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Redesigning traditional weed management practices in faba bean fields to optimize food-feed production in the smallholder system

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Abstract

Duringthe main cropping season, Ethiopian farmers deliberately weed faba bean (*Vicia faba* L.) fields much later than recommended and use the weed herbage mass as feed. This study examined the rationale behind farmers' practices and explored options to further improve productivity. The study involved two experiments. The first compared the overall benefit from the traditional weed management regime against the frequent weeding recommendation. Sixty farmers participated, each preparing two plots. The plots were randomly assigned to either traditional (one late weeding) or improved (two early weeding) management. The second examined the suitability of intercropping faba bean with oat (*Avena sativa* L.). It involved a 5 × 3 factorial experiment, three management practices (traditional, improved, and faba bean oat intercropping) and five faba bean varieties repeated over 3 yr. In the first experiment the improved weed management increased grain yield (2.49 vs. 2.12 Mg ha^{-1}) compared to the traditional. But the traditional management produced higher (P < .01) weed forage biomass (2.12 vs. 0.27 Mg ha^{-1}) compared to the improved. The analysis showed the opportunity costs associated with the loss in weed forage biomass were not convincingly offset by the economic gains from increased grain yields. In the second experiment, grain yield was again highest for the improved weed management and lowest for the intercropping. Analysis of economic returns revealed that the intercropping management provides greater benefit over the traditional management practice. Farmers' decisions have a rational economic basis and building on the traditional practicewith improved forage intercropping would allow to further optimize productivity.

1 | INTRODUCTION

Livestock are important components of the livelihood strategies of smallholder farmers in Ethiopia, providing a variety of products and services to rural households as they are a

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; ITVOMD, in vitro true organic matter digestibility; ME, metabolizable energy; NDF, neutral detergent fiber; OC, opportunity costs; OM, organic matter; VCR, value/cost ratio.

source of food, cash income, farm power, savings, insurance, social capital, and manure as well as women's empowerment (Herrero et al., 2013; Kebebe et al., 2014). The demand for livestock products such as milk and meat is increasing in Ethiopia as a result of increasing population, urbanization, and rising income. The increasing demand for livestock products offers opportunities for smallholders to realize better livelihoods (Delgado, 2003; Francesconi et al., 2010).

Whereas the growing demand for livestock products in Ethiopia is well recognized, the sector has not been able to produce adequate livestock products to satisfy demand. Shortage of adequate supplies of quality feeds is one of the major constraints to increasing livestock productivity (Ayele et al., 2012). The feed shortage is fueled by continual conversion of pasturelands into arable lands due to high population pressure and growing demands for food crop production (Mekuria et al., 2018). As a result, crop residues and stubble grazing have increasingly become the main feed resources in the mixed crop–livestock system, although these feed resources are generally too poor in quality to meet requirements for a reasonable level of livestock production (Ayele et al., 2012; Duncan et al., 2016; Mengesha et al., 2017). Feed availability has become highly seasonal with supplies dwindling to a critically low level towards the beginning of the cropping season, when most arable lands are covered with crops.

In a diagnostic study Ellis-Jones et al. (2013) reported that farmers in southern and Amhara regions of Ethiopia have a traditional practice of deliberately weeding their faba bean (*Vicia faba* L.) fields much later than is recommended by the extension system. They use the weed herbage mass from the faba bean fields as a livestock feed during the main cropping season when stubble grazing is unavailable, and crop residue stocks are low. The bulk of this weed herbage mass is composed of grass volunteers from cereals and broadleaved weeds that emerge and grow within the tilled part of fields. In conventional agriculture, volunteer weeds are usually treated as a nuisance in much the same way as other weeds, as they have the potential to incur yield and quality losses through competition with the crop (Chauhan et al., 2012). Faba bean is a major food crop grown in Ethiopia and the country is the leading faba bean producers in the world next to China (FAO, 2019). Annually, the crop is grown on approximately 0.44 million hectares of land in the country by smallholder farmers (CSA, 2018). Given the economic and nutritional importance of faba bean grain and farmers' adequate knowledge of the effect of weed competition on grain yield (Merga et al., 2019), the reason behind their reluctance to adopt frequent weeding recommendations (referred as improved management) was not well understood by the extension system. We hypothesized that farmers do not apply improved weed management practices because the practices do not adequately improve the overall benefits (food-feed) that farmers derive from faba bean plots under their traditional management (feeding weeds to their livestock). The objectives of this study were therefore to: (a) compare the farmer-preferred traditional practice against the recommended practice of weed management on the likely overall benefits derived from faba bean plots when the value of the weed forage produced is also considered, (b) evaluate if intercropping forage oat (*Avena sativa* L.) with faba bean crop can increase food or feed production to better meet the demands of smallholders, (c) evaluate the performance of faba bean varieties under the different weed management practices.

Code Ideas

- Faba bean farmers have a traditional practice of using weeds as forages.
- The traditional practice was confirmed to provide an added advantage over improved practices.
- Use of weeds as forages gave greater overall productivity than frequent weeding.
- Introducing forage oat as an intercrop with faba bean can further improve incomes.

2 | MATERIALS AND METHODS

2.1 | Study districts

The study was conducted in two districts (woreda) of Ethiopia, namely Lemo and Basona, located in the southern and Amhara regions of Ethiopia, respectively. Lemo district lies between 07^{o}22'–07^{o}45' N and 37^{o} 40′–38^{o} 00′ E, with an altitude range of 2,000–2,500 m above sea level. The mean annual rainfall in this district varies between 1,100 and 1,170 mm, with mean maximum and minimum temperature of 23 and 15 ˚C, respectively. Basona district is located between 09^{o}01'–09˚35' N and 38^{o}48'–39˚29' E, with elevations ranging between 2,000 and 3,000 m above sea level. The mean annual rainfall in this district varies between 1,100 and 2,220 mm, with mean maximum and minimum temperature of 21 and 8 ˚C, respectively.

The climate in both districts is characterized by a long rainy season extending from June to September, followed by a short rainy season that extends from February to March. The dominant soil types in Lemo are vertisols and nitisols whereas in Basona soils include cambisols, vertisols, and lithosols. Cattle, sheep, donkey, and horses are the livestock species widely reared by farmers in both districts. The dominant crops grown in Lemo include wheat (*Triticum aestivum* L.), faba bean, teff [*Eragrostis tef* (Zuccagni) Trotter], and enset [*Ensete ventricosum* (Welw.) Cheesman], whereas the dominant crops in Basona are wheat, faba bean, barley (*Hordeum vulgare* L.), and potato (*Solanum tuberosum* L.).

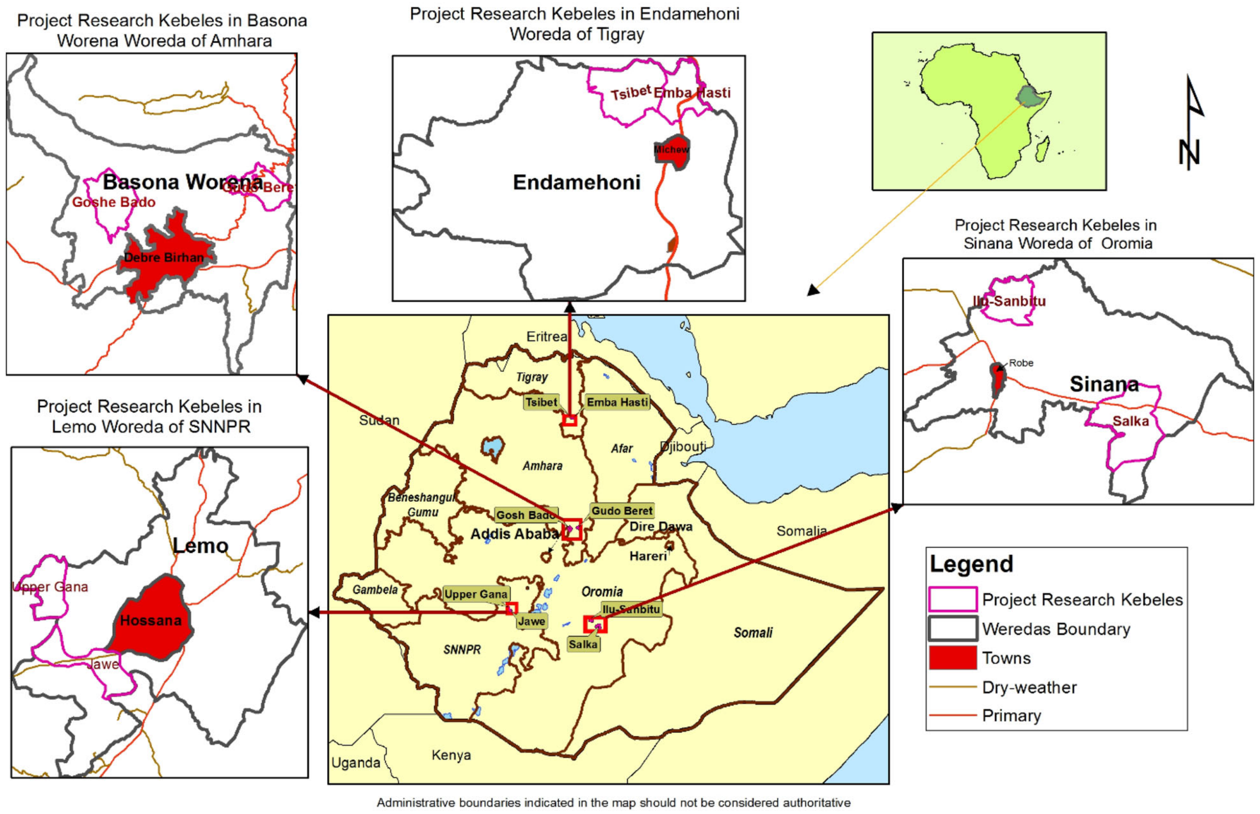

FIGURE 1 Map of Africa Research In Sustainable Intensification for the Next generation (Africa RISING) project districts in the Ethiopian highlands

The two districts are among research sites for the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) project of the Ethiopian highlands (Figure 1). They were selected for this study based on a preliminary observation that local farming communities in these areas intentionally leave weeds to grow with faba bean crops longer than recommended by the extension service for use as feed during the main cropping season.

2.2 | Experimental design

The study involved two on-farm experiments that were conducted sequentially. Results from the first experiment led to the initiation of the second experiment which evaluated sustainable intervention options. Experiment 1 was aimed at comparing farmers' traditional management of weeds in faba bean plots against improved management recommendation by the extension system on land productivity and income of smallholder farmers. This experiment was conducted in 2014 by involving a total of 60 farmers, 30 from each of the two districts. The traditional weed management practice involved one late weed harvest for forage use (at 6 wk after planting), whilst the improved management required two additional early weeding episodes (the first early in the growth of the faba bean – 2 wk after planting, and the second before the onset of flowering – 4 wk after planting). Each farmer prepared two 10 by 10 m plots and planted the faba bean variety called CS-20DK (developed from a local landrace population and widely grown by farmers) by applying the recommended fertilizer (100 kg diammonium phosphate (DAP) ha^{-1}) and seeding rates (200 kg ha^{-1}) (Agegnehu et al., 2006). Afterwards the plots were randomly assigned to either traditional or improved management practices.

Experiment 2 was intended to explore if introducing improved forage oat into the traditional faba bean production practice can increase food or feed production and to examine differences in competition tolerance among faba bean varieties. This experiment was conducted only in Lemo from 2015 to 2017. The study involved a 3 × 5 factorial experiment with three faba bean management practices (traditional, improved, and faba bean oat intercropping) and five faba bean varieties (CS-20DK, Tumsa, Walki, Gebelchu, and Dosha) in a completely randomized design with three replications. The five faba bean varieties used in this study were among those released by the national agricultural research system and are used by farmers in the area. The plot size for each treatment combination was 3 by 2 m, and the spacing between faba bean rows was 40 cm. In addition, replicates of pure forage oat plots were established as a reference to calculate land equivalent ratios. While the traditional and improved management practices were as described in Experiment 1, the faba bean oat intercropping management regime involved planting of oat forage between faba bean rows. The oat seed rate for the intercropping was 33 kg ha^{-1}. Di-ammonium phosphate was applied to all plots at the time of planting at a rate of 100 kg ha^{-1}.

2.3 | Data collection

Faba bean plant height and tiller count were recorded from 10 random plants per plot across the treatments when approximately 50% of the crop reached flowering stage in each treatment. Weed herbage mass and type were collected for the traditional management, after 6 wk of growth of the faba bean which coincided with the time when farmers traditionally harvest weeds for livestock feed. The weed herbage mass from the traditionally managed plots was recorded by harvesting and weighing the whole weed biomass within each experimental plot of all farmers who participated in the trial. The weed herbage mass from each farm was sorted according to species and subsequently the weed species were subsampled (500 g) for laboratory analysis.

Pods of 10 faba bean plants from three randomly placed 0.5 by 0.5 m quadrants in each plot were counted and the average number of pods per plant was calculated. Number of seeds per pod was estimated by dividing the number of seeds obtained by the number of pods collected from the sampled plants. Oat forage under the intercropping management was harvested (5–7 cm stubble height) when oat reached 40-cm height. Harvested was repeated two additional times to manage the oat regrowth from competition with the faba bean plant. Fresh biomass was weighed after each harvest and subsamples (500 g) were taken for further analysis. At maturity, all faba bean plots were harvested to 5–7 cm stubble height, weighed, and separated into faba bean grain, faba bean haulm, oat fodder, and weeds, weighed after sorting and subsampled (500 g) for analysis.

2.4 | Chemical analysis

Analyses of the samples took place at the animal nutrition laboratory of the International Livestock Research Institute in Addis Ababa, Ethiopia. All samples were dried at 65 ˚C for 48 h in a forced draft oven. Samples of faba bean haulm, weed, oat forage were ground to pass through a 1-mm sieve. Organic matter (OM), nitrogen (N), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin, in vitro true organic matter digestibility (ITVOMD), and metabolizable energy (ME) were estimated for faba bean haulm, oat, and weeds with near infrared spectrophotometry (NIRS) using predictive equations developed based on previously conducted conventional analysis on more than 500 samples (AOAC, 1990; Van Soest et al., 1991).

2.5 | Data analysis

2.5.1 | Experiment 1

Analysis of variance was conducted for yield and other agronomic data using the following model to examine management and site effects on the different yield components:

$$Y_{ijk} = \mu + S_i + M_j + S \times M_{ij} + e_{ijk}, \quad (1)$$

where Y is the dependent variable, μ is the overall mean, S is the effect of site, M is the effect of management, S × M is the interaction effect of site and management and e the error term.

For a value/cost ratio (VCR) analysis, monetary values were assigned for each of the three yield components (grain, haulm, and weed herbage mass) and incremental labor costs associated with the improved management, by considering local market prices at the time of the study. Then incremental return due to the improved faba bean management was calculated as:

$$y = \left(G_I - G_T\right) + \left(S_I - S_T\right) + \left(F_I - F_T\right) \quad (2)$$

where

y is the incremental return,

G_I and G_T are monetary values of grain yield from the improved and traditional management, respectively,

S_I and S_T are monetary values of haulm yield from the improved and traditional management, respectively

F_I and F_T are monetary values of forage yield from the improved and traditional management, respectively

Then the increamental labor costs associated with the improved management was deducted from the incremental return to calculate the net incremental return.

Opportunity costs (OC) of the improved mangement were calculated as the monetary values of the weed herbage mass generated in the traditional practice as follows:

$$\text{OC} = \text{total weed herbage mass harvested from the traditional management} \left(\text{tonne}^{-1}\right) \times \text{unit price of herbage mass} \left(\text{birr tonne}^{-1}\right) \quad (3)$$

Then the VCR was calculated for the improved management to examine the level of economic incentives for adopting the improved management over the traditional practice.

VCR = Netincrementalreturns ÷ OC (4)

where VCR = value/cost ratio, OC = opportunity costs

TABLE 1 Comparison between traditional and improved weed management practices on the agronomic performance of faba bean crop in Lemo and Basona districts of the highlands of Ethiopia

Site	Management	Plant height	Weed herbage mass	Haulm yield	Grain yield
		cm	Mg DM ha^{-1}		Mg ha^{-1}
Lemo	Improved	92	0.41	2.24	2.17
	Traditional	81	1.96	1.77	1.74
Basona	Improved	184	0.12	3.58	2.81
	Traditional	149	2.22	3.01	2.50
SEM		6.8	.075	.107	.055
Site		<.001	.187	.001	<.001
Management		.038	<.001	.043	<.001
Site × Management		.502	.651	.395	.134

Note. DM = dry matter; SEM = standard error of the mean.

2.5.2 | Experiment 2

Data were analyzed using the General Linear Model procedure of SAS:

$$Y_{ijk} = \mu + V_i + M_j + P_k + V \times M_{ij} + e_{ijkm}, \quad (5)$$

where V is the effect of variety, M the effect of management, $V \times M$ the effect of variety and management interactions. Tukey's Student Range Test was used to separate means at $P < .05$.

To further evaluate if intercropping faba bean with forage oat improves land productivity for smallholders, land equivalent ratio (LER) was calculated.

$$LER = r_{oat} + r_{fababean} \quad (6)$$

where r_{oat} is the ratio of oat yield obtained under intercropping to that under sole cropping; r_{fababean} is the ratio of yield of faba bean obtained under intercropping to that under sole cropping.

TABLE 2 Value/cost ratio analysis of improved vs. traditional practices at two districts in Ethiopia

Variables	Lemo	Basona
Incremental returns due to improved management		
Incremental faba bean grain yield, Mg ha^{-1}	0.43	0.31
Incremental faba bean residue biomass, Mg ha^{-1}	0.47	0.57
Total incremental returns, birr	7,390	5,790
Incremental variable costs		
Labor cost, birr	1,440	1,440
Net incremental returns, birr	5,950	4,350
Opportunity costs		
Total weed herbage mass from traditional practice, Mg ha^{-1}	1.55	2.15
Total opportunity costs, birr[a]	3,100	4,300
Value/cost ratio	1.92	1.01

[a]Price of forage in the local market: 2,000 birr Mg^{-1}.

3 | RESULTS

3.1 | Comparison between traditional and improved faba bean management practices

Results of the first experiment where traditional and improved weed management practices were compared on the overall yield performance of faba bean plots across the two study districts is presented in Table 1. The improved weed management resulted in greater grain yield and haulm yields. The traditional practice on the other hand produced greater (<0.05) amount of weed herbage mass. The economic data is presented in Table 2. The VCR for the Basona district was just on the break-even threshold (1.0) and that for Lemo was well above the break-even point.

3.2 | Weed species and chemical composition from traditionally managed faba bean plots

The composition of weed species, chemical composition, and metabolizable energy are shown in Table 3. The two districts had different weed species composition. Out of the 11 weeds identified three of them were found in both districts. Basona district had more diversified weeds than Lemo district. *Phalaris* and *Medicago* species were the dominant species in Basona district contributing approximately 58% of

TABLE 3 Weed species composition, chemical composition and metabolizable energy (ME) concentration of common weeds used for forage growing in traditional faba bean farms in two districts of the Ethiopian highlands

Weed species	Weed species composition, percentage on dry matter basis		Nutrient composition						
	Basona	Lemo	OM	CP	NDF	ADF	ADL	IVTOMD	ME
	%		g kg^{-1} DM						MJ kg^{-1} DM
Phalaris spp.	32	–	921	77	711	390	42	580	8.8
Avena fatua	1.3	41	860	96	710	441	50	581	8.1
Lolium spp.	3.4	–	972	66	702	419	44	562	9.0
Medicago polymorpha	25.5	–	911	162	531	390	64	661	9.7
Trifolium spp.	4.5	–	902	195	502	372	61	703	11
Snowdenia spp.	3.0	–	920	75	694	449	101	559	8.5
Scorpiurus muricatus	4.8	–	943	201	493	222	54	603	9.4
Setaria spp.	–	1.8	852	116	660	430	44	718	9.8
Galinsoga spp.	3.1	12	821	114	440	421	84	819	11.4
Guizotia scabra	–	9.8	780	128	412	443	101	778	12.8
Polygonium spp.	1.0	12.4	840	85	459	388	87	840	11.5
Other weed spp.	21.4	23	833	109	509	371	58	731	8.9
Avena sativa[a]			901	101	572	413	62	682	8.8

Note. OM = organic matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; IVTOMD = in vitro true organic matter digestibility; DM, dry matter.
[a]Improved oat forage.

the total weed dry matter, whereas *Avena fula* was the dominant one in Lemo district accounting for 41% of the weed dry matter harvested. Unidentified weeds accounted 21 and 23% of the weed dry matter yield in Basona and Lemo districts, respectively. The chemical composition of the weeds varied widely, with the CP content ranging from 6.6% (*Lolium* spp.) to 20.1% (*Scorpius* spp.), NDF content from 41% (*Guizotia scabra)* to 71% (wild oat, *Avena fatua* L.), IVTOMD from 58% (wild oat) to 84% (*Polygonium* spp.), and ME content from 8.1 MJ kg^{-1} DM (wild oat) to 12.8 MJ kg^{-1} DM (*Guizotia scabra*).

3.3 | Effect of intercropping faba bean with forage oat

Table 4 presents the results of observations of the grain, haulm, and forage yields for the traditional weed management, improved weed management and intercropping practices using different faba bean varieties over 3 yr. There were significant differences ($P < .05$) in grain, haulm, and forage yields due to management practice. Varietal differences ($P < .05$) were observed for haulm and forage yield, but not for grain yield. However, there was no management × variety interaction on the yield variables, indicating similar trend in the performance of the different varieties when subjected to the three management practices. Seasonal differences were significant for grain and forage yields. The forage yield from the improved practice was almost nil due to the frequent weeding, while that from the traditional practice averaged 1.25 Mg DM ha^{-1}. By intercropping faba bean with forage oat, it was possible to double the forage yield over the traditional practice with little compromise on grain yield.

The economic gains from the three management practices are presented in Table 5. The calculations showed that intercropping faba bean with oat forage has a potential to increase the gross income that farmers derive from their faba bean farms by approximately 8%, providing much needed forage for livestock during the main cropping seasons. The land equivalent ratio as shown in Figure 2 was above unity for all faba bean varieties. This indicates that the intercropping practice can contribute to land productivity, reducing the area required by a factor of 1.08–1.33 to produce the same quantity of yield that can be obtained using the sole cropping practice.

3.4 | Varietal differences in the chemical composition of the haulm

The chemical composition and ME content of the faba bean haulms is presented in Table 6. The results showed varietal

TABLE 4 Effects of weed management practices and intercropping faba bean with forage oat on grain, haulm, and forage yields using different faba bean varieties over 3 yr in the highlands of Ethiopia

Management	Faba bean variety	Faba bean grain yield	Faba bean haulm yield	Oat or weed yield
		Mg ha^{-1}		
Traditional	CS-2ODK	2.71	5.08	1.35
	Tumsa	2.91	6.82	1.03
	Walkie	3.10	6.97	1.52
	Gebelcho	2.90	5.95	1.28
	Dosha	3.00	7.07	1.19
Improved	CS-2ODK	3.30	6.44	0.20
	Tumsa	3.10	8.33	0.13
	Walkie	3.39	7.04	0.05
	Gebelcho	3.06	6.94	0.08
	Dosha	3.31	7.62	0.11
Intercropping	CS-2ODK	2.88	6.41	2.01
	Tumsa	3.49	7.97	2.09
	Walkie	3.09	6.88	2.13
	Gebelcho	2.99	5.86	3.85
	Dosha	2.98	6.96	3.49
Season				
	Year 1	3.26	6.32	1.24
	Year 2	2.91	6.58	2.93
	Year 3	3.15	7.11	1.64
SEM		.056	.144	.102
P values				
Management		.031	.008	<.001
Variety		.191	.002	.811
Season		.173	.081	<.001
Management × variety		.83	.61	.99

Note. SEM = standard error of the mean.

TABLE 5 Estimated average income from the use of different faba bean management practices in Lemo, southern Ethiopia

Management	Returns from sales				Costs			Income
	Grain	Haulm	Forage	Total	Labor	Forage seed	Total	
	birr							
Traditional	44,100	9,645	3,630	57,375	3,600	–	3,600	53,775
Improved	48,150	10,905	–	59,055	4,800	–	4,800	54,255
Intercropped	45,750	9,990	9,240	64,980	6,000	910	6,910	58,070

differences in CP, fiber fractions (NDF, ADF, and , acid detergent lignin [ADL]), IVTOMD, and ME concentration of the haulms. The CP concentration ranged from 7.4% (Tumsa) to 10.4% (Walkie). The NDF content of the haulms ranged from 55% (CS-20DK) to 67% (Gebelcho). Two of the varieties, CS-20DK and Walkie, had similar levels of NDF of around 55%, while the others had NDF content of 66–67%. The haulm TIVOMD varied between 60% (Tumsa) and 70% (CS-20DK). All in all, looking at the chemical composition and ME concentration, the haulm derived from CS-20DK appeared to have a better fodder quality, whereas that derived from Tumsa had lower quality.

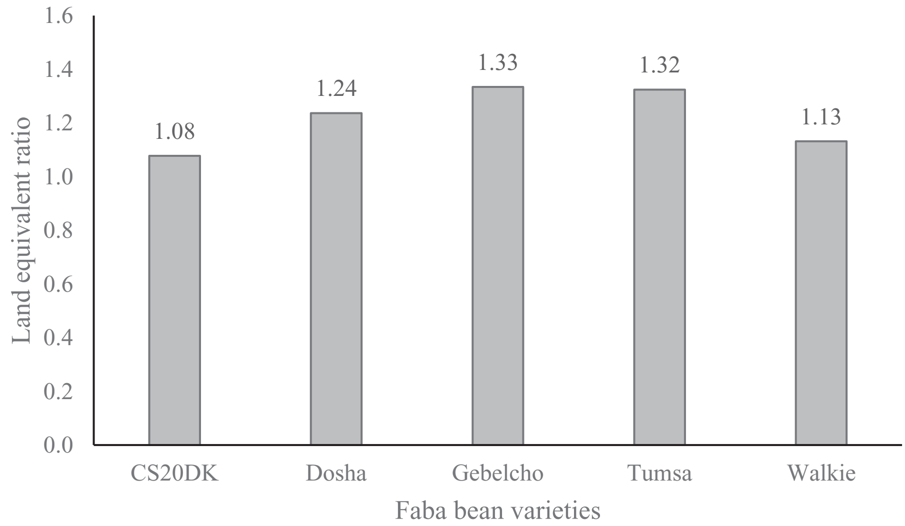

FIGURE 2 Land equivalent ratio for the faba bean oat forage intercropping practice as influenced by faba bean varieties

TABLE 6 Chemical composition and metabolizable energy (ME) of haulms of faba bean varieties studied

Variety	CP	NDF	ADF	ADL	IVOMD	ME
			g kg^{-1} DM			MJ kg^{-1} DM
CS-2ODK	102	554	527	92	698	7.5
Tumsa	74	663	632	124	599	6.5
Walkie	104	546	524	93	657	7.2
Gebelcho	101	671	644	105	654	7.1
Dosha	79	664	638	125	610	6.9
Mean	92	620	593	108	644	7.0
SEM	1.06	6.20	6.09	1.74	4.16	.63
P value	<.001	<.001	<.001	<.001	<.001	<.01

Note. CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; IVTOMD = in vitro true organic matter digestibility; SEM, standard error of the mean.

4 | DISCUSSION

4.1 | Experiment 1

The observed differences in tiller count, plant height, grain and haulm yield between the management practices appeared to be associated with the level of weed competition under the two practices and are line with previous reports that the agronomic performance of faba bean plant is directly related to the level of weed infestations (Grenz et al., 2005). The experiment confirmed that the traditional practice produces significant amounts of weed herbage mass at the expense of grain yield, and farmers are willing to lose some level of grain yield and keep their livestock in the mixed farming system.

The chemical composition and ME concentrations of the weed herbage samples indicated that the weed forages can be classified as moderate to good quality, with almost all the weeds fulfilling the minimum CP concentration required for normal ruminant functioning and showing moderate to high IVOMD (Bezabih et al., 2013; Meissner et al., 2000; Van Soest, 1994). In fact, some of the weed species, such as *Medicago polymorpha*, *Scorpiurus muricatus*, and *Guizotia scabria* can serve as protein supplements for ruminants fed on low quality straw basal diets (Mengesha et al., 2017).

While the forages produced have a direct market value, the total ME produced from the weed forage biomass is estimated to be approximately 18 GJ per hectare from the traditional management practice. This amount of energy would be enough to fulfil maintenance requirements of five to six mature cattle for approximately 3 mo (NRC, 1996). Alternatively, it would enable farmers to satisfy the maintenance and milk production requirements of three lactating cows with a potential to produce 6 L of milk per day for 3 mo (NRC, 2001). All these show the importance of forage weeds in bridging feed shortfalls during the main cropping season, which usually lasts for about 3 mo.

A commonly applied rule of thumb for smallholder systems is that a value/cost ratio (VCR) of at least 2 is required to sufficiently convince farmers and incentivize them to adopt new management practices (Jayne et al., 2002). In the present result, the VCR analysis indicated little economic benefits of the improved management practices at Basona, and still less than the minimum threshold expected for adoption at Lemo. The analysis thus indicated that the opportunity costs associated with the loss in weed herbage mass when the improved practices were adopted were not adequately offset by the economic gains from increased grain yield and crop residue biomass for the smallholder crop livestock system. This analysis showed that farmers make decisions from a systems perspective and choose a practice that optimizes the overall benefit from their small plot of land. This system thinking of farmers and their logic for adoption or lack of adoption of a new practice has long been acknowledged (Vanclay & Lawrence, 1994).

Furthermore, our VCR calculations do not account for socio-economic factors that potentially pose greater barriers to adoption. For instance, some farmers have no other options for providing feed for their livestock during the periods when these weeds would be available. Foregoing this indispensable forage resource at a critical time would force these farmers to sell their animals for lower prices. As livestock is an essential component of the mixed system, being almost the sole source of farm power (traction), selling of an animal at a reduced price or forgoing milk production for household consumption would aggravate the loss of farmers. Generally, this study confirms the initial hypothesis that farmers place considerable value on livestock in the farming system, and that their chosen practice indeed optimizes the overall benefit that they can derive from their plots.

4.2 | Experiment 2

The benefits of the traditional practice are clear, so it is valuable to find ways to build on these existing traditional practices for a further intensification of the mixed system. In the present analysis, introducing improved forages as an intercrop with faba bean was considered for the intensification trajectory for two main reasons. First, under the traditional management, weeds are normally harvested for livestock feeding before the onset of seed formation by the weeds, and continuous removal of the weeds over the years may result in depletion of soil seedbanks for the "preferred" weeds and favor emergence of undesirable weed species which have less value as livestock feed. This was indicated in the informal discussions held with farmers in the Lemo district, during which farmers noted that the quality of the weed herbage mass they harvest has changed over time, and now they believe that the feeding quality of the weed herbage mass has declined (personal communication, 2015). Second, as land is in short supply farmers would relatively easily adopt to produce improved forages as intercrops in the same way they grow volunteer weeds for feed. The results of the second experiment indicated that forage oat can indeed provide additional benefit (Table 4) by doubling the feed biomass obtained compared to that of volunteer weeds without a considerable effect on grain yield. This result is generally in line with previous reports which indicated that intercropping legumes such as faba bean with cereals increases biomass and grain yield as well as land equivalent ratio compared with sole cropping (Helenius & Jokinen, 1994; Neumann et al., 2009; Schröder & Köpke, 2012). Forage oat has a potential to regrow after early first cut, and it can be harvested at least twice before the faba bean plant flowers, allowing farmers to have a steady supply of forage during the crop growing period. An important advantage of this practice is that it would not be a major departure from the traditional management they have been practicing, except that they need to have access to forage oat seeds to plant with the faba bean. Farmers can multiply forage oat seeds in the same way as wheat or barley. In general, this study highlights that in subsistence mixed farming systems where land is in short supply to meet food and feed demands, capitalizing on traditional practices and introducing forages as intercrops can provide better results towards improving the livelihood of farmers.

4.3 | Choice of faba bean varieties

It is important to note that when improved forages such as forage oat are intercropped with faba bean, the competition between the main crop and the forage may increase due to higher growth potential of the forage (Grenz et al., 2005). The mixture needs to be managed closely so that the forage does not overtake the faba bean plant due to its fast growth. Choosing faba bean varieties that are capable of tolerating competition with weeds and forage intercrops is very important. In the present study, varietal differences in grain yield were not significant, indicating that all of them competed similarly when subjected to the different management practices. However, varietal differences were observed in haulm yield and haulm fodder quality. While Tumsa and Dosha varieties showed higher haulm yield, CS-20DK, Walkie, and Gebelcho varieties were found to be better in CP concentration and IVTOMD. The haulm quality of these varieties is generally in line with the established knowledge that pulse haulms have better nutritional quality than cereal straws, with higher CP and digestible nutrients (Gizachew & Smit, 2005; Smil, 1999). Looking at haulm yield and composition, Tumsa and Walkie varieties may provide better results.

5 | CONCLUSION

The present study highlighted farmers rational thinking in their decision-making process and the importance they give to their livestock. Capitalizing on the existing indigenous weed management practice would help to identify adoptable intensification strategies. Intercropping faba bean with forage oat appears to be in line with farmers preference and it would help to optimize food-feed production by smallholders under prevailing resource constraints. Future variety development efforts for the smallholder mixed systems may need to consider competition tolerance as an important trait.

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CONFLICT OF INTEREST

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

AUTHOR CONTRIBUTIONS

Melkamu Bezabih: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing-original draft; Writing-review & editing. Kindu Mekonnen: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Writing-review & editing. Aberra Adie: Data curation; Formal analysis; Investigation; Methodology; Investigation. Tamene Tadesse: Investigation. Ajebu Nurfeta: Investigation; Methodology. Workneh Dubale: Data curation; Investigation; Project administration. Tesfaye Habiso: Investigation. Tessema Z. Kelkay: Investigation; Methodology. Million Getnet: Investigation; Writing-review & editing. Kebebe Ergano: Conceptualization; Data curation; Investigation. Alan J. Duncan: Conceptualization; Methodology; Writing-review & editing. Peter Thorne: Conceptualization; Data curation; Formal analysis; Funding acquisition; Project administration; Resources;Visualization

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