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Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia

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ABSTRACT

Crop residues have several uses in smallholder mixed crop-livestock systems. This paper examines determinants of households' maize stover use as livestock feed, fuel and soil amendment in maize-based systems in Ethiopia. In these systems maize stover is primarily used as feed (56% of biomass) and fuel (31%), with the feed use share negatively associated with maize production potential. We develop a Seemingly Unrelated Regression model to capture the interdependence of crop residue uses. Results show extension training on crop residue retention in the field results in more residue use for soil amendment and less for feed. Farmers with more livestock tend to use more residues for feed and less for soil mulch. Cropping pattern, farm size, agro-ecology and crop residue production also influence crop residue utilization. Conservation agriculture interventions have implications for crop residue use and need to consider access to information, cropping patterns, resources endowments and other socio-economic factors in their development and targeting.

1. Introduction

Population growth in many developing countries tends to increase the area under cultivation and push the agricultural frontier into more marginal lands. It also tends to increase intensity of land use which leads to continuous cultivation of farmlands without fallowing (Drechsel et al., 2001). But without adequate investment in agricultural land management this contributes to land degradation (Unger et al., 1991; Reicosky et al., 1995) and low agricultural productivity (Lal, 2009).

Sustainable intensification practices are needed to mitigate environmental degradation and increase agricultural productivity (Blanco-Canqui and Lal, 2009). Crop residues are the by-product of crop production and include stover and straw from cereal crops after harvesting the grain. The retention of such residual biomass in crop fields as a soil amendment reduces surface runoff, enhances soil moisture, improves soil structure and potentially suppresses weed growth (Barnes and Putnam, 1983; Erenstein, 2002, 2003; Blanco-Canqui and Lal, 2009; Andersson and Giller, 2012; Turmel et al., 2015). Studies show that a 30% soil cover from crop residue mulch can reduce soil erosion by 80% (Allmaras and Dowdy, 1985; Erenstein, 2002; Giller et al., 2009). However, mixed crop-livestock farming systems typically use crop residues for (livestock) feed, this often becoming increasingly important due to expansion of crop land and low productivity of rangelands (Alkemade et al., 2012; Thorne et al., 2002). Especially where feed is scarce, feeding crop residues to livestock provides benefits to farmers within a given production year (FAO, 2001). In Ethiopian highlands crop-livestock systems prevail and 70% of crop residues are reportedly used as feed (Tsigie et al., 2011).

Despite crop residues having alternative uses, only a few studies have tried to understand the implications of retaining crop residues as a soil amendment/mulch in mixed crop-livestock systems (Erenstein, 2002; Jaleta et al., 2013; Latham, 1997; Valbuena et al., 2012; Baudron et al., 2014). Moreover, most of the previous studies focused on explaining crop residue use of a single crop though farmers typically produce combinations of crops where the residue production and use of one crop has implications on the use of other crop residues. Understanding such interactions and crop residue use in mixed crop-livestock systems is important to increase crop residue production, improve crop residue use and deal with the residue use trade-offs.

The objective of this paper is to characterize crop residue utilization and explain the determinants of alternative and competing uses of crop residues (as a feed, fuel or soil amendment) in mixed maize-based farming systems in Ethiopia. The rest of this paper is organized as follows. Section 2 discusses survey data, conceptual

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framework and empirical model specification, and variables used in the analysis. Section 3 discusses analysis results and section 4 concludes.

2. Data and methods

2.1. Study area and data

The paper focuses on maize-based farming systems in Ethiopia where smallholder mixed crop-livestock systems prevail. Three cereals dominate in Ethiopia in terms of area and production: *tef* (*Eragrostis tef*, a small grained cereal native to the horn of Africa), wheat and maize, with maize having become the largest cereal in terms of production.

The paper draws on data from a cross-sectional survey conducted in 2011 in 30 maize growing districts. The districts were proportionately selected based on their potential for maize production. The CSA/IFPRI 2002 dataset provided the average maize productivity at the district level from 139 maize producing districts: 2.1 tons/ha with 0.7 standard deviation. The maize producing districts were then grouped into three clusters or maize potential zones: '*high*', '*medium*' and '*low*' using a one-standard deviation cut-off point above and below the mean productivity. Accordingly, districts with average maize productivity of 2.8 tons and above were categorized as *'high potential'*, below 1.4 tons/ha as *'low potential*' and in-between as '*medium potential'*. Using a proportionate to size sampling method, 4, 20 and 6 districts were randomly selected from the high, medium and low potential districts, respectively. In each randomly selected district, maize producing peasant associations (PAs) were identified and four peasant associations were randomly selected. From each selected peasant association, 16–18 farm households were randomly selected and interviewed. Accordingly, the survey covered 1554 sample households from the 30 sample districts lying in four regional states (Tigray, Amhara, Oromia, and SNNPR/Southern Nations, Nationalities and Peoples Regional State) of Ethiopia (Table 1). Of the total 1554 sample households, 1492 (96%) had grown maize in 2009/10 production year and 1430 (92%) reported their crop residue use. Given the focus of the study, the analysis will primarily use and focus on these 1430 maize producing households with reported crop residue use.

In the survey, households were inter alia asked the type of crops they had grown during 2009/10 production season, the volume of harvest both as grain and crop residue, proportion of crop residue of each cereal crop used for different purposes (i.e. used for fuel, feed, left on the field as soil amendment, and other uses, including construction, burnt *in-situ*, sold). In addition, household and farm characteristics, livestock owned, participation in extension services, and other relevant data were captured in the survey.

There was some inconsistency between what farmers themselves estimated as crop residue yield and what a derived estimate based on the farmer reported grain yield and generally established harvest indexes (Lal, 2005). In this analysis, we used the second option as farmers typically had less difficulty estimating and reporting grain harvest compared to residual biomass.

Table 1
Sample household distribution by maize potential zone and regional states.

Region	Maize potential zone			Total
	Low	Medium	High	
Tigray	54	0	0	54
Amhara	87	183	45	315
Oromia	147	570	151	868
SNNPR[a]	0	193	0	193
Total	288	946	196	1430

[a] Note: SNNPR is Southern Nations, Nationalities, and Peoples' Regional State.

2.2. Conceptual framework and empirical model specification

There is limited biomass trade in rural Ethiopia and markets for crop residues are particularly thin and underdeveloped. Thus, we assume that maize producing farmers maximize the utility derived from maize stover produced ($\overline{R}_m$) as by-product from maize grain production over the different competing uses: feed (R_{fd}), fuel (R_{fl}), and soil amendment (R_{sl}) Stover allocation to these competing purposes is subject to maize stover supply, availability of crop residues from other cereal crops, household and farm characteristics, etc. The utility maximization objective function limited only to the three major uses of maize stover is specified as:

$$\max U(R_{fd}, R_{fl}, R_{sl} : \overline{R}_m, \overline{R}_k, h) \tag{1}$$

where $\overline{R}_k$ and h are the household specific crop residues from other cereals produced in the same year and household and farm characteristics, respectively. The specified utility function is maximized subject to a '*budget constraint*', i.e., a virtual maximum income (benefit) generated or total cost saved ($I^*_{\overline{R}}$) through allocating the total volume of available maize stover to alternative purposes. This is specified as:

$$P^*_{fd}R_{fd} + P^*_{fl}R_{fl} + P^*_{sl}R_{sl} \leqslant I^*_{\overline{R}} \tag{2}$$

where P^*_{fd}, P^*_{fl}, and P^*_{sl} are household specific shadow (endogenous) prices attached to maize stover used for feed, fuel, and soil amendment, respectively. Using a Lagrangian optimization method to get the first order conditions, the optimal allocation of maize residue for the three purposes is given as:

$$\frac{U_{R_{fd}}}{U_{R_{fl}}} = \frac{P^*_{fd}}{P^*_{fl}}; \frac{U_{R_{fd}}}{U_{R_{sl}}} = \frac{P^*_{fd}}{P^*_{sl}}; \text{ and } \frac{U_{R_{fl}}}{U_{R_{sl}}} = \frac{P^*_{fl}}{P^*_{sl}} \tag{3}$$

where $U_{R_j} = \frac{dU(\cdot)}{dR_j}$; *j = feed, fuel, and soil amendment*. Accordingly, the optimal allocation of maize residue for the specific alternative purposes is specified as a function of explanatory variables affecting the relative utility of residue use for the specific purposes, and stated as:

$$R_j = f(h, \overline{R},\ P^*) \tag{4}$$

With this understanding and assuming R_j as the optimal quantity of maize residue allocated to purpose j, the set of residue use equations for the three most important purposes (j = 1,2,3; *i.e.*, 1 = *feed*; 2 = *fuel and* 3 = *soil amendment*) is specified as:

$$R_1 = X'_1\beta_1 + \delta_{m1}\overline{R}_m + \delta_{k1}\overline{R}_k + \epsilon_1 \tag{5a}$$

$$R_2 = X'_2\beta_2 + \delta_{m2}\overline{R}_m + \delta_{k2}\overline{R}_k + \epsilon_2 \tag{5b}$$

$$R_3 = X'_3\beta_3 + \delta_{m3}\overline{R}_m + \delta_{k3}\overline{R}_k + \epsilon_3 \tag{5c}$$

where X is a vector of household and farm characteristics, and agroecology variables. β and δ are vector of parameters to be estimated. The decision to use a crop residue for a specific purpose will influence the decision to use for other purpose, implying the possible correlation among the three error terms (ϵ_1, ϵ_2 and ϵ_3). Estimation without accounting for this correlation will lead to bias and inefficient estimates.

The appropriate econometrics technique to capture correlation among error terms when we have continuous dependent variables is the Seemingly Unrelated Regression model (Zellner, 1962). It estimates parameters in the three equations 5a, 5b and 5c jointly using sampling weights to correct for the standard errors resulted from our sampling procedure (cluster or stratified sampling).

2.3. Dependent and explanatory variables

The dependent variables used in the empirical model are the volume of maize stover allocated to each particular use – i.e. as feed, fuel and soil amendment. These three uses combined constitute above 93% of the total maize stover allocation. In terms of proportion used, feed use stands first, followed by stover use for fuel. However, in high potential areas use of maize stover for fuel becomes relatively more important than its use as feed (Table 2).

The model includes a number of explanatory variables to explain the variations in the three main crop residue uses (Table 2). The major explanatory variables and associated hypotheses are briefly discussed below:

Maize potential zone: The maize potential zone reflects the average level of grain production and hence the biomass production – linked inter alia to agro-ecological factors such as rainfall, temperature and soil type. In high maize potential areas, the *absolute* quantity of maize stover allocated to alternative purposes could increase due to its availability, but we expect that *proportionally* less maize stover is used as feed and fuel, and more is left *in-situ* as soil amendment/mulch (Jaleta et al., 2013).

Resource endowments: Resource endowment affects household's time preference (Di Falco et al., 2011). Poor households have a higher discount factor on resource use and exploit the existing opportunities – rather than conserving for attainable long term benefits (Shiferaw and Holden, 2000). Williams et al. (1997) also argue that crop residue use depends on resource endowments and production goals. Thus, we expect resource poor households to use crop residue more for feed and fuel rather than soil amendment, which would require years to see the overall cumulated effect. In this paper, total land owned by farm households is taken as a proxy to household's resource endowment.

Portfolio of crops produced: Residue from one crop might partly substitute the role of residue from another crop. Households producing other cereals in addition to maize may retain a larger proportion of maize stover on their farm plots as soil mulch. For instance, maize and sorghum stalks could be substitutes for construction and fuel. Similarly, *tef*, wheat and barley straw could substitute as feed and reduce the pressure on maize stover as feed.

Extension and/or training service: In Ethiopia there is a widespread network of rural extension agents. In most of the survey villages, there are typically three development agents (one each trained in crop production and management; livestock production and management; and natural resource management) giving extension services and trainings to farmers on a wide range of areas related to agricultural production, agricultural technologies, and resource management. Households who received training(s) on soil fertility management and particularly on the associated need to retain crop residue on farm plots are expected to retain more crop biomass as soil amendment.

Family size: Larger families likely need to use more energy for cooking and maize and sorghum stalks are important rural fuel sources. Furthermore, households with larger families may have more labour to collect crop residue from fields. Thus, we expect positive association between family size and the quantity of crop residue used for fuel and feed.

Livestock owned: Livestock are an integral part of these mixed crop-livestock systems and have multiple uses. Since there is typically limited (if any) purposive forage production, it is common to feed livestock with crop residues, including productive animals (oxen and milking cows). Thus, a positive association is expected between the livestock herd owned and crop residue use for feed. Contrary, livestock holding is expected to negatively affect crop residue allocation for fuel and soil amendment.

Household head characteristics: age, gender and education of household heads could affect level of farmers' awareness on soil quality and fertility management (Di Falco et al., 2011). Educated household heads are expected to retain more crop residues as soil amendment.

Table 2
Descriptive statistics of variables used in the empirical analysis by maize potential zone.

Variables		Maize Potential Zone			Total (*N* = 1430) Mean (SD)
		Low (*n* = 288) Mean (SD)	Medium (*n* = 946) Mean (SD)	High (*n* = 196) Mean (SD)	
Dependent variables	Maize residue used as a feed (tons)	0.56(0.81)	0.79(1.25)	0.84(1.51)	0.75(1.22)
	Maize residue used as a fuel (tons)	0.20(0.46)	0.46(0.82)	0.94(1.51)	0.48(0.92)
	Maize residue used as a soil amendment (tons)	0.04(0.24)	0.09(0.38)	0.35(0.92)	0.12(0.48)
Explanatory variables					
Household characteristics	Age of household head (years)	43.0(12.1)	43.1(12.7)	42.4 (11.3)	43.0(12.4)
	Sex of household head (1 = Male, 0 = Female)	0.89(0.31)	0.94(0.23)	0.96(0.21)	0.93(0.25)
	Education of household head (years of schooling)	2.02(2.59)	3.03(3.38)	2.50(3.20)	2.75(3.24)
	Family size (number)	6.57(2.42)	6.53(2.43)	6.52(2.27)	6.53(2.41)
Household resources	Livestock owned (TLU)	5.0(4.8)	5.6(5.3)	5.3(3.6)	5.5(5.0)
	Farmland owned (ha)	1.79(1.94)	1.98(2.13)	2.27(1.83)	1.98(2.06)
Crop residue production level	Maize residue produced (tons, estimate)	0.9(1.2)	1.6(2.2)	2.8(3.9)	1.6(2.4)
	Combined residue produced from other cereals (tons, estimate)	0.5(0.6)	0.7(1.1)	0.7(0.9)	0.7(1.0)
Access to plots and extension services	Distance of maize plots from homestead (walking minutes)	13.4(22.1)	11.8(18.9)	10.1(12.0)	11.9(18.9)
	Households received training on crop residue retention on plots (1 = Yes, 0 = No)	0.56(0.50)	0.59(0.49)	0.78(0.42)	0.61(0.49)
Agro-ecology and Cropping system	High Maize potential districts (1 = Yes, 0 = No)	0	0	1.00	0.14
	Medium maize potential districts (1 = Yes, 0 = No)	0	1.00	0	0.66
	Low maize potential districts (1 = Yes, 0 = No)	1.00	0	0	0.20
	Cropping pattern (1 = household grows only maize , 0 = household grows maize and other cereals)	0.19(0.39)	0.25(0.43)	0.17(0.58)	0.23(0.48)

Note: Only sample households growing maize and reporting residue utilization.

3. Results and discussion

3.1. Descriptive analysis

The average maize producing household in our sample owns 2 ha of land and 5.5 tropical livestock units (TLU) and comprises 6.5 people with a household head who is typically male (93% of households), 43 years old and with 2.8 years of schooling. Only farm size and schooling are positively associated with the maize potential gradient (Table 2).

By default all retained sample households produce maize – given our focus on maize producing districts and analytical focus on maize producing households reporting crop residue use. In addition to maize, three-quarters of the surveyed maize producing households also produce another cereal – particularly *tef* (45% of households), sorghum (38%), wheat (20%) and barley (17%). On average, a farm household cultivates 1.7 ha – about half of which is dedicated to maize, 17% to *tef*, 12% to wheat and the remaining 23% to other crops (Table 3). The average cropped area increases along the maize potential gradient – although the maize area share remains around half.

In Ethiopia's predominantly mixed systems, livestock play a crucial role in crop production (oxen for draft power and tillage) and provision of food and income to the farm household. About 93% of the households own at least one adult cattle whereas 80% of them own at least one ox for ploughing and one cow for milking and breeding. Households also own other livestock types (small ruminants, equines and poultry) but for the purpose of this study we focussed on cattle in view of their ability to digest low quality feed and dry roughage from crop residues (William et al., 1997). On average, each household owns 5.5 heads of adult cattle – comprising 2.1 cows, 1.8 oxen, 0.7 bulls and 1 heifer (Table 4). The number of cattle is positively associated with the maize potential, largely reflecting an increase in the number of oxen which in turn is associated with the increasing cultivated area.

The average maize producing household is estimated to produce an average of 1.6 tons of maize stover per year – a quantity positively associated with the maize potential gradient increasing from an average of 0.9 to 2.8 tons (Table 2). In addition, farms produce an average of 0.3 tons of sorghum stover and 0.2 tons of *tef* straw. Wheat and barley production in these predominantly maize producing areas is limited and the straw production per farm for these two crops is low. The combined residues produced from other cereals averages 0.7 tons per year for the sample households. Overall, maize, *tef* and sorghum are the three main contributors to crop residue biomass produced in the sample.

Crop residues are often the main feed source for cattle – and given the predominance of maize, maize stover constitutes over two-thirds of the crop residues used as feed overall, with its share increasing along the maize production potential gradient (Fig. 1). *Tef* straw, wheat straw, sorghum stover and barley straw complement maize stover in the overall feed ration (Fig. 1). Compared to the relative biomass volumes produced, straw from *tef*, wheat and barley appears to be preferred as feed over sorghum stover.

Farmers were asked to estimate the proportion of residue biomass by type of use for each cereal (Table 5). Feed comprises the largest share for each of the five crops – albeit with particularly high shares for the cereal straws (*tef*, wheat and barley, 77–82%), an intermediate shares for maize stover (56%) and the lowest for sorghum stover (36%). The preferential use of straw is consistent

Table 3
Land use indicators of maize producing sample households by maize potential zone.

	Maize Potential Zone						Total (*n* = 1430)	
	Low (*n* = 288)		Medium (*n* = 946)		High (*n* = 196)			
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Crop area *(ha)*	1.31	1.27	1.75	1.48	2.22	1.69	1.72	1.49
Crop area share (%)								
Maize	46	34	46	31	53	28	47	31
Tef	13	23	20	25	10	16	17	24
Wheat	14	25	10	17	20	19	12	19
Barley	7	16	6	14	0	2	5	14
Sorghum	5	11	3	8	1	3	3	9
Others	15	24	15	19	16	24	15	20
Percent of maize farmers growing other crops (%):								
Tef	32		51		34		45	
Wheat	23		23		6		20	
Barley	23		14		8		17	
Sorghum	25		35		69		38	

Note: Only includes sample households that grow maize and reported crop residue use. *n* = number of sample households.

Table 4
Livestock ownership by maize potential zone *(head count)*.

Type	Maize potential							
	Low (*n* = 288)		Medium (*n* = 946)		High (*n* = 196)		Total (*N* = 1430)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Adult cattle	4.8	5.5	5.6	5.5	5.8	4.1	5.5	5.3
Cows	1.9	3.7	2.1	3.1	2.1	1.6	2.1	3.1
Oxen	1.5	1.2	1.8	1.4	2.1	1.3	1.8	1.4
Bulls	0.5	0.9	0.7	1.4	0.7	1.2	0.7	1.4
Heifers	0.9	1.3	1.0	1.5	1.0	1.2	1.0	1.5
Calves	1.1	1.5	1.4	3.3	1.3	2.1	1.3	2.9
Total cattle	5.9	6.4	7.0	7.4	7.1	5.3	6.8	7.0

Note: SD is standard deviation and *n* = number of sample households.

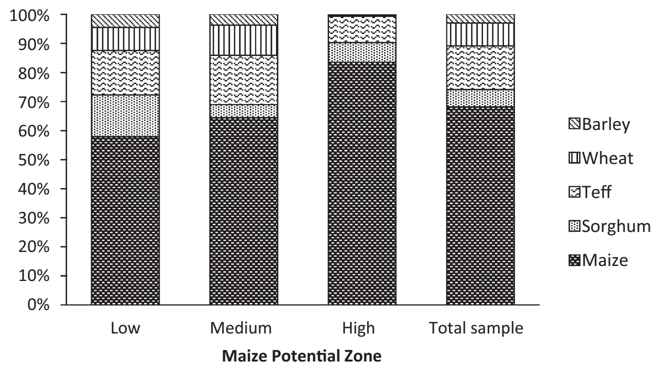

Fig. 1. Contribution of maize and other cereals to crop residue use as feed by maize potential zone.

along the maize potential gradient. In contrast, stover use shows a marked decline along the same gradient – both for maize and sorghum – associated with the less preferred use of stover as feed and its lower digestibility and their increased production. In the case of maize, about 71% of maize stover is used as feed in the low potential zone against 39% in high potential zone; whereas for sorghum stover use declines from 63% to 18% when going from the low to high maize potential zone. The low potential areas are known for their annual feed and biomass shortages and farmers tend to use any available biomass including stover as feed to manage feed scarcity during the dry season (Thorne et al., 2002).

With feed use comprising the lion's share of cereal straw use – straw amounts used for other purposes is relatively limited, with some surplus used as soil amendment (wheat, barley) or burned *in-situ* at the time of land preparation (wheat). In contrast cereal stover use is more diverse and fuel represents the next biggest use (26–31%), followed by construction for sorghum stover (23%). Maize stover use as fuel shows a marked association with the maize potential gradient, increasing from 21% in the low potential zone to 43% in the high. In the case of sorghum stover, only the construction share appears similarly associated with the gradient.

Sales of crop residues are only sparingly reported. In line with feed preference, sales are most common for *tef* straw (5.5%). Despite feed scarcities, crop residue markets are not well developed and in many areas the crop stubble after harvesting becomes common property.

Overall, limited amount of biomass is used as soil amendment. The highest such use was reported for wheat and barley straw in the high maize potential areas (28.5–30%). Crop residue scarcity indeed seemed to be the least pressing in the high potential zone – where a tenth of the maize and sorghum stover was burnt *in-situ*, albeit with a similar share for wheat straw being burnt across the gradient (included in other uses, Table 5).

3.2. Empirical model analysis

Since residue use decisions are made post-harvest, estimations are made only for those households growing the specific crop under consideration. In our case, we focus on maize producing households and their allocation of maize stover for feed, fuel and soil amendment.

The Breusch–Pagan likelihood test for the overall correlation of the error terms [$\chi^2(3) = 177.065$; $p = 0.000$] rejects the null hypothesis that the error terms are independent (Table 6). This supports the estimation of maize residue use using the Seemingly Unrelated Regression model rather than three separate equations. Moreover, the negative signs of all the three estimated correlation coefficients confirm the existing competition for maize residue among the major alternative uses (feed, fuel, and soil amendment).

Table 6 presents the coefficient estimates of the Seemingly Unrelated Regression analysis. Results show that from every additional unit of maize stover produced, on average, farmers allocate 43%, 31%, and 6% to feed, fuel and soil amendment, respectively (Table 6). Increased stover production therefore only marginally contributes to increased retention volumes as soil amendment given the large relative allocations to feed and fuel in the current context.

Households who received extension training on crop residue use as soil amendment/mulch retained more maize stover on farm

Table 5
Residue utilization by crop type and maize potential zone (% of crop residue biomass, farmer estimate).

Crop type[*]	Purpose	Maize potential zone			
		Low Mean(SD)[a]	Medium Mean(SD)	High Mean(SD)	Total Mean(SD)
Maize	Fuel	21.4(24.5)	31.2(23.5)	42.5(22.5)	30.8(24.3)
	Soil amendment	3.2(15.2)	6.8(16.1)	11.5(19.9)	6.7(16.7)
	Feed	71.2(30.8)	55.0(29.1)	38.7(21.4)	56.1(30.0)
	Other uses[b]	5.8(21.9)	7.7(19.4)	12.3(23.7)	7.9(20.5)
Tef	Fuel	0.2(1.9)	0.2(2.7)	0.8(4.3)	0.3(2.8)
	Soil amendment	3.5(18.2)	3.6(15.9)	3.8(14.6)	3.6(16.2)
	Feed	85.6(31.8)	82.1(31.3)	76.3(30.2)	82.2(31.3)
	Other uses	13.6(30.2)	12.7(26.3)	20.1(27.6)	13.5(27.2)
Wheat	Fuel	0.0	0.7(7.3)	0.0	0.5(6.2)
	Soil amendment	10.4(26.5)	7.9(25.1)	25.0(45.2)	9.2(26.6)
	Feed	76.2(38.0)	74.5(41.1)	58.3(51.5)	74.2(40.9)
	Other uses	12.2(30.6)	14.0(32.2)	8.3(28.7)	13.3(31.7)
Barley	Fuel	0.0	4.6(19.1)	0.0	3.2(16.0)
	Soil amendment	7.6(25.2)	5.2(18.9)	24.7(41.9)	7.0(22.9)
	Feed	79.8(39.0)	75.4(39.4)	67.0(47.0)	76.0(39.8)
	Other uses	8.0(26.8)	10.9(28.1)	1.8(6.7)	9.6(27.1)
Sorghum	Fuel	29.0(25.7)	28.6(28.9)	17.5(21.8)	26.2(27.3)
	Soil amendment	2.2(8.9)	7.9(18.9)	9.1(17.8)	7.2(17.5)
	Feed	62.6(30.8)	34.6(34.0)	17.7(26.7)	35.6(34.8)
	Other uses	6.9(17.5)	27.5(34.0)	59.3(32.3)	31.1(36.0)

[*] Note: Mean proportion for those households producing the specific crop.
[a] Note: SD is standard deviation.
[b] Note: Other uses include residue used for construction, sale, and/or burnt *in-situ*.

Table 6
Determinants of maize stover use (Seemingly Unrelated Regression, weighted for sampling cluster by maize potential).

	Feed Coef.(Std. Err.)	Fuel Coef.(Std. Err.)	Soil amendment Coef.(Std. Err.)
Household characteristics			
Age of household head	−1.15(1.08)	−0.55(0.90)	1.09(0.66)
Sex of household head	−5.31(42.66)	5.99(33.55)	10.62(21.87)
Education of household head	2.87(5.26)	−6.38(4.59)	0.66(2.17)
Family size	18.51(8.49)**	−4.42(5.88)	−7.68(5.18)
Household resources			
Farmland owned	−37.11(13.58)***	−4.70(12.94)	16.75(6.46)***
Livestock owned	11.72(4.07)***	1.43(3.76)	−5.77(2.22)***
Crop residue production level			
Maize residue produced	0.47(0.03)***	0.31(0.03)***	0.06(0.02)***
Combined residue produced from other cereals	0.08(0.03)**	−0.04(0.03)	−0.02(0.02)
Access to plots and extension services			
Distance of maize plots from homestead	−0.29(0.93)	0.06(0.61)	0.07(0.34)
Households received training on crop residue retention on plots	−58.56(31.59)*	27.38(28.50)	58.34(11.73)***
Agro-ecology and cropping pattern			
High Maize potential districts	−409.40(57.72)***	221.19(48.73)***	155.02(43.08)***
Medium maize potential districts	−84.72(27.39)***	61.76(22.69)***	11.90(13.27)
Cropping pattern	100.59(39.72)**	−43.32(31.69)	−55.00(24.36)**
Constant	93.02(78.53)	22.15(64.34)	−41.99(34.99)
Observations	1171	1171	1171
RMSE	502.5	417.5	305.4
R-square	0.738	0.623	0.150
Breusch-Pagan Chi(2) test for the correlation of residuals			
	Fuel	Soil amendment	
Feed	−0.0747	−0.3475	
Fuel		−0.1577	
Breusch-Pagan test of independence: Chi2(3) = 177.065, Pr = 0.0000			

Note: ***, **, and * are significant at 1%, 5%, and 10% level, respectively.

plots and used less as feed. Compared to households in low maize potential districts, households in high maize potential districts used more maize stover as soil amendment and less as feed – which seems primarily a reflection of the larger volume of biomass produced in high potential areas. Though residue retention is potentially beneficial for soils in all maize agro-ecologies, its allocation as soil amendment/mulch would likely be particularly beneficial in low maize potential districts that tend to be more moisture stressed and where such use could contribute to moisture conservation. Compared to households from low maize potential districts, the volume of maize residue used as fuel is higher for households in medium and high maize potential districts.

Farm size is negatively associated with maize stover volumes allocated to feed and positively to its retention as soil amendment. Larger farms are likely to be richer, have lower discount rates, and have more biomass production and more alternative sources for feed and fuel, which may ease stover retention as soil amendment. Not surprisingly, there is a positive and strong association between the livestock herd and maize stover use as feed and a negative association with soil amendment. Such a marked competition between residue use for feed and soil amendment is a common phenomenon in countries like Ethiopia – particularly given the large livestock population and open-access stubble grazing after crop harvest.

Households growing only maize and no other cereal crops are using more maize stover as feed and less as soil amendment. Implicitly, this suggests diversifying cereals produced at household level reduces the pressure on retaining maize stover as soil amendment. There also is an interaction between maize stover use and the combined availability of other cereal residues: maize stover use as feed increases with increased residue production from other cereals. The observed complementary effect could be due to the severity of feed shortage where farmers complement maize stover with other cereal residues to meet feed needs. Finally, the volume of maize stover used as feed also increases with family size, which is a proxy for labour availability to collect and store crop residues.

4. Conclusions and implications

Although conservation agriculture is advocated as instrumental for more sustainable and resilient crop production, crop residue use as soil amendment/mulch remains a major challenge for Ethiopia's mixed crop-livestock systems. Using empirical methods, this paper identified key factors associated with alternative crop residue uses.

Maize stover utilization in Ethiopia is co-determined by biomass production of maize and other cereals, extension advice on crop residue utilization, livestock ownership, farm size and agro-ecology. Improving cereal grain yields through sustainable intensification is important so as to enhance the available biomass for different purposes including feed – but would only marginally increase retention as soil amendment in the current context. However, the positive association between extension advice and the retention of crop residues as soil amendment highlights the potential for capacity building.

The negative association between farm size and maize stover use as feed and fuel (and positive association with use as soil amendment) highlights that larger farms are less residue constrained and more able to free residues for alternative purposes such as soil amendment. Compared to high maize potential areas, farmers in low maize potential districts use more maize stover as feed and less as fuel or soil amendment. In low maize potential districts, therefore, alternative feed sources could contribute towards reducing feed scarcities and free maize stover for soil amendment.

A combination of increased crop biomass production through improved crop productivity and alternative feed sources and training on biomass utilization could thus enhance maize stover retention as soil amendment on farm plots in Ethiopia's mixed crop-livestock systems. This calls for appropriate sustainable intensification practices for these resource constrained farming systems. In turn, increased retention of crop residues as soil amendment would enhance soil fertility and reduce runoff and increase crop productivity.

Finally, this study used cross-sectional survey data which do not capture the dynamics of crop residue allocation to competing uses and also do not control for unobserved factors that may influence such allocation. Future research considering these issues is important and would enhance the design of appropriate intensification strategies and efficient biomass utilization. It would also contribute to enabling Ethiopia's resource poor farmers to sustainably intensify their mixed crop-livestock systems and continue their quest to adapt to and cope with continuing population growth, resource degradation and the vagaries of climate change.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agsy.2014.08.010.

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