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Tracing the benefits of tree germplasm distributions by ICRAF: *Calliandra calothyrsus* and *Gliricidia sepium*

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Abstract

Tree-based production systems provide numerous ecosystem services that are important in sustaining the life of vast plant and animal populations. Although the optimization of these services is contingent on sufficient tree diversity, drivers of change such as population pressure and related agricultural expansion have significantly contributed to tree diversity loss, with adverse consequences. The realization of this fact has led to significant efforts to conserve tree genetic diversity, in which the International Centre for Research in Agroforestry (ICRAF) plays a key role. This study investigates the impacts from the use of the two most popular species among smallholder farmers, sourced from the ICRAF genebank, namely, *Calliandra calothyrsus (Calliandra)* and *Gliricidia sepium (Gliricidia)*. Through a user survey, we also examine factors affecting agroforestry adoption, given the limited uptake of agroforestry interventions. Concerning the impacts of use, we find that improved food security, higher incomes, increased milk production, and reduced vulnerability to drought were identified as the main benefits linked to the use of *Calliandra*. Improved food security, higher incomes, and enhanced soil fertility were cited as the main use impacts associated with *Gliricidia*. The findings demonstrate the important role of the genebank in conserving and distributing unique, high quality germplasm.

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Contents

1. Introduction

The African drylands, despite their ecosystem fragility, comprise over 43% of Africa's land surface and account for over 75% of crop production; rendering their restoration a key priority (Place et al. 2016) . Tree-based production systems, on the basis of their resilience and multi-purpose benefits, have been suggested as one of the possible solution pathways to the myriads of ecosystem challenges facing the African drylands (Cervigni and Morris 2016) .Nourishment, pest regulation, habitat, climate buffering, temperature regulation and carbon sequestration are some of the appealing ecosystem benefits derived from diverse tree-based production systems (Bromhead 2012).

The optimization of these crucial ecosystem services is contingent on tree diversity. Tree diversity plays an important role in maintaining floral and faunal diversity by regulating underlying interactions(Nesper et al. 2017). Tree diversity is also crucial in sustaining ecosystem services against a backdrop of increasing pressures from drivers of change (Morgenroth et al. 2016).Nonetheless, aggressive advances from drivers of change, such as population pressure and related agricultural expansion, threaten tree diversity in Africa (Jew et al. 2015; 2016). On the other hand, climate change pressures will necessitate an increased reliance on tree diversity as buffers (Midega et al. 2017). 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 in Africa.

The ICRAF Genetic Resources Unit (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." The genebank currently holds 5,300 accessions (representing over 190 tree species) of which 3,706 are stored at the Nairobi seed genebank. The 3,706 accessions held in Nairobi represent over 10 species with *Calliandra calothyrsus (Calliandra)* and *Gliricidia sepium (Gliricidia)* the two most requested species. An analysis of the genebank distribution data from 2008 to 2017 reveals that the GRU has received approximately 679 requests for the two trees, 431 requests for *Calliandra* and 248 for *Gliricidia*. Overall, the genebank has distributed approximately 445 samples of *Calliandra* weighing 106 kg whereas it has distributed 245 samples of *Gliricidia* weighing 133 kg (Table 1). A further look at requests by accessions and species, reveals that accession Number ICRAF 05527 is the most requested and distributed accession of *Calliandra*; whereas in the case of *Gliricidia* it is ICRAF 04891 that takes the lead.

The demand for *Calliandra* is fuelled by its multipurpose attributes that confer numerous production and ecosystem benefits for smallholder farmers. The appeal of *Calliandra* among smallholder dairy farmers, for example, lies in the fact that it is an affordable protein rich fodder (Franzel et al. 2014). *Gliricidia*, also a multipurpose leguminous tree, is appreciated for its role as a soil fertility enhancer. Specifically, its role is appreciated within the maize sub-sector given that maize is a major food crop in many parts of Africa including Kenya (Alene et al. 2008). Poor soil fertility, particularly nitrogen depletion, is one of the major factors that limit maize productivity gains in Africa (Mafongoya et al. 2006). Moreover, resource-poor smallholder farmers are unable to afford mineral fertilizers to supplement soil nutrients. It is within this context that *Gliricidia* – known for its nitrogen fixation and carbon sequestration abilities – has been integrated in what is known as "Gliricidia maize mixed intercropping'' as a "nutrient fixing" alternative for resource poor farmers (Makumba et al. 2007).

A brief insight into the benefits of two of the numerous species that the genebank strives to conserve points to the crucial role of genebanks in diversity conservation. Germplasm from these species is difficult to come by from sources other than the genebank, highlighting the priority role of conservation by genebanks. That said, sustained tree diversity conservation demands significant financial resources to support crucial operations (Koo, Pardey, and Wright 2003). The continued support of genebanks, as with any other investment venture, is anchored on the existence of an up-to-date portfolio of evidence on genebank impacts. The contribution of this study, therefore, is twofold. First, to the best of our knowledge, no study has yet attempted to investigate genebank impacts rising from the direct utilization of ICRAF germplasm by smallholder farmers. Secondly, striving to understand the determinants of agroforestry adoption and its perceived benefits remains an active research area given that adoption of agroforestry interventions is not widespread despite recognized benefits (Mbow et al. 2014). Understanding adoption factors is important in order to identify germplasm-related constraints and provide valuable feedback to the genebank to inform future interventions.

This paper assesses the factors influencing the adoption of these fodder trees (i.e. *Calliandra* and *Gliricidia*) and the benefits of their use for smallholder farmers. We do this by analyzing information from key informant interviews and a user survey. The rest of the paper is organized as follows: Section 2 presents the context of fodder tree use; Section 3 outlines the data and methods used in the study: Section 4 presents the results; Section 5 presents the discussion; finally, Section 6 concludes.

2. Context

2.1 Overview of the dairy and maize sector in Kenya

The dairy sector is one of the key defining industries within Kenya's agricultural landscape. The sector plays a pivotal role in Kenya's economic portfolio both from a macroeconomic and microeconomic perspective. The sector accounts for 14% of Kenya's agricultural Gross Domestic Product (GDP) (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 Kenyan population. It is estimated that Kenya has the highest per capita of milk consumption in the developing world (Kiambi et al. 2018).

Nonetheless, it is acknowledged that the sector is yet to operate at its true potential due to numerous constraints, particularly low feed quality. Low feed quality, a constituent of sub-optimal feeding, is one of the factors limiting the productivity of Kenya's dairy industry (Franzel et al. 2014) . 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). Crop residues are also an important source of feed for livestock. However, Napier is low in protein content and as such it cannot wholly meet livestock's recommended protein needs which in turn has implications for productivity(Manaye, Tolera, and Zewdu 2009). Ordinarily, farmers would need to purchase concentrates to supplement the protein content from Napier. However, many smallholders are resource-limited and are not able to purchase these concentrates at all, consistently, or in the recommended quantities.

Maize production is another sector that merits special attention, not only in Kenya but also in many regions in the world. Maize is an important crop for food security in Sub-Saharan Africa, Latin America, and Asia regions, with combined output from these regions estimated at 300 million tonnes from 90 million hectares (Cairns and Prasanna 2018). Maize is the major food crop in Kenya and, as such, it is widely recognized that maize availability is synonymous with food security (Alene et al. 2008) . Smallholder farmers and medium scale producers account for approximately 75% of production. Moreover, it is estimated that 98% of Kenya's 3.5 million farmers cultivate maize, a fact that further reinforces the domineering presence of the crop within Kenya's economic fabric (Kirimi et al. 2011).

Poor soil fertility, and particularly low soil nitrogen, is a serious limiting factor to maize productivity in Kenya and many parts of Africa. Low soil nitrogen has been estimated to reduce maize yields by 76% in Africa(Kassie et al. 2018) . This should not be surprising given that nitrogen has been identified as the most important input for plant growth. Synthetic fertilizers are one of the avenues through which farmers can supplement low soil nitrogen. However, transaction costs in input markets significantly limit participation of smallholders in fertilizer markets as well as the intensity of fertilization (Alene et al. 2008).

2.2 The role of fodder trees in enhancing productivity in the dairy and maize sub-sectors

Fodder trees have been identified as one of the affordable pathways through which the aforementioned challenges can be addressed as they confer multifunctional benefits to farmers. *Calliandra* has been identified as a suitable protein substitute or supplement within the smallholder dairy farming context. One kilogram (kg) of dry matter contains approximately 24% crude protein and is estimated to have 60% digestibility whereas 1 kg of dairy meal is estimated to have 16% crude protein and 80% digestibility. It is estimated that 2 kg of dry matter can be a suitable substitute for concentrates that are otherwise beyond the reach of many smallholders (Kiptot, Franzel, and Degrande 2014).

Gliricidia, on the other hand, is known for its role as a soil fertility improver. The success of this fodder tree has been especially conspicuous in Southern Africa, within the maize intercropping systems. The rich nitrogen content in the trees' foliage renders it an important source of soil nitrogen replenishment. The fodder tree's annual biological fixation is estimated at 108 kg/ha whereas annual coppiced biomass yield is estimated at 5.4 tonnes/ha, demonstrating the trees' role in soil replenishment (Thangata and Alavalapati 2003; Coulibaly et al. 2017). The appeal of *Gliricidia*, is not only confined to its "relative affordability" but is also based on empirical evidence supporting the rational for organic manure integration into soil fertility management. It is acknowledged that mineral fertilizers should be used in combination with organic manure given that the latter is essential for maintaining soil structure and the longevity of soil fertility, accentuating crop response to fertilizer inputs.

The overview of the dairy and maize sectors provides an appropriate lens through which to understand the importance of tree diversity signified by the diverse roles that these species can confer onto the agricultural landscape. Finally, the overview sheds light on the contribution of the ICRAF genebank in conserving high quality germplasm, which in itself is a prerequisite to the realization of these benefits to smallholders.

3. Data and methods

3.1 Sampling

A purposive sampling design frame was employed to select 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 (Appendix 1).

Stratified random sampling was employed to select the sample of requestors from the distribution data provided by ICRAF genebank for each of the two species. Requestors were grouped into the four strata of 1) individual farmers, 2) research institutions or universities, 3) farmer-based, community-based, or non-governmental organizations, and 4) private organizations. Beginning in 2008, the distribution data categorized requestors as either individuals or organizations. After 2015, additional sub-categories (ICRAF itself, 2 and 3 above) were included to reflect the diversity of organization recipients. The ICRAF category was omitted in the study to reduce bias. Before sampling, a list of unique users was developed given that the distribution data include multiple requests from the same requestor. Only those requestors with a listed phone contact retained in the list. Those whose contact was listed as N/A were dropped from the list. The final list of requestors list comprised of 213 users. The 213 users fell into the following sub-categories: 10 (research institution/university), 31 (private organization), 154 (individual farmers), and 16 (farmer/community/non-governmental based organizations).

The study targeted a minimum sample of 119 respondents (56% of the final user list). All requestors in the research institution/university and the farmer/community/non-governmental based organizations strata were selected to participate given their low overall representation. Stratified random sampling was applied in the strata comprising individual farmers and organizations which resulted in 75 individual farmers and 18 organization-based users being selected. The final user sample, based on the actual 51 interviews that took place (a 43% response rate), is presented in Appendix 2.

3.2. Data collection instruments

The study employed a semi-structured protocol to collect information from the key informants and users respectively. The respective surveys were designed using Ordinary Tool Kit and later verified and uploaded on the ONA server platform. Open Data Tool Kit is a technology that facilitates the collection of data through mobile devices or other electronic devices (tablets, laptops) and also its transmission to on online server (ONA) where the data is stored securely. Once the survey has been verified (verification in this case is to ensure that the appropriate coding syntax has been used), it is possible to upload the questionnaire to the server after which the survey can be administered. Each response is stored in a unique record within a form.

The Key Informant Interview questions were guided by an extensive literature review process that sought to understand the dominant themes in the fodder tree adoption and dissemination literature. The understanding of these themes helped to formulate simple and effective probing questions that would lay the foundation for a rich and detailed open-ended discussion. The semi-structured protocol was used to collect information on the major uses of the two fodder trees, constraints to their adoption and dissemination mechanisms.

The user survey was designed in consultation with the genebank unit and was approved after the third draft by all parties. The semi-structured protocol was employed to collect information on the reasons for germplasm request, the uses of requested germplasm, the benefits of requested germplasm and finally the quality of ICRAF germplasm (see Appendix 3). A total of nine questions were featured in the survey. The majority of these facilitated open-ended discussions (see Appendix 4).

3.3 Data collection

The cross-sectional study was implemented between 11 and 29 September 2018.

Consent was sought prior to the engagement of respondents in both the Key Informant Interviews (KII) and user surveys. Key Informant Interview respondents 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.

The Key Informant Interviews were administered either via Skype or in person where possible. Respondent information was recorded electronically via the ONA webforms. The user survey was administered through phone interviews and recorded in a similar manner to the Key Informant Interviews.

3.4 Data analysis

Qualitative thematic analysis was applied to analyze the data from the Key Informant Discussions, whereas both thematic and content analysis were employed to analyze the user surveys. These methods are appropriate given the qualitative nature of the data and the intent of the analysis.

Qualitative thematic analysis is a methodological tool employed for the purposes of identifying, analyzing, and reporting themes within the data set (Vaismoradi, Turunen, and Bondas 2013). Specifically, this study employed a theoretical thematic approach given that 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. Thematic analysis can be summarized under six key steps: data familiarization; initial code generation; theme searching; reviewing of theme; theme definition and naming; and finally, report production (Braun and Clarke 2006).

Content analysis is an analytical technique that involves systematically coding and categorizing large amounts of textual data for the purposes of identifying word trends and patterns, their recurrences, their relationships and related structure (Elo and Kyngäs 2008).The intent of content analysis is to condense large volumes of textual data into meaningful, leaner categories or concepts. Content analysis differs from thematic analysis, in that coding within content analysis allows for transformation of qualitative nature into quantitative nature based on category frequencies (Vaismoradi, Turunen, and Bondas 2013).This was deemed an appropriate analytical tool for the user survey, given that the descriptive data would be partly subjected to quantitative analysis in the form of summary statistics. Content analysis involves the three stages of preparation, organization and coding.

4. Results

4.1 Determinants of fodder tree adoption: *Gliricidia* and *Calliandra*

The thematic analysis of discussions with key informants reveals that the factors determining the adoption of fodder trees are the same factors that influence the adoption of trees on farms in general. These fall into five main categories: policy, institutional, germplasm, 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 such, 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 ICRAF have done significant work in promoting fodder trees. However, the scaling efforts of ICRAF have been curtailed by germplasm constraints given that research-oriented institutions supply small quantities of germplasm that are unable to facilitate massive scaling.

In this regard, it is acknowledged that a proliferation of private nursery operators would be a solution 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, so as to 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 the successful management of nurseries and delivery of quality germplasm. Continued extension linkages are crucial given that fodder trees are knowledge intensive and as such farmers require adequate management skills to ensure successful growth as well as to mitigate otherwise undesirable effects such as species invasion.

Strong private sector research linkages, however, are contingent on the revival of research within the fodder tree sector. There has not been significant research on *Calliandra* in the last 25 years, as pertains to selection management, tree establishment, and biophysical aspects of the tree, which in themselves are important research priorities in relation to adoption scaling interventions. Non-governmental organizations (NGOs) have played both an antagonistic as well as synergistic role 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 losses due to poor sales. It is worthwhile, however, to highlight the positive role of these institutions in fodder tree promotion. *Calliandra* has been heavily promoted by the East Africa Dairy Development Program (Heifer International) and Vi Agroforestry (Swedish Development Organization) as a feed option among a total of 230,000 dairy smallholders within East Africa and Kenya, respectively. *Gliricidia* has enjoyed similar success in Zambia through Community Markets for Conservation (COMACO), a holistic venture where farmers living around the park, formerly involved in poaching, have been offered an alternative income source through the use of fertilizer trees that could double or triple their products.

Fodder-specific aspects have also led to differential success in terms of adoption rates. Despite its wide agroecological range, *Gliricidia* adoption has not peaked due to associated palatability issues. This reason has alienated it as a fodder option within the lucrative dairy value chain, hence limiting 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 improver take some time, hence its poor prioritization in agroforestry decisions by farmers—who cannot quickly discern the economic benefits of adoption. This is suggested by the figures presented in Tables 1 and 3, where requests for *Calliandra* exceed those of *Gliricidia* based on farmers' perception of realized benefits.

4.2 Impacts of ICRAF germplasm distributions

4.2.1 Sharing of germplasm

The sharing of germplasm among recipients is presented in Table 3. 60 percent of germplasm recipients shared the germplasm they received with secondary parties. Table 4 presents survey responses concerning sharing of seeds by species. The majority of the sharing was among *Calliandra* recipients. This observation is not surprising given that *Calliandra* not only dominated germplasm requests but has also been deemed preferable by farmers for fodder use. Concerning the entities with whom the germplasm was shared, it is observed that individual farmers were the key beneficiaries of shared germplasm (see Table 5). Table 6 presents results on sharing by purpose. Direct use dominated germplasm requests. Concerning direct use, the majority of the shared germplasm was intended for fodder.

4.2.2 Satisfaction from received germplasm

Tables 7 and 8 present results on satisfaction in general and by species. It is observed that the majority of recipients were satisfied with the germplasm they received from the ICRAF genebank. Table 9 presents the results on the rating of genebank services. A good proportion of recipients rated the genebank services positively though there were a few isolated cases of extreme dissatisfaction. 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. Table 10 presents results on the specific reasons for satisfaction and dissatisfaction. The satisfaction from the majority of respondents 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 their case obstructed successful germination.

4.2.3 Access to germplasm from ICRAF genebank

The survey also sought to understand how the recipients would be affected in the event that they could not access germplasm from the ICRAF Genebank (Table 11). 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 it is not guaranteed. It is also worth noting that private suppliers are few and sparsely distributed, which is the reason why a number of respondents were at a loss 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 given that many cited the prohibitive cost of alternatives such as dairy meal. There are also implications in terms of time costs, given that some recipients stated that they would need to expend a lot of time looking for private commercial suppliers who are scarce or relying on multiplication—which is also time consuming. A few respondents were unaffected given that their use centered more on ornamentation and experimentation.

Table 12 presents results on alternative sources. Kenya Forestry Research Institute (KEFRI) and private commercial suppliers are listed as the leading alternative sources. The challenges with these sources are as reported above—that recipients are not guaranteed of seed availability (*Calliandra* and *Gliricidia* are rare) and in the event that they are available, the cost is prohibitive. Concerning preferences, 90% of respondents preferred ICRAF as the first choice when sourcing germplasm (Table 13).

4.2.4 Benefits of *Calliandra* as perceived by germplasm recipients

The numerous benefits of *Calliandra* as perceived by germplasm recipients are presented in Table 14. Improved food security and incomes, increased milk production, and reduced vulnerability to drought were identified as the main benefits derived from the use of the fodder tree.

A majority of users utilized the fodder tree as a substitute for dairy meal concentrate, an input which smallholder farmers cited as prohibitively expensive. Farmers utilized *Calliandra* in a number of ways, such as in combination with Napier grass, in combination with Napier and local grasses (such as Sudan Grass), or in combination 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 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.

Reduced vulnerability to drought was the third major benefit cited, 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* whereas one respondent remarked that he utilized 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. The appreciation of *Calliandra* for firewood stemmed from the fact that it saved on time that would otherwise be used to seek firewood outside the farm. Finally, one respondent observed that when left in wild for regeneration, *Calliandra* attracts biodiversity such as birds, resulting in lucrative eco-tourism opportunities on their farm.

4.2.5 Benefits of *Gliricidia* as perceived by germplasm recipients

The benefits of *Gliricidia* as perceived by germplasm recipients are presented in Table 15. Improved food security and incomes and soil fertility improvement were cited as the main benefits associated with planting the leguminous tree. According to farmers, improved food security and incomes associated with the fodder trees was as a result of increases in maize production, healthier crops, and improved fruit quality. Soil fertility improvement was associated with farmers' perception that the soil has improved quality after the introduction of the fodder tree in the field. Additionally, soil fertility improvement was associated with improved soil texture.

Other indirect benefits associated with *Gliricidia*, though not 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. It is noteworthy that the benefits associated with *Gliricidia* contrast sharply with those of *Calliandra*. The benefits of *Gliricidia*, particularly on soil fertility improvement, are gradually realized. At the time of the survey, some farmers were yet to fully realize the results of soil fertility improvement. Secondly, many farmers cited palatability issues with *Gliricidia* and as such the fodder tree has not been widely adopted as a fodder source which would afford more discernible benefits.

5. Discussion

5.1 Determinants of fodder tree adoption: *Gliricidia* and *Calliandra*

Consistent with our findings, one of the limiting factors to greater agroforestry adoption is the alienation of tree-based production systems from policy documents intended to ameliorate agricultural outcomes (Mbow et al. 2014). This is partly explicated by the fact that agriculture and forestry have traditionally been managed in a sectoral manner that has more often than not pitted them as antagonistic (Reed et al. 2017; Timko et al. 2018)

Further, limited access to high quality germplasm, poor technical skills in producing high quality germplasm, and inadequate market incentives to produce high quality germplasm have indeed presented serious impediments to the scaling up of agroforestry interventions (Gregorio et al. 2015; Ofori et al. 2014).This assertion is echoed in our results: we find that poor technical skills are a contributing factor to non-germination of *Gliricidia.* The huge emphasis on proper expertise to undertake regeneration is crucial given that it has low viability rates.

In addition, the non-immediate fruition of tree-based production systems benefits greatly curtails widespread agroforestry (Mbow et al. 2014) adoption given that farmers have a bias for investments that realize benefits in the shortest time possible (Etshekape, Atangana, and Khasa 2018).This can explain the differential adoption rates of *Calliandra* and *Gliricidia*, which many key informants attributed to the immediate benefit of fodder for the former, contrasted with a gradual benefit of soil improvement for the latter. Fodder trees cultivation are knowledge intensive, and as such adoption is significantly curtailed where farmers lack expertise on their utilization. Many farmers are unaware that the palatability of *Gliricidia* can be improved with wilting/partially drying, whereas the nutritional value of *Calliandra* is optimized when it is administered fresh (tanning polymerization and tanning protein affinity is lower in fresh leaves) (Stewart et al. 1998; Maasdorp, Muchenje, and Titterton 1999). Finally, consistent with our findings, there is a need to undertake more field trials involving agroforestry species to ascertain the genotype environment interaction, to infer about suitability beyond the testing site, and to guarantee productivity of superior germplasm through effective site matching (Nyoka, Simons, and Akinnifesi 2012).

5.2. Impacts of ICRAF germplasm distributions

5.2.1 Sharing of germplasm

The dominance of farmer seed networks, as evidenced by our findings on germplasm sharing, is not surprising. Farmer seed networks are the main channel of seed provision in the developing world, with the informal exchange seed system accounting for approximately 90% (Kansiime and Mastenbroek 2016). Further, farmer seed networks may be the only source of seed for crops that have limited commercial viability, as evidenced by the case of *Gliricidia* and *Calliandra* whose availability in commercial seed channels is either extremely limited or non-existent in many parts of Kenya (Coomes et al. 2015). The dominance of *Calliandra* over *Gliricidia* in farmer seed exchange is also not surprising given that farmers have experienced palatability issues with *Gliricidia* leading to its limited use as a fodder resource (Stewart et al. 1998).

5.2.2 Satisfaction from received germplasm

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 “preferred standard” that ensures that the germplasm supplied is of high quality (Koo, Pardey, and Wright 2003).

The adherence to the “preferred standard” quality of operation 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 (Ofori et al. 2014). 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 trees cultivation are knowledge intensive (Franzel et al. 2014), and in the absence of extension support, farmers require proper instructions (starting from nursery management to transplanting) to achieve successful germination. Concerning dissatisfaction, one respondent noted that the seedlings germinated well but failed to mature in the nursery after transplanting due to termite invasion, hence his emphasis on the imperative to convey such information to recipients. Nyoka, Simons, and Akinnifesi 2012 echo this sentiment very well in their advocacy for multiple accession trials beyond the trial site so as to infer about suitability in diverse agroecological zones.

5.2.3 Access to germplasm from ICRAF genebank

Given that many farmers relied on *Calliandra* and *Gliricidia* for fodder purposes, constraints to germplasm access would have great implications on protein fodder supply. Many farmers noted that they would have to rely on grass as the fodder source given that the cost of purchase was prohibitive. Reliance on grasses entirely would compromise protein content which in turn would have adverse implications on milk production (Pamo et al. 2006). A few farmers alluded that they would pursue the option of purchase from private suppliers, an option that is time consuming, expensive and fraught with risk due to the fact that germplasm quality is not guaranteed (Gregorio et al. 2015). Other farmers said they opted to purchase commercial dairy meal to supplement the basal diet of consisting of grass. However in both instances (purchasing fodder tree germplasm or dairy meal) farmers would have to bear additional costs of production hence reducing profitability margins (Kiptot, Franzel, and Degrande 2014). The preference for the ICRAF genebank comes as no surprise given that farmers keen on accessing germplasm from alternative sources must incur high transactions costs (Ofori et al. 2014).

5.2.4 Benefits of *Calliandra* as perceived by germplasm recipients

We use the framework by (Franzel et al. 2014) to discuss fodder tree benefits. Feed scarcity and low feed quality have been cited as some of the major factors limiting ruminant livestock productivity in the tropics (Salem et al. 2006). Natural pastures and crop residues, which constitute the main source of ruminant diets, are of poor nutritional value given their low content of nitrogen and digestible nutrients (Ondiek et al. 1999). Browse fodder, such as *Calliandra*, have been identified as suitable protein supplements to low quality basal diets given that their nitrogen content is estimated to exceed that of maize stover 5 to 6 times over (Maasdorp, Muchenje, and Titterton 1999). These trees have relatively high protein content compared to grasses, in addition to the fact that their nutritive content does not vary significantly across seasons unlike grasses whose nutritional value declines with maturity. Supplementation with *Calliandra* and *Leucaena* has also been observed to significantly reduce incidences of abortion in goats, which improve reproduction rates and result in greater weight gain among goats after parturition especially in the dry season (Pamo et al. 2006).

Moreover, *Calliandra* has also been associated with increased daily milk production (estimated at 0.6 to 1.3kg per day per cow for each kg of dried *Calliandra* leaves fed) and gains in sheep live weight (Richards et al. 2016; Franzel et al. 2014; Kiptot, Franzel, and Degrande 2014) .Three kilograms of fresh *Calliandra* are estimated to be equivalent to 1 kg dairy meal concentrate, providing an effective supplement to the basal feed of Napier grass and crop residues. Many smallholders cited the cost of dairy meal as prohibitive and as such they appreciated the role of *Calliandra* as an effective supplement (Kabi and Bareeba 2008).

The benefits of soil fertility improvement are attributed to the ability of the tree to biologically fix nitrogen as well as its deep root structure that facilitates the absorption of leached nutrients by its roots and foliage which are then later returned to the soil in the form of green manure. The tree's ability to fix nitrogen as well cycle nutrients has been associated with improved soil texture as well as reductions in fertilizer costs (Cortés et al. 2009).The associated soil erosion control benefit corroborates evidence presented in previous literature. Contour hedgerows consisting of Napier grass and *Calliandra* have been shown to significantly reduce control soil erosion owing to *Calliandra*'s strong stem structure as well as Napier grasses' massive near surface lateral root system (Angima et al. 2002).

Further, the benefit of firewood highlighted by some respondents directly improves women's welfare given that firewood fetching is their responsibility and as such its availability on farm allows women to concentrate on other equally important tasks such as cooking and child rearing (Kiptot, Franzel, and Degrande 2014).

5.2.5 Benefits of *Gliricidia* as perceived by germplasm recipients

The associated benefit of *Gliricidia* with improved food security and incomes from increased maize production is well-documented in literature. Low soil nitrogen is a problem in Africa with perverse consequences on staple food productivity. *Gliricidia*'s foliage is rich in nitrogen, estimated to be as high as 4%, which renders it a good source of green manure (Beedy et al. 2010). Moreover, the fodder tree, by virtue of being leguminous, is recognized for its ability to biologically fix nitrogen in the soil (Nyoka, Simons, and Akinnifesi 2012). *Gliricidia*-maize intercrop has been associated with an increase in Soil Organic Matter (SOM), Particulate Organic Matter (POM), POM-Nitrogen, and POM-Carbon, all essential elements for good crop performance. SOM acts as a reservoir for nutrients whereas POM refers to the soil fractions that are readily available for decomposition, hence the emphasis on their accumulation in relation to soil fertility improvement (Beedy et al. 2010).The benefit of improved soil texture is also an important aspect of soil fertility improvement given that soil texture is an important determinant of the extent to which SOM fractions are accessible to the soil for decomposition (Beedy et al. 2010).

The benefit of increased milk production is associated with the highly nutritive nature of *Gliricidia,* its low fiber content and high digestibility (Stewart et al. 1998) -- aspects that have been found to have a positive effect on voluntary dry matter intake, digestibility, and overall live weight gain in ruminant livestock. (Ondiek et al. 1999) noted that the supplementation of the basal diet with *Gliricidia* was associated with increased dry matter intake of the basal diet, increased digestibility and increased average daily gain in dairy goats. Similarly, (Abdulrazak et al. 1997) found that supplementation with *Gliricidia* increased live weight gain in crossbred steers as well as voluntary dry matter intake. The aspect of increased voluntary dry matter intake as well as digestibility is a matter of great emphasis because of its implication on animal productivity. Maize stover, a major feed during the dry season, is high in lignocellulose and low in nitrogen, hence its low nutritive value (Abdulrazak et al. 1997). Moreover, its high fiber content is associated with low voluntary intake among ruminant livestock further compromising on livestock productivity.

Browse fodder trees such as *Calliandra*, though rich in protein, have a relatively high content of condensed tannins, a diverse group of phenolic compounds, that have a high affinity for protein which limit microbial degradation of the proteins (low digestibility) and also adversely affect voluntary dry matter intake (Cortés et al. 2009). Despite the positive attributes of *Gliricidia* compared with other fodder trees in relation to tannins, its use as fodder has not flourished in Kenya as evidenced by user requests. As reported by farmers, limited apparent demand seems to be mainly associated with low palatability. This trend is not unique to Kenya but has been observed in West Africa, though the tree has flourished in other regions such as Sri Lanka (Stewart et al. 1998).

6. Conclusion

The conservation of tree diversity is a matter of great priority given that tree diversity plays a crucial role in maintaining life through the provision of ecosystem services. Nonetheless, aggressive anthropogenic activity linked to agricultural production is one of the major factors threatening tree diversity and limiting the socioeconomic contribution of trees. It is on this basis that the conservation of tree diversity is of utmost importance, now and in future, due to the need to mitigate adverse consequences linked to drivers of change.

In this regard, the ICRAF genebank merits special mention given that it is wholly dedicated to the conservation of tree diversity used in agroforestry systems. That said, the conservation of diversity in genebanks demands significant resources to maintain essential operations, hence the imperative of guaranteed resource allocation streams.

This study investigated two objectives: factors influencing the adoption of two *Calliandra* and *Gliricidia* and the benefits associated with germplasm distribution of the two species from the ICRAF genebank.

Understanding the factors that influence agroforestry adoption remains an active research area given that adoption rates remain modest. Moreover, to the best of our knowledge, there is limited research tracing the benefits of ICRAF germplasm distributions in general or related to these species. Our analysis relied on thematic and content analysis of information from key informant interviews and a user survey to interrogate the aforementioned objectives.

Concerning adoption, we find that a number of factors limit the adoption of fodder trees. 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 realization of benefits influenced the differential uptake among the two species. Concerning impacts of direct use by smallholder farmers, we find that improved food security and incomes, increased milk production and reduced vulnerability to drought were identified as the main benefits linked to the use of *Calliandra*. Improved food security and incomes and soil fertility improvement were cited as the main use impacts associated with *Gliricidia*.

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 with 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, they 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. We expect that the role of tree genebanks will become increasingly more pronounced in the quest to find cost effective, environmental solutions to the numerous agricultural and ecosystem challenges our plant is projected to face.

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8. Tables

Table 1. Distribution data summary analysis of *Calliandra* and *Gliricidia* for the period 2008-2017

Species	Number of requests	Number of samples distributed	Quantity of samples distributed (kg)
Calliandra	431	445	106
Gliricidia	248	245	133
Total	**679**	**680**	**239**

Source of data: ICRAF GRU

Table 2. Distribution data analysis of *Calliandra* and *Gliricidia* by user for the period 2008-2017

	User Typology (%)	
Requests by user category	***Calliandra***	***Gliricidia***
Farmer	76	66
Organization	24	34
Total	**100**	**100**

Source of data: ICRAF GRU

Table 3. Sharing of seeds among farmers

If shared	Frequency	Percentage	Cumulative percentage
No	20	40	40
Yes	30	60	100
Total	**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 4. Sharing of seeds among farmers by species

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

Source of data: 2018 ICRAF GRU user survey

Table 5. With whom were seeds shared

Entities	**If shared**
Advanced research institutes	0
Universities	0
National genebank	0
International agricultural research institutes	0
International genebank	0
Regional genebank	0
Individual farmers	26
Farmer Groups	2
NGOs	0
Commercial company other	0
Other: Relative	1
Other: Diverse residents of village	1
Total	30

Source of data: 2018 ICRAF GRU user survey

Table 6. Purpose for sharing seed

Purposes	**Response**
Breeding	0
Evaluation	0
Characterization	0
Research	1
Direct use	26
Education	2
Other: Conservation	1
Total	**30**

Source of data: 2018 ICRAF GRU user survey

Table 7. Satisfaction with seed supplied

	Frequency	**Percentage**	**Cumulative percentage**
Response to satisfaction			
n/a	4	8	8
No	6	12	20
Yes	40	80	100
Total	**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 8. Satisfaction with seed supplied by species

	Calliandra	*Gliricidia*	Total
Response to satisfaction			
n/a	1	3	4
No	5	1	6
Yes	33	77	40
Total	**39**	**11**	**50**

Source of data: 2018 ICRAF GRU user survey

Table 9. Rating of services from the ICRAF genebank

Rating	Frequency	Percentage	Cumulative percentage
8	16	32	32
9	10	20	52
7	8	16	68
n/a	7	14	82
10	3	6	88
6	3	6	94
1	1	2	96
2	1	2	98
3	1	2	100
Total	**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 10. Reasons for satisfaction and dissatisfaction

Reasons		Frequency	Percentage	Cumulative percentage
Customer friendly requisition process		1	2	2
Did not germinate despite following instructions		3	6	8
Good germinate rate and clear instructions		5	10	18
Good germination and no cost for obtaining germplasm		1	2	20
Good germination rate		27	54	74
Good instructions		3	6	80
Good instructions and good customer service		1	2	82
n/a	Cannot comment because project is in Rwanda	1	2	84
n/a	Has not followed up on farmers	1	2	86
n/a	Not yet planted	4	8	94
n/a	Germination failed due to poor management	1	2	96
n/a	Did not source from ICRAF due to unavailability	1	2	98
Did not grow because of termite invasion		1	2	100
Total		**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 11. How would you be affected

Reasons		Frequency	Percentage	Cumulative percentage
Abandon planting		1	2	2
Abandon conservation project		1	2	4
Expend a lot of time looking for alternatives		2	4	8
Have to purchase at high cost		12	24	32
Have to purchase from other farmers		1	2	34
Increased costs of dairy production		2	4	38
loss of soil fertility		1	2	40
Self multiplication which would take time		1	2	42
No alternative source		6	12	54
No protein fodder		7	14	68
Unaffected	Would look for seedlings at alternative places	1	2	70
Unaffected	Request was for experimentation	1	2	72
Unaffected	Would look for other varieties	2	4	76
not applicable		6	12	88
Unaffected	Has other feed sources	1	2	90
Plant other varieties at significant cost		1	2	92
Reduced milk productivity		1	2	94
Risk of intrusion due to no fence		1	2	96
Risk of wrong informative from alternative sources		1	2	98
Seed quality from private suppliers not guaranteed		1	2	100
Total		**50**	**100**	

Table 12. Alternative sources for seedlings other than ICRAF genebank

Sources	Frequency	Percentage	Cumulative percentage
Egerton Njoro	1	2	2
Green Belt Movement	1	2	4
Individual farmer	3	6	10
Kitale Research Station	1	2	12
Karura Forest	1	2	14
Kenya Agricultural Research Institute	3	6	20
Kenya Forestry Research Institute	13	26	46
Kenya Forestry Service	1	2	48
Rwanda Agricultural Board	1	2	50
n/a	1	2	52
private commercial supplier	11	22	100
Total	**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 13. First choice for requestors

Sources	Frequency	Percentage	Cumulative percentage
Green Belt movement	1	2	2
ICRAF	45	90	92
KEFRI	1	2	94
n/a	1	2	96
Private commercial supplier	2	4	100
Total	**50**	**100**	

Source of data: 2018 ICRAF GRU user survey

Table 14. Benefits of *Calliandra calothrysus* according to farmers

Type of benefits	Number of farmers (*N*=23)
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	**43**

Source of data: 2018 ICRAF GRU user survey

Table 15. Benefits of *Gliricidia sepium* according to farmers

Type of benefits	Number of farmers (*N*=5)
Improved food security and incomes	4
Increased milk production	1
Reduced vulnerability to drought	1
Soil erosion control	1
Soil fertility improvement	2
Total	**9**

Source of data: 2018 ICRAF GRU user survey

9. Appendix

Appendix 1. Key Informant details

Name	**Position**	**Interview Date**
Joan Kimaiyo	Research Assistant-Developing value chain innovation for improved food security project (ICRAF)	12/9/2018
Dr Roeland Kindt	Senior Ecologist-Tree diversity, domestication and delivery science domain (ICRAF)	18/9/2018
Dr Ravi Prabhu	Deputy Director General (Research) (ICRAF)	19/9/2018
Dr Jonathan Muriuki	Kenya Country Representative (ICRAF)	19/9/2018
Eric Otieno	Research assistant-Regreening Africa project; Wood fuel project	19/9/2018
Anne Kuria	Research Fellow-Trees for food security project	19/9/2018
Dr John Nyaga	Research Associate - Systems themes	19/9/2018
Dr Steven Franzel	Principal scientist; Leader of ICRAF rural advisory services unit	20/9/2018
Dr Dennis Garrity	Senior Fellow, *EverGreen* Agriculture Partnership Chair	25/9/2018

Appendix 2.

GENEBANK IMPACTS USER SURVEY

Introduction and Consent to Participate in the Research

Hello,

My name is Kavengi Kitonga, a research fellow with the Crop Trust's Genebank Impacts fellowship program at the ICRAF genebank. On behalf of the Crop Trust and The International Centre for Research in Agroforestry, I would like to request your consent to participate in a mini-survey that seeks to understand the user impacts of germplasm from the ICRAF genebank.

You have been selected to participate in this survey because you have previously requested for germplasm from the ICRAF genebank. Participation in this study is voluntary. You have the right to refuse to participate in this study; if you refuse or stop your participation at any time, there will be no consequences.

If you agree to participate in this research it will take approximately 15 minutes of your time. Feel free to let me know what you are uncomfortable to answer and also note that all information solicited from you will be kept strictly confidential. We shall not in any way disclose you personally in resultant documents, or data sharing processes.

Yes	
No	

1. What is the name/names of the tree species that you requested from ICRAF Genebank?

2. What was the intended purpose of the requested tree seed/seedling/planting material? (Please explain in detail the purpose and also the percentage. (Open-ended; categorize later)

PURPOSE REQUESTED	PERCENTAGE USE
Breeding/Pre-breeding	
Evaluation of agronomic or other traits	
Characterization	
Research	
Direct use	
Education	
Other Please Specify	

3. Were the seeds/seedlings/planting materials used for the purpose it was intended? (If no, explain why they were not use for intended purpose)

Yes	
No (give reason)	

4. For the seeds/seedlings/planting materials requested, which aspects/attributes do you think are most important to you? (open-ended; categorize later)

Aspects/Attributes	Rank according to priority (1=low priority, 2= intermediate, 3= high priority)
Fodder	
Apiculture	
Firewood	
Timber	
Charcoal	
Shade	
Medicine	
Soil fertility	
Soil erosion control	
Fencing	
Poison	
Ornamental	
Fruit/food	
Bio-energy	

5. Did you share the seeds/seedlings/planting materials to other institutes, groups or growers? If yes, to whom and for what purpose?

Choice	Response	Types of institutes
Yes (if yes indicate to whom)		Advanced research institutes
		Universities
		NARS or national genebank
		International agricultural research center or International genebank or Regional genebank
		Individual farmers
		Farmer groups
		NGOs
		Commercial Company
		Others
No		

6. Reason for sharing? Elaborate on purpose of sharing

Breeding

Evaluation

Characterization

Research

Direct use

Education

Other (specify)

7. On a scale of 1-10 (where 10 is the highest) rate your satisfaction with the seeds/seedlings/planting materials requested from ICRAF germplasm?

1	2	3	4	5	6	7	8	9	10

8. If you did not have access to seeds/seedlings/planting materials from ICRAF genebank, how would your intended use be affected?

9. What are your other alternative sources of seed/seedling/planting material?

10. Between ICRAF and the listed sources above in Q#9, where do you first make your request?

ICRAF	Listed source

THANK YOU FOR YOUR PARTICIPATION