of four browse species used by smallholder farmers for livestock in Eastern Cape Province, South Africa. Applied Animal Husbandry and Rural Development 14, 40–49.

Mueller-Harvey, I., Bee, G., Dohme-Meier, F., Hoste, H., Karonen, M., Kölliker, R., Lüscher, A., Niderkorn, V., Pellikaan, W.F., Salminen, J.P., Skøt, L., Smith, L.M.J., Thamsborg, S.M., Totterdell, P., Wilkinson, I., Williams, A.R., Azuhnwi, B.N., Baert, N., Brinkhaus, A.G., Copani, G., Desrues, O., Drake, C., Engström, M., Fryganas, C., Girard, M., Huyen, N.T., Kempf, K., Malisch, C., Mora-Ortiz, M., Quijada, J., Ramsay, A., Ropiak, H.M., Waghorn, G.C., 2019. Benefits of condensed tannins in forage legumes fed to ruminants: Importance of structure, concentration, and diet composition. Crop Sci 59, 861–885. https://doi.org/10.2135/cropsci2017.06.0369

Mugunieri, G.L., Omiti, J., Irungu, P., 2004. Integrating community-based animal health workers into the formal veterinary service delivery system in Kenya. Agrekon 43, 89–100.

Mulumpwa, M., 2018. The potential of insect meal in improving food security in Malawi: An alternative of soybean and fishmeal in livestock feed. J Insects Food Feed 4, 301–312. https://doi.org/10.3920/JIFF2017.0090

Mupangwa, J.F., Ngongoni, N.T., Topps, J.H., Ndlovu, P., 1997. Chemical composition and dry matter degradability profiles of forage legumes Cassia rotundifolia cv. Wynn, Lablab purpureus cv. Highworth and Macroptilium atropurpureum cv. Siratro at 8 weeks of growth (pre-anthesis). Anim Feed Sci Technol 69, 167–178.

Musa, F.B., Kamoto, J.F.M., Jumbe, C.B.L., Zulu, L.C., 2018. Adoption and the role of fertilizer trees and shrubs as a climate-smart agriculture practice: The case of Salima District in Malawi. Environments - MDPI 5, 122. https://doi.org/10.3390/environments5110122

Mutonyi, S., 2019. The effect of collective action on smallholder income and asset holdings in Kenya. World Dev Perspect 14, 100099. https://doi.org/10.1016/j.wdp.2019.02.010

Muyanga, M., Nyirenda, Z., Lifeyo, Y., Burke, W.J., 2020. The Future of Smallholder Farming in Malawi.

Nanganga, J., Safalaoh, A.C.L., 2020. Climate Change and Weather Variability Effects on Cattle Production: Perception of Cattle Keepers in Chikwawa, Malawi, in: Singh Bal Ram and Safalaoh, A. and A.N.A. and E.L.O. and S.B.K. and L.R. (Ed.), Climate Impacts on Agricultural and Natural Resource Sustainability in Africa. Springer International Publishing, Cham, pp. 213–225. https://doi.org/10.1007/978-3-030-37537-9_12

Ndah, H.T., Schuler, J., Nkwain, V.N., Nzogela, B., Mangesho, W., Mollel, R., Loina, R., Zander, P., Paul, B.K., 2022. Determinants for Smallholder Farmers' Adoption of Improved

Forages in Dairy Production Systems: The Case of Tanga Region, Tanzania. Agronomy 12, 305. https://doi.org/10.3390/agronomy12020305

Ndaru, P.H., Huda, A.N., Marjuki, Prasetyo, R.D., Shofiatun, U., Nuningtyas, Y.F., Ndaru, R.K., Kusmartono, 2020. Providing high quality forages with hydroponic fodder system, in: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing, p. 012054. https://doi.org/10.1088/1755-1315/478/1/012054

Nhantumbo, N.S., Zivale, C.O., Nhantumbo, I.S., Gomes, A.M., 2016. Making agricultural intervention attractive to farmers in Africa through inclusive innovation systems. World Dev Perspect. https://doi.org/10.1016/j.wdp.2016.12.003

Nhundu, T., Mutandwa, E., Stark, J., Chamboko, T., Vambe, A.T., 2023. Determinants of smallholder livestock farmers' adoption decisions of improved fodder technologies in Insiza District. African Journal of Science, Technology, Innovation and Development 15, 805–816. https://doi.org/10.1080/20421338.2023.2196199

Nkosi, B.D., Meeske, R., 2010. Effects of ensiling totally mixed potato hash ration with or without a heterofermentative bacterial inoculant on silage fermentation, aerobic stability, growth performance and digestibility in lambs. Anim Feed Sci Technol 161, 38–48. https://doi.org/10.1016/j.anifeedsci.2010.07.015

Nuvey, F.S., Arkoazi, J., Hattendorf, J., Mensah, G.I., Addo, K.K., Fink, G., Zinsstag, J., Bonfoh, B., 2022. Effectiveness and profitability of preventive veterinary interventions in controlling infectious diseases of ruminant livestock in sub-Saharan Africa: a scoping review. BMC Vet Res 18, 332. https://doi.org/10.1186/s12917-022-03428-9

Nyaata, O.Z., O'Neill, M.K., Dorward, P.T., Keatinge, J.D.H., 2002. Harvesting strategies for improved mixtures of calliandra and napier grass in the central kenyan highlands. Journal of Sustainable Agriculture 19, 77–95. https://doi.org/10.1300/J064v19n03_08

Nyamakwere, F., Esposito, G., Dzama, K., Raffrenato, E., 2021. A review of artisanal cheese making: An african perspective. S Afr J Anim Sci 51, 296–309. https://doi.org/10.4314/sajas.v51i3.3

Nyamushamba, G.B., Mapiye, C., Tada, O., Halimani, T.E., Muchenje, V., 2017. Conservation of indigenous cattle genetic resources in Southern Africa's smallholder areas: Turning threats into opportunities - A review. Asian-Australas J Anim Sci. https://doi.org/10.5713/ajas.16.0024

Okello, A.O., Nzuma, J.M., Otieno, D.J., Kidoido, M., Tanga, C.M., 2021. Farmers' perceptions of commercial insect-based feed for sustainable livestock production in Kenya. Sustainability (Switzerland) 13. https://doi.org/10.3390/su13105359

Okorio, J., Sekatuba, J., Agaba, H., Wandui, C., Musaana, S., Ongodia, G., Opolot, V., Wafula, D., 2004. Potential of agroforestry in improving livelihoods in eastern and mid-northern Uganda. Uganda Journal of Agricultural Sciences 9, 893–899.

Omphile, U.J., Aganga, A.A., Malamba, B., 2005. Diets and forage preference of communally grazed range goats in an acacia bush savanna in southeast Botswana. Journal of Biological Sciences 5, 690–693.

Oni, A.O., Arigbede, O.M., Oni, O.O., Onwuka, CF.I., Anele, U.Y., Oduguwa, B.O., Yusuf, K.O., 2010. Effects of feeding different levels of dried cassava leaves (Manihot esculenta, Crantz) based concentrates with Panicum maximum basal on the performance of growing West African Dwarf goats. Livest Sci 129, 24–30. https://doi.org/10.1016/j.livsci.2009.12.007

Oweis, T., Hachum, A., 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. Agric Water Manag 80, 57–73. https://doi.org/10.1016/j.agwat.2005.07.004

Oyewole, B., 2022. Boosting smallholder farmers' productivity to feed Africa against the looming food crisis, AfDB Virtual Evaluation.

Paramesh, V., Ravisankar, N., Behera, U.K., Arunachalam, V., Kumar, P., Rajkumar, S.R., Misra, D.S., Kumar, M.R., Prusty, A.K., Jacob, D., Panwar, A.S., Mayenkar, T., Reddy, V.K., Rajkumar, S., 2022. Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. Food Energy Secur 11, e321. https://doi.org/10.1002/fes3.321

Paul, B.K., Groot, J.C.J., Maass, B.L., Notenbaert, A.M.O., Herrero, M., Tittonell, P.A., 2020. Improved feeding and forages at a crossroads: Farming systems approaches for sustainable livestock development in East Africa. Outlook Agric 49, 13–20. https://doi.org/10.1177/0030727020906170

Pawlak, K., Kołodziejczak, M., 2020. The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. Sustainability (Switzerland) 12, 5488. https://doi.org/10.3390/su12135488

Phiri, A., Chipeta, G.T., Chawinga, W.D., 2019a. Information needs and barriers of rural smallholder farmers in developing countries: A case study of rural smallholder farmers in Malawi. Information Development 35, 421–434. https://doi.org/10.1177/0266666918755222

Phiri, A., Chipeta, G.T., Chawinga, W.D., 2019b. Information needs and barriers of rural smallholder farmers in developing countries: A case study of rural smallholder farmers in Malawi. Information Development 35, 421–434. https://doi.org/10.1177/0266666918755222

Phiri, C.K., Njira, K., Chitedze, G., 2023. An insight of chickpea production potential, utilization and their challenges among smallholder farmers in Malawi – A review. J Agric Food Res. https://doi.org/10.1016/j.jafr.2023.100713

Ragasa, C., 2018. Supply of and demand for agricultural extension services in Malawi - A synthesis.

Rahaman, M.F., Jahan, C.S., Mazumder, Q.H., 2019. Rainwater harvesting: Practiced potential for Integrated Water Resource Management in drought-prone Barind Tract, Bangladesh. Groundw Sustain Dev 9, 100267. https://doi.org/10.1016/j.gsd.2019.100267

Ravhuhali, K.E., Msiza, N.H., Mudau, H.S., 2022. Seasonal dynamics on nutritive value, chemical estimates and in vitro dry matter degradability of some woody species found in rangelands of South Africa. Agroforestry Systems 96, 23–33. https://doi.org/10.1007/s10457-021-00683-x

Reynolds, L., 2006. Country Pasture/Forage Resource Profiles MALAWI. Rome.

Rodriguez, J.M., Moinar, J.J., Fazio, R.A., Sydnor, E., Lowe, M.J., 2008. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. Renewable Agriculture and Food Systems 24, 60–71.

Rogé, P., Snapp, S., Kakwera, M.N., Mungai, L., Jambo, I., Peter, B., 2016. Ratooning and perennial staple crops in Malawi. A review. Agron Sustain Dev 36, 50. https://doi.org/10.1007/s13593-016-0384-8

Rojas-Downing, M.M., Nejadhashemi, A.P., Harrigan, T., Woznicki, S.A., 2017. Climate change and livestock: Impacts, adaptation, and mitigation. Clim Risk Manag 16, 145–163. https://doi.org/10.1016/j.crm.2017.02.001

Rusere, F., Mkuhlani, S., Crespo, O., Dicks, L.V., 2019. Developing pathways to improve smallholder agricultural productivity through ecological intensification technologies in semi-arid Limpopo, South Africa. African Journal of Science, Technology, Innovation and Development 11, 543–553. https://doi.org/10.1080/20421338.2018.1550936

Rusinamhodzi, L., van Wijk, M.T., Corbeels, M., Rufino, M.C., Giller, K.E., 2015. Maize crop residue uses and trade-offs on smallholder crop-livestock farms in Zimbabwe: Economic implications of intensification. Agric Ecosyst Environ 214, 31–45. https://doi.org/10.1016/j.agee.2015.08.012

Safalaoh, A.C.L., Kavala, E., 2020. In Search of Climate-Smart Feeds: The Potential of Pearl Millet (Pennisetum glaucum, L.) to Replace Maize as an Energy Feed Ingredient in Broiler Diets in Malawi, in: Singh Bal Ram and Safalaoh, A. and A.N.A. and E.L.O. and S.B.K. and L.R. (Ed.), Climate Impacts on Agricultural and Natural Resource Sustainability in Africa. Springer International Publishing, Cham, pp. 201–212. https://doi.org/10.1007/978-3-030-37537-9_11

Safaloah, A.C.L., Chapotera, J., 2007. A preliminary evaluation of the stockfeed industry in Malawi. Malawi Journal of Agricultural Science 3, 32–39.

Salawu, M.B., Acamovic, T., Stewart, C.S., Roothaert, R.L., 1999. Composition and degradability of different fractions of Calliandra leaves, pods and seeds. Anim Feed Sci Technol 77, 181–199.

Salima, W., Manja, L.P., Chiwaula, L.S., Chirwa, G.C., 2023. The impact of credit access on household food security in Malawi. J Agric Food Res 11, 100490. https://doi.org/10.1016/j.jafr.2022.100490

Salmon, G., Teufel, N., Baltenweck, I., van Wijk, M., Claessens, L., Marshall, K., 2018. Trade-offs in livestock development at farm level: Different actors with different objectives. Glob Food Sec 17, 103–112. https://doi.org/10.1016/j.gfs.2018.04.002

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M., West, P.C., 2016. Subnational distribution of average farm size and smallholder contributions to global food production. Environmental Research Letters 11, 12010. https://doi.org/10.1088/1748-9326/11/12/124010

Saraiva, T.A., Monteiro, C.C.F., Feitosa, E.M.S., Moraes, G.S.O., Netto, A.J., Cardoso, D.B., Magalhães, A.L.R., de Melo, A.A.S., 2020. Effect of association of fresh cassava root with corn silage in replacement for cactus cladodes on dairy cow performance. Trop Anim Health Prod 52, 927–933. https://doi.org/10.1007/s11250-019-02087-7

Savadogo, M., Zemmelink, G., Nianogo, A.J., van Keulen, H., 2000. Cowpea (Vigna unguiculata L. Walp) and groundnut (Arachys hypogea L.) haulms as supplements to sorghum (Sorghum bicolor L. Moench) stover- intake, digestibility and optimum feeding levels. Anim Feed Sci Technol 87, 57–69.

Savodogo, M., Zemmelink, G., Nianogo, A.J., 2000. Effect of selective consumption on voluntary intake and digestibility of sorghum (Sorghum bicolor L. Moench) stover, cowpea (Vigna unguiculata L. Walp.) and groundnut (Arachis hypogaea L.) haulms by sheep. Anim Feed Sci Technol 84, 265–277.

Sekaran, U., Lai, L., Ussiri, D.A.N., Kumar, S., Clay, S., 2021. Role of integrated crop-livestock systems in improving agriculture production and addressing food security – A review. J Agric Food Res. https://doi.org/10.1016/j.jafr.2021.100190

Selle, P.H., Cadogan, D.J., Li, X., Bryden, W.L., 2010. Implications of sorghum in broiler chicken nutrition. Anim Feed Sci Technol. https://doi.org/10.1016/j.anifeedsci.2010.01.004

Shikuku, K.M., Valdivia, R.O., Paul, B.K., Mwongera, C., Winowiecki, L., Läderach, P., Herrero, M., Silvestri, S., 2017. Prioritizing climate-smart livestock technologies in rural Tanzania: A minimum data approach. Agric Syst 151, 204–216. https://doi.org/10.1016/j.agsy.2016.06.004

Sibale, B., Kafakoma, R., Shaba, A., Macqueen, D., 2013. History of on-farm tree-based enterprise development in Malawi, in: Trees On-Farm: Removing the Obstacles to Enterprise: A Review of Current Climate-Smart Tree-Based Experiences in Malawi. pp. 13–23.

Simpson, J.E., 2000. Some socio-economic factors affecting the conservation and utilisation of farm animal genetic resources in Malawi, in: ILRI (International Livestock Research Institute) and GTZ (German Agency for Technical Cooperation)

(Eds.), 2002: Animal Genetic Resources. Virtual Library. Addis-Ababa, Ethiopia, CD-ROM. ILRI (International Livestock Research Institute) and GTZ (German Agency for Technical Cooperation), Addis Ababa.

Singh, S., Bhat, B.V., Shukla, G.P., Gaharana, D., Anele, U.Y., 2017. Nutritional evaluation of different varieties of sorghum stovers in sheep. Anim Feed Sci Technol 227, 42–51. https://doi.org/10.1016/j.anifeedsci.2017.03.011

Singh, S., Kushwaha, B.P., Nag, S.K., Mishra, A.K., Singh, A., Anele, U.Y., 2012. In vitro ruminal fermentation, protein and carbohydrate fractionation, methane production and prediction of twelve commonly used Indian green forages. Anim Feed Sci Technol 178, 2–11. https://doi.org/10.1016/j.anifeedsci.2012.08.019

Steinfeld, H., Wassenaar, T., Jutzi, S., 2006. Livestock production systems in developing countries: status, drivers, trends. Revue scientifique et technique 25, 505–516.

Steinfield, C., Wyche, S., Chiwasa, H., Cai, T., Mchakulu, J., 2015. Using Participatory Video for Smallholder Farmer Training in Malawi A Report from the GCFSI and LUANAR ICTD Project Team. Michigan, USA. .

Stevens, T., Madani, K., 2016. Future climate impacts on maize farming and food security in Malawi. Sci Rep 6, 36241. https://doi.org/10.1038/srep36241

Stifkens, A., Matthews, E.M., McSweeney, C.S., Charmley, E., 2022. Increasing the proportion of Leucaena leucocephala in hay-fed beef steers reduces methane yield. Anim Prod Sci 62, 622–632. https://doi.org/10.1071/AN21576

Szymczak, L.S., de Faccio Carvalho, P.C., Lurette, A., de Moraes, A., de Albuquerque Nunes, P.A., Martins, A.P., Moulin, C.-H., 2020. System diversification and grazing management as resilience-enhancing agricultural practices: The case of crop-livestock integration. Agric Syst 184, 102904. https://doi.org/10.1016/j.agsy.2020.102904

Tadele, Z., 2017. Raising crop productivity in Africa through intensification. Agronomy 7, 22. https://doi.org/10.3390/agronomy7010022

Tanga, C.M., Egonyu, J.P., Beesigamukama, D., Niassy, S., Emily, K., Magara, H.J.O., Omuse, E.R., Subramanian, S., Ekesi, S., 2021. Edible insect farming as an emerging and profitable enterprise in East Africa. Curr Opin Insect Sci 48, 64–71. https://doi.org/10.1016/j.cois.2021.09.007

Tanga, C.M., Kababu, M.O., 2023. New insights into the emerging edible insect industry in Africa. Animal Frontiers 13, 26–40. https://doi.org/10.1093/af/vfad039

Tebug, S.F., Kasulo, V., Chikagwa-Malunga, S., Wiedemann, S., Roberts, D.J., Chagunda, M.G.G., 2012. Smallholder dairy production in Northern Malawi: Production practices and constraints. Trop Anim Health Prod 44, 55–62. https://doi.org/10.1007/s11250-011-9887-0

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash, N.S., Rusinamhodzi, L., 2013. Maize-based conservation agriculture systems in Malawi:

Long-term trends in productivity. Field Crops Res 142, 47–57. https://doi.org/10.1016/j.fcr.2012.11.010

Thornton, P.K., Herrero, M., 2015. Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. Nat Clim Chang 5, 830–836. https://doi.org/10.1038/nclimate2754

Thornton, P.K., van de Steeg, J., Notenbaert, A., Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agric Syst 101, 113–127. https://doi.org/10.1016/j.agsy.2009.05.002

Timler, C.J., 2020. Exploring and assessing trade-offs, synergies and diversity for smallholder agriculture.

Timler, C.J., Groot, J.C.J., Snapp, S.S., Tittonell, P.A., 2023. Strategies Steering Intensification Pathways of Farmers in Central Malawi. Hum Ecol 51, 455–469. https://doi.org/10.1007/s10745-023-00413-0

Tittonell, P., Gérard, B., Erenstein, O., 2015. Tradeoffs around crop residue biomass in smallholder crop-livestock systems - What's next? Agric Syst 134, 119–128. https://doi.org/10.1016/j.agsy.2015.02.003

van den Berg, H., Ketelaar, J.W., Dicke, M., Fredrix, M., 2020. Is the farmer field school still relevant? Case studies from Malawi and Indonesia. NJAS - Wageningen Journal of Life Sciences 92, 1–13. https://doi.org/10.1016/j.njas.2020.100329

van Huis, A., Oonincx, D.G.A.B., 2017. The environmental sustainability of insects as food and feed. A review. Agron Sustain Dev. https://doi.org/10.1007/s13593-017-0452-8

Van Ittersum, M.K., Van Bussel, L.G.J., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., Claessens, L., De Groot, H., Wiebe, K., Mason-D'Croz, D., Yang, H., Boogaard, H., Van Oort, P.A.J., Van Loon, M.P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Makoi, J.H.J.R., Ouattara, K., Tesfaye, K., Cassman, K.G., 2016. Can sub-Saharan Africa feed itself? Proc Natl Acad Sci U S A 113, 14964–14969. https://doi.org/10.1073/pnas.1610359113

Vanlauwe, B., Descheemaeker, K., Giller, K.E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., Zingore, S., 2015. Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. Soil 1, 491–508. https://doi.org/10.5194/soil-1-491-2015

Walls, H., Johnston, D., Matita, M., Kamwanja, T., Smith, R., Nanama, S., 2023. The politics of agricultural policy and nutrition: A case study of Malawi's Farm Input Subsidy Programme (FISP). PLOS Global Public Health 3, e0002410. https://doi.org/10.1371/journal.pgph.0002410

Wan, M., Colfer, C.J.P., Powell, B., 2011. Forests, women and health: opportunities and challenges for conservation. International Forestry Review 13, 369–387.

Warburton, H., Blake, R., Coupe, S., Pasteur, K., Phillips, E., 2011. Bridging the gap between resource-poor farmers and extension services: The role of community-based extension systems, in: Proceedings Innovations in Extension and Advisory Services International Conference.

Wasihun, A.A., Berhe, G.G., Sbhatu, D.B., Abay, K.H., Gebreyohannes, GG., 2023. Quality jam from Baobab (Adansonia digitata L) fruit pulp powder: Formulation and evaluation of Its physicochemical and nutritional properties. J Food Qual 2023, 8816526. https://doi.org/10.1155/2023/8816256

Wolf, J., Chen, M., Asrar, G.R., 2021. Global rangeland primary production and its consumption by Livestock in 2000–2010. Remote Sens (Basel) 13, 3430. https://doi.org/10.3390/rs13173430

Wudil, A.H., Usman, M., Rosak-Szyrocka, J., Pilař, L., Boye, M., 2022. Reversing Years for Global Food Security: A Review of the Food Security Situation in Sub-Saharan Africa (SSA). Int J Environ Res Public Health. https://doi.org/10.3390/ijerph192214836

Yolcu, H., Dasci, M., Tan, M., Çomakli, B., 2008. Nutrient value of some lucerne of cultivars based on chemical composition for livestock. Asian Journal of Chemistry 20, 4110–4116.

Zerssa, G., Feyssa, D., Kim, D.G., Eichler-Löbermann, B., 2021. Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. Agriculture (Switzerland). https://doi.org/10.3390/agriculture11030192

Zervas, G., Tsiplakou, E., 2012. An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2011.11.039

Zhang, H., Asutosh, A., Hu, W., 2018. Implementing vertical farming at university scale to promote sustainable communities: A feasibility analysis. Sustainability (Switzerland) 10, 4429. https://doi.org/10.3390/su10124429

Zhang, J., Yue, Z., Sun, Y., Wang, Z., Zhang, Y., Huang, L., Tu, J., Shi, B., Shan, A., Ma, Q., 2022. Effects of sweet potato vine silage supplementation on growth performance, nutrient digestibility, and intestinal health in finishing pigs. Czech Journal of Animal Science 67, 218–227. https://doi.org/10.17221/209/2021-CJAS

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