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ORIGINAL PAPER

Use and benefits of tree germplasm from the World Agroforestry genebank for smallholder farmers in Kenya

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Abstract

The World Agroforestry (ICRAF) in Kenya plays a key role in conserving tree genetic diversity, thereby contributing to the delivery of ecosystem services in tree-based production systems. This study explored the benefits of using the two most popular fodder tree species among smallholder farmers, sourced from the ICRAF genebank: *Calliandra calothyrsus* (Calliandra) and *Gliricidia sepium* (Gliricidia). Through a survey of key informants and genebank users, we examined the benefits derived from the adoption of Calliandra and Gliricidia and the unique role of the ICRAF genebank as the main source of tree germplasm for Kenyan smallholders. The constraints to germplasm access could limit protein fodder supply and the intensity of fertilization in farmers' fields, which in turn could affect productivity in livestock and maize sectors in Kenya. We find that improved food security, higher incomes, increased milk production, reduced vulnerability to drought, reduced soil erosion, and enhanced soil fertility are identified as the main farmer-perceived benefits linked to the use of Calliandra and Gliricidia. The findings demonstrate the importance of agroforestry in the delivery of ecosystem services, in the light of climate change and heightened pressure for sustainable agricultural practices, and the crucial role of the genebank in conserving and distributing unique, high quality tree germplasm.

Keywords Calliandra · Gliricidia · Genebanks · Tree germplasm · Kenya · Agroforestry

1 Introduction

Agroforestry systems are one of the possible solution pathways to the myriad of challenges facing the African drylands (Franzel and Scherr 2002). Nourishment, pest regulation, habitat, climate buffering, temperature regulation, and carbon sequestration are some of the ecosystem benefits derived from diverse tree-based production systems (Bromhead 2012). The optimization of these crucial ecosystem services is contingent on tree diversity. However, climate change, population pressure, and related agricultural expansion threaten tree diversity in Africa. The multifunctional role of trees as well as their projected importance in the context of climate change renders the conservation of tree diversity a serious priority for Africa's agricultural landscape. With access to agroforestry germplasm, smallholder farmers have a source of food and fuel for consumption or income and could reduce their vulnerability during climate extremes (Evangelista 2014).

Livestock and dairy sectors are important for food security and economic growth in low-income countries in Africa, and fodder trees constitute a vital component in livestock productivity. In Kenya, the dairy sector accounts for 14% of the country's agricultural gross domestic product (Kiambi et al. 2018). Annual milk production is estimated at 4.8 million tonnes, of which 4.6 million tonnes is attributed to cattle (Makau et al. 2018). Moreover, the sector is a key livelihood contributor to approximately two million smallholder dairy farmers and their constituent households. Income generation, nourishment, cash buffering, and risk mitigation are just some of the important livelihood benefits that livestock farming confers to these households (Ferner et al. 2018). Indirectly, the sector is an important source of nourishment to the wider

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Kenyan population. Kenya is the biggest milk producer in East Africa, at 4.8 million tonnes, and its estimated per capita milk consumption of 95 kg/capita is above the global average of 90 kg/capita (FAOSTAT 2019).

However, one of the key challenges for livestock farmers is the availability of high quality fodder. Trees can play a significant role in addressing some of the factors that limit the sustainability and productivity of livestock production. Currently, most fodders used in developing regions are derived largely from grasses and crop residues, which are bulky and low in nutrients and minerals. Napier grass is the major source of feed for smallholder farmers involved in intensive and semi-intensive livestock management systems in Kenya (Wamalwa et al. 2017). However, Napier is low in protein content, and as such, it cannot wholly meet the recommended protein needs for livestock, which in turn has implications for productivity (Manaye et al. 2009). Farmers would need to purchase concentrates to supplement the low protein content of Napier. However, many poor smallholders are either unable to purchase these concentrates at all, consistently, or in the recommended quantities.

Maize production is another sector that merits special attention regarding access to high quality fodder trees, not only in Kenya but in many regions in the world. Maize is a major food crop in Kenya. The total land area under maize production was about 2.1 million hectares in 2017, with an annual average production estimated at 3.2 million tonnes (FAOSTAT 2019). The national mean yield of 1.5 t per hectare (t/ha) is below the average for East Africa at 1.8 t/ha and for the African continent at 2 t/ha. Poor soil fertility in smallholder systems, particularly low soil nitrogen, is a serious limiting factor to maize productivity and equitable development in much of sub-Saharan Africa (Franzel 1999). While synthetic fertilizers are one of the means through which farmers can supplement low soil nitrogen, the costs of inputs significantly limit the intensity of fertilization. Forage trees with high nutritive value offer an affordable solution to improve soil fertility in marginal areas. A Gliricidia–maize intercropping system is being widely promoted in sub-Saharan Africa and has improved soil fertility, particularly in areas where farm size is small and the use of synthetic fertilizers is low (Thangata and Alavalapati 2003; Makumba et al. 2006).

This paper assesses the factors influencing the adoption of fodder tree germplasm and the benefits of their use for smallholder farmers. We analyzed distribution data and other information provided by the Genetic Resources Unit (GRU) of World Agroforestry (ICRAF), interviewed key informants, and implemented a survey of germplasm recipients from ICRAF. The ICRAF GRU was established in 1993 with the mandate to 'collect, conserve, document, characterize and distribute a diverse collection of agroforestry trees, mainly focusing on indigenous species in all ICRAF working regions' (ICRAF GRU 2019).

Calliandra calothyrsus (Calliandra) and *Gliricidia sepium* (Gliricidia) are the two most requested species from the seed genebank in Nairobi. Calliandra is an affordable protein-rich fodder and has been identified as a suitable protein substitute or supplement within the smallholder dairy farming context. Gliricidia is appreciated for its role as a soil fertility enhancer due to its nitrogen fixation and carbon sequestration abilities, and hence, it is considered a 'nutrient-fixing' alternative for resource-poor maize farmers. However, germplasm from these species is difficult to obtain from sources other than the ICRAF genebank, highlighting the priority role of conservation by genebanks. That said, sustained tree diversity conservation demands significant financial resources to support crucial operations (Koo et al. 2003).

The contribution of this study is twofold. First, to the best of our knowledge, no study has yet attempted to investigate the impact of forage trees directly distributed to smallholder farmers by ICRAF genebank. Secondly, striving to understand the determinants of agroforestry adoption and its perceived benefits remains an active research area, given the adoption of agroforestry interventions is not widespread despite its recognized benefits (Mbow et al. 2014). Understanding the factors that affect the adoption of agroforestry trees is important to identify germplasm-related constraints and provide valuable feedback to the genebank to inform future interventions.

2 Data and methods

2.1 Data

This paper assesses the factors influencing the adoption of Calliandra and Gliricidia germplasm and the benefits of their use for smallholder farmers. We do this by analyzing seed distribution data from ICRAF GRU and by implementing a user survey and key informant interviews (KIIs). We employed a semi-structured survey protocol, designed in consultation with the genebank, to collect information from the genebank users and key informants.

Between 2008 and 2017, the genebank received 671 requests for the two trees, 434 for Calliandra and 237 for Gliricidia. A list of unique users was first developed given that the distribution data include multiple requests from the same requestor. Only those requestors with a listed phone contact were retained in the list. Those whose contact was listed as N/A were dropped from the list. The final list of requestors contained 213 users. The 213 users fell into the following sub-categories: research institutions/universities (10), private organizations (31), individual farmers (154), and farmer/community/non-governmental-based organizations (16). We identified the 154 farmers in the list as our target respondents. Further, since more than 95% of requests for the two species came from within the country, we focused our analysis on farmers from Kenya.

The final sample is based on 50 interviews that took place between 12 and 29 September 2018. Many users from the target list were not reachable. We assume that a number of contact details had changed. Further, because of the voluntary nature of the survey, there are also those who were contacted by email and phone, but did not respond to the survey. The user survey collected information on the reasons for germplasm request, the uses of requested germplasm, the benefits of requested germplasm, and the quality of germplasm received from the ICRAF genebank.

The survey was designed using Open Data Kit and later verified and uploaded on an online server platform. Open Data Kit facilitates the collection of data through mobile devices or other electronic devices (tablets, laptops) and transmits to an online server where the data is stored securely. Once the survey was verified, we uploaded the questionnaire to the server, after which the survey was administered. Each response was stored in a unique record within a form.

We purposively selected nine key informants based on their diverse and recognized experience in the promotion of fodder trees. The identification of key informants was based on referrals within the ICRAF network and on recognition of their published work in the topic area. The key informant questions were guided by an extensive literature review process that sought to understand the dominant themes in fodder tree adoption. The understanding of these themes provided a framework to put into context the results from the user survey.

2.2 Methods

Consent was sought prior to the engagement of respondents in both the KIIs and user surveys. Key informants were first contacted via an introductory e-mail that sought to introduce the survey, seek their consent, and arrange for a specific interview date. An introductory phone call was used to seek consent from shortlisted user survey participants. KIIs were administered either via Skype or in person where possible. Respondent information was recorded electronically via the online webforms. The user survey was administered through phone interviews and recorded in a similar manner to the KIIs.

Descriptive analysis was conducted on the germplasm distribution data and user survey results. We applied qualitative thematic analysis to the data from the KIIs and the user survey. Qualitative thematic analysis is a methodological tool employed for the purposes of identifying, analyzing, and reporting themes within the data set (Vaismoradi et al. 2013). Specifically, this study employed a theoretical thematic approach, given the data were collected within the context of specific research questions, hence the existence of pre-existing latent themes (Braun and Clarke 2006). The objective of this analysis, given the existence pre-existing themes, was to allow for in-depth discussion of the research questions under investigation. These methods are appropriate given the qualitative nature of the data and the intent of the analysis.

3 Results and discussion

3.1 Distribution of Calliandra and Gliricidia

The ICRAF genebank in Nairobi, Kenya, conserves the diversity of a wide range of agroforestry tree species. More than 16,000 accessions are stored as seed or in field genebanks in the regions where ICRAF works. Because the conservation of tree species poses special difficulties (due to large number of genera, long generation times, and seeds that often cannot be dried for conventional storage), the GRU has to maintain decentralized field genebanks. The seed genebank currently holds 5391 seed accessions (representing 192 tree species) and 11,236 accessions in field genebanks (accessible at http://old.worldagroforestry.org/products/grunew/). ICRAF GRU supplies germplasm to researchers and to farmers wanting direct access to agroforestry plant genetic resources.

Between 2008 and 2017, the genebank distributed 690 seed samples, 448 samples of Calliandra (weighing 107 kg) and 242 samples of Gliricidia (weighing 131 kg) (Table 1). Accession number ICRAF 05527 (https://doi.org/10.18730/K74TT) was the most requested and distributed accession of Calliandra during the time period, while accession number ICRAF 04891 (https://doi.org/10.18730/KA1BV) took the lead for Gliricidia. However, requests vary every year. Figure 1 shows changes in accessions distributed in the past 10 years and show, in recent years, ICRAF 07305 (https://doi.org/10.18730/K9P30) and ICRAF 05537 (https://doi.org/10.18730/K722C) are the most requested accessions of Calliandra and ICRAF 07306 (https://doi.org/10.18730/S9CNN) of Gliricidia.

3.2 Feedback from ICRAF genebank users

3.2.1 Satisfaction from services and germplasm received

Most recipients were satisfied with the services and germplasm they received from the ICRAF genebank. Figure 2 shows the results on satisfaction with genebank services in general, while Fig. 3 presents results on satisfaction with the germplasm they received.

A good proportion of recipients rated the genebank services positively, though there were a few isolated cases of extreme dissatisfaction (Table 2). Some respondents, indicated by non-applicable, were not in a position to rate the services based on the fact that they had either not planted or could not account for germplasm use. The satisfaction from the

Table 1 Total germplasm distribution of *Calliandra* and *Gliricidia*, 2008–2017

Species requested	Accession number	Number of requests	Number of samples distributed	Quantity (kg) shipped
Calliandra	ICRAF 05527	168	168	50.6
	ICRAF 07305	72	77	8.4
	ICRAF 04622	64	64	13.0
	ICRAF 04897	55	55	8.3
	ICRAF 04873	23	23	4.6
	ICRAF 06612	12	21	10.0
	ICRAF 05420	20	20	8.1
	ICRAF 05726	10	10	2.0
	ICRAF 05537	6	6	0.5
	ICRAF 05673	2	2	1.1
	ICRAF 8/99	1	1	0.1
	ICRAF 07296	1	1	0.1
Calliandra, Total		**434**	**448**	**106.8**
Gliricidia	ICRAF 04891	162	162	117.2
	ICRAF 07306	61	66	7.1
	ICRAF 04693	6	6	1.0
	ICRAF 03375	5	5	0.5
	ICRAF 03299	3	3	5.6
Gliricidia, Total		**237**	**242**	**131.4**

Source: data from ICRAF GRU

germplasm materials received was attributed to the good germination rate, signifying high quality germplasm. Good customer services and easy instructions on the seed package were also identified as additional advantages associated with sourcing germplasm from the ICRAF genebank. Dissatisfaction was cited when germination did not occur despite the fact that recipients followed the instructions diligently. Additionally, one recipient highlighted the need for additional instructions tailored to address agroecological peculiarities such as termites, which in this case obstructed successful germination.

The dominance of good germination rate as a measure of satisfaction of ICRAF germplasm is heavily echoed in the agroforestry literature pertaining to tree seed quality. Poor planting stock material is a major impediment to the success of agroforestry interventions in the tropics. Constraints in the supply of high quality germplasm not only impedes the growth of a robust private sector market but also limits adoption of agroforestry interventions by farmers (Gregorio et al. 2015).

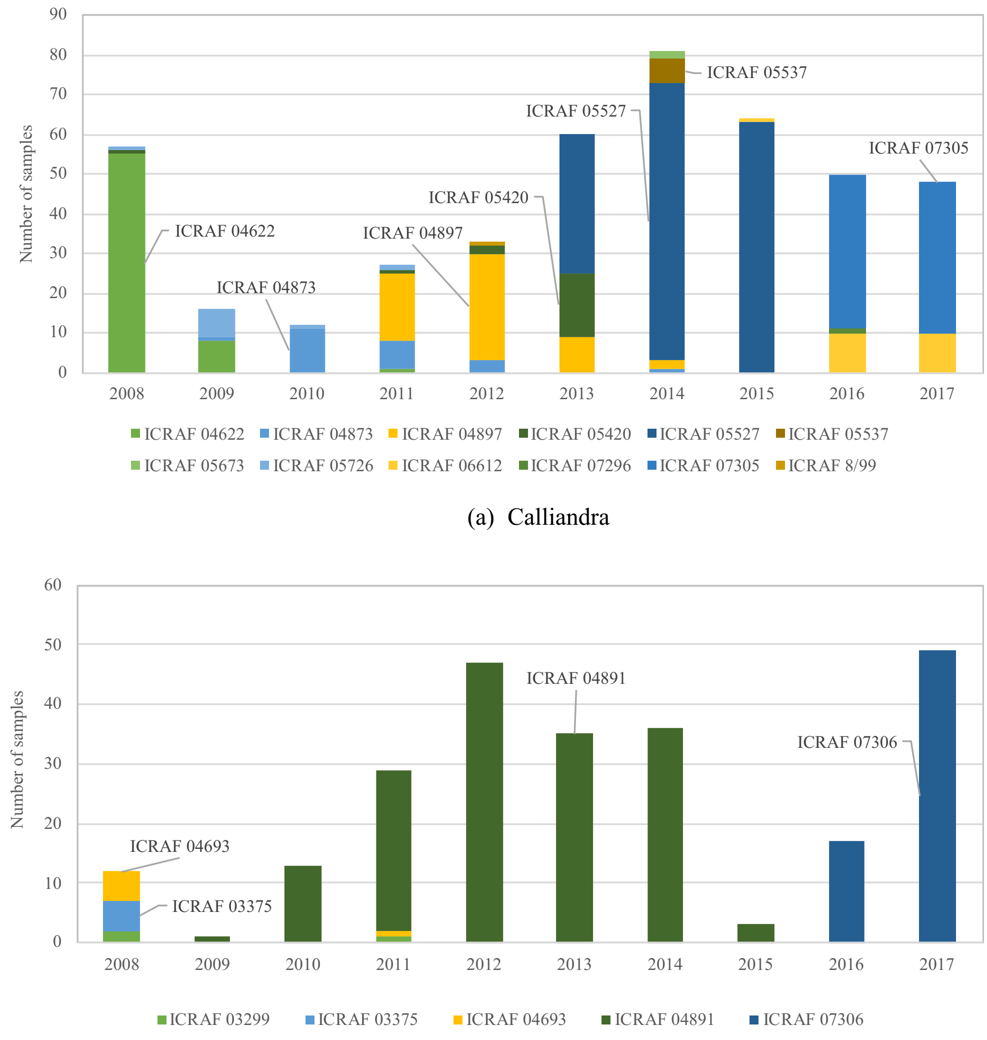
The ICRAF genebank strives to conserve germplasm according to the international genebank standards to ensure that the germplasm supplied is of high quality. The adherence to the international genebank standards is especially appreciated given that high quality germplasm (such as in the case of Calliandra and Gliricidia) is not guaranteed amongst private commercial operators. Satisfaction from the services also stemmed from the fact that high quality germplasm could be accessed at no cost. High transaction costs in accessing tree planting material is another contributor to limited uptake of agroforestry interventions. Farmers keen on accessing high quality germplasm of the two species would have to rely on institutions such as the Kenya Forestry Research Institute (KEFRI), though at a significant cost.

The citation of good instructions as measure of satisfaction is not trivial. Fodder tree cultivation is knowledge intensive, and in the absence of extension support, farmers require proper instructions (starting from nursery management to transplanting) to achieve successful germination. For example, one respondent noted that the seedlings germinated well but failed to mature in the nursery after transplanting due to termite invasion, and he emphasised the need to convey such information to recipients.

3.2.2 Alternative sources of germplasm

We sought to understand how the recipients would be affected if they could not access germplasm from ICRAF (Table 3). KEFRI and private commercial suppliers are listed as alternative sources (Table 4), but the ICRAF genebank remains the preferred source of germplasm for the 90% of respondents (Table 5). Given that many farmers relied on Calliandra and Gliricidia for fodder purposes, constraints to germplasm access would have great implications on protein fodder supply. Respondents noted that they are not guaranteed of seed

Fig. 1 Annual germplasm distribution of **a** Calliandra and **b** Gliricidia, 2008–2017. Source: data from ICRAF GRU**.** Note: Between 2008 and 2017, the genebank distributed 690 seed samples. (Calliandra = 448; Gliricidia = 242)



(b) Gliricidia

availability, and if they are available, the cost is prohibitive or quality is not guaranteed.

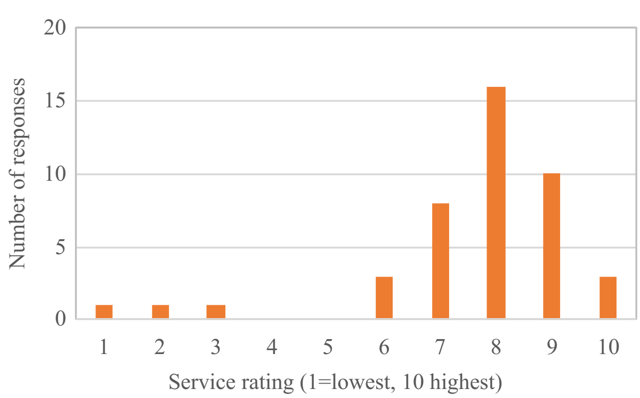


Fig. 2 Satisfaction with services received from the ICRAF genebank. Source: data from the 2018 ICRAF GRU user survey. Number of responses = 50

Farmer seed networks are an important alternative source for tree germplasm. The user survey revealed that seed-sharing among farmers is common, particularly for Calliandra species. Thirty-nine out of 50 respondents (60%) shared the germplasm they received with other farmers (Table 6). Farmer seed networks are the main channel of seed provision in the developing world (Kansiime and Mastenbroek 2016). This is especially true for Gliricidia and Calliandra whose availability in commercial seed channels is either extremely limited or non-existent in many parts of Kenya because of limited commercial viability (Coomes et al. 2015).

Respondents reported that they would have to resort to purchasing the germplasm at significant cost from private commercial suppliers. In addition to incurring high costs, a number of respondents were also apprehensive of germplasm quality from private nurseries, stating that quality is not guaranteed. Private suppliers

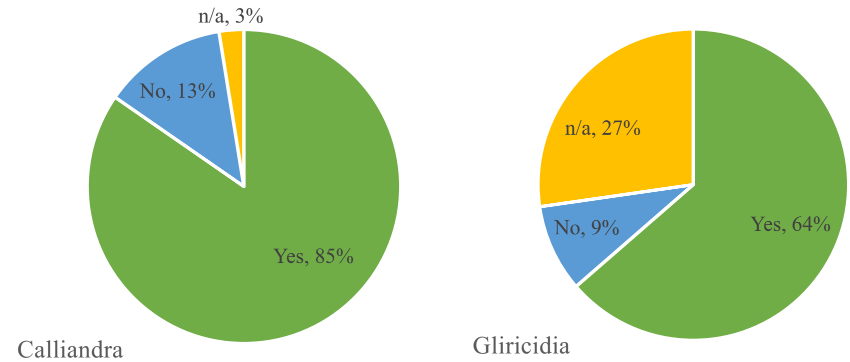


Fig. 3 Satisfaction with germplasm received from ICRAF genebank. Source: data from the 2018 ICRAF GRU user survey. Number of responses: Calliandra = 39; Gliricidia = 11; Total = 50

are few and sparsely distributed, which is the reason why a number of respondents were unable to report alternatives beyond ICRAF.

For farmers who were not able to purchase the seeds either due to cost or scarcity, the implications would be the reduction of protein fodder or increased reliance on grass as fodder, given that many cited the prohibitive cost of alternatives such as dairy meal. However, reliance on grasses entirely would compromise protein content, which in turn would have adverse implications on milk production. There are also implications in terms of time costs, given that some recipients stated they would need to expend additional time looking for private commercial suppliers who are scarce and fraught with risk due to the fact that germplasm quality is not guaranteed. A few respondents were unaffected given that their use centred more on ornamentation and experimentation.

3.2.3 Farmer-perceived benefits of Calliandra

Respondents confirmed the numerous farm-level benefits of planting Calliandra. They identified improved food security and incomes, increased milk production, and reduced vulnerability to drought as the main benefits of using the fodder tree (Table 7).

Most farmers used the fodder tree as a substitute for dairy meal concentrate, an input that smallholder farmers cited as prohibitively expensive. Farmers used Calliandra in a number of ways, such as in combination with Napier grass, with Napier and local grasses (such as Sudan grass), or with Napier, Gliricidia, Desmodium, and hay.

Additionally, aside from reducing dairy meal concentrate purchases, some farmers mentioned that the use of Calliandra reduced their purchases of Napier grass. One farmer mentioned that he had significantly saved on transport costs, given

Table 2 Reasons for farmer satisfaction and/or dissatisfaction with the services of the genebank

Reasons		Frequency
Customer friendly requisition process		1
Did not germinate despite following instructions		3
Good germinate rate and clear instructions		5
Good germination and no cost for obtaining germplasm		1
Good germination rate		27
Good instructions		3
Good instructions and good customer service		1
n/a	Cannot comment because project is in Rwanda	1
n/a	Has not followed up on farmers	1
n/a	Not yet planted	4
n/a	Germination failed due to poor management	1
n/a	Did not source from ICRAF due to unavailability	1
Did not grow because of termite invasion		1
Total responses		**50**

Source: data from the 2018 ICRAF GRU user survey

Table 3 How farmers would be affected by the unavailability of germplasm from ICRAF

Reasons		Frequency
Abandon planting		1
Abandon conservation project		1
Expend a lot of time looking for alternatives		2
Have to purchase at high cost		12
Have to purchase from other farmers		1
Increased costs of dairy production		2
Loss of soil fertility		1
Self-multiplication, which would take time		1
No alternative source		6
No protein fodder		7
Unaffected	Would look for seedlings at alternative places	1
Unaffected	Request was for experimentation	1
Unaffected	Would look for other varieties	2
Not applicable		6
Unaffected	Has other feed sources	1
Plant other varieties at significant cost		1
Reduced milk productivity		1
Risk of intrusion due to no fence		1
Risk of wrong informative from alternative sources		1
Seed quality from private suppliers not guaranteed		1
Total responses		**50**

Source: data from the 2018 ICRAF GRU user survey

that he would have needed to travel to the main town to purchase dairy meal concentrate. The utilization of Calliandra as a protein supplement, in addition to dairy meal concentrate, played an important role in increased milk production for a number of smallholders, thereby increasing family incomes through sales as well as improved nutrition.

Table 4 Alternative sources for seeds other than ICRAF genebank

Sources	Frequency
Egerton University, Njoro	1
Green Belt Movement	1
Individual farmer	3
Kitale research station	1
Karura forest	1
Kenya Agricultural Research Institute	3
Kenya Forestry Research Institute	13
Kenya Forestry Service	1
Rwanda Agricultural Board	1
n/a	1
Private commercial supplier	11
Total responses	**50**

Source: data from the 2018 ICRAF GRU user survey

Reduced vulnerability to drought was the third major benefit cited for the use of Calliandra fodder, given that many farmers identified scarcity of feed quality and quantity as serious challenges, especially in the dry season. Concerning soil fertility improvement, some respondents noted improvements in soil texture with the introduction of Calliandra, with one respondent remarking that he used less fertilizer per acre in his maize plot after planting the tree. The benefit of soil erosion control was attributed to the deep root structure of the leguminous tree. Farmers valued Calliandra as firewood since it saved time used to collect firewood outside the farm. Finally, one respondent observed that when Calliandra was left to

Table 5 Primary source of tree germplasm

Sources	Frequency
Green Belt Movement	1
ICRAF	45
KEFRI	1
n/a	1
Private commercial supplier	2
Total responses	**50**

Source: data from the 2018 ICRAF GRU user survey

Table 6 Sharing of seeds among farmers by species

Species	Yes	No	Total
Calliandra	28	11	39
Gliricidia	2	9	11
Total responses	**30**	**20**	**50**

Source: data from the 2018 ICRAF GRU user survey

grow wild for regeneration, the trees attracted biodiversity, such as birds, resulting in lucrative eco-tourism opportunities on their farm.

3.2.4 Farmer-perceived benefits of Gliricidia

The perceived benefits of Gliricidia by germplasm recipients are presented in Table 8. The recipients cited improved food security, incomes, and soil fertility as the main benefits associated with planting the leguminous tree. According to farmers, improved food security and incomes associated with the fodder trees resulted from increases in maize production, healthier crops, and improved fruit quality. Soil fertility improvement was associated with farmers' perception of improved soil quality after the introduction of the fodder tree in the field, including improved soil texture.

Other indirect benefits associated with Gliricidia, though not as prominent as the aforementioned, were increased milk production, reduced vulnerability to drought, and reduction in soil erosion. Concerning soil erosion, one respondent noted that the tree was very effective in trapping silt. Reduced vulnerability to drought was cited as another advantage, given that the scarcity of feed quality and quantity for ruminant livestock is most acute in the dry season.

Table 7 Benefits of Calliandra according to farmers

Type of benefits	Frequency
Biodiversity attraction	1
Enhanced environmental resilience	1
Fencing	2
Firewood	5
Improved food security and incomes	15
Increased milk production	9
Reduced vulnerability to drought	5
Soil erosion control	2
Soil fertility improvement	3
Total responses	**43**

Source: data from the 2018 ICRAF GRU user survey. Note: Multiple responses are allowed. The 43 responses came from 23 out of 39 users of Calliandra

Table 8 Benefits of Gliricidia according to farmers

Type of benefits	Frequency
Improved food security and incomes	4
Increased milk production	1
Reduced vulnerability to drought	1
Soil erosion control	1
Soil fertility improvement	2
Total responses	**9**

Source: data from the 2018 ICRAF GRU user survey. Note: Multiple responses are allowed. The 9 responses came from 5 out of 11 users of Gliricidia

3.3 Factors affecting fodder tree adoption

The livestock and maize sectors provide an appropriate opportunity to understand the importance of tree diversity and the diverse roles that these species can confer onto the agricultural landscape. Discussions with key informants reveal that the factors determining the adoption of fodder trees fall into five main themes: policy, institutional, germplasm as well as market- and farm-level constraints.

According to key informants, agricultural policies are often married to a paradigm that does not recognize the potential of trees in ameliorating agricultural outcomes. Hence, agroforestry solutions are excluded in agricultural policy interventions and the public extension systems. Traditionally, many agriculturalists have neither been trained in agroforestry nor exposed to evidence-based documentation of the ameliorating effects of trees on farm. As a result, they have a limited understanding of the potential of trees within smallholder production systems. In the absence of public sector participation in fodder tree awareness, research institutions, such as the ICRAF, have done significant work in promoting fodder trees. However, the scaling efforts of ICRAF have been curtailed by germplasm constraints, given that research-orientated institutions supply small quantities of germplasm that are inadequate for facilitating massive scaling.

An expansion of the private nursery sector could be one of the solutions in overcoming germplasm constraints, provided that bottlenecks within the seedling system and capacity constraints of private entrepreneurs are addressed. The managerial and technical capacity of nursery operators can be fostered through stronger research linkages that facilitate the transfer of nursery management expertise to operators. Greater institutional support (i.e. organization, extension support, water) has a pivotal role to play in ensuring that tree germplasm can be accessed by budget-constrained smallholder farmers. The successful management of nurseries, delivery of quality germplasm, and continued extension linkages are crucial given that fodder trees are knowledge intensive, and as such, farmers require adequate management skills to ensure successful growth and mitigate undesirable effects, such as species invasion.

Strong private sector research linkages, however, are contingent on active research within the fodder tree sector. The production and distribution of planting material for trees is more complicated than for crops, because trees often require nurseries and most countries have few mechanisms for the production and distribution of tree germplasm (Franzel and Scherr 2002). Unfortunately, there has not been significant research on selection management, tree establishment, and biophysical aspects of Calliandra in the last 25 years. These topics are important research priorities in relation to adoption scaling interventions.

Non-governmental organizations have played both antagonistic and synergistic roles in fodder tree promotion in Kenya. The donation of free seedlings to farmers has often been a source of antagonism from private nursery operators who have had to endure loss of sales. However, it is worthwhile highlighting the positive role of these institutions in fodder tree promotion. Calliandra has been heavily promoted by the East Africa Dairy Development Program (project by Heifer International) as a feed option among dairy smallholders within East Africa (Heifer 2008). Gliricidia has enjoyed similar success in Zambia through Community Markets for Conservation, which is a holistic venture where farmers living around the South Luangwa National Park, which was formerly involved in poaching, have been offered an alternative income source by using fertilizer trees that could double or triple their products (Mseteka 2015).

Fodder-specific aspects have also led to differential success in terms of adoption rates between Gliricidia and Calliandra. Despite its wide agroecological range, the adoption rate for Gliricidia is lower due to associated palatability issues. This reason has alienated it as a fodder option within the lucrative dairy value chain and limited its adoption. Secondly, Gliricidia generally has low viability, i.e. percentage of seedlings that have successfully germinated may be low; hence, successful nurturing is highly contingent on the possession of technical expertise in regeneration. Thirdly, the benefits of Gliricidia as a soil enhancer take some time, making it a low priority in agroforestry decisions made by farmers.

4 Conclusion

The objectives of this study were to identify: 1) factors influencing the adoption of Calliandra and Gliricidia germplasm, and 2) benefits associated with germplasm distribution of the two fodder tree species by the ICRAF genebank. To the best of our knowledge, there is limited research tracing the benefits of ICRAF genebank germplasm distributions to smallholder farmers. Our analysis relied on distribution data from the genebank as well as thematic and content analysis of information from the user survey and key informant interviews.

The user survey revealed that improved food security and incomes, increased milk production, and reduced vulnerability to drought were the main benefits linked to the use of Calliandra. Improved food security and incomes and soil fertility improvement were cited as the main benefits associated with Gliricidia. The responses confirmed that smallholder farmers value the indirect benefits resulting from the adoption of fodder tree species. The adoption of Calliandra and Gliricidia reduces the dependency of farmers from input markets by providing alternative substitutes for purchased inputs such as dairy concentrates or synthetic fertilizer.

From the key informant interviews, we find that a number of factors limit the adoption of fodder tree germplasm. Key among them is the exclusion of agroforestry in food security policy interventions, germplasm constraints relating to quality and quantity, limited technical expertise, and limited infrastructure at the farmer level. Moreover, we also find that fodder attributes pertaining to palatability and long-term realization of benefits influenced the differential uptake among the two species.

Although small sample sizes do not permit quantitative analysis, thematic analysis facilitated a discussion that leads to several useful policy implications. First, the study findings reaffirm the important role that agroforestry diversity has in providing cost-effective solutions to agricultural challenges faced by smallholder farmers who have resource constraints. The most common benefit cited by users of either tree species is improved food security and income. This confirms that agroforestry should be recognized as an integral part of national strategies to achieve food security. Second, our findings highlight the essential function that quality tree germplasm from ICRAF serves in the absence of markets or other reliable public providers. Developing tree value chains could contribute to stronger effective demand. Third, user perceptions regarding palatability and germination rates for Gliricidia underscore the significance of continued investment in fodder tree research and germplasm constraints.

The feedback from ICRAF germplasm users is crucial in the implementation of agroforestry programs that could impact smallholder farmers in Kenya and in other developing countries. We expect the role of tree genebanks to become increasingly pronounced in the quest to find cost-effective, environmentally sound solutions to the numerous agricultural and ecosystem challenges we face.

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Compliance with ethical standards

Conflict of interest The fourth author is currently the manager of ICRAF GRU. The second author is an agricultural economist at the Crop Trust. The remaining authors declare no conflict of interest.

References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Bromhead, M. A. (2012). *Forest, trees, and woodlands in Africa: An action plan for World Bank engagement*. Washington, DC: World Bank https://openknowledge.worldbank.org/handle/10986/11927. Accessed 15 September 2018.

Coomes, O. T., McGuire, S. J., Garine, E., Caillon, S., McKey, D., Demeulenaere, E., Jarvis, D., et al. (2015). Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy*. https://doi.org/10.1016/j.foodpol.2015.07.008.

Evangelista, R. (2014). *Trees help farmers adapt to climate change*. Nairobi: ICRAF http://www.worldagroforestry.org/blog/2014/09/19/trees-help-farmers-adapt-to-climate-change. Accessed 1 December 2019.

FAOSTAT. (2019). *Rome: FAO*. http://www.fao.org/faostat. Accessed 1 December 2019.

Ferner, J., Schmidtlein, S., Guuroh, R. T., Lopatin, J., & Linstädter, A. (2018). Disentangling effects of climate and land-use change on west African drylands' forage supply. *Global Environmental Change, 53*, 24–38. https://doi.org/10.1016/j.gloenvcha.2018.08.007.

Franzel, S. (1999). Socioeconomic factors affecting the adoption potential of improved tree fallows in Africa. *Agroforestry Systems, 47*, 305–321. https://doi.org/10.1023/A:1006292119954.

Franzel S. & Scherr, J. S. (2002). Trees on the farm: Assessing the adoption potential of agroforestry practices in Africa. Oxon, UK: CAB international and Nairobi, Kenya: ICRAF.

Gregorio, N., Herbohn, J., Harrison, S., & Smith, C. (2015). A systems approach to improving the quality of tree seedlings for agroforestry, tree farming and reforestation in the Philippines. *Land Use Policy, 47*, 29–41. https://doi.org/10.1016/j.landusepol.2015.03.009.

Heifer International. (2008). East Africa Dairy Development Project: Fostering sustainable dairy markets. https://www.heifer.org/our-work/flagship-projects/east-africa-dairy-development-project.html. Accessed 1 December 2019.

ICRAF GRU (World Agroforestry - Genetic Resources Unit). (2019). Tree productivity and diversity. World Agroforestry. http://www.worldagroforestry.org/sd/tree-diversity/genetic-resources-unit-gru. Accessed 1 December 2019.

Kansiime, M. K., & Mastenbroek, A. (2016). Enhancing resilience of farmer seed system to climate-induced stresses: Insights from a case study in West Nile region, Uganda. *Journal of Rural Studies, 47*, 220–230. https://doi.org/10.1016/j.jrurstud.2016.08.004.

Kiambi, S., Alarcon, P., Rushton, J., Murungi, M. K., Muinde, P., Akoko, J., Aboge, G., Gikonyo, S., Momanyi, K., Kang'ethe, E. K., & Fèvre, E. M. (2018). Mapping Nairobi's dairy food system: An essential analysis for policy, industry and research. *Agricultural Systems, 167*, 47–60. https://doi.org/10.1016/j.agsy.2018.08.007.

Koo, B., Pardey, P. G., & Wright, B. D. (2003). The economic costs of conserving genetic resources at the CGIAR Centres. *Agricultural Economics, 29*, 287–297. https://doi.org/10.1016/S0169-5150(03)00056-2.

Makau, D. N., VanLeeuwen, J. A., Gitau, G. K., Muraya, J., McKenna, S. L., Walton, C., & Wichtel, J. J. (2018). Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya. *Preventive Veterinary Medicine, 161*, 60–68. https://doi.org/10.1016/j.prevetmed.2018.10.017.

Makumba, W., Janssen, B., Oenema, O., Akinnifes, F. K., Mweta, D., & Kwesiga, F. (2006). The long-term effects of a gliricidia–maize intercropping system in southern Malawi, on gliricidia and maize yields, and soil properties. *Agriculture, Ecosystems & Environment, 116*, 85–92. https://doi.org/10.1016/j.agee.2006.03.012.

Manaye, T., Tolera, A., & Zewdu, T. (2009). Feed intake, digestibility and body weight gain of sheep fed Napier grass mixed with different levels of *Sesbania sesban*. *Livestock Science*, https://doi.org/10.1016/j.livsci.2008.07.020*, 122*, 24–29.

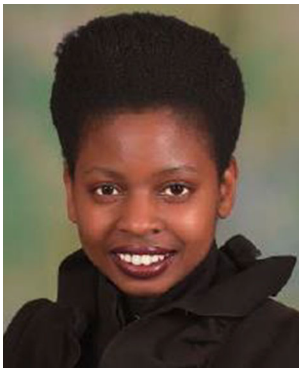
Mbow, C., Noordwijk, M. V., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability, 6*, 61–67. https://doi.org/10.1016/j.cosust.2013.10.014.

Mseteka, E. (2015). Agro-firm adopts Gliricidia cultivation. Zambia Daily Mail, 15 April 2015. https://www.daily-mail.co.zm/agro-firm-adopts-gliricidia-cultivation/. Accessed 1 December 2019.

Thangata, P. H., & Alavalapati, J. R. R. (2003). Agroforestry adoption in southern Malawi: The case of mixed intercropping of Gliricidia sepium and maize. *Agricultural Systems*. https://doi.org/10.1016/S0308-521X(03)00032-5.

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing and Health Sciences, 15*, 398–405. https://doi.org/10.1111/nhs.12048.

Wamalwa, N. I. E., Midega, C. A. O., Ajanga, S., Omukunda, N. E., Muyekho, F. N., Asudi, G. O., et al. (2017). Screening Napier grass accessions for resistance to Napier grass stunt disease using the loop-mediated isothermal amplification of DNA (LAMP). *Crop Protection, 98*, 61–69. https://doi.org/10.1016/j.cropro.2017.02.005.



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