Tradeoffs in Crop Residue Utilization in Mixed Crop-Livestock Systems and Implications for Conservation Agriculture and Sustainable Land Management

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Abstract

Crop residue use for soil mulch and animal feed are the two major competing purposes and the basic source of fundamental challenge in conservation agriculture (CA) where residue retention on farm plots is one of the three CA principles. Using survey data from Kenya and applying bivariate ordered Probit and bivariate Tobit models, this paper analyzes the tradeoffs in maize residue use as soil mulch and livestock feed in mixed farming systems. Results show that both the proportion and quantity of maize residue used for soil mulch and livestock feed are strongly affected by agroecology and livestock holding. Farmer knowledge about alternative use of crop residues and farmer perception of soil erosion risk (proxied through plot steepness) positively affect the amount of residue farmers retain on maize plots. Results imply that crop residue use as soil mulch in conservation agriculture is challenged in mixed crop-livestock systems and particularly by smallholder farmers owning cross-bred and exotic dairy animals. In general, reducing the demand for crop residues as livestock feed through the introduction of alternative feed sources, better extension services on the use of crop residue as soil mulch and designing agroecology specific strategies and interventions could facilitate the adoption and expansion of CA-based practices in mixed crop-livestock systems.

Keywords: Maize residue, Mixed farming system, Conservation agriculture, Bivariate model, Kenya.

1. Introduction

Mixed crop-livestock systems in the developing countries support two-third of the world population and produce about half of the world food (Herrero *et al.,* 2010). Yet, these systems are under a significant pressure caused by the rising demand of human population, increased income, and rates of urbanization (Delgado *et al.,* 1999; Herrero *et al.,* 2009). To cope up with this pressure and attain the increasing demand for food, feed and energy at no or minimum damage to natural resources, adopting and adapting more resilient, intensified and sustainable agricultural production systems is indispensable (Hobbs, 2007; Gowing and Palmer, 2008; Kassam *et al.,* 2010; McDermott *et al.,* 2010).

In this regard, conservation agriculture[1] (CA) could be seen as a potential option that could help in maintaining and improving crop yield, attaining more resilient farming systems with reduced risks and hazards, while protecting and stimulating the biological function of the soil (Hobbs, 2007; FAO, 2008). Although CA was introduced to some of the Sub-Sahara African countries a couple of decades ago, its adoption in smallholder agriculture in the region as a whole package has been low (Ekboir *et al.,* 2002; Pascal and Josef, 2007). Moreover, whether CA fits to most farming systems in Sub-Saharan Africa and especially in mixed crop-livestock systems is still debated (Gowing and Palmer, 2008; Giller *et al*., 2009; 2011). The debate mainly arises from the potential tradeoffs in the allocation of resources (Giller *et al.,* 2011) and the socioeconomic setups influencing resource use in the mixed crop-livestock systems (Umar *et al.,* 2011).

[1] As defined in FAO (2008), conservation agriculture (CA) is a concept for resource-efficient agricultural crop production based on an integrated management of soil, water and biological resources combined with external inputs and achieved through its three principles (minimum or no mechanical soil disturbance, permanent organic soil cover, and diversified crop rotations) that enhance biological processes above and below the ground.

In mixed crop-livestock systems, use of crop residues as livestock feed is one of the major interactions between crop and livestock production[2] (McIntire and Gryseels, 1987; Latham, 1997; Erenstein and Thorpe, 2010; Moritz, 2010). At the same time, crop residue use as livestock feed exerts a competitive pressure on residue use as soil mulch, which is one of the three principles of conservation agriculture.

Maize is the main crop grown in Eastern and Southern Africa where Kenya is one of the major producers. Maize provides grain for food and stover or residue which is widely used for feeding livestock during the dry season. Eastern and western parts of Kenya are known for their maize-based mixed crop-livestock system but, to some extent, have different levels of interactions and intensifications in crop and livestock production that could enable to examine and compare the tradeoffs in crop residue use and its implications for conservation agriculture.

Though there is a wide literature on crop residue use and the potential tradeoffs in its use as feed and soil mulch, there is a dearth of information explaining the implications of crop residue use tradeoffs on conservation agriculture and sustainable land management. The main objective of this paper is, therefore, to assess the tradeoffs in maize residue use as feed and soil mulch in eastern and western Kenya, and examine the determinants of crop residue use for feeding livestock and soil fertility management and implication for the expansion of conservation agricultural practices in maize-based systems.

The paper is organized as follows. Section 2 presents conceptual framework of the study. Section 3 describes the study area and data. Section 4 presents methodologies used in data analysis.

[2] In addition to crop residue, manure use as soil fertility management, draft power in land preparation and cultivation practices, and financing the purchase of inputs in crop production through livestock sale are other major sources of interactions between crop and livestock subsystems (Erenstein and Thorpe, 2010).

Section 5 discusses analysis results and, based on the empirical findings, section 6 draws major conclusions and implications.

2. Conceptual Framework

Retaining permanent organic soil cover, as one of the three pillars in conservation agriculture, is strongly recommended in reducing surface run-offs, improving rain water infiltration, suppressing and controlling weed growth, etc. (Hobbs, 2007; FAO, 2008; Giller *et al.,* 2009). In conservation agriculture, 30% organic soil cover is set as a minimum requirement based on studies showing a 30% organic soil cover could reduce soil erosion by 80% (Erenstein, 2002; 2003; Giller *et al.,* 2009; Mazvimavi and Twomlow, 2009). After harvest, soil could be covered by growing forage legumes, green manure cover crops, or other food or feed crops. But, when farmers lack these options or such practices are less common, use of crop residue from previous harvest as soil mulch becomes essential. However, in a mixed crop livestock system, crop residue has several other purposes among which its use as livestock feed exerts a substantial challenge on residue use as organic soil cover. This potential tradeoff in residue use is critical in areas where farmers experience long dry spell between successive cropping seasons and with no or limited alternative feed sources. On top of that, households also use crop residue as firewood, construction of fences, storage, or other structures, and as a source of income through sale. Some households may also burn crop residue on plots with the aim of making land preparation/tillage easy and reducing the population of pests, insects, and rodents (Erenstein, 2003).

In areas where there is more than one cropping season, the length and nature of off-periods between two successive cropping seasons are usually not the same and could affect farmers' decisions in the proportion of crop residue allocated to different purposes. Under such circumstances, analyzing households' crop residue use by season is relevant. At a household level, the size and type of livestock holding could influence the quantity of crop residue demanded for feed. On the other hand, the amount of crop residue retained on farm plots as soil mulch is subject to plot characteristics which include soil depth, soil fertility, slope and distance from homestead. Plots with fertile and deep soils usually produce more biomass that could increase the volume of residue produced and made available to be used as feed and/or soil mulch. Households could use crop residue as soil mulch to reduce the intensity of run-off and increase rainfall infiltration into the soil particularly in plots with steep slopes (Thierfelder and Wall, 2009). Compared to plots closer to homestead, collection of crop residue from distant plots for livestock feed and other purposes could be laborious. This may contribute towards retaining more crop residue as soil mulch on distant plots and extracting residue from nearby plots for feed and other purposes.

Agroecology influences the diversity and biomass of crop production. Moreover, human and livestock population density, availability of feed and grazing land, etc. are agroecology specific. Thus, households in different agroecologies could use available crop residue resources in a unique pattern. In addition, available institutional services like extension and training on livestock production and management, agronomic practices that could include best way of using crop residue, etc. could influence farmers' behavior in residue use. Households tend to make use of rented-in lands in a more productive way that could maximize their overall benefits. Particularly when the lease contract is for a short period, there could be a possibility of soil mining and low interest in maintaining soil fertility through crop residue management or other options. Thus, one could expect lower rate of crop residue retention on rented-in lands than own plots.

3. Description of Study Sites and Data

3.1. Study sites

The study was conducted in five districts purposively selected from the eastern and western parts of Kenya, namely: Embu, Meru South and Imenti South from the Eastern Province, and Bungoma and Siaya from the Western and Nyanza Provinces, respectively. These districts are where the International Maize and Wheat Improvement Center (CIMMYT), The World Agroforestry Center (ICRAF) and Kenyan Agricultural Research Institute (KARI) are collaborating and conducting conservation agriculture based on-farm trials in selected villages and households. In addition, these districts are known for their large proportion of maize production but have a contrasting agroecology and farming systems that could help to make a comparison on the crop residue use and its implications on the adoption and adaptation of conservation agriculture practices. In the Eastern Province, the agroecology is more of semi-humid mid-lowland with relatively lower rainfall. The province is densely populated and farmers practice intensive farming. However, districts in the western part (Bungoma and Siaya) are mainly in a mid-highland agroecology with better rainfall where population density is relatively low and extensive farming is more common.

3.2. Data

Data used in this analysis was collected from 613 sample households in five districts mentioned above. The survey was conducted during January and February 2011 using a structured survey instrument and administered as a personal interview by experienced and trained enumerators. The data collection process was closely monitored and supervised by KARI-Embu, KARI-Kakamega, and CIMMYT staffs in the field. Within each district, divisions and villages were randomly selected from which the sample households were randomly selected proportionately to the total farm households. Table 1 presents the distribution of sample households by District and gender of the household head.

< TABLE 1 HERE >

The survey data in table 2 shows that maize is an important crop in the selected study areas. During the 2010 production year, from the total 613 sample households, 583 and 452 of them produced maize during season 1 and 2, respectively.[3] About 74% of the households producing maize in season 1 are also maize producers in season 2. On average, maize covers above 67% of the total cultivated land per household in both seasons. More than 97% of the households producing maize in 2010 used maize residue at least for one of the alternative purposes: firewood, soil mulch, animal feed, construction, sale, or burn *on-situ.* Majority of the households (about 54 and 57% of the households in season 1 and 2, respectively) used maize residue for a single purpose. During both seasons, about 33-35% of the sample households used maize residue both as feed and soil mulch, 59-61% used either as feed or soil mulch, and only about 5% of the households used neither as feed nor as soil mulch.

< TABLE 2 HERE>

Looking at the proportion of maize residue used for feed and soil mulch in table 3, larger number of households used maize residue for livestock feed. Of the total 580 households reported their maize residue use in the first season, 253 households (i.e., 43.6%) used more than 66% of their

[3] There are two cropping seasons both in the eastern and western parts of Kenya. Season 1, as referred throughout this paper starts in March/April and goes till June/July whereas season 2 starts in August/September and ends in November. In the cycle of cropping seasons, relatively, there is a short duration between season 1 and 2 than between season 2 and 1.

maize residue as feed. For the same season, only 22.9% of the households retained more than 66% of maize residue on plots as mulch. In season 2, about 48.2% of the households who reported the proportion of their maize residue use indicated that more than 66% of their maize residue production was allocated to livestock feed. In the same season, the proportion of households who retained more than 66% of their maize residue is only 20.3%. This clearly shows to what extent the use of maize residue for livestock feed is dominating the alternative use for soil mulch.

< TABLE 3 HERE>

The sample household heads have an average age of 50.3 years and 7 years of schooling. About 19% of the sample households are female headed and the average family size is 5.7 per household. On average, sample households are about 6 km far from main markets. Majority of the households (84%) own livestock (ruminants) that could be fed on crop residue. On average, each household has 1.5 TLU (Tropical Livestock Unit) of cattle and 2 small ruminants (sheep or goat). About 29% and 39% of the households got extension and training services on livestock production and crop residue use as soil mulch, respectively. Details of household characteristics across the five districts are presented in table 4 below.

< TABLE 4 HERE>

4. Empirical models

In this section, first, a bivariate ordered Probit model for the proportion of crop residue use as feed and mulch classified in three categories is presented. Then, a bivariate Tobit model is specified to estimate the quantity of maize residue use as livestock feed and soil mulch jointly. Explanatory variables used in the specifications and hypotheses to be tested are discussed briefly.

4.1. Proportion of maize residue use: Bivariate Ordered Probit Model

On whatever quantity of maize residue households produce, analyzing the proportion used for alternative purposes could help in identifying the importance of each specific purpose in household's maize residue use. The data shows maize residue use as feed and soil mulch constitute more than 83% of the total maize residue use in both seasons of the 2010 production year, Accordingly, throughout the analyses, we considered only these two important and competing purposes of maize residue use. Looking at the distribution of the proportion of maize residue use reported by the sample households, which is mainly concentrated at 0%, 50%, and 100%, and the 30% minimum organic soil cover requirement in conservation agriculture to reduce runoff by 80% (Erenstein, 2002; 2003; Giller *et al.*, 2009; Mazvimavi and Twomlow, 2009), we grouped the proportionate residue use in three categories (0 if below 34% is used for the specific purpose, 1 if the percentage use is between 34 and 66%, both inclusive, and 2 if the percentage use is >66%). This gives ordinal discrete values (0, 1, 2) that can be estimated using ordered Probit model (Verbeek, 2004). However, the proportion of maize residue used either as feed or soil mulch is not independent to each other. For a specific season, both residue use for feed and soil mulch purposes are satisfied from the same residue harvest. Therefore, in estimating the likelihood of using more proportion of maize residue as feed or mulch, we opted for a bivariate ordered Probit model that accounts both for the ordinal nature of the categories and the potential interdependence between the two alternative uses (feed and mulch).

Following Sajaia (2008), the bivariate ordered Probit model is specified as:

$$\begin{pmatrix} Y_{f,i}^* \\ Y_{m,i}^* \end{pmatrix} = \begin{pmatrix} \alpha_f \\ \alpha_{sm} \end{pmatrix} + \begin{pmatrix} \beta_f \\ \beta_m \end{pmatrix} \begin{pmatrix} X_{f,i} \\ X_{m,i} \end{pmatrix}' + \begin{pmatrix} \varepsilon_{f,i} \\ \varepsilon_{m,i} \end{pmatrix} \quad \text{where, } \varepsilon \sim BVN(0, \Sigma) \text{ , and } \Sigma = \begin{bmatrix} 1 & \sigma_{fm} \\ \sigma_{mf} & 1 \end{bmatrix} \qquad (1)$$

Where $Y_{f,i}^*$ and $Y_{m,i}^*$ are the latent proportion of maize residue used as livestock feed and soil mulch, respectively. α and β are parameters to be estimated, X_f and X_m are vector of explanatory variables in feed and soil mulch equations , respectively. ε is error term assumed to follow a bivariate standard normal distribution. The actual proportion of maize residue used as feed ($Y_{f,i}$) and soil mulch ($Y_{m,i}$) reported by farmers and grouped in three categories (0, 1, and 2) is specified as:

$$Y_{f,i} = \begin{cases} 0 & if \quad Y_{f,i}^* \leq \gamma_{f,1} \\ 1 & if \quad \gamma_{f,1} < Y_{f,i}^* \leq \gamma_{f,2} \\ 2 & if \quad Y_{f,i}^* > \gamma_{f,2} \end{cases} \quad \text{and} \quad Y_{m,i} = \begin{cases} 0 & if \quad Y_{m,i}^* \leq \gamma_{m,1} \\ 1 & if \quad \gamma_{m,1} < Y_{m,i}^* \leq \gamma_{m,2} \\ 2 & if \quad Y_{m,i}^* > \gamma_{m,2} \end{cases} \qquad (2)$$

Where $\gamma_{f,1}$, $\gamma_{f,2}$, $\gamma_{m,1}$ and $\gamma_{m,2}$ are unknown boundaries/cutting points of the categories in the latent variables.

Generally, the probability that a given household falls in one of the possible combinations (say category j in feed and k in mulch) is given as:

$$\begin{aligned} Pr\left(Y_{f,i} = j;\ Y_{m,i} = k\right) &= Pr\left(\gamma_{f,j-1} < Y_{f,i}^* \leq \gamma_{f,j}\ ,\ \ \gamma_{m,k-1} < Y_{m,i}^* \leq \gamma_{m,k}\right) \\ &= Pr\left(Y_{f,i}^* \leq \gamma_{f,j}\ ,\ Y_{m,i}^* \leq \gamma_{m,k}\right) \\ &\quad - Pr\left(Y_{f,i}^* \leq \gamma_{f,j-1}\ ,\ Y_{m,i}^* \leq \gamma_{m,k1}\right) \\ &\quad - Pr\left(Y_{f,i}^* \leq \gamma_{f,j}\ ,\ Y_{m,i}^* \leq \gamma_{m,k-1}\right) \\ &\quad + Pr\left(Y_{f,i}^* \leq \gamma_{f,j-1}\ ,\ Y_{m,i}^* \leq \gamma_{m,k-1}\right) \qquad (3) \end{aligned}$$

4.2. Quantity of maize residue use: Bivariate Tobit Model

There could be households with the same proportion of maize residue used as feed and soil mulch but differ when we look at the quantity allocated to these purposes. For any quantity of maize residue produced, which was estimated from maize grain production using a harvest index of 0.5 (Hay and Gilbert, 2001), the proportion used in one purpose affects proportion left for the other. However, a household could increase the quantity of residue used for both purposes by increasing the volume of crop residue production. Thus, analysis on the quantity of maize residue used for soil mulch and feed is important to examine the overall demand for maize residue as feed and mulch. As indicated above in the descriptive statistics, there are households who did not use maize residue as feed and/or soil mulch. Thus, the quantity of residue used as feed and mulch are censored at lower level. The censored nature of residue use data for alternative purposes necessitates the use of Tobit model. Moreover, there is a joint decision between the two major alternative residue uses (feed and mulch) where the proportion or volume used in one purpose depends on the other. Under such circumstances, separate Tobit estimation for each alternative purpose may not result in a robust estimation. Assuming $R^*_{f,i}$ and $R^*_{m,i}$ are, respectively, the latent quantities of maize residue allocated as feed (f) and mulch (m) by household i, a bivariate Tobit model is specified as:

$$\begin{cases} R^*_{f,i} = X_{fi}\beta_f + \varepsilon_{fi} \\ R^*_{m,i} = X_{mi}\beta_m + \varepsilon_{mi} \end{cases} \quad \text{where} \quad \varepsilon \sim \mathrm{N}\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_f^2 & \sigma_{sf} \\ \sigma_{fs} & \sigma_m^2 \end{pmatrix}\right] \tag{4a}$$

and

$$R_{f,i} = \begin{cases} R^*_{f,i} > 0 \\ 0 \quad Otherwise \end{cases} \quad \text{and} \quad R_{m,i} = \begin{cases} R^*_{m,i} > 0 \\ 0 \quad Otherwise \end{cases} \tag{4b}$$

Where $R_{f,i}$ and $R_{m,i}$ are the actual quantity of maize residue used as livestock feed and soil mulch, respectively. X_f and X_m are vectors of explanatory variables used in the feed and mulch equations. Details of the explanatory variables used in each equation are discussed in the subsequent section. If the covariance between the two specifications ($\sigma_{fm} = \rho\sigma_f\sigma_m$) is equal to zero, i.e., $\rho = 0$, then, the two Tobit equations could be estimated separately as a univariate Tobit. In addition, it is worth noting that plot characteristics are included in the soil mulch equation but not in the livestock feed equation. This is due to the fact that plot characteristics have more direct effect on household decisions in crop residue retention as soil mulch than using it as livestock feed. Thus, the set of explanatory variables in both equations are not exactly the same, which could help to solve the identification problem in a joint estimation.

4.3. Explanatory variables

In the equation on maize residue use for livestock feed, the following set of explanatory variables are included: household characteristics (age, gender, and education of the household head, active agricultural labor force in the family), livestock types owned (indigenous cow, cross-bred cow, exotic cow, trained oxen, bulls, heifers, calves, small ruminants), extension and/or training service received on livestock production, maize plot size used in a specific season, proportion of own maize plots from the total maize plots used in a specific season, weighted distance to maize plots from homestead, number of mature trees in maize plots, total quantity of maize residue produced in a specific season, and district dummies.

On the other hand, most explanatory variables used in the feed equation are included in the soil mulch equation. In the later, owned livestock types are aggregated as cattle and small ruminants. Moreover, instead of extension on livestock production, we used extension and/or training service received on retaining crop residue. On top of these adjustments, plot characteristics aggregated at a household level and only for those producing maize in a specific season are also included. The plot characteristics considered here include: intensity of manure used on maize plots during the specific season, weighted average level of soil fertility *(1=poor, 2=medium, 3=good)*, weighted average soil depth *(1=shallow, 2=medium, 3=deep)*, and weighted average slope of maize plots *(1=flat, 2=gentle slope, 3=steep slope)*. These plot characteristics were weighted by the respective plot area under maize production in a specific season.

4.4. Hypotheses to be tested

Based on the above econometric specifications; the following selected hypotheses are tested.

Size and type of livestock owned: generally, ownership of larger number of livestock is expected to increase the demand for crop residue as feed. Moreover, the demand for crop residue as feed potentially depends on the livestock type households keep (Erenstein and Thorpe, 2010). Feed requirement of exotic breeds are higher than indigenous ones. Thus, households owning large number of exotic breed are expected to use more proportion and quantity of maize residue as animal feed. Similarly, small ruminants could positively affect the demand for residue as feed but at a lower extent compared to cattle.

Soil fertility and depth: Households growing maize on relatively fertile and deep soil are expected to produce larger maize biomass and be able to satisfy both soil mulching and livestock feed, which are the two purposes maize residue is mainly used for. Thus, good soil fertility and soil depth helps to have more residues both for feed and soil mulch. On the other hand, households using maize plots with relatively better depth and fertile soil might be less concerned about soil fertility management, at least in the short term, and could tend to prefer using crop residue as livestock feed than soil mulch.

Soil slope: compared to plots on flat land, steep sloped plots under conventional tillage are more degraded in soil quality. Thus, households growing maize on steep slopes are expected to retain more crop residue in fields. However, this could be influenced by other physical structures on the plots to conserve soil movement and water infiltration, which is not considered in this analysis.

Quantity (biomass) produced: The competition between use of residue as soil mulch and livestock feed could be severe when the biomass production is low. Unless residue is marketed for the purpose of livestock feed in the vicinity, there could be a threshold quantity of biomass production above which the competition between these two alternative uses is no more serious Thus, increased biomass production is expected to have a positive effect both on the quantity of residue use as soil mulch and livestock feed.

Extension/training service: Provision of extension or training service to farmers on the use of crop residue as soil mulch is expected to affect the proportion and quantity of residue they retain on farm plots (Mazvimavi and Twomlow, 2009).

Agroecology: cropping patterns, population and livestock density, residue use, and availability of resources potentially differ by agroecology. Comparing humid and semi-arid agroecologies in the Indo-Gangetic plains, Erenstein (2003) shows that relatively larger proportion of crop residue is left on plots in humid than semi-arid agroecologies due to the availability of other alternative sources for feed, construction and firewood in the humid parts. Thus, due to better amount of rainfall and humid climate in the western part of Kenya, we expect larger proportion of residue use as soil mulch in Bungoma and Siaya districts.

5. Results and Discussions

5.1. Analysis of descriptive results

Mean equality test in table 5 shows no significant seasonal difference in the average proportion of maize residue use as feed and soil mulch. However, the average quantity of maize residue used as feed and mulch are significantly higher for residue produced in season 1. In addition, in season 1, households are using relatively far-away plots to grow maize and the total plot size allocated to maize is larger in the same season. Moreover, compared to season 2, the average proportion of rented-in plots to the total plot size used to grow maize is lower in season 1.

< TABLE 5 HERE >

5.2. Empirical results

Results from the empirical analysis are presented below in two sub sections. First, joint estimation results from the bivariate ordered Probit model on the determinants of maize residue proportions used as feed and mulch are presented. Then, the bivariate Tobit model estimation results on the determinants of the quantity of maize residue used as feed and soil mulch are discussed. Both the proportion and quantity analyses are made for the two seasons separately.

5.2.1. Determinants of proportion of residue use as feed and soil mulch

Bivariate ordered Probit estimation on the proportion of maize residue use shows the existence of regional differences in the use of maize residue both for livestock feed and soil mulch (Table 6). Compared to Bungoma, the likelihood of using larger proportion of maize residue as livestock feed is higher for households in Embu, Meru South and Imenti South districts (Eastern Province). On contrary, compared to Bungoma, the likelihood of leaving larger proportion of maize residue on plots is as soil mulch is lower for these districts. In the western part, the likelihood of using relatively larger proportion of maize residue as soil mulch is higher in Siaya than in Bungoma.

The farther the maize plots from homestead, as weighted by plot area, the lower the likelihood of using larger proportion of maize residue used for feed. Similarly, households growing maize on larger plots are using less proportion of their maize residue for livestock feed. This could be due to the increased biomass production from increased maize plot area.

As expected, the proportions of residue use both as feed and soil mulch strongly depends on the size of livestock owned and particularly the number of dairy cows. The effect on the proportion of maize residue use for feed is positive and higher for households owning cross-bred and exotic cows during both cropping seasons. Though not as strong as the exotic breeds, the number of indigenous cows owned also has a significant effect on the proportion of maize residue use for feed purpose. Number of bulls owned in season 1 affects the proportion of residue used for feed positively. More educated households use less proportion of maize residue as livestock feed.

Coming to soil mulch, those households who received extension and/or training services on retaining crop residue on plots left larger proportion of maize residue during both seasons. The effect of maize plots size on the proportion of maize residue left on farm is significant only during season 1. Larger proportion is left on farm by households using larger maize plots in season 1. Opposite to the proportion of residue use as feed, the farther the maize plots from homestead, the larger proportion of maize residue left on farm. This might be associated with the demand for more labor to collect and transport maize residue to a living quarter where usually animals are fed. The proportion of residue left on plots by households that are growing maize on a relatively fertile land is negative. As expected, larger proportion of maize residue is retained by households growing maize on relatively steeper slopes, which could reduce the intensity of soil erosion and increase rain water infiltration.

< TABLE 6 HERE >

5.2.2. Determinates of maize residue quantity used as feed and mulch

In explaining the variation in the quantity of maize residue used as feed and soil mulch, a bivariate Tobit model is estimated. Estimation results in table 7 indicate that, during both seasons, quantity of residue use as feed increases with the number of dairy cows owned. The effect of indigenous cows is not significant in season 1 but in season 2. Since there is a dry season between season 2 and season 1 cycle, the number of small ruminants owned also affects the quantity of residue used as feed positively. Households growing maize on larger plots are able to retain more quantities of reside on plots during both seasons and also able to provide larger quantity as feed. This apparently shows how biomass production could help to reduce the competition between feed and mulch.

Contrary to our expectations, the quantity of maize residue retained as soil mulch decreases with the proportion of maize plots owned from the total maize plots operated in season 1. The further the maize plots from homestead, the lower the quantity of residue used as feed. Existence of large number of mature trees in farm plots also decrease the quantity of residue used as feed. This could be due to the fact that some of these tree leaves and shoots might be used to feed livestock and reduce the pressure on maize stover as feed. Further study on this particular issue seems important as the dataset used in this study tells only the number of trees but not the specific tree species in the maize plots. Larger quantity of maize residue is retained by households using relatively fertile plots to grow maize. This could be a result of increased biomass production on fertile plots and the produced biomass exceeds household's livestock feed requirement. Moreover, compared to Bungoma, the quantity of maize residue used as mulch is significantly lower for districts in the Eastern province. On the other hand, compared to the quantity of residue used as livestock feed in Bungoma, quantity used as feed in Meru South and Imenti South is higher while it is lower in Siaya district in the West.

< TABLE 7 HERE >

6. Conclusions

Using survey data from eastern and western Kenya, this study assessed the tradeoffs in crop residue use for livestock feed and soil mulch and its implications for conservation agriculture and sustainable land management. A bivariate ordered Probit and bivariate Tobit models, respectively, were used to estimate the effect of farm and household level characteristics on the proportion and quantity of maize residue used as feed and mulch during different production seasons.

The results revealed a clear regional difference between the eastern and western provinces of Kenya in maize residue use as livestock feed and soil mulch. In the eastern part, maize residue is used more as livestock feed while in the western part a larger proportion is retained in the field as soil mulch. This difference emanates from the relatively different intensity of farming in both regions. Such a difference calls for targeting different strategies in promoting conservation agriculture in different agroecologies.

Moreover, households with larger livestock holding clearly allocated larger proportion of their maize residue to feed. The importance of this increases with the number of dairy cows owned.

The volume of maize residue used as livestock feed increases with the number of cross-bred and exotic cows owned by the farm households. Under intensive dairy production, the introduction of alternative feed sources is crucial to reduce the pressure on residue use as livestock feed and to increase the proportion of residue retained on farmland as soil mulch.

Provision of extension and training services on the importance of crop residue use as soil mulch helps in increasing awareness among farmers and could enhance their current level of maize residue use as soil mulch. Increasing biomass production of maize residue could also help in reducing the severe competition between animal feed and soil mulch. Retention of crop residues on farm plots can be beneficial in the long term to improve crop productivity and hence production of more biomass to meet the competing residue use for soil fertility and feeding livestock. For households to gradually achieve this benefit, giving focus to maize varieties with higher potential of biomass production (without compromising grain yield) and the introduction of alternative feed sources could be crucial.

Generally, interventions introducing and promoting conservation agriculture and sustainable land management through crop residue management should account for tradeoffs related to alternative and competing uses of crop residue as livestock feed and soil mulch. In some cases crop residue may also be used as source of bio-energy or firewood for cooking and heating which exerts more competitive pressure and need to be addressed as well. Finally, strategies designed in retaining more crop residue on farm plots should be context specific based on agroecology, cropping systems and the existing level of crop-livestock interactions.

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Table 1. Distribution of the sample households surveyed

Province	District	Male headed	Female headed	Total	Percent
Western	Bungoma	131	19	150	24.4
Nyanza	Siaya	110	39	149	24.3
Eastern	Embu	82	28	110	17.9
Eastern	Meru South	84	18	102	16.6
Eastern	Imenti South	87	15	102	16.6
	Total	**494**	**119**	**613**	**100.0**

Table 2. Distribution of the sample households in maize production and residue use (2010 production year)

	Season 1			Season 2		
Variables	*Obs*	*Freq.*	*%*	*Obs*	*Freq.*	*%*
Number of households producing maize	613	585	95.1	613	456	73.7
Households reported maize residue use	585	580	99.5	456	438	96.9
Number of households used maize residue as:						
Livestock feed	580	422	72.8	438	321	73.3
Soil mulch	580	332	57.2	438	241	55.0
Firewood	580	59	10.2	438	15	3.4
Construction	580	1	0.2	438	1	0.2
Sale	580	35	6.0	438	25	5.7
Burn on plots	580	36	6.2	438	22	5.0
Feed and soil mulch	580	205	35.3	438	146	33.3
Feed, soil mulch, and firewood	580	36	6.2	438	9	2.1

Table 3. Distribution of the sample households by their proportion of maize residue use for feed and soil mulch.

		Season 1				Season 2			
		Soil mulch				Soil mulch			
	Proportion	≤ 33%	34-66%	>66%	Total	≤ 33%	34-66%	>66%	Total
Feed	≤ 33%	*74*	*23*	*133*	230	*47*	*13*	*89*	149
	34-66%	*31*	*66*	*0* [a]	97	*17*	*61*	*0*	78
	> 66%	*253*	*0*	*0*	253	*211*	*0*	*0*	211
	Total	358	89	133	580	275	74	89	438

Note: [a] *Combinations of (34-66%, >66%), (>66%, 34-66%) and (>66%, >66%) for feed and mulch cannot exist due to the fact that higher use in one purpose (>66%) decreases the proportion made available to the other (≤33%).*

Table 4. Descriptive statistics of household and farm characteristics (N=613)

Variable	Mean	Std. Dev.
Age of household head *(years)*	50.31	14.76
Gender of household head *(1=male)*	0.81	0.40
Education of the household head *(years of schooling)*	7.38	3.97
Family size *(persons)*	5.74	2.64
Households owning large ruminants *(%)*	74.55	-
Households owning small ruminants *(%)*	52.36	-
Households owning large or small ruminants *(%)*	84.18	-
Number of indigenous cows owned	0.54	1.19
Number of cross-bred cows owned	0.20	0.54
Number of exotic breed cows owned	0.14	0.53
Number of oxen owned	0.15	0.64
Number of bulls owned	0.24	0.58
Number of heifers owned	0.19	0.71
Number of calves owned	0.58	0.99
Total cattle owned *(TLU)* [a]	1.48	1.85
Number of small ruminants owned	2.03	2.81
Got extension/training service on residue use as soil mulch *(1=yes)*	0.29	0.46
Got extension/training on livestock production *(1=yes)*	0.39	0.49

Note: [a] *TLU is Tropical Livestock Unit as defined in Storck et al. (1991).*

Table 5. Mean comparison test for selected variables that vary by season

Variables	Obs	Season 1 Mean	Season 1 Std. Err.	Season 2 Mean	Season 2 Std. Err.
Proportion of maize residue used as feed *(0 if ≤33%; 1 if 34≤X≤66%; 2 if >66%)*	417	2.14	0.04	2.13	0.04
Proportion of maize residue used as soil mulch *(0 if ≤33%; 1 if 34≤X≤66%; 2 if >66%)*	418	1.58	0.04	1.59	0.04
Quantity of maize residue used as livestock feed [a] *(kg)*	392	668.14***	41.01	536.99	34.54
Quantity of maize residue used as soil mulch [a] *(kg)*	393	390.57***	41.68	208.48	19.09
Amount of maize grain produced *(kg)*	431	654.98***	43.96	443.47	24.73
Maize area *(acre)*	432	1.16***	0.04	1.09	0.04
Proportion of maize area owned to total maize area *(ratio, 1=owned)*	429	0.89**	0.01	0.87	0.01
Weighted average distance to maize plots (by area) from homestead *(minutes)*	429	6.83	0.76	7.59**	0.77
Number of mature trees in the maize plots	432	12.52	2.02	12.46	1.97

*Note: ***, ** and * are significantly different from the mean in the other season at 1%, 5%, and 10% level, respectively.*

[a] Derived from maize grain production (as 2:1 ratio) and proportion of residue allocated to the specific purpose.

Table 6. Bivariate Ordered Probit estimation results on the proportion of maize residue use by season

	Season 1				Season 2			
	Feed		Soil Mulch		Feed		Soil Mulch	
Explanatory variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age of HH head *(year)*	0.004	0.004	0.003	0.005	-0.002	0.005	0.001	0.005
Sex of HH head *(1=male)*	0.410**	0.161	-0.396**	0.162	0.321*	0.184	-0.357**	0.179
Education of HH head *(year)*	-0.008	0.018	0.013	0.017	-0.018	0.022	-0.004	0.020
Active agricultural labor *(persons)*	0.023	0.056	-0.128*	0.066	-0.034	0.064	-0.083	0.079
Indigenous cows owned *(number)*	0.182***	0.063			0.214***	0.072		
Crossed cows *(number)*	0.596***	0.100			0.501***	0.156		
Exotic cows owned *(number)*	0.380***	0.090			0.422***	0.129		
Trained oxen owned *(number)*	0.093*	0.058			0.153**	0.062		
Bulls owned *(number)*	0.204***	0.061			0.155**	0.071		
Heifers owned *(number)*	0.037	0.051			0.047	0.090		
Calves owned *(number)*	-0.018	0.053			-0.009	0.064		
Cattle *(TLU)*			-0.110***	0.039			-0.095***	0.036
Small ruminants owned *(number)*	-0.001	0.022	0.012	0.022	0.020	0.022	0.008	0.023
Received extension/training on livestock production *(1=yes)*	-0.023	0.090			-0.062	0.115		
Received extension/training on retaining crop residue on plots *(1=yes)*			0.335***	0.099			0.393***	0.119
Maize area *(acre)*	-0.072*	0.040	0.086**	0.041	0.096*	0.059	-0.043	0.069
Share of owned maize area from the total maize area *(by season)*	0.115	0.212	-0.482**	0.224	0.194	0.250	-0.116	0.256
Weighted distance of maize plots from homestead *(minutes)*	-0.009***	0.003	0.011***	0.003	-0.006	0.004	0.008**	0.004
Number of mature trees in maize plots	-0.002**	0.001	0.001	0.001	-0.001	0.001	0.000	0.001
Intensity of manure used on maize plots *(kg/acre/season)*			0.000	0.000			0.000	0.000
Weighted soil fertility of maize plots *(1=poor, 2=medium, 3=good)* [a]			-0.005	0.061			0.133	0.083
Weighted slope of maize plots *(1=flat, 2=medium, 3=steep)* [a]			0.171**	0.079			0.283***	0.104
Weighted soil depth of maize plots *(1=shallow, 2=medium, 3=deep)* [a]			0.024	0.073			0.043	0.089
Embu_*Dummy (1=Embu, 0=else)*	1.495***	0.195	-1.635***	0.237	1.285***	0.268	-1.272***	0.290
Meru South_*Dummy (1=Meru South, 0=else)*	1.726***	0.205	-1.879***	0.241	1.389***	0.263	-1.467***	0.294
Imenti South _*Dummy (1=Imenti South, 0=else)*	2.023***	0.202	-1.941***	0.240	1.624***	0.280	-1.460***	0.307
Siaya_*Dummy (1=Siaya, 0=else)*	0.004	0.154	0.637***	0.156	-0.348	0.234	0.955***	0.254
Number of observations	*528*				*390*			
Wald $Chi^2(21)$	*274.65*				*190.65*			
Prob > Chi^2	*0.000*				*0.000*			
Log pseudo-likelihood	*-636.67*				*-471.89*			
Wald $Chi^2(1)$ [b]	*181.22*				*128.86*			
Prob > Chi^2 [b]	*0.000*				*0.000*			
Rho12	*-0.895****				*-0.862****			

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

[a] *Weighted by area of each plot and then aggregated.*

[b] *Wald test for the independence of the two equations.*

Table 7. Bivariate Tobit estimation results on the quantity of maize residue use by season

Explanatory variables	**Season 1**				**Season 2**			
	Feed		**Soil mulch**		**Feed**		**Soil mulch**	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Age of HH head *(year)*	1.63	2.11	3.92	3.28	0.11	0.88	0.89	0.95
Sex of HH head *(1=male, 0=female)*	167.02**	79.61	-139.46	105.80	10.98	29.95	-8.46	24.91
Education of HH head *(year)*	0.68	13.52	13.79	17.46	-2.72	3.81	1.25	3.75
Active agricultural labor *(persons)*	58.89	41.93	-85.27*	45.54	13.72	10.48	-3.23	10.97
Indigenous cows owned *(number)*	102.50***	34.99			24.23*	14.62		
Crossed cows *(number)*	208.74***	64.59			54.56**	26.28		
Exotic cows owned *(number)*	160.35*	83.60			46.55*	28.04		
Trained oxen owned *(number)*	-30.17	58.59			8.12	13.60		
Bulls owned *(number)*	63.97	61.85			11.26	16.38		
Heifers owned *(number)*	-78.80	81.40			2.37	18.47		
Calves owned *(number)*	-6.76	36.48			2.19	13.91		
Cattle (*TLU*)			7.61	28.33			-3.51	7.33
Small ruminants owned *(number)*	23.10	17.32	-29.19	25.52	6.12	4.62	-4.04	4.95
Extension/training on livestock production *(1=yes)*	-93.97	66.45			-48.11**	22.54		
Extension/training on retaining crop residue on plots *(1=yes)*			143.98*	75.69			73.83***	21.88
Maize plot size *(acre)*			33.67	29.37			13.90	10.66
Share of own maize plots from the total maize plots *(by season)*	22.35	171.80	-17.01	190.81	71.70	56.32	-49.17	58.22
Weighted distance of maize plots from homestead *(minutes)*	-3.89*	2.15	3.87*	2.12	-1.87	1.64	1.11	1.11
Number of mature trees in maize plots	-1.31*	0.79	-0.59	0.85	-0.24	0.25	-0.21	0.24
Intensity of manure used on maize plots *(kg/acre/season)*			0.00	0.00			0.00	0.00
Soil fertility of maize plots *(1=poor, 2=medium, 3=good)* [a]			-0.10	53.19			27.08*	16.08
Slope of maize plots *(1=flat, 2=medium, 3=steep)* [a]			4.58	56.48			32.14*	18.47
Soil depth of maize plots *(1=shallow, 2=medium, 3=deep)* [a]			88.71	56.71			45.14***	15.34
Total maize residue produced *(kg/hh/season)*	0.26	0.18	0.68***	0.20	0.72***	0.06	0.23***	0.06
Embu_*Dummy (1=Embu, 0=else)*	239.32	151.78	-427.42**	178.66	112.69**	46.60	-172.32***	42.29
Meru South_*Dummy (1=Meru South, 0=else)*	403.43***	141.65	-747.72***	176.22	158.22***	47.47	-247.14***	51.26
Imenti South_*Dummy (1=Imenti South, 0=else)*	365.74**	154.12	-495.51***	174.54	124.03***	47.72	-180.57***	46.26
Siaya_*Dummy (1=Siaya, 0=else)*	-203.98	154.57	284.82	200.34	-119.99***	44.05	110.69***	41.33
Constant	-499.45	339.53	-667.94	523.94	-212.90**	86.19	-215.97**	104.57
Number of observations	*527*				*381*			
Wald $Chi^2(41)$	*3906.06*				*2042.55*			
Prob > Chi^2	*0.000*				*0.000*			
Log pseudo-likelihood	*-5727.33*				*-3370.79*			
Rho12	*-0.79****				*-0.67****			

Note: ***, ** *and* * *are significant at 1%, 5%, and 10% level, respectively.* [a] *Weighted by area of each plot and then aggregated.*