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SPECIAL SECTION: DEVELOPING FODDER RESOURCES FOR SUB-SAHARAN COUNTRIES

Feed and forage development in mixed crop–livestock systems of the Ethiopian highlands: Africa RISING project research experience

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Abstract

Africa Research in Sustainable Intensification for Next Generation (RISING) project has conducted action research on livestock feed and forages starting in 2012 to bridge gaps on feed availability and quality. The objectives of this paper are to share approaches on how Africa RISING project enabled smallholder farmers to intensify feed and forage resources; present research findings of selected cultivated forages, fodder trees, and postharvest feed and forage utilization innovations; and highlight key lessons evolving from the feed and forage action research and scaling interventions. The project established partnership with CGIAR and local partners, conducted participatory need assessment, prioritized researchable issues, identified and validated different forages and utilization innovations, and created development partnership to facilitate wider scaling. Training activities and multistakeholder platforms were used to enhance cross learning of project partners. The cultivated forages grown under farmers' fields and management conditions provided high biomass yield of good nutritional quality. For instance, oat (*Avena sativa* L.)–vetch (*Vicia villosa* Roth) mixture, lablab [*Lablab purpureus* (L.) Sweet], vetch–desho grass (*Pennisetum pedicellatum* Trin.) intercropping, sweet lupin (*Lupinus albus* L.), alfalfa (*Medicago sativa* L.), and fodder beet (*Beta vulgaris* L.) yielded on average 15, 3.4, 5.5, 2.9, 15.3, and 20.2 t dry matter ha^{-1}, respectively. Animal response trials showed an increase in milk yield of 30–50% with supplementation of oat–vetch mixture and fodder beet. Feed wastage was considerably reduced (>30%) due to the use of feed troughs and storage sheds, with high economic incentives to invest in such innovations. Integrating and intensifying feed and forage resources and postharvest innovations at farm level remains a priority to improve livestock productivity and food security.

Abbreviations: Africa RISING, Africa Research in Sustainable Intensification for the Next Generation; DM, dry matter; FRG, farmer research group; FTC, farmer training center; NGO, nongovernmental organization.

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1 | INTRODUCTION

Population growth and urbanization are evident in Ethiopia. As a result, demand for livestock products is increasing rapidly (Shapiro et al., 2015). Despite having one of the largest livestock populations in Africa, the Ethiopian traditional livestock management system is not keeping pace with the expected contributions of the sector. Difficulties in accessing reliable and quality livestock feed resources, poor postharvest feed handling, and inefficient utilization practices are critical constraints to Ethiopia's livestock sector, alongside other key constraints such as animal health and breeding services (Balehegn et al., 2020; Shapiro et al., 2015). Forage seed supply is also found to be a critical constraint because it is often too expensive for smallholder producers, and some promoted species produce low yields and are poorly adapted to production environments (Balehegn et al., 2020).

The feed resource base in the mixed farming system of the Ethiopian highlands has been declining due to the continual conversion of grazing lands to arable lands and concomitant loss of fertility and land degradation on the remaining pasture lands (Amsalu & Addisu, 2014). This has forced farmers to rely heavily on feeding crop residues to their livestock. Over 50% of the diets of ruminants are derived from crop residues particularly during the long dry period when green forage becomes scarce (Tolera et al., 2012). Heavy reliance on crop residues for livestock nutrition has many implications for livestock productivity and the sustainability of the mixed farming system in the highlands. Nutritionally, crop residues are poor in quality, though residues from legume and pulse crops have better quality than those from cereals. Crop residues fed alone rarely fulfill the maintenance requirements of animals (Chalchissa et al., 2014; Mahesh & Mohini, 2014). Complete removal of residues from crop lands for livestock feeding contributes significantly to the gradual depletion of soil organic matter content, low water holding capacity, and subsequent loss of soil fertility of arable lands. Therefore, for a sustainable improvement in crop–livestock productivity, it is imperative to improve the feed resource base of the mixed farming system in the highlands by introducing well-adapted and high yielding fodder crops and efficient utilization practices.

The livestock subsector in Ethiopia contributes about 47% to the agricultural gross domestic product (ICPALD, 2013). In its second growth and transformation plan, the government of Ethiopia has given special emphasis to the livestock subsector with the objective of adequately exploiting its potential for rural poverty reduction, food security, export earnings, and job creation for youth and women. Improving animal feed resources is one of the main strategies to realize these objectives together with breed improvements and better management of animal health issues (NPC, 2015).

Currently, the government is also prioritizing soil and water conservation projects at watershed level throughout the country. Terraces have been built on sloping areas to minimize soil erosion and improve water percolation and infiltration into cropping and grazing lands. These physical structures (terraces and soil bunds) need biological reinforcement to serve their purpose for extended periods and realize their benefits. Planting of multipurpose fodder trees and perennial grasses on these niches can create a synergy to protect the environment and at the same time increase the feed biomass available to improve livestock productivity. Thus, such integration of forage production in the cropping system at scale has the potential to intensify the mixed farming system, while shaping it to be resilient to climatic shocks.

Core Ideas

- Action research approaches improved familiarization of farmers to feed and forage innovations.
- Cultivated forages and fodder trees provided high biomass yield of good nutritional quality.
- Feed utilization innovations reduced wastage (>30%) and increased resource-use efficiency.
- Model farmers, farmers training centers, and cooperatives supported forage seed production systems.

With the development of watersheds, regional administrations have started to develop policy directions and community bylaws aimed at promoting controlled (as opposed to free) grazing, improving livestock productivity per head (through improved breeds and nutrition), and reducing livestock herd sizes. Realizing these policy directions, step-by-step, needs among other things, a long-term forage development plan to ensure adequate feed biomass availability that will pave the way for the adoption of a sustainable cut-and-carry feeding system. In addition, it is important to equip farmers with the necessary skills to feed livestock balanced rations (according to requirements) and avoid unnecessary wastage of feed biomass while feeding and during storage. The Africa Research in Sustainable Intensification for the Next Generation (RISING) project in the Ethiopian highlands has introduced integrated feed and forage development interventions such as cultivated forages, fodder trees, improved feeding troughs, feed conservation practices, and storage sheds. These have the capacity to address livestock feed- and forage-related challenges and thereby contribute to the improvement of livestock productivity, income diversification, and household nutrition (https://africa-rising.net/ethiopian-highlands/).

The objectives of this paper are to share the approaches used by Africa RISING-enabled smallholder farmers to intensify different feed and forage resources; to present research findings of selected cultivated forages, fodder trees, and postharvest feed and forage utilization innovations; and to

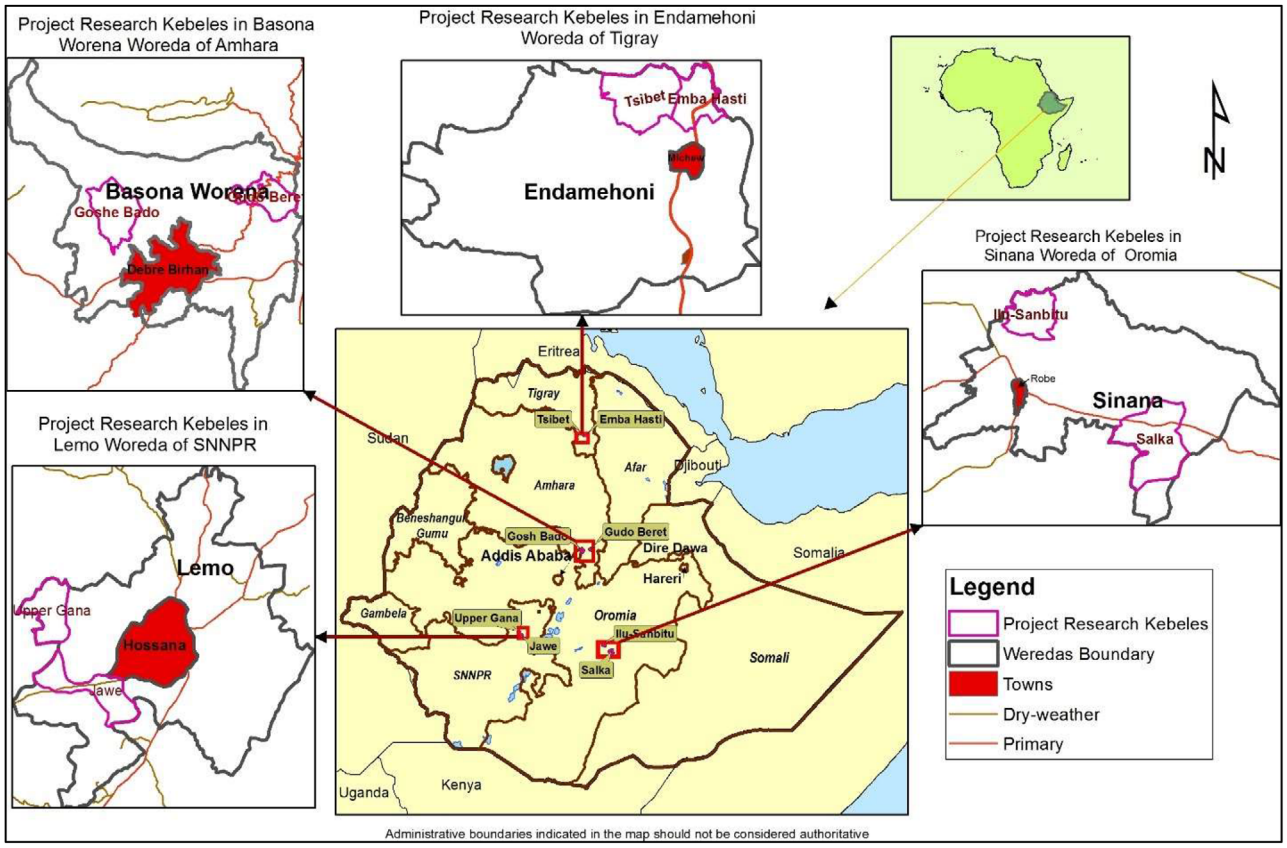


FIGURE 1 A map showing Africa Research in Sustainable Intensification for the Next Generation (RISING) operational areas in the Ethiopian highlands. SNNPR, Southern Nations, Nationalities, and Peoples' Region

highlight key lessons evolving from the feed and forage action research and scaling interventions.

2 | MATERIALS AND METHODS

2.1 | Selection and description of operational sites

Livestock feed and forage development research is one of the seven Africa RISING project thematic areas in the Ethiopian highlands. The project research sites were selected by a team of researchers in consultation with local administrators, agricultural bureaus, universities, and research institutions of the four major Ethiopian regions to implement feed and forage and other crop and natural resources management (water, soil, and high-value fruit trees) and related research project initiatives. Amhara; Tigray; Oromia; and Southern Nations, Nationalities, and People are the four regions selected for project operation. The Ethiopian government administrative structure from top to bottom (largest to smallest administrative unit) is in the following order: federal, regions, zones, districts (woredas) and subdistricts (kebeles). In each region one representative woreda was identified. In the context of the Africa RISING project each project woreda corresponds to a project site. In each project site, two kebeles were selected, giving a total of eight research kebeles from the four project research sites (Figure 1).

The four sites exhibit distinct and contrasting crop–livestock combinations and farming system challenges. The Lemo (Southern Nations, Nationalities, and Peoples' Region) and Sinana (Oromia) sites have better soil fertility and rainfall distribution than the Basona (Amhara) and Endamehoni (Tigray) sites (Table 1). The latter two sites are characterized by more severe land degradation than the former two sites. The Lemo and Sinana sites have 180–240 growing d yr^{-1}, whereas the Basona and Endamehoni sites have 120–180 growing d yr^{-1} (MoA, 2000).

Demand for livestock feed is high both in the dry as well as cropping seasons. Farmers in all the project sites grow different forage plants to supplement feeding of dairy cows, ploughing oxen, and small ruminants. However, uptake of improved forages varies from site to site due to small farm size, lack of access to forage seed and planting materials, inadequate technical and extension support, and shortage of labor. At the Sinana site, landholdings are larger than at other sites. As a result, farmers adopt mechanized systems for crop production and are less engaged with agricultural

TABLE 1 Climate, soils, and crop production characteristics of the eight Africa RISING research kebeles in the Ethiopian highlands

Region	Woreda	Kebele	Elevation range	Annual rainfall	Mean annual max. temp	Mean annual min. temp	Dominant soil type	Major crops	Priority issues and problems
				mm	——————°C——————				
Amhara	Basona	Goshe Bado	2,001–3,800	912–1,127	22	9	Cambisols, Vertisols, Lithosols	Wheat,[a] faba bean, barley,[b] potato[c]	Land degradation, soil depletion, low crop and livestock productivity
		Gudo Beret	2,500–3,800	1,128–2,228	20	6	Regosols, Cambisols, Lithosols		
Oromia	Sinana	Salka	2,000–2,800	950–1,000	20	6	Vertisols, Fluvisols, Nitisols	Wheat, faba bean, emmer wheat[d]	Wheat dominated monocropping system, poor human and livestock nutrition, crop diseases
		Ilu Sanbitu	2,000–2,500	950–1,000	22	8	Vertisols		
SNNPR	Lemo	Jawe	2,000–2,300	1,100–1,120	23	18	Vertisols	Wheat, faba bean, teff[e], enset[f]	High population, feed shortage, soil acidity, enset disease
		Upper Gana	2,000–2,500	1,120–1,170	22	18	Vertisols, Nitisols, Cambisols		
Tigray	Endamekoni	Emba Hazti	2,000–3,800	700–750	15	6	Cambisols, Regosols, Lithosols	Wheat, barley, faba bean, potato	Shortage of protein rich fodder, few income diversifications options, water shortage, soil depletion, low crop yield
		Tsibet	2,500–3,800	700–750	12	4	Cambisols, Regosols, Lithosols		

Note. Africa RISING, Africa Research in Sustainable Intensification for the Next Generation; SNNPR, Southern Nations, Nationalities, and Peoples' Region.

[a] *Triticum aestivum* L.

[b] *Hordeum vulgare* L.

[c] *Solanum tuberosum* L.

[d] *Triticum dicoccum* L.

[e] *Eragrostis tef* (Zuccagni) Trotter.

[f] *Ensete ventricosum* (Welw.) Cheeseman.

Source: Ellis Jones et al., 2013; Ethiopian Institute of Agricultural Research Geographic Information Systems (personal communication, 15 Oct. 2015); authors' own expert knowledge.

TABLE 2 Average annual dry biomass and nutritive value of selected forage options in the project sites of the Ethiopian highlands observed from 2013 to 2020

Forage types	Scientific names	Observed dry matter	Reference yield*	CP	ME	IVOMD
		t ha^{-1}		%DM	MJ DM kg^{-1}	%
Oat	*Avena sativa*	14.5	12.2	10.5	8.7	60.0
Vetch	*Vicia villosa*	9.6	5.0	18.0	10.8	67.4
Lablab	*Lablab purpureus*	5.3	6.1	16.0	8.6	63.0
Sweet lupin	*Lupinus albus*	3.4	3.7	21.0	9.26	65.5
Alfalfa	*Medicago sativa*	15.3	18.0	22.0	11.4	80
Brachiaria	*Brachiaria* cultivars Mulatto I and Mulatto II	7.5	8.5	19.0	7.8	57.5
Phalaris	*Phalaris aquatica*	8.5	14.0	9.0	7.4	56.0
Fodder beet	*Beta vulgaris*	20.2	31.0	7.5	11	79
Desho grass	*Pennisetum pedicellatum*	8.4	10.0	11	7.5	62
Tree lucerne	*Chamaecytisus palmensis*	8.7	10.2	22.5	9.0	70
Faba bean–oat intercropping	*Vicia faba–Avena sativa*	5.5	NA	10	8.5	64
Oat–vetch mixture	*Avena sativa–Vicia villosa*	15	12.0	15	9.5	66
Desho grass–vetch intercropping	*Pennisetum pedicellatum–Vicia villosa*	11	NA	14	9.2	65

Note. CP, crude protein; ME, metabolizable energy; IVOMD, in vitro organic matter digestibility; DM, dry matter; NA, not available. Reference average yields were derived from Feedipedia (https://www.feedipedia.org/) and tropical forages database (https://www.tropicalforages.info/).

technologies that demand labor for planting, harvesting, and handling. On the other hand, landholdings are smaller in Endamehoni, which hinders farmers wishing to adopt and grow more forage species. Inadequate supply and poor access to quality forage seed and planting material is a challenge that affects uptake of improved forage technologies across all sites.

2.2 | Participatory needs assessment, research interventions and formation of farmer research groups

Initially, systems diagnostic assessments aimed at identification of opportunities and research needs and priorities of communities in the eight Africa RISING research kebeles were carried out through participatory community analysis and household survey tools (Ellis-Jones et al., 2013). The diagnostic studies were conducted in 2012. Based on the diagnostic assessments, feed and forage development was formulated as one of the thematic research areas under which cultivated feed and forages, fodder trees, and postharvest feed and forage management and utilization protocols (proposals) were developed in 2013.

Communities at each selected kebele were invited to gather at a central place for a participatory discussion on how to address the feed and forage challenges. The Africa RISING feed and forage development research teams explained the idea of the feed and forage development on-farm action research initiative to the communities and presented different livestock feed and forage intervention options. The research team encouraged elective engagement of participating farmers for the feed and forage development options to ensure a demand-driven focus. Farmers who had an interest in engaging in one or more feed and forage intervention options and could allocate appropriate parcels of land for the on-farm research were identified and registered during the community consultation meetings. Farmers interested in participating in the different feed and forage intervention options were grouped into farmer research groups (FRGs). Some of the feed and forage options taken on by FRGs include tree lucerne [*Chamaecytisus palmensis* (Christ) F.A. Bisby & K.W. Nicholls (excluded)], oat (*Avena sativa* L.)–vetch (*Vicia villosa* Roth) mixture, faba bean (*Vicia faba* L.)–forage intercropping, sweet lupin (*Lupinus albus* L.), fodder beet (*Beta vulgaris* L.), alfalfa (*Medicago sativa* L.), desho grass (*Pennisetum peicellatum* Trin.), brachiaria [*Brachiaria* (Trin.) Griseb.], and feeding trough (Table 2). One FRG per kebele was formed for each of the feed and forage development options. Each FRG consisted of 25–30 men and women farmers representing a range of social groups.

2.3 | Validation of different cultivated forages, fodder trees, and postharvest feed management and utilization innovations

Meetings were held each year to identify the needs of individual farmers with respect to feed and forage technologies.

Researchers and farmers who decided to engage in the different feed and forage intervention options jointly managed the on-farm action research. Researchers provided all inputs necessary for field research and built capacities of farmers. Farmers allocated land, contributed labor, managed the on-farm research plots, and shared their field observations and experiences with the researchers, neighboring farmers, and those who visited them during field days and other capacity building events. The International Livestock Research Institute livestock feed and forage researchers, Africa RISING site coordinators, local partners working on feed and forage, and farmers established different on-farm action research experimental fields in 2014 and continued the research afterwards. Biophysical, biological, and socioeconomic data that match with each of the interventions were collected. Review and planning workshops were organized regularly to evaluate research results and plan for follow-up experimentation. Innovation platforms formed at site and kebele level served as a venue to bring farmers, researchers, extension experts, nongovernmental organizations (NGOs), local government authorities, and market actors together, which enhanced evaluation of the on-farm research activities and planning on emerging issues. The kebele and site level innovation platforms members met a minimum of two times per year. One of the meetings was scheduled during the cropping season so as to visit on-farm research activities on the ground. The other meeting ran outside the cropping season to get updates on research results and review new plans. An innovation platform is a stakeholder forum established to facilitate interaction and learning among stakeholders often selected from a commodity chain or system to undertake a participatory diagnosis of problems, joint exploration of opportunities, and investigation of solutions leading to the promotion of innovation along a targeted value chain (Homann-Kee et al., 2013). Finally, some of the collected data were processed and used to produce various communication products (blogs, briefs, proceedings papers) and journal articles.

2.4 | Demonstration of best bet feed and forage intervention options, and postharvest utilization innovations

Different feed and forage intervention options were demonstrated within and outside Africa RISING research kebeles to encourage adaptation by users. Three approaches were used to demonstrate validated feed and forage intervention options.

- Model farmers: These are farmers who have been participating in the validation of different feed and forage intervention options and managing them successfully. Most of these farmers have gained benefits and shown an interest in allocating more land and resources to maintain and expand cultivated forages, fodder trees, and postharvest utilization of intervention options in their farms. These model farmers are visited by neighboring farming communities and other farmers from different localities and serve as one of the feed and forage innovations demonstration options to enhance wider adoption.
- Farmer training centers (FTCs): The FTCs have been established in different kebeles to demonstrate livestock, crop, and natural resources management innovations and equip farmers with essential farming knowledge and skills. The validated feed and forage intervention options were established in selected FTCs and demonstrated to farmers from different areas.
- Contractual land: Forage demonstrations on mother–baby plots were established on contractual land in different Africa RISING project research kebeles. Those plots consisted of diverse grass, legume forage, and fodder tree species. Farmers visited the forage mother–baby plots during field days and other events.

Model farmers, FTCs, and contractual land technology demonstration approaches contributed to the uptake of feed and forage innovation options in many ways. First, they enabled farmers to visit and see the performance and benefits of the innovations because of their proximity to villagers. Second, the model farmers created more interest and enhanced willingness of farmers to practice the innovations as a result of sharing their successes. Third, they served as a means of quick transfer of knowledge and information, which improved uptake of feed and forage innovations. In most cases, farmers were convinced when they heard from those farmers who have become successful because of adopting or practicing feed and forage innovations and other agricultural technologies.

2.5 | Exploration of different options for forage seed multiplication

Access to improved forage seed is a challenge for farmers in Ethiopia. Forage seed suppliers are very few, and their capacity to supply adequate seed is limited. Cooperatives, unions, model farmers, NGOs, local universities, and research centers were identified as potential partners to multiply forage seed in different Africa RISING sites. Those partners initially received starter seed for multiplication and later used the seed to distribute to large numbers of farmers on a seed-revolving system arrangement. The farmers who received improved forage seed were expected to either return equivalent amounts of seed or pay cash for the cost of the seed.

2.6 | Creation of development partnership to facilitate wider scaling of feed and forage technological options

Africa RISING worked with a wide range of partners during the first phase of its action research and second phase of scaling. The project worked with a total of 41 partners. Seven of them were from CGIAR-based projects, eight of them from the national research system (mainly from regional agricultural research centers), five of them were from higher education and technical and vocational colleges, and 18 of them were from the public extension system. During the two phases of Africa RISING, namely the action research and scaling phases, the different partners played various roles. Working with a multistakeholder partnership model enabled Africa RISING researchers to work with a systems approach, lowered the field research cost, increased the knowledge and capacity of partners on the forage innovations generated during the research process, and facilitated scaling of forage innovations. For example, a partnership with the International Center for Tropical Agriculture's watershed research team enabled the forage researchers to capture landscape-related considerations in their research. The partnership with an International Water Management Institute research team also enabled the forage researchers to incorporate irrigation and hydrological dimensions in their research work. Local researchers took responsibilities including field data collection, planting, field monitoring, and field evaluation. The close collaboration with local extension service providers was also useful in mobilizing farming communities to take part in capacity building and scaling of feed and forage innovations.

Capacities of local partners on all aspects of validated feed and forage innovations including scaling was built in various ways. For instance, training of trainers was organized for extension experts to enable them to be fully familiar with the feed and forage innovations. The extension experts who attended the training of trainers managed to provide practical and theoretical training to farmers at different sites. Showcase documents on feed and forage innovations, manuals, video clips, posters, briefs, and factsheets were prepared and shared with the local partners. These training materials consisted of detailed information and guidelines on how to implement the feed and forage innovations. Organizing learning events, exhibitions, practical exchange field visits, and demonstration of feed and forage innovations in representative sites also contributed to enhancing the knowledge of the local partners on the feed and forage innovations and wider scaling efforts.

Several steps were followed to develop and maintain partnerships and facilitate scaling of feed and forage validated intervention options as indicated below:

- Validated feed and forage intervention options ready for scaling were identified.
- Information of validated innovations was packaged into factsheets.
- Contact with potential development scaling partners was established to share research findings and requirements of the innovations.
- A template to collect information on the capacity of each of the development partners to scale feed and forage intervention options was developed.
- Contact persons were identified at site level to facilitate communication, supervision, data collection, and evaluation.
- Training was provided for experts, development agents, and farmers on the scalable feed and forage intervention options.
- Starter forage seed was purchased and provided to cooperatives, unions, model farmers, extension FTCs, NGOs, and local universities to multiply and distribute to farmers on a revolving seed arrangement.
- Different forage seed multiplication approaches were tested to recommend the best model to the extension system in the respective project sites.

2.7 | Capacity building activities and multistakeholder platforms

Capacity building of farmers, extension experts, researchers, NGOs, and private sector groups on feed and forage intervention options was managed in a variety of ways, all of which were designed to respond to demand from all partners. The capacity building scheme also focused on knowledge sharing and cross learning through field days, workshops, experience sharing visits, regular meetings, and training programs that included all partners on feed and forage development and scaling activities.

Innovation platforms were established and used to engage different local partners that have a stake in livestock feed and forage value chain. The members of the innovation platforms met twice per year to review the feed and forage research agenda as well as discuss research results.

3 | RESULTS AND DISCUSSION

3.1 | Biomass production and nutritive value of selected feed and forage intervention options

3.1.1 | Cultivated forages

Cultivated forages validated under farmers' management conditions in a sole and mixed or intercropped arrangement at

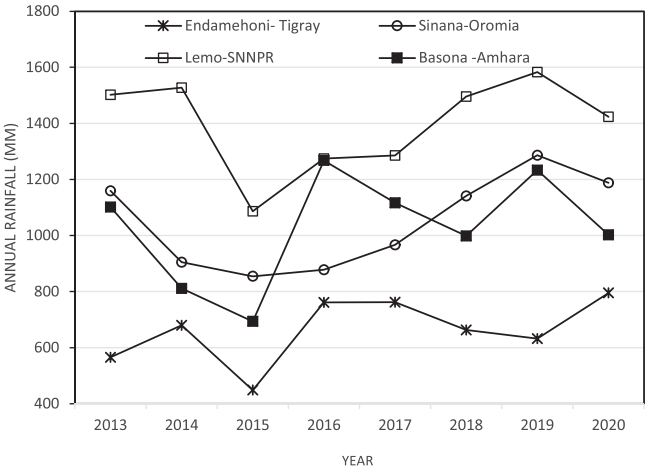


FIGURE 2 Annual rainfall of different sites from 2013 to 2020. SNNPR, Southern Nations, Nationalities, and Peoples' Region

the sites included oat–vetch mixture, sweet lupin, alfalfa, fodder beet, desho grass, lablab [*Lablab purpureus* (L.) Sweet], brachiaria, phalaris (*Phalaris arundinacea* L.), vetch–desho grass mixture, and faba bean–forage intercropping (Table 2). Productivity of the cultivated forage options and their nutritive values varied from site to site because of climatic, edaphic, and management factors. The average biomass yield (t dry matter [DM] ha^{-1}) and nutritive value obtained across sites under farmers' fields and management conditions are shown in Table 2, and the rainfall amounts over the observation years are indicated in Figure 2. A common feature observed in most of the forages evaluated was the high herbage mass yield of good nutritional quality. This appears very important given the current feed supply and quality constraints in the country. Grazing lands that have served as traditional feed sources in the country have declined in size due to continual conversion into arable lands to meet food demands of the growing population (Mekuria et al., 2018). Moreover, land degradation has affected pasture availability on existing grazing lands (Tefera et al., 2007), and the natural pasture yield often does not exceed 2 t DM ha^{-1} (Bezabih et al., 2014). Crop residues have low nutritional quality and increasingly constitute the bulk of the diet of ruminants in the mixed system (Duncan et al., 2016). Apart from the poor quality and seasonality of available feed resources, smallholder farmers are largely unable to feed their animals ad libitum, often leading to below-maintenance nutrient intake and weight losses during dry seasons (Bezabih et al., 2014). A recent feed inventory and feed balance report for the major livestock-producing regions of the country indicated that feed deficiency stood at 10% as DM, and 45% as metabolizable energy (FAO, 2018).

The improved forages introduced and validated can play a key complementary role to the traditional feed resources in two aspects. First, these forages, such as fodder beet, alfalfa, and vetch provide 8–10 times more yield than naturally growing pastures. Second, these forages are of sufficient quality to promote optimal livestock productivity. For instance, the legume forages including lablab, vetch, sweet lupin, and alfalfa had crude protein concentration in the range of 16–22%, with in vitro organic matter digestibility of 63–80%. A minimum of 7% crude protein is required in the diet of ruminants to maintain normal microbial growth and fermentation in the rumen, and for optimal livestock productivity, the crude protein content of the diet should be well above 10% (Van Soest, 1994). However, in the mixed farming system, poor quality crop residues with low protein concentration (less than 5%) and digestibility (less than 50%) have become the major source of diet for livestock (Bezabih, Duncan, et al., 2016; Duncan et al., 2016). One way to improve the situation and, therefore, animal productivity in this system is to enhance the quality of the diet by mixing crop residues with cultivated forages (Mengesha et al., 2017). In this respect, the forage legumes mentioned above have a great potential to serve as important protein supplements and modulate the nutritional requirements of livestock. Sweet lupin, in addition to being a source of high-quality forage, provided optimal grain yield comparable to other pulse crops. The grain of this crop can be used as a supplement for fattening animals or as food for humans. The grass forages, including oat forage, showed optimal protein and energy contents for ruminant livestock production (Bezabih et al., 2013). These grasses can be used as a basal feed or mixed with other feed resources to increase feed intake and animal productivity. In this respect, the oat–vetch mixture appears to be a balanced feed with its high protein (15% crude protein) and energy concentrations (9.5 MJ metabolizable energy kg^{-1} DM) able to support optimal animal productivity for lactating cows and fattening animals. Overall, the cultivated forages validated proved to be promising in improving the productivity of livestock and contributing to livelihood improvements. In addition to the economic benefits, integration of forages and fodder trees on soil and water conservation structures improves soil fertility and minimizes water runoff and soil erosion (Amare et al., 2014; Tanto & Laekemariam, 2019).

3.1.2 | Fodder trees

The fodder tree research of the Africa RISING project of the Ethiopian highlands focused mostly on tree lucerne because this tree species is adapted to the different project sites and performs well in cooler highland locations. Tree lucerne in well-managed farm fields can grow to a reasonable size for harvest and used as animal feed within 9 mo of planting (Mekonnen et al., 2019). It produces a relatively large quantity of leaves compared with edible branch and stem (wood) biomass if cutting frequencies are well designed. Tree lucerne

produced an average annual DM leaf of 3.4 t ha^{-1} (71.7% of the biomass yield) when harvested at 2 mo cutting intervals, and 4.6 t ha^{-1} of leaf (45.3% of the biomass yield) when harvested at 6 mo cutting intervals (Assefa, 1998). However, the quantity of biomass obtained from tree lucerne can vary depending on growing localities and niches, planting density, age, and management practices (McGowan & Mathews, 1992). It proved possible to obtain >8 t ha^{-1} average annual dry biomass yield of tree lucerne under farmer management conditions in the project sites of the Ethiopian highlands (Froche, 2016). Assefa et al. (2012) reported annual average dry biomass yield of 7.27 t ha^{-1} of tree Lucerne that grew on Nitisols in the central Ethiopian highlands. On a similar location, Mekonnen et al. (2006) reported 14 t ha^{-1} average annual dry biomass of tree lucerne. The annual average dry biomass of tree lucerne in New Zealand ranged from 12 to 16 t ha^{-1} (Townsend & Radcliffe, 1987). This shows that if management practices are optimized, the foliage yield can be substantially increased. As a fodder tree with a deep root system, tree lucerne can provide green feed supplement during the main dry season when such feed becomes scarce. The foliage has high crude protein (22.5%) and organic matter digestibility (70%), which makes it a suitable supplement to both fattening and lactating animals. For instance, farmers can mix about 70% of poor-quality crop residues with 30% of tree lucerne foliage to obtain a mixture containing 10% crude protien, which can support optimal livestock production under smallholder conditions.

3.2 | Reducing wastage through postharvest feed management and utilization options

Proper utilization of available feed resources is one of the ways to cope with feed shortages that challenge smallholder farmers in the Ethiopian highlands. In the project sites, it has been observed that wooden feed troughs and feed storage sheds reduce feed wastage during utilization and storage by ~30–50% (Bezabih, Mekonnen, et al., 2016). A report from Tanzania showed the contribution of feed troughs to reduced wastage varied between 20 and 30% (Lukuyu et al., 2015). Farmers were also able to minimize the labor demand for feeding and taking care of animals when they are tethered and offered feed in feeding troughs. Other perceived benefits by farmers in Africa RISING sites and other areas in Africa and India include reduction of the risk of infections (respiratory problems) of different livestock species because of access to clean feed and forage resources (Lukuyu et al., 2015). Construction of feeding troughs for different classes of animals is important to implement a sustainable cut-and-carry feeding system in the highlands. This type of innovation is popular where promotion of controlled grazing is taking place and free movement of animals is prohibited by local bylaws. The feed troughs can be constructed easily from locally available materials with minimal input of industrial materials like nails or corrugated iron sheets, which can also be replaced by grass thatching. The affordability of the designs coupled with the tremendous benefit it provided made it easily adoptable and scalable in the project sites.

3.3 | Effect of improved forage supplementation on livestock performance

Forage supplementation trials were conducted at different project sites to evaluate their contribution to animal weight gain of small ruminants, improvement of milk yield of dairy cows, and income diversification for smallholder farmers. Supplementary feeding of sheep with 200 g of irrigated oat–vetch fodder per day for ~70 d resulted in a mean daily body weight gain ranging from 52 to 110 g in the Lemo site of southern Ethiopia (Bezabih, Duncan, et al., 2016). This weight gain performance was found to be comparable to earlier reports where commercial concentrates were used for fattening of Doyogena sheep (Hassen et al., 2002; Manaye et al., 2009). As concentrate mixes are often expensive and not easily accessible to smallholders, the on-farm produced oat–vetch fodder provides an alternative option to improve the productivity of their animals. Inventory of feed resources and feeding practices in the Lemo site indicated that under farmers' practices, the body weight gain would remain less than 35 g d^{-1}, which was far less than that achieved with oat–vetch fodder supplementation (Bezabih, Duncan, et al., 2016).

Protein is a limiting nutrient in livestock nutrition in the smallholder systems of Ethiopia, and leaf of tree lucerne is known for its high crude protein content and digestibility. In another feeding trial in Basona site where yearling Menz rams were supplemented with dried tree lucerne leaf at 100, 200, 300, and 400 g d^{-1} head^{-1}, average daily body weight gains ranging from 20 to 73 g d^{-1} head^{-1} were obtained, with a linear increase in body weight gain as the supplementation increased. The trial also showed increased feed conversion efficiency from 0.04 to 0.10 and dressing percentage from 40 to 48% as the supplementation of tree lucerne dried leaf increased from 100 to 400 g d^{-1} (Mengesha et al., 2017). The effect of on-farm grown improved forages on milk yield of lactating cows was also evaluated by measuring milk yield of cows before and after supplementation of oat–vetch fodder. The results indicated that providing ~2 kg oat–vetch mixture hay per lactating cow on top of the farmer practice in the Endamehoni site can increase milk yield by 50–70% (Hailesilassie, 2016). In a similar study, beet supplementation to lactating cows at the Sinana site resulted in milk yield increases of 14–29%. The improvement in animal body weight gains and milk yield caused by supplementation with the improved

TABLE 3 The testing and uptake of cultivated forage, fodder tree, improved feed storage, and feeding trough innovations by households in the project sites of the Ethiopian highlands

Innovation	Trialed	Stopped using	Decreased use	Steady use	Increased use
	n	%			
Tree Lucerne	319	12	2	11	76
Feed troughs	146	12	1	2	85
Feed storage	139	18	0	2	80
Oat–vetch mixture	148	43	0	4	53
Desho grass	135	10	1	16	74
Phalaris grass	77	32	0	1	66
Alfalfa	44	30	0	9	62
Fodder Beet	13	46	0	0	54
Sweet lupin	10	60	0	0	40
Napier grass	6	17	0	33	50
Faba bean–oat intercrop	5	0	0	20	80

Note. The values in the second column show the number of households that chose to trial each innovation (out of a total sample size of 779), and the values in the third through sixth columns show the change in the degree of use of each technology (measured by survey in 2018, after 4 yr of testing). The proportions are calculated relative to the number of households that trialed each intervention, and the degree of use was relative to the amount initially trialed.

forages would translate into income gains and additional job opportunities (Omore et al., 2004).

3.4 | Adoption of feed and forage innovations

Researchers encouraged elective engagement of participating farmers for cultivated forages and fodder trees to ensure a demand-driven focus. Decisions on what type of forages and fodder trees to trial were taken by farmers. There were two stages of participatory selection: first, the selection of innovations to be promoted, which was done through focus groups discussion (in 2012–2013); and second, the decision on what to trial on each farm, which was taken by each farmer individually (2014 onwards). Farmers could choose to stop using technologies at any time. Therefore, if an innovation was widely trialed, and the extent to which it was used on each farm increased, that implied it was desirable to the farmers. Table 3 reports responses from a household survey conducted in 2018 (4 yr after trials began), in which respondents were asked which technologies they had trialed, and for each technology, they were asked if the degree of use had changed since they first began using the technology. Tree lucerne was the most widely trialed and widely taken up feed innovation (Table 3).

Over three-quarters of the households who trialed tree lucerne continued to increase the degree of use. Feeding troughs and improved feed storage were both also very popular with the households who trialed those innovations, although they were not trialed as widely as tree lucerne, perhaps due to the relatively higher upfront investment cost and demand variation from site to site. The popularity of tree lucerne, feed storage, and feed troughs was fairly similar across the four sites.

Cultivated forage crops were more variable in terms of uptake. Desho grass was mainly trialed in Lemo and was the most popular in terms of the total number of trials and continuation rates, where 74% increased their use and only 10% of households discontinued using it. Oat and vetch were trialed widely (in all four sites) but did not achieve such widespread uptake: 43% of households discontinued it, and 53% increased their use of oat–vetch, suggesting that in some circumstances, it was viable and useful. The pattern was similar across all four sites, although a higher discontinuation rate was observed in Sinana. Phalaris grass was trialed in Basona Worena and Endamehonei sites, where about one-third of households discontinued use and about two-thirds increased their use. There was a slightly higher preference for phalaris grass in Endamehonei site compared with Basona Worena site. Phalaris grass adapts and performs well in Basona Worena site. Alfalfa was mainly trialed in Endamehonei and Lemo sites, where about two-thirds of households continued or increased their use of it. Fodder beet and sweet lupin were not widely trialed and were not so popular among those who did trial them. Napier grass (*Pennisetum purpureum* Schumach.) and faba bean intercroppings were also trialed by few households but were quite popular in terms of continuation.

Tree lucerne, feed storage, and feed troughs were similarly popular in all locations (except for Sinana site, where none of these feed interventions were very popular) (Figure 3).

At the Basona Worena site, oat–vetch and phalaris were preferred. In Endamehonei, oat–vetch, phalaris, alfalfa, and

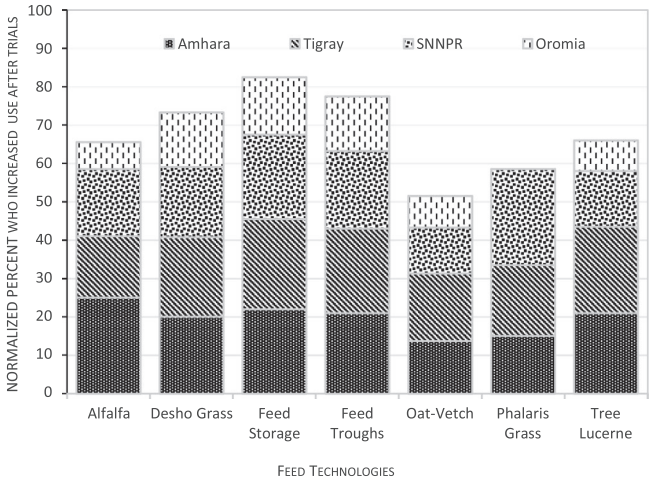


FIGURE 3 The proportions of respondents who increased the degree of use of specific feed and forage technologies, after trialing them on a farm. SNNPR, Southern Nations, Nationalities, and Peoples' Region

desho grass were all trialed and generally popular. In Lemo, desho grass was a major cultivated feed trialed, and it was very popular. In Sinana, none of these innovations were widely trialed, and there was a higher rate of discontinuation for all feed and forage innovations, suggesting either that they were inappropriate or there was not much demand for the innovations. Due to the highly grain-oriented farming systems, the latter explanation may be more likely.

3.5 | Synergistic effect of postharvest feed management innovations vs. adoption of cultivated forage innovations

Interestingly, there was no evidence that the use of postharvest feed management innovations increased uptake of cultivated forages. In fact, there was evidence to the contrary: that households who trialed postharvest feed innovations were less likely to continue using cultivated forage crops (Table 4). This could be due to a number of factors, and it should also be noted that there was no controlling for household characteristics such as wealth or livestock ownership. One possible and interesting explanation could be related to the rebound effect of being able to use feed more efficiently—then, there was less demand for feed and less impetus to cultivate dedicated feed crops.

3.6 | Seed system models for feed and forage innovations

One of the main constraints in promoting cultivated forage crops has been access to quality seed. Despite observed increased interest in forage crops, supply falls short in many parts of the country. Efforts to increase availability of forage seed in past years have had mixed success. On the one hand, currently there is a better awareness of the importance of forage crops by farmers and livestock keepers (Duncan et al., 2020). On the other hand, past investments either were not successful or, if they have been successful, they inhibited the development of a sustainable seed supply system because the seed is provided for free (Duncan et al., 2020). Accordingly, while many farmers appreciate the importance of cultivated forages for their livestock, they do not consider it their task to invest in these crops. They either wait for NGO or public handouts or they are not willing to pay for forage seed at prices that reflect the real cost of production (Negassa et al., 2016).

Most forage seed in Ethiopia is farmer produced, mostly for their own consumption. However, farmer level production tends to be very small in quantity, and when it is supplied to the market, it is often through government and NGO subsidy. This has been the case for many forage seed supply projects in the past. In what is called "farmer-based forage seed system," individual farmers are contracted to produce forage seed for government agencies or NGOs that would then distribute the seed to other farmers often free of charge or with high subsidy (Alemayehu & Assefa, 2012). A recent study by Negassa et al. (2016) indicated that the persistent high subsidy or free handout of forage seed is an indication that forage seed businesses are not yet profitable for many forage species. Farmers were found to be willing to pay only less than the amount of the current price of forage seed available in the market. Negassa et al. (2016) also found that the breakeven point for production of many of the forage species required significant increase in

TABLE 4 The role of postharvest feed management innovations in adoption of cultivated forage crops by households

Site	Cultivated forage	Cultivated forage plus postharvest feed management
	% continuing to use cultivated forage	
Basona Worena	92	48
Endamehonei	77	68
Lemo	88	73
Sinana	38	42

Note. Postharvest feed management innovations were crop storage buildings and feeding troughs for more efficient feed use. All the cultivated forage crops mentioned in Table 3 were here combined into a single group. The two numerical columns show the proportion of households that continued to use cultivated forage crops, for those that trialed only cultivated forages, and those that trialed cultivated forages in combination with postharvest feed management innovations.

seed production productivity per hectare. Hence, the forage sector in Ethiopia may remain informal and subsidized for a while for two reasons. First, the current low level of intensification of the livestock sector does not encourage forage production business, in general, and formal forage seed production, in particular. Second, for most forage species, seed productivity per hectare is too low to warrant a formal business approach and subsequent withdrawal of subsidies (Negassa et al., 2016).

If the informal forage seed sector is here to stay, it is important to ask how best we can support it and pave the way for its gradual transition into a business model. This has been the preoccupation of Africa RISING researchers. They started with action research on forage innovations in 2012. They introduced various forage species to understand the niche environments that support forage production in the project operational areas to create awareness and promote use of forage crops. "Project operational areas" refer to wider areas that extend to zones and regions in which the project reached through scaling of validated feed and forage innovation options. As the project moved into a scaling phase, the question then became the following: How do we make sure that the forage crops we introduced also produced seed for the subsequent season? This question emerged out of pragmatic financial considerations. With increasing number of beneficiaries during the scaling phase, the annual expenditure on forage seed was also increasing. The only way to reduce this cost was to encourage local seed production.

Accordingly, three seed system models, namely model farmer, FTC, and cooperative approaches that support informal forage seed production emerged from Africa RISING work (Table 5). The model farmer approach is the easiest to implement, but hard to coordinate and sustain in the long run. The FTC model tackles the deficiencies of a model farmer approach, but it suffers from the limited land available within FTCs for a wider promotion of forage seed business. We would hope that the cooperative approach is an innovative one in the long run. We believe that the approach could build social capital of farmers to produce forage and forage seed. Cooperatives can be used to finance the forage seed requirement. Hence, the approach could pave the way for a business model for future forage seed supply. Farmers could use their cooperatives to aggregate their forage seed as well as serve as forage seed retailers for private suppliers.

3.7 | Scaling of feed and forage innovations

Africa RISING in its second phase (2016–2021) has targeted to benefit 126,059 households with feed and forage innovations. In the last 4 yr (2017–2020) alone, the project has managed to reach and benefit more than 73,612 households with its validated feed and forage innovations (Figure 4). The geographical and administrative coverage of the feed and forage innovations has also increased from 4 to 31 woredas and from 4 to 9 zones. The Africa RISING project reached and benefited farmers with its validated innovations through direct researcher engagement, development partnership, and spillover scaling models and approaches.

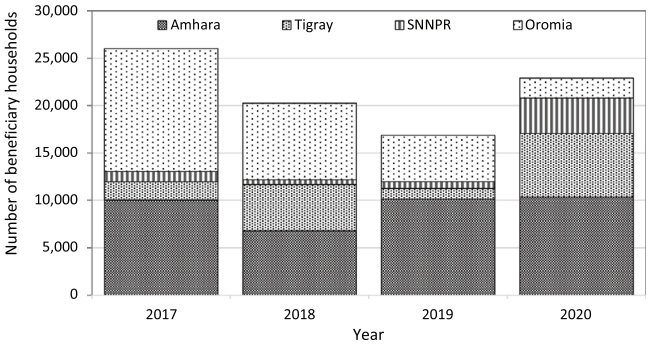


FIGURE 4 Beneficiaries of farm households from feed and forage interventions from 2017 to 2020. SNNPR, Southern Nations, Nationalities, and Peoples' Region

The direct researcher engagement scaling occurred when researchers demonstrated the feed and forage innovation options in selected representative farms and locations. This approach aims at creating demand of livestock keepers to engage in wider scaling of feed and forage innovations. Development partnership scaling has worked in a coinvestment arrangement, where the Africa RISING project provided training and demonstration for development partners who allocated resources and facilitated wider scaling of the feed and forage innovations. There has been scaling of Africa RISING validated feed and forage technologies within and beyond the project target communities without the involvement of Africa RISING researchers but through other actors, which we refer to as spillover effects. Spillover agents such as Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa, Innovation Lab for Small-Scale Irrigation, and Grass2cash projects similar goals of promoting improved feed and forage technologies and increasing livestock productivity in a sustainable manner. The approaches they followed were similar to Africa RISING, which started with on-farm research for development trials followed by, and working with, partner institutes to scale the technologies. The spillover agents directly took Africa RISING validated technologies for demonstration and promotion in their respective sites.

Some of the remaining challenges are the lack of good quality seed of the improved forage options to facilitate wider scaling, unaffordable seed price, competing use of forages for various products and services (feeding at early stage rather than managing a portion for seed production), shortage of financial resources, and lack of proper varietal release policy and seed certification.

TABLE 5 Description, potentials, and challenges of feed and forage seed multiplication models

Forage seed multiplication models	Brief description of the model	Feed and forage innovations	Observed potentials	Observed challenges
Model farmers	Model farmers are farmers who are open to experiment with forage innovations and are willing to take the risks associated with it. They are also farmers who can overcome constraints of forage seed production.	Oat, vetch, and desho grass	(a) In areas where there is land shortage, most farmers use their backyard to produce forage seed, and the number of farmers that allocate land for forage seed production is increasing. (b) In areas where farmers have relatively larger land size, such as in Oromia region, farmers allocate increasingly larger land size for forage production. (c) In some areas, such as the Amhara region, the high market price often encourages model farmers to produce vetch.	(a) Despite the increases over the years, farmers often still allocate only a small portion of their land for forage and forage seed production. (b) Across sites, feed shortages often tempt farmers to graze the forage before it sets seeds. (c) Across sites, free grazing during off seasons is a major challenge. (d) Across sites, market access for the limited forage seed produced is a constraint.
Farmer training centers (FTCs)	FTCs are village-based public extension delivery units. The centers have up to three dedicated staff and demonstration plots of 1–2 ha. The demonstration plots are divided for crop-, livestock-, and NRM-related technologies. In some of the Africa RISING operational areas, FTCs allocate part of their plot for forage seed production.	Oat and vetch	(a) The commitment in all Africa RISING operational areas to use FTCs for forage seed production is high. (b) FTCs are often fenced, limiting the possibility of free grazing. (c) Grazing before seed setting is also minimal. (d) The high market value of vetch seed is an incentive for FTCs.	(a) The FTCs have relatively little land to reach out to a large number of farmers. (b) FTCs tend to prioritize enterprises that would bring them more income. (c) Some FTCs are not fenced and have no guards, risking free grazing.
Farmer associations and cooperatives	Starting from 2020, Africa RISING encouraged local partners to deliver initial seed provided by Africa RISING through local cooperatives. The seed was provided to the cooperatives on a revolving basis, where cooperatives were required to return the amount of seed they received for the subsequent planting season. This approach was assumed to serve two interrelated purposes: (a) It would allow enforcement of seed production, as cooperatives could better control their members. (b) The approach would allow a market-based approach, because the cooperative could serve as either aggregators or retailers depending on the approach used.	Oat and vetch	(a) At all the sites, it is possible to find local cooperatives who are willing to engage in forage seed production. (b) All the cooperatives we worked with are able to provide the seed to their members with a commitment to return the seed or a cash equivalent. (c) When local cooperatives are members of local unions, it opens the possibility of forage seed certification and formal seed production .	(a) The model may exclude poor farmers who cannot pay for the seed upfront or take the risk of paying later. (b) The absence of dedicated private suppliers of early generation seed makes cooperative dependent on initial supply of seed either through government or project outlets like Africa RISING. (c) Some farmers are afraid of making a commitment to return the seed or pay for later in cash. (d) Limited market access to forage seed is also a concern for cooperatives.

Note. NRM, natural resources management; Africa RISING, Africa Research in Sustainable Intensification for Next Generation.

4 | KEY LESSONS LEARNED

4.1 | Continuous follow up and interaction with farming communities led to better performance and adoptability of feed and forage innovations

The Africa RISING project is peculiar compared with many other projects in terms of continuous close follow up of the action research activities as well as interaction with farmers and other actors. Partnership with local organizations, establishment of innovation platforms, presence of site coordinators, organization of various cross learning capacity building events, and conducting annual review and planning meetings contributed to the follow up and implementation of planned feed and forage innovations. The continuous follow-up approach has also assisted in drawing lessons and identifying challenges that have emerged while implementing the feed and forage innovations. Continuous interaction of Africa RISING site coordinators with farmers and extension staff improved the knowledge and skill on the application and use of feed and forage innovations at different sites. Mekonnen et al. (2008) reported how frequent follow-ups and backups are helpful to slowly raise the awareness and knowledge of some farmers who adopt and manage multipurpose trees. Continuous follow-up and interaction has been particularly important when there was extension staff turnover (one of the serious problems), and there is less attention given by the implementing partners when they are loaded with other office assignments.

4.2 | Demonstration of integrated feed and forage innovations enhances adoption and effective use of resources

Africa RISING project used demonstration of validated feed and forage innovations as one of the approaches to enhance familiarization and adoption at farm and landscape scale. Demonstration of forage innovations together with postharvest feed management and utilization practices at central locations such as FTCs and selected fields of innovative farmers improved their visibility and acceptability by farmers and extension workers. Formation of farmer research groups based on farmer interest and priority, and organization of periodic group visits for farmers was found to be useful to enhance innovation and cross-learning (Mekonnen et al., 2019). Those farmers who adopted integrated feed and forage innovations were able to mix crop residue and forages and used feed troughs to feed dairy cows and small ruminants and attained productivity and economic gains.

4.3 | Flexibility of feed and forage technological options enhances wider application

Flexibility of some of the feed and forage innovations such as feed troughs accelerated acceptance and adoption by smallholder farming communities. Farmers in the different project sites modified the feed trough technology in several ways depending on their needs, economic capacities, and ecological conditions. Some farmers constructed two-sided troughs (one side for cows and the other side for sheep and calves) and others one-sided troughs (for cows or sheep). Some used iron sheets for shading, and others constructed the feed trough under trees. Some farmers who own more livestock constructed large troughs, while those with few livestock constructed feed troughs that can feed 2–4 animals.

4.4 | Inadequate supply of seed remains a major challenge for scaling of forage innovations

The forage seed issue is a multilevel, complex problem requiring coordinated actions at user and supplier levels. At present, very few private sector actors such as Anno Seed Company, Eden Field – Agri Seed Enterprise, and a group of small forage seed entrepreneurs are engaged in forage seed production. These private sector actors have very limited capacity to produce enough forage seed to satisfy demand among livestock keepers (Aranguiz & Creemers, 2019). Africa RISING efforts to support the informal seed sector have faced challenges with competing use of forage for feed vs. seed at farmers' level. Because transitioning from the current near total informal forage seed supply to a formal system requires a complex intervention, it is important to continue experimenting with innovative approaches that would progressively help the transition. In this regard, the Africa RISING project found it important to work with farmer organizations such as cooperatives. Local cooperatives showed potential to bring together farmers' social capital for collective action, such as collective marketing of forage innovation inputs and outputs and coordinated actions of actors in the forage value chains.

4.5 | Transition from forage research to scaling requires a combination of complementary sets of actions

The combination of the action research approach, demonstration of technologies at farm conditions, engagement in multistakeholder platforms, joint planning and review of field activities, and capacity building of local partners were found crucial in progressive transitioning from research for

development activities to wider scaling. These approaches helped local partners to own the forage innovations and whenever they had the opportunity, tap into financial resources from elsewhere to scale them.

4.6 | Wider scaling of forage innovations requires a continuous effort to capitalize on existing opportunities and continually build an enabling environment

Past and current research for development efforts in Ethiopia showed mixed success. The future of the livestock sector also brings its own unique opportunities and challenges. There may not be a magic bullet to solve all the forage supply related problems. We believe that there is a need to continue putting in efforts to capitalize on existing opportunities and continually build an enabling environment. This includes, among others, to continue the support for the informal forage supply, to develop interest and create demand for forage innovations, to link forage innovations to output-oriented livestock products such milk and meat production, to strengthen the role of farmer organizations in forage supply, to address systemic constraints facing private forage seed suppliers, to improve the regulatory environment through initiatives such as forage seed certification, and to support a progressive transition from the current free handout of forages and forage seeds toward market-led business models.

5 | CONCLUSIONS

The Africa RISING project in the Ethiopian highlands worked closely with different partners to assess demands of smallholder farmers related to feed and forage innovations, validated the innovations with active participation of different groups of farmers, and facilitated scaling of the innovations with development partnership arrangements. The participatory and action research approaches improved familiarization and exposure of farmers to different feed and forage innovations. Our research approach also enabled the feed and forage research scientists to capture emerging issues, understand concerns of farmers, and solicit technological options that bridge feed supply and demand gaps. Research findings on livestock feed and forage waste reduction (30–50%) using postharvest feed and forage management and utilization innovations is an important development to increase resource-use efficiency leading to reduced greenhouse emissions per unit of product.

We draw the following key lessons based on our feed and forage action research approaches and wider scaling initiatives in the Ethiopian highlands. First, we identified the importance of continuous follow-up and interaction with farming communities as one of the tools to lead to better performance and adoptability of feed and forage innovations. Second, demonstration of integrated feed and forage innovations were found to be useful to enhance adoption and effective use of resources. Third, we realized how flexibility of feed and forage innovations (feed troughs) for modifications enhanced wider application. Fourth, we understood how inadequate supply of forage seed remains as a major challenge for wider scaling of forage innovations. The forage seed issue calls upon innovative seed multiplication strategies, enabling policy environment and active engagement of relevant stakeholders.

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AUTHOR CONTRIBUTIONS

Kindu Mekonnen: Methodology; Project administration; Supervision; Validation; Writing-original draft; Writing-review & editing. Melkamu Bezabih: Data curation; Supervision; Writing-review & editing. Peter Thorne: Funding acquisition; Project administration; Supervision; Writing-review & editing. Million Getnet Gebreyes: Validation; Writing-review & editing. Jim Hammond: Writing-review & editing. Aberra Adie: Data curation; Supervision; Validation.

CONFLICT OF INTEREST

Authors declare no conflict of interest in relation to this publication.

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