Article

Barley Straw Use for Animal Feed and Soil Mulch in Ethiopian Highlands Mixed Crop-Livestock Systems

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Abstract: Barley straw serves as livestock feed and mulch for soil and water conservation in the mixed barley-livestock systems of the Ethiopian highlands. High demand for barley straw biomass in the system creates competition between the two uses. This study aimed to identify the determinants of the utilization of barley straw for mulch and feed. Data on the production and use of barley straw were collected from 236 households using a structured questionnaire. Use of the straw for the purposes of soil mulch at three levels, 0–15% (marginal mulching), 15–35% (optimal mulching), 35–100% (over-mulching), was analyzed using a multinomial logit model. The optimal proportion of barley straw used as soil mulch was positively affected by the educational level of the household head, family size, distance between cropping land and homestead, number of equines in the household and amount of straw production. Female-headed households were more likely to mulch less than the optimal amount of barley straw. In general, the more the farmer's exposure to formal extension, the less the proportion of barley straw used for soil mulching. This study provides guidance for the proportional utilization of barley straw. This will contribute to the design of appropriate biomass utilization strategies in barley-livestock farming systems.

Keywords: barley; barley-livestock farming system; livestock; straw

1. Introduction

Mixed crop-livestock farming systems are the backbone of farmers' livelihoods in developing countries [1,2]. In these systems, the use of crop residues is important for various uses that include soil mulching and livestock feeding [3]. In cereal-based crop-livestock systems, residues include stover and straw from cereal crops after harvesting the grain. The retention of such residual biomass in crop fields has the potential to improve soil quality by reducing surface runoff, enhancing soil moisture, improving soil structure and potentially suppressing weed growth [4]. However, mixed crop-livestock farming systems typically use crop residues for livestock feed. This often becomes increasingly important due to the expansion of cropland, low productivity of natural pasture and prevailing livestock feed scarcity [5]. In the Ethiopian highlands where crop-livestock systems are prevalent, the contribution of straw to the total dry matter fed to livestock ranges from 10% to 70% [5]. The efficient utilization of straw resources will decrease soil erosion, enhance soil fertility, improve livestock feed supply, decrease pollution, produce biofuels and create jobs in rural societies. In Ethiopia, the barley-livestock farming system is predominantly found in the Central Highlands [6].

Barley is a major food crop in the highland areas of Ethiopia. The annual main season area covered by barley crop is 0.92 million ha, making up 13% of the total area in the country [7]. This system includes tree crop production with the emergence of apples and small backyard garden patches. Sheep are the dominant livestock type, with one or two cattle for milk production and equines for the transportation of goods. Livestock is fed mainly on natural pasture, rangelands and barley straw. Agricultural activities and petty trade are important sources of income. Poverty is severe in these systems with deteriorating food security [6]. The pressure on the barley-livestock farming system is increasing due to the increase in human and livestock populations, income and rate of urbanization [1]. These challenges tend to intensify land use, which results in the continuous cultivation of cropping lands without fallowing [8,9]. Without suitable investments in agricultural land management, this may contribute to land degradation and the deterioration of productivity [10]. It has been reported that leaving 30% of the straw on crop farm plots decreases soil erosion by up to 80% [11]. Barley straw is a key resource in mixed crop-livestock systems in the country. Production of 1 metric ton of barley grain is accompanied by 1.2 metric tons of straw. Barley straw has a better nutritive value compared to wheat straw with an average of 90.9% dry matter, 3.8% crude protein and 6 MJ metabolizable energy per kg of dry matter [12]. However, it is rich in lignocellulose and poor in calcium and phosphorus. Ruminant animals have the ability to utilize barley straw since the ruminal microbes have the ability to ferment cell walls. Caecal microbes in equines also have the ability to digest fiber [12,13].

Maize crop residue (i.e., stover) is also used for soil mulching and livestock feeding in Ethiopia. Extension outreach has been shown to encourage farmers to leave more maize stover on crop plots. Farmers who keep more livestock in the household were more likely to use more maize stover for feed and less for soil amendment. Cropping pattern, farm size, agro-ecology and crop residue production affect maize stover use in the mixed farming systems of Ethiopia [14]. The use of cereal and pulse straw by smallholder farmers in mixed farming systems in Ethiopia has also been studied [15]. The use of cereal and pulse straw for soil amendment was positively influenced by the education level of the farmer, the distance between the homestead and the cropping plot, extension service, awareness about soil amendment, the cropping plot slope, farmer-to-farmer extension and the stock of crop residue [15].

Farming at higher slopes without leaving crop residues as mulch can accelerate soil erosion [16]. One of the impacts of soil erosion is the loss of soil productivity over time. Therefore, the cost of soil erosion can be conceptualized as the monetary value of reduced crop yield(s) resulting from lost soil productivity. In Ethiopia, the estimated cost of soil erosion assuming a soil loss rate of about 20 metric tons per hectare per year is an average of a 0.4% annual decline in value for all cereals [17]. The impacts of soil erosion are not just for one year but can continue over multiple years until erosion is reduced through soil conservation measures such as mulching of crop residues [18].

While prior research has identified factors that encourage or discourage Ethiopian farmers from using crop residues for soil conservation, the focus so far has been on pulses, corn grain and other cereals. No studies have evaluated straw use exclusively for barley-livestock systems in Ethiopia. Therefore, this study aims to fill this knowledge gap around the challenges to using the optimal proportion of barley straw as mulch and as livestock feed/bedding by Ethiopian highland farmers. The objectives of our research are to (1) determine the relative values of use of barley straw as mulch for reduced erosion compared to use as livestock feed/bedding and (2) identify the characteristics of farmers more or less likely to use barley straw as mulch for soil conservation and as feed for livestock feeding. This can help agricultural extension and other stakeholders design more targeted approaches to encourage farmers to use the optimal proportion of barley straw as mulch and as livestock feeding.

2. Material and Methods

2.1. Study Area and Data

The study was conducted in cereal-based farming systems of six districts of Oromia Regional State, Ethiopia. These sites represent highland regions of the country that have the potential for barley production. The average minimum temperature ranges between 6–17 °C and the average maximum temperature between 20–36 °C. The mean annual rainfall varies between 900 to 3800 mm (Table 1). Barley is grown between June and December. The dominant soil type of the locations is loam soil, sandy soil, black vertisols, red nitisols and camisols. The sources and provision mechanisms of agricultural extension services are similar across the districts only the skills of the extension workers vary. A total of 236 households randomly selected from 12 farmer associations within six districts were interviewed (Table 1, Figure 1). Households within each farmer association were selected using a proportionate-to-size sampling method. Data from farmers, including household characteristics and barley straw allocations, were collected using a structured questionnaire. Barley straw was calculated by a straw-to-grain ratio of 1.2 [19].

Table 1. Description of sites and distribution of households surveyed.

Zone	District	Village	N	Altitude	Temp (°C)	Rainfall (mm)
West Arsi	Kofele	Germama	21	2700	19.5	1800
		Guchi	21			
Oromia	Sululta	Nono Sayo	8	2450	16.5	1060
		Waresa Malema	9			
North Shewa	Degem	Digalu Kidame	26	2878	18.5	1118
		Digalu Bora	12			
Arsi	Tiyo	Dosha	19	2200	19.5	1118
		Hora Bulbula	22			
	Lemu Bilbilo	Lemu	26	2567	16	1100
		Chiba Mikael	29			
	Degaluna Tijo	Digalu Kidame	27	2700	17.5	2750
		Digalu Bora	12			

2.1.1. Erosion Cost and Mulch Value Calculations

Straw Value as Feed and Mulching

It has been reported that leaving 30% of crop residue in the cropping plot after harvest would decrease soil erosion by 80%. Using lower than 15% of barley straw for soil mulching would lead to soil deterioration while using more than 35% would be a waste of biomass. Thus, the allocation of barley straw to soil mulch was recoded into an ordinal variable, 1 if it was between 0% and 15%, 2 if it was between 15 and 35 and 3 if higher than 35%.

Data on the value (cost) of one metric ton of straw for feeding and straw yield per ha were collected using questionnaires and the straw value per ha in USD/ha/yr (Etb/ha/yr) was estimated by multiplying the straw yield by the mean value (cost) per metric ton.

The difference in total cost per ha for farmers not using versus using barley mulch was considered the present value of straw for mulching.

The future value of straw for mulch was estimated from the present value by considering a 10% discount rate and summing up the entire stream of values from all the years in a future time horizon of 10 years. An infinite time horizon was assumed for the computation of gross discount future value: some researchers used 100 years [17], 25 years [20] or 10 years as the time horizon [21]. There was no specific or standard time horizon; therefore, 10 years was used for this study as a time horizon.
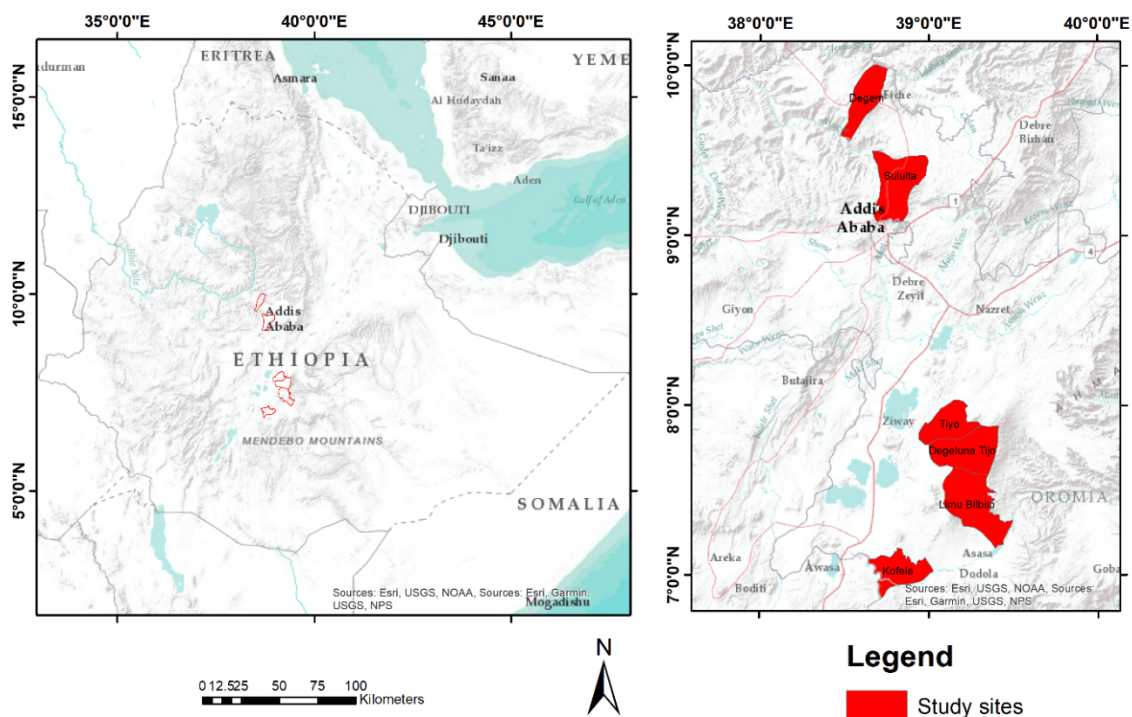
Figure 1. Ethiopian municipalities used for farmer surveys.

Straw Value and Erosion Cost Calculations

The study area required quantifying soil loss. Soil loss was estimated using the universal soil loss equation (USLE) [22] adapted to Ethiopia [23].

$$A = R*K*L*S*C*P \tag{1}$$

where A is the estimated soil loss (metric tons/ha/year), R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor; C is the land cover factor and P is the management practice factor. The erosivity factor (R) was calculated based on tabular values [18] used specifically for Ethiopia [19] based on long-term annual rainfall (P) and defined as

$$R = -8.12* + (0.562*P). \tag{2}$$

The rainfall data in Table 1 were used as long-term annual rainfall (P) for this calculation. The tabular values for the soil erodibility factor (K), slope length factor (L), slope gradient factor (S), land cover factor (C) and management practice factor (P) were also determined using values adapted for Ethiopia [23]. A summary of the range of values used for this calculation is presented in Table 2.

Table 2. Summary of the range of values used for calculating erosion.

Factors	Range of Value Used
Rainfall erosivity factor(R)	586–1532
Soil erodibility factor (K)	0.15–0.25
Slope length factor (L)	0.5–3.8
Slope gradient factor (S)	0.4–4.3
Land cover factor (C)	0.001–0.4
Management practice factor (P)	0.5–1

Higher soil erosion for farmers not using barley mulch versus those using it can result in 0.4% lower crop yields for un-mulched systems [16]. The annual cost of erosion was estimated by multiplying the amount of such soil loss measured in metric tons (t) per hectare (ha) by the value of crop losses attributed to such soil loss. The total monetary value of both grain and straw yield reduction from soil erosion was estimated to be USD 5.20 for an assumed soil loss of 20 t/ha [16]. Thus the value of reduced barley grain and straw yield of USD 5.20 divided by 20 t/ha equals USD 0.26/t (Etb 10.65/t) of eroded soil. This is the estimated present monetary cost per one metric ton of soil loss. The difference in monetary value (USD $12.69 - 8.14 = 4.55$ or $524 - 336$ Etb $= 188$ Etb) per ha for farmers not using versus using barley is conceptually the present value of using straw mulch for preventing yield loss.

The future monetary costs of not using straw mulch are the successive losses in crop yield and the values expected in future years discounted to the present day. We used the standard formula for discounting future values to present value (PV):

$$PV = FV \times (1/(1+r)^n) \tag{3}$$

where FV is a future value of the cost of erosion, r is the assumed discount rate of 10% and n is the time period into the future whose FV is being discounted to the present day.

2.1.2. Empirical Analysis

The theoretical framework adopted for this study is based on the random utility model. The model is described as follow:

$$U = X\beta + \varepsilon \tag{4}$$

where U is a farmer's decision on barley straw utilization, X is the explanatory variable, β is the parameter to be estimated and ε is the error term associated with the estimation. Assuming Y_{ia} and Y_{ib} are the farmer ($_i$) selections on the three levels of barely straw mulching, which are based on the utilities obtained from them, they can be presented as U_{ia} and U_{bi}. The option picked by the farmer ($_i$) between the three uses reveals which one has a higher utility; however, the farmer's utility is latent. Thus, the observed indicator is equal to 1 if $U_{ai} > U_{bi}$ and 0 if $U_{ai} \leq U_{bi}$. This is specified as:

$$U_i^a = X_i\beta_{ia} + \ell_{ia} \tag{5}$$

$$U_i^b = X_i\beta_{ib} + \ell_{ib} \tag{6}$$

Given the proposition that a farmer prefers the option with the highest net benefit, the observable discrete choice option is related to the latent continuous dependent variable as specified in the equation:

$$Y_{ia} \begin{cases} 1 \; if \; U_i^a > U_i^b \\ \\ 0 \; if \; otherwise \end{cases} \tag{7}$$

Thus, Y_{ia} is a binary dependent variable and takes the value 1 if farmer ($_i$) adopts option ($_a$) over others; and 0 if otherwise [24]. The probability that farmer ($_i$) will choose option ($_a$) over other options is given as follows:

$$P(Y_{ia} = 1|X) = PU_i^a > U_i^b \tag{8}$$

Integrating Equations (2) and (3) into Equation (5) results in the following equation:

$$\begin{aligned} P(Y_{ia} = 1|X) &= P(X\beta_{ia} + \ell_{ia} - X_i\beta_{ib} - \ell_{ib} > 0|X) \\ &= P[(\beta_{ia} - \beta_{ib})X_i + \ell_{ia} - \ell_{ib} > 0|X] \\ &= P(\beta^*X_i + \ell^* > 0|X = F(\beta^*X_i) \end{aligned} \tag{9}$$

where β^* is a vector of the parameters to be estimated, ℓ^* is a disturbance term, $F(\beta^* X_i)$ is a cumulative distribution of the disturbance term evaluated at $\beta^* X_i$. Depending on the distribution of the random disturbance term, the linear probability, Logit or Probit are suitable qualitative choice models for such a scenario. Provided that the identified options are more than two, the multinomial logit and multinomial Probit models are the most applicable econometric models. The multinomial Logit model is widely used in determining the influence of explanatory variables on a dependent variable with multiple but unordered categories of options [25]. The explanatory variables of the regression model are presented in Table 2. Data were analyzed using R [26].

3. Results

3.1. Descriptive Analysis

Table 3 summarizes the socioeconomic and biophysical characters of the households included in the current study. The households produced ~8 metric tons of barley straw on average. Of the households, 50% reported leaving some of their straw on the plots as soil mulch while only 14.4% of the households reported that they allocated more than 30% of the barley straw biomass for soil mulching. About 95% of the households reported using barley straw for livestock feeding. The correlation between the allocation of barley straw to soil mulch and livestock feeding was strong and negative (r = −0.9, $p < 0.001$). In total, 77% of the households used less than 15% of their barley straw for soil mulching, 11.5% of the households mulched 15–45% of the barley straw while 11.5% of them mulched more than 45% of the barley straw.

Table 3. Explanatory variables used in the empirical models.

Variable	Unit	Mean	Std. Dev.
Household head			
Age	Years	41	12
Gender (Female)	%	14	
Education	Years of formal schooling	6	3
Family size	Persons	7	4
Cultivated land			
Land area	Ha	2.7	1.7
Distance to homestead	Minutes of walking	16	12
Slope	(1 to 3)	1.8	0.8
Livestock (heads)			
Small ruminant	Head	5	5
Cattle	Head	6	3
Equine	Head	1	1
Aggregated livestock units	Tropical livestock units [25]	5	3
Extension			
Number of friends and relatives	Persons	16	9
Official extension	%	55	
Straw			
Straw production	T	7.89	4.07
Straw price	Etb/kg	1.7	

Etb, Ethiopian birr; 1 USD = 36 Etb (2018) exchange rate at the year of the study.

Table 4 shows that the overall soil loss in the study area was 46.7 metric tons (t)/hectare (ha)/year (yr), the main annual soil loss in metric ton per hectare for those farmers that did not use barley straw for soil mulch in the study area was 49.2 t/ha/yr, which is the mean annual soil loss for farmers using barley straw as a mulch was 31.5 t/ha/yr. The result shows that farmers who did not use barley straw for soil mulch had an average cost of USD 12.67 (Etb 524) per hectare of land per year and those using barley straw for mulching had a cost of USD 8.13 (Etb 336)/ha/year.

Table 4. Soil loss in metric tons (t) per hectare (ha) per year (yr) and erosion costs for Ethiopian barley-livestock systems with and without barley straw mulch.

Mulch	Soil Loss (t/ha/yr)	Annual Cost		Costs Over 10 Years	
		Ethiopia birr/ha/yr	USD/ha/yr	Ethiopian birr/ha/yr	USD/ha/yr
Not used	49.2	524	12.69	8122	196.66
Used	31.5	336	8.14	5208	126.10
Total	46.7	498	12.13	7719	186.90

The cost of straw per metric ton in the study area at the local market was USD 41.16 (Etb 1700) and the yield of straw per ha was 2.9 metric tons. The total cost of straw for feeding per hectare was estimated at USD 119.37 (Etb 4930). The cost of straw per ha used as soil mulch in the first year was estimated at USD 4.55 (Etb 188) but this value increased to USD 70.56 (Etb 2914) in 10 years (Table 5).

Table 5. Estimated monetary value of barley straw per ha when it was used for feed and mulch.

Value of Barley Straw	Monetary Value for 1 Metric Ton of Barley Straw	
	Ethiopian birr/ha	USD/Metric Ton
Feed	4.930	119.37
Mulch (present value)	188	4.55
Mulch (future values discounted over 10 years)	2914	70.56

3.2. Empirical Analysis

The effect of the socioeconomic and biophysical characteristics of households on the use of barley straw for soil mulching is presented in Table 6. The higher the education level of the household head and the larger the size of the household, the higher the probability to use the optimum amount of barley straw for soil mulching. The further the farming plot from the homestead, the higher the probability of optimizing barley straw mulching. The more equines kept within the household, the higher the probability of optimizing barley straw mulching. More exposure to formal extension is associated with a lower probability of using the optimal amount of straw for soil mulching. The more the straw production, the higher the probability that the farmer would use the optimal amount of barley straw for soil mulching. The wastage of barley straw as soil mulch was negatively associated with household head age but positively associated with family size. The decrease in the probability of wasting barley straw as soil mulch is associated negatively with exposure to formal agricultural extension. The more the production of barley straw in the household, the higher the probability of over-mulching the barley straw.

Table 6. Multinominal Logit regression analysis of the use of barley straw for mulching as a function of household characteristics.

Explanatory Variables	Coefficient (Standard Error)	
Household Head	15–35% of Barley Straw Used for Soil Mulch	35–100% of Barley Straw Used for Soil Mulch
Age	−0.042 (0.03)	−0.157 (0.064) **
Sex (Female)	−5.88 (2.52) **	−3.2 (3.66)
Education	−0.197 (0.1) **	−0.031 (0.125)
Size	0.108 (0.066) *	0.231 (0.112) **

Table 6. *Cont.*

Explanatory Variables	Coefficient (Standard Error)	
Household Head	**15–35% of Barley Straw Used for Soil Mulch**	**35–100% of Barley Straw Used for Soil Mulch**
Cultivated land		
Land area	−0.364 (0.251)	−0.079 (0.292)
Distance to homestead	0.175 (0.038) ***	0.289 (0.054) ***
Slope	−0.622 (0.44)	−0.867 (0.582)
Livestock		
Small ruminants	0.036 (0.052)	0.049 (0.084)
Cattle	0.218 (0.122)	0.201 (0.194)
Equine	0.059 (0.225) *	−1.35 (0.486)
Extension		
Number of friends and relatives	−0.001 (0.023)	−0.008 (0.05)
Official extension	−1.06 (0.59) **	−2.33 (0.948) **
Straw		
Straw production	0.026 (0.009) ***	0.039 (0.012) ***
Straw price	0.031 (0.033)	−0.013 (0.056)
Model good of fitness		
Correctly predicted (%)	88	
Log−likelihood	−79.4	
Chi square test	210 ***	
Pseudo R^2	0.684	

*, **, ***: significant at 0.1, 0.05 and 0.01 respectively.

4. Discussion

Soil erosion is a key limitation to soil fertility and thus crop production in developing countries. Up to 30% of soil cover by crop residue mulch can reduce soil erosion by 80% [23]. Half of the households in the study did not leave any barley straw for soil mulch. Only 14% adhered to the soil mulching recommendations issued by extension services. In line with our results, previous studies reported on farmers' low interest in applying crop residue soil amendment [14,15]. Thus soil fertility and biomass productivity of crop plots can be prone to gradual deterioration from soil erosion. To avoid that, farmers should be encouraged to mulch adequate amounts of barley straw to preserve the fertility of their cropping plots.

One tropical livestock unit requires roughly 7.5 kg of dry matter daily [27]. In the current study, the households thus required a total of 13.1 metric tons of dry matter to feed their livestock. However, barley straw production per household was only 7.1 metric tons of dry matter. If barley straw is the main forage available for livestock, the demand for barley straw for both livestock production and soil conservation is far higher than the production, especially in the case of deterioration in biomass and nutritive value of natural pastures. The strong correlation between the use of barley straw for livestock feeding and soil mulch in the current study confirms this high pressure. The high pressure on crop residues for livestock feeding and soil mulching was reported for maize-livestock systems in Ethiopia [4,14]. Given the limited resources of most farmers in the region, optimization of the use of barley straw for soil mulch and livestock feeding is warranted.

4.1. Soil Erosion Loss

The overall soil loss in the study area was 46.7 metric tons (t)/hectare (ha)/year (yr), which is a severe soil loss area according to [28]. Our soil erosion estimates were lower than the range of 84 to 300 t/ha/yr reported by some studies [29–33]. They were consistent with soil losses of 42 to 47.3 t/ha/yr reported by others [28,34–36], yet higher than other measurements of 10 to 31 t/ha/yr [17,37–44]. This may be due to the intensification of agricultural production in the study area. The mean annual soil loss for those farmers that did not use barley straw for soil mulching in the study area was 49.2 t/ha/yr, which is higher than the overall soil loss, whereas the mean annual soil loss for farmers using barley

straw as mulch was 31.5 t/ha/yr. This means that using barley straw for soil mulch is associated with a reduction in soil loss of 17.7 t/ha/yr, or 36%, compared to not using barley straw for mulching in our study. Factors such as heavy concentrated rainfall, steep topography, deforestation, over-grazing, use of marginal land and agricultural intensification can accelerate soil erosion in mixed crop-livestock farming systems in Ethiopia [27,45].

In the first scenario, by considering the short-term impact of soil mulch, most farmers would prefer using barley straw for feeding rather than mulching, which is the case of our study. If the farmers left 30% of straw yield on the plot, they would indirectly lose USD 35.81 (Etb 1479)/ha/yr, or 30%, of the total value of barley straw when it is used for feeding since the estimated value of barley straw when used for feeding is USD 119.37 (Etb 4930). That amount is much higher than the cost reduction of USD 4.55 (Etb 188)/ha/yr from using barley straw for soil mulch. That figure is valid when only the present value is considered but when the future value is considered, the value of using barley straw for mulch would become USD 70.56 (Etb 2914).

In the second scenario, the long-term effect of using barley straw for mulching was not valued by the farmers in the study area. This is clearly because the farmers are not fully aware of the long-term cost of soil deterioration on grain yield and straw yield.

4.2. Empirical Analysis

Female-headed households were more likely to mulch less barley straw in the cropping land. In addition to that, the increasing education of the household head lowered the probability of optimal mulching. This is in agreement with the authors of [14,15] who found an effect of household socioeconomic characters on crop residue use in the mixed farming systems.

4.2.1. Distance

According to a previous study [46], the ability of farmers to carry materials to and from the cropping land affects the probability of optimal mulching. Farmers economize their labor by using barley straw as feed/bedding only when the fields are close enough. Our results deviate from prior research that has reported that farmers mulched crop fields less for fields that were farther from their homesteads [4,14,15] or shown that there is no significant effect of distance on soil mulching [47]. Unlike past studies, our results suggest that soil erosion may be more aggravated closer to farm homesteads since soil mulching there is less compared to more remote fields. Such an imbalance in the distribution of crop residues highlights the need for more even spreading of barley straw residues in the Ethiopian highlands for better carbon cycling and soil conservation. The farms that are closer to the homestead thus tend to have less barley straw as soil mulch and are, therefore, more prone to erosion. Farmers with more remote plots tend to leave excess amounts of barley straw as mulch, which is a wastage of biomass.

4.2.2. Role of Extension

Our results highlight the significance of agricultural extension in encouraging the use of barley straw as mulch in mixed farming systems. Similar results were found by other researchers [14,15,19,48–52] on the importance of extension when it comes to farmer adoption of conservative agricultural practices. Extension outreach can also help encourage more efficient use of equines to transport crops and crop residues. Our current study shows that the farmers who have more equines, which is the only way to efficiently transport farm products in Ethiopia, were better at optimizing the use of barley straw for soil mulch.

Extension workers thus could improve the profile of barley straw use by encouraging the culture of equine exchange within mixed farming systems. This would help the farmers with remote cropping plots to carry more straw to the household to feed the livestock and leave the optimal amount on the plot as soil mulch. Plot slope did not influence farmers' intention to increase the use of barley straw as soil mulch. This is in contrast with other studies [14,15], which found a positive association between plot slope and the

use of crop residues for soil mulch. Steeply sloped plots in barley-livestock systems in Ethiopia are prone to severe soil erosion as they do not receive optimal amounts of straw mulch. Households with fields on greater slopes need more extension service outreach on the importance of soil mulching when it comes to reducing soil erosion. An efficient extension approach to optimizing the use of barley straw should consider the differences in household characteristics. Households with steep plots close to the homestead should be warned that they may be leaving too much barley straw. Households with more remote plots or that have more equines should be made aware by the extension service that they might be leaving too much barley straw in the field.

Currently, extension services discourage farmers from using more than 15% of their barley straw for soil mulching. This could be due to the limited feed options in these systems. The mission of the formal extension service to encourage optimal soil mulching could be facilitated by improving the feed supply. The current study indicates that higher barley straw biomass production may allow for the enhanced use of barley straw for soil mulch. This is in line with previous studies [14,15,17], which reported that easing the pressure on crop residues, by providing new feed resources to livestock, would encourage farmers to leave more crop residues in fields; therefore, improving barley straw biomass in terms of yield. Improving feed nutritive value through genetic selection may have important long-term effects of increased mulching as a strategy against soil erosion. In addition, other management practices that might improve barley straw biomass utilization include optimizing animal bedding, mulching of the soil with non-edible residues and optimal timing of harvest to avoid the decrease in the nutritive value of straw as a result of over-maturity [53]. Most Ethiopian households store crop residues in exposed heaps [15], which might lead to heavy loss in biomass and nutritive value due to feed spoilage. Consequently, improved crop residue storage may improve the nutritive value of straw, thus avoiding wastage. This may result in an increased supply of straw for soil mulching and livestock feeding on farms. However, future research considering the feasibility of these solutions is important and would enhance the design of efficient biomass utilization and appropriate intensification strategies.

5. Conclusions

There is pressure to use barley straw as livestock feed in barley-livestock mixed farming systems in Ethiopia due to low straw yield, which is further constrained by competing uses and low nutritive value. Generally, farmers tended to use barley straw for livestock feeding rather than for soil mulching. This is because farmers allocate barley straw to different uses based on the short-term benefits. Farming land in barley-livestock farming systems is, therefore, expected to deteriorate, leading to a decrease in grain and straw production.

Agricultural extension in the Ethiopian highlands should focus more on the long-term benefit of soil mulching to preserve soil health. Formal extension outreach had a statistically significant effect on farmers' greater use of barley straw as soil mulch. Interventions, training and extension services promoting context-specific crop residue management for both agriculture and livestock components are imperative to facilitate the optimal utilization of barley straw in Ethiopian mixed farming systems.

Introducing new feed resources in barley-livestock farming systems would increase the feed supply to livestock. This would increase the use of barley straw as soil mulch. Improving straw yield besides grain yield via breeding would increase the supply of straw to not only meet livestock feed needs but also provide enough crop residues for soil mulching. More studies on decreasing post-harvest loss in barley straw should be undertaken. In order to discourage the excessive application of barley straw as mulch, agricultural extension workers should focus on farmers with remote crop fields and with limited access to equines. This can be part of a process that could evenly distribute and effectively utilize crop residues in mixed farming systems in Ethiopia as well as other regions of the world.

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