Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa

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Abstract

Crop residues are a key livelihood resource in smallholder mixed crop-livestock systems in Sub-Saharan Africa. With expansion of arable land and resultant decline in grazing resources, crop residues are becoming an increasingly important component of livestock feeds. This demand for livestock feeds has implications for the long-term sustainability of such systems since failure to return biomass to soils has implications for soil quality and the capacity of soils to support long-term productivity. Biomass allocation patterns are likely to vary with overall level of productivity and hence availability. In this study we used a household survey to quantify crop residue allocation patterns across a gradient of productivity in Eastern Africa focusing on two sites in Ethiopia and one in Kenya. We assessed the underlying determinants of crop residue allocation patterns with a view to understanding how productivity increases through intensification will influence biomass allocation in Eastern Africa and how livelihood and natural resource management objectives could be optimized. Results showed that farmers strongly favour allocation of residues to livestock feeding but that allocation to soil increases along the productivity gradient. This reduced feeding to livestock and increased allocation to soil fertility is associated with smaller farm sizes leading to reduce animal traction needs for tillage, increased overall livestock productivity, increased use of inputs and a reduced reliance on farm-based activities in overall livelihood strategies. The implications of these trends are that productivity increases in smallholder systems are likely to reduce pressure on biomass in the long term and that measures that enhance the prospects for farmers to intensify their production systems are likely to increase soil health and sustainability objectives in general. A key conclusion of the work is that intensification of livestock production could reduce crop residue allocation to soils with long term implications for soil productivity.

Key words: crop residue, livestock feed, intensification, soil

1. Introduction

Mixed crop livestock systems form the basis for rural livelihoods for the majority of the world's rural poor. They are also the source of much of the world's food and recent estimates put the contribution of mixed systems to global food production at around 50% (Herrero et al. 2010). The integrated nature of mixed crop livestock farming means that livestock provide key inputs for arable production including manure and traction, while crops provide reciprocal inputs to livestock production, notably in the form of crop residues (straws and stovers) to sustain livestock (Powell et al. 2004). Further integration occurs at the level of the soil; livestock sustain soil fertility through returns of excreta (Rufino et al. 2007). However a key trade-off in maintaining the integrity of mixed crop livestock systems relates to crop residue use. In order to maintain soil fertility, in particular soil organic carbon, biomass needs to be returned to the soil on a regular basis and in adequate amounts. However, farmers also need to sustain their livestock and there is pressure to remove residual biomass in the form of straws and stovers and feed them to livestock (Giller et al. 2009). Feeding residue to livestock does not necessarily break the cycle of nutrient and biomass return to the soil since these can be returned in the form of livestock manure which provides a good source of relatively stable organic carbon and of readily useable nutrients to improve soil fertility. However, manure is bulky and the labour costs of returning manure to fields in meaningful quantities in the absence of mechanization tend to be prohibitive. Furthermore nutrient losses at various points between manure production and return to the field can lead to very low nutrient cycling efficiencies (Castellanos-Navarrete et al. 2015; Rufino et al. 2007). Continual removal of biomass from arable land leads to nutrient mining, loss of soil organic matter, attendant loss in water holding capacity and gradual soil degradation and undermining of crop yields (de Ridder & van Keulen 1990) although the benefits of biomass return are highly context specific (Bationo et al. 1995; Rufino et al. 2007; Turmel et al. 2015). This is the trade-off at the core of the research reported here. At issue is the basis for decision making at farm level about how to allocate crop residues to various competing demands. What lies behind farmers' decisions to remove biomass and feed to livestock at the expense of long-term crop yields? What could be done to ease pressure on biomass for the sake of environmental integrity and individual farm-based livelihoods?

Recent reviews have analysed the global drivers of change in developing world smallholder farming (Hazell & Wood 2008; Herrero et al. 2010; McDermott et al. 2010). Of interest here are the regional pressures which directly impinge upon crop residue use patterns. Chief among the relevant drivers in Eastern Africa is continuing expansion of cultivated land related to population growth (Ruthenberg 1980). Expansion of arable land is typically at the expense of the common pool resources - including pastures and rangelands - and this has implications for the composition of livestock diets (Lambin et al. 2003). Grazed feed resources used to form the major component of livestock diets in Ethiopia but crop land has expanded at the expense of rangeland resources in recent decades (Aklilu Mekasha et al. 2014; Berhe 2004; Dessie & Kleman 2007) leading to a gradual substitution of grazed feed resources by crop residues. In other Eastern African countries such as Kenya and Uganda there has been a longer tradition of confined feeding but none-the-less, pressure on scarce biomass resources is increasing as a result of arable expansion (Baldyga et al. 2008). Loss of rangeland also reduces domestic fuel resources leading smallholders to rely on crop residues which would otherwise be left in situ or fed to livestock. The pattern is therefore one of increasing pressure on increasingly scarce common pool resources and of increasing reliance on crop residues from cultivated areas. Reduced biomass in both cultivated and common areas potentially leads to increased soil erosion and degradation.

One reason for expansion of cultivation has been the failure to sufficiently increase productivity of staple cereals to meet the food demands of a growing population (Eberhardt 2008; Hazell & Wood 2008). Because of the close correlation between grain and crop residue yields (harvest index) this also limits residual biomass availability and this is another pressure point in smallholder production.

In animal traction-dependent systems, a major share of crop residues goes towards maintaining oxen (Baudron et al. 2013). These needs are eased by increased mechanization but in the Eastern

African study countries there is still little mechanization of tillage operations. In Ethiopia, oxen are still the dominant source of traction whereas in Western Kenya hand hoeing is the norm. The demands of traction animals for feed are a further pressure point on biomass use in smallholder systems in Eastern Africa, particularly Ethiopia.

These various drivers steadily increase pressure on biomass in mixed smallholder systems in Eastern Africa. The focus of this paper is to examine the immediate implications of this increasing pressure on biomass for household decisions on crop residue use and to assess the further implications for future livelihoods and the possibilities for sustainable intensification. Sustainable intensification is defined as “producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services” (Pretty et al. 2011). Our overarching objective was to characterize current crop residue allocation patterns to different uses: livestock feeding, retention in the field, and other uses such as for construction and domestic fuel. To help in understanding possible future scenarios of biomass allocation patterns, we selected study sites along a gradient of agricultural intensification and productivity. Allocation patterns and the underlying farm characteristics that influence them are expected to vary as systems intensify. Our study design allowed us to make a comparative analysis of the study sites variously located along the gradient with a view to (i) understanding how allocation patterns are likely to evolve as systems intensify and become more productive and (ii) assessing the implications for research-for-development.

2. Methods

Study sites: agro-ecology and socio-economic context

Three case study sites with mixed crop-livestock farming systems were identified in Eastern Africa (Ethiopia and Kenya). In Kenya, Kakamega in the west of the country was selected. In Ethiopia, Nekemte in the west of the country was selected along with Kobo in the north-east of the country (Figure 1). Sites were selected based on a gradient of market access, agro-ecology and intensity of production: from Kakamega (wet; dairy; diverse cropping, intensive) to Kobo (drier; subsistence livestock; cereal-based, less intensive). The three sites were purposively selected to capture contrasting cereal (maize and sorghum) -based systems. Maize-beans, maize-teff[1] and sorghum-teff are dominant crops in Kakamega, Nekemte and Kobo, respectively. The Nekemte site is within the highland zone of Ethiopia with a mean altitude of 2088 metres above sea level (masl) while the Kobo and Kakamega sites are lower at between 1468 and 1535 masl respectively (Table 1). The dominant soils in Nekemte and Kakamega are acidic and fix phosphorus making it unavailable to crops. Vertisol is the dominant soil type in Kobo with high clay content, a tendency to crack during the dry season and a capacity to hold much water during the rainy season.

Because of the productivity gradient used for site selection, the socio-economic context of the three sites is very diverse, particularly between the Kenyan and the other sites. Human and cattle population densities are much higher in Kakamega than in the Nekemte and Kobo sites (Table **1**). These high human and cattle densities in Kakamega have resulted in expansion of cultivated lands and depletion of soils and other natural resources. In all three sites a high proportion of land is under cultivation. In terms of market access, Kakamega is better placed because of an improved road network and the presence of a large number of small villages and towns. Farmers can easily access these towns to sell crop and livestock products and purchase inputs. Private land ownership

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[1] Teff (*Eragrostis tef*) is a prominent staple cereal in Ethiopia.

prevails in Kakamega, and this encourages citizens to buy and sell land. Property rights are less well developed in the Ethiopian sites. Extension support to farmers in the areas of agriculture and human health has become stronger in Ethiopia in general in recent years. As a result, farmers can in theory access technological information that enables them improve agricultural productivity. Extension provision in the Kenyan site is less well developed.

Data

Eight villages were selected using Google Earth images in each of our three sites around a central market town with all dichotomous combinations of proximity to the central market (near – far) and proximity to a road (near – far), and 2 village combinations. For this, two main roads from the major market town were randomly selected (sometimes there were only two). For each of these roads, the distance between this town and the next market town was calculated. The point on the road at which the two towns were equidistant was marked as the “far from market” point of reference. The point at which a tenth of the distance between the major market town and the next market town was marked as the “near to market” point of reference. Villages on either side of the road at these points along the nearest passable side road were then selected within a radius from the market town along the direction of the main road of $0 – 10^0$ for the “near to road” villages and between $10 – 30^0$ for the “far from road” village. A total of 24 villages were therefore surveyed in the three sites.

A household survey was conducted in 2011 to gather detailed information at the household (HH) level. Based on census lists of all the farmers of each village, a total of 160 HH were selected from the eight villages of each study site giving a total sample size of 480 households across the 3 study sites. Twenty HH per village were considered for the HH questionnaire survey. The number of households per village averaged 126, 47 and 192 in Kobo, Bako and Kakamega respectively. The average proportion of households per village interviewed was thus 0.20, 0.46 and 0.14 in Kobo, Bako and Kakamega respectively. Households were selected by conducting a village census to gather basic information on land holdings and wealth categories for each household. These were used to develop a wealth index and households were then stratified into 4 wealth classes and 5 households per village per wealth class were randomly selected.

The household questionnaire incorporated major issues such as household characteristics, access to market, credit and extension, land owned and cultivated, crop production on a per plot basis, crop residue allocation, livestock herd structure and dynamics, feeding strategies, income sources and expenditure, and limitations for crop and livestock production. Each household survey took between 3-4 hours to complete and was answered mostly by the household head.

The factors influencing the different crop residues uses were assessed through econometric analysis of all crop level observations with data on crop residue use, crop type, and cultivated area. Accordingly, 15, 5, and 4 households from the respective districts of Kobo, Nekemte, and Kakamega that miss data on one or more of the latter variables were excluded.

The analysis was conducted on 3 crop groups and 3 residue use groups. The crop groups considered for the analysis were: i) maize and sorghum combined (both having coarse stover and either being the prevailing cereal), ii) teff (having fine straw, an important cereal in Ethiopia), and iii) the remaining crops combined (comprising 16 crops, each with too few observations for separate analysis and with no other prominent sub-grouping). Residue uses were grouped together according to the broad purpose they serve: i) retained in the field either as residual mulch on the soil or burnt during land preparation, ii) used as cattle feed either through stubble grazing by own cattle or used as stall feed, and iii) the category of all other uses, which includes 9 different crop residue uses including use as household fuel, construction material, and used by other households.

3. Results

System characterization

Closely related to the agro-ecology and demographics, the study sites broadly represented a productivity gradient with Kobo being the most marginal site, Nekemte being of intermediate productivity and Kakamega being the most productive site. This gradient can be detected in data related to cropping and livestock production as follows.

Cropping. The area allocated to cultivation per household decreased with increasing productivity from an average of 1.6 ha per household in Kobo to an average of 0.4 ha per household in Kakamega (Table 2). Large grained cereals, specifically maize and sorghum predominated in the extensive conditions in Kobo and were present but to a lesser extent in the more intensive systems in Nekemte and Kakamega. Small grained cereals predominated in Nekemte while horticultural crops were important in Kakamega. Among small-grained cereals, teff was important in the Ethiopian sites; wheat was also strongly present in Nekemte. Other crops grown in Kakamega included beans, sugar cane, sweet potato and banana plants among others (data not shown). Legume use generally increased along the productivity gradient. Allocation of land to fallow was relatively insignificant in all sites.

Input use indicators generally followed expectations with increasing use moving up the productivity gradient from Kobo to Kakamega (Table 2). Application of all types of fertilizer (farm yard manure, urea, di-ammonium phosphate) was consistently higher in Kakamega than in the Ethiopian sites and generally higher in Nekemte than in Kobo although fertilizer use in all sites was still low relative to recommendations (Ethiopian Agricultural Research Organization 2004; Mandefro Nigussie et al. 2009). Use of improved seeds was also more prominent in Kakamega than in the Ethiopian sites. Between the Ethiopian sites, improved seed use was higher in Kobo than in Nekemte. The proportion of land under small-scale irrigation was generally low but slightly higher in the more productive sites. Mechanized tillage was absent in the Ethiopian sites and unusual even in Kakamega. In Kakamega, land was largely tilled by hand. Herbicide and fungicide use were common in Ethiopian sites but unusual in Kakamega against the general pattern of increased input use with increasing intensity of production.

Marketing of cereal grains, as an indicator of output production, was highest in Kakamega at between 30-50% of grain being sold in the market. It was intermediate in Kobo at between 30-40% of grain being marketed (Table 2). Grain sales were lowest in Nekemte at 13-16% of production being sold. Sales of other crops (mainly vegetables and legumes) ranged between 40 and 60% depending on site.

Livestock. Overall livestock holdings per household did not systematically follow the productivity gradient with households in Nekemte holding the most livestock at around 5 TLU’s per household. Households in Kobo held around 4 TLU’s and those in Kakamega held the smallest holdings at around 3 TLU’s per household. However, when farm size was taken into account, livestock pressure followed the productivity gradient with much higher livestock holdings per unit area in the most intensified site at Kakamega (Table 3). The livestock holding in all sites was dominated by cattle and in both Ethiopian sites cattle were almost exclusively of indigenous breeds. In Kakamega around a quarter of the holding was made up of improved cross-bred cows. Small ruminants also made up a small proportion of the livestock holding with roughly equal numbers of sheep and goats overall. There was a tendency for households in the more intensive Kakamega site to favour sheep and those in the less extensive Kobo site to favour goats. Equids were common in the extensive system represented by Kobo, were also present in Nekemte, but were not present in the Kakamega households. Households in all sites kept a few backyard poultry, especially in Kakamega.

Livestock feeding strategies varied considerably by site (Table 3). In general grazing was the predominant means of feeding livestock in both Nekemte and Kakamega with farmers estimating that around 60% of livestock nutrition was derived from grazing in these sites. Crop residues also represented an important component of the diet both in the form of in situ grazing of stubbles and the feeding of straws and stovers (dry fodder) to confined animals. Feeding of residues was especially important in the least intensified site at Kobo where dry fodder (stall fed and stubbles) was estimated by farmers to make up 50% of the diet. In the more intensified sites of Nekemte and Kakamega the proportions were around 25% and 18% respectively. Feeding of green fodder to confined animals made up 15-30% of the diet depending on site. Feeding of concentrates was negligible but accounted for around 3% of the diet in Nekemte and Kakamega.

Milk productivity of cattle increased with increasing intensification (Table 3). Thus milk yields of indigenous cows increased from 0.9 l/d/cow in Kobo to 3.0 l/d/cow in Kakamega[1]. Cross-bred cows were only present in Kakamega but these yielded even more at 4.1 l/d/cow. The proportion of the livestock holding sold or bartered each year was variable across sites and did not systematically follow the productivity gradient.

Crop residue use. To allow comparison across all three sites only the combined maize and sorghum residues are considered in the following. The general pattern of maize and sorghum residue allocation was that more residue was left in the fields in the more productive sites while more was allocated to livestock feeding in the more marginal sites (Figure 2). Almost no residues were left in the field in Kobo with farmers estimating the figure to be around 3%. This contrasted with a figure of

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[1] Data on milk yield are indicative. Farmers were asked to estimate average milk yield per female cow per day. All respondents were asked the same question so the data give a good indication of relative milk yield in different sites and for different cow types. However because lactation length and lactation curves are variable the absolute milk yield values need to be treated with caution.

36% in Kakamega. In situ burning of residual residues was unusual, although in Nekemte farmers reported burning 12% of their residues.

Almost 70% of maize and sorghum residues were fed to livestock in Kobo, mainly through feeding to confined animals. In Nekemte and Kakamega, the percentage was roughly 35% with stubble grazing predominating in Nekemte and stall feeding predominating in Kakamega.

Other uses were important in all sites with use of maize and sorghum residues for domestic fuel being a particularly prominent use especially in the Ethiopian sites. Sale of maize and sorghum residues was a minor use in all 3 sites as was use for construction. Taken together, all uses other than mulching and feeding accounted for roughly 30-50% of maize and sorghum residue use depending on site.

General household characteristics are presented in Table 4 and illustrate the household trends associated with the productivity gradient including a diminishing reliance on farm income, increased labour availability, reduced use of farm-produced food, increased marketing of farm produce especially livestock products, and increased organization of farmers including access to credit.

Determinants of crop residue use

Model results to assess the factors related to allocation patterns for the combined maize and sorghum residues are shown in Table 5 – with the descriptive statistics of the model variables included in the previous Table 4. Area of cultivated land had relatively consistent effects with larger farms both retaining and feeding more residues and using proportionally less for other uses such as fuel and construction. Livestock pressure expressed as TLU per hectare also showed consistent effects: in general higher livestock density led, as expected, to more feeding and less retention and other uses. Data related to the proportion of livestock products marketed showed consistent effects. The general pattern showed that where livestock product marketing was important, households fed more residues and retained less on the soil and used proportionately less for other uses including fuel and construction. The effect was strong in Nekemte and especially in Kakamega where dairying is prominent (data not shown). Access to alternative feed sources would be expected to reduce the amount of residue fed to livestock and increase retention – there was some suggestion of this effect in the data although the tendency was not significant.

Use of improved seed was also related to a higher proportion of residue being fed to cattle perhaps related to higher residue biomass yields allowing more scope for feeding residues to cattle. Travel time to crop output markets had consistent effects on residue use: those households situated further from markets tended to feed more to livestock and generally allocate less to other uses. The proportion of crops marketed however had minimal effects on crop residue use and the effects were not systematic across crops. Food self-sufficiency data indicate that in general, food secure households feed more residues to livestock and retain less on soils. Association membership had strong effects on crop residue allocation: more residue retention on soil and less feeding.

There were also site differences in allocation patterns (Table 5). Farmers in Kakamega retained more residues on fields than in Nekemte and those in the extensive Kobo site retained the least. For feed, the opposite pattern applied with farmers in Nekemte and Kakamega allocating less to feed than those in Kobo. Other uses were higher in Nekemte and Kakamega than in Kobo. Effects of labour availability were inconsistent and difficult to interpret, with an indication that increased labour availability allowed more residue retention. Access to credit did not have a strong systematic effect on crop residue use although it generally led to less use of residues for mulching and more feeding of residues. Access to information did not influence residue use. Education level of the household head also had minimal effect, and similarly on-farm income as a proportion of total income had minimal effects on allocation patterns.

Discussion

Biomass allocation is a critical issue in the debate on sustainable intensification in smallholder systems in Sub-Saharan Africa (SSA). Some argue strongly about the benefits of Conservation Agriculture and particularly the need to return biomass to the soil in order to sustain soil fertility (Hobbs 2007). Others point out that the realities of smallholder farming in mixed systems in SSA do not allow such an approach – smallholders have livestock to feed and simply do not have the luxury of sparing biomass for return to the soil (Giller et al. 2009). Biomass allocation patterns are a crucial element of the future sustainability of smallholder systems. Continued removal of biomass for uses such as fuel, construction and livestock feeding lead to detrimental cumulative effects on soil properties, including negative impacts on soil organic carbon concentrations and soil structure, reduced water holding capacity and reduced resistance to erosion (Bationo et al. 1995). However, in SSA, the pressure not to return crop residues to soils remains strong. A high proportion of farmers are food insecure and are not in a position to forego short-term livelihood needs derived from feeding livestock in the interests of building long term natural capital in the form of healthy soils (Giller et al. 2009).

Use of crop residues for fuel, construction and a variety of other uses (aside from feeding and returning residues to the soil) was substantial at 30-50% of overall residues depending on site. The results of our analysis show that as cultivated area increases the proportion of residues used for purposes other than feeding and retention on soil declines. This suggests that the absolute amount of residue required for fuel and construction is generally fairly stable per household so that as farm size increases, proportionately more residue is available for livestock feeding and return to the soil. With rising populations and decreasing farm size (Masters et al. 2013) across Sub-Saharan Africa this could lead to diminishing availability of residues for productive use. This trend will be balanced by increasing use of modern construction materials and alternative sources of fuel as development occurs. The results on farm size also have implications for biomass allocation patterns and their relationship with resource endowment of different farms. Poorer farmers with smaller holdings are likely to have relatively less biomass to allocate to soil and livestock feed uses because of the fixed requirement for fuel and construction purposes. In the long term this could lead to increased divergence in resource endowment among farms with wealthier farms being able to invest in long term soil improvement while poorer farms become locked into a cycle of soil degradation, a conclusion also reached in previous studies (Shepherd & Soule 1998; Tittonell et al. 2010). Our results showing an increase in allocation to livestock feeding as cultivated area per farm increases contrast with those of Jaleta et al. (2013) who found an opposite trend. This may relate to the narrower range in farm size in the latter study which focused on maize producers in Ethiopia.

Our results emphasise the pressure that smallholders are under to allocate crop residues for livestock feeding. However, by studying a gradient of productivity our results allow us to understand potential trajectories of change as systems intensify and become more productive. The data indicate that intensification will lead to more opportunity to allocate crop residues to soil fertility purposes. (Vanlauwe et al. 2014) also argue that increasing overall productivity through increased fertilizer use is a key pathway to achieving conservation agriculture objectives. In the extensive site at Kobo, where livestock production is mainly subsistence in nature, farmers feed 70% of residues to their cattle. They are completely reliant on cattle for traction purposes and their productivity per animal in terms of milk production, for example, is low. These farmers use very limited inputs, such as commercial fertilizer and improved seeds. They are also heavily reliant on on-farm income for their livelihoods. In the more productive Kakamega site, the situation is different. Here farmers feed around 30% of their residues to livestock and retain around 35% on soil. Here farm sizes are smaller and reliance on cattle for traction is less significant. Per animal productivity, illustrated by milk production, is relatively high. Moderate levels of inputs including commercial fertilizer and improved seeds are used. Furthermore, farmers are less reliant on the farm to support their livelihoods – a significant proportion of income derives from off the farm. Looking to the future, intensification trends such as reduced reliance on oxen for traction, increased use of inputs leading to yield increases and diversification of livelihoods beyond the farm are likely to reduce pressure to allocate crop residues to livestock feeding thus providing more flexibility for their use in soil fertility improvement.

Rationale for crop residue allocation patterns

Our results help understand residue allocation patterns by farmers – which in turn allows us to predict how allocation patterns change as systems intensify. An over-riding factor in the observed pattern of crop residue allocation is the nature of livestock production as also reported by Jaleta et al. (2013). The relatively large farms in the extensive Kobo site need to be tilled by cattle since mechanization is not available. This represents a fixed cost for these households; oxen need to be fed in order to have sufficient energy for field operations (Pearson 1993); the most readily available feed source is crop residues so this is the farmers' first priority. This was also reflected in the results on determinants of crop residue use. Increased livestock density led to more feeding of crop residues. It can be argued that as livestock production intensifies and becomes more market-driven, the importance of crop residues diminishes. Feed quality of crop residues is inherently low and residues are thus generally regarded to be insufficient to support the needs of higher productivity of milk and meat production, whereas market-oriented livestock production enables farmers access to improved feed. Our data do not support this argument, however: increased marketing of livestock products led to greater allocation of crop residues to livestock feeding. Presumably this relates to a combination of the study site selection and the fact that overall, the study sites were at a relatively early stage of livestock intensification and we might expect a reduced proportion of residue use for livestock feeding later in the intensification process.

Demand for livestock products is increasing as a result of urbanization, dietary changes and rising incomes. This so-called Livestock Revolution presents potential opportunities for poor livestock keepers to increase their income through market oriented production given an enabling policy environment (Barrett 2008), but the potential implications of increased feeding of crop residues on local natural resources need to be considered. An increased emphasis on feeding crop residues to livestock to support livestock production for the market could lead to even less crop residues being returned to the soil.

Other elements of intensification also influenced crop residue allocation patterns. Access to inputs, in this case improved seed, led to higher allocation of residues to livestock feeding. Overall biomass availability affects the absolute amount of crop residue that can be allocated to different uses. In the global study of which this work was a component, we found that even in highly intensive smallholder systems in South Asia, substantial proportions of crop residues were still fed to livestock. However, the increased overall amount of crop residue available in these systems provided opportunities to still return substantial absolute amounts of crop residues to soil (Valbuena et al. 2014).

It could be argued that feeding residues to livestock is a rational choice for farmers as a means of stabilizing nutrients and making them more available for crop use. Manure has a lower C/N ratio than crop residue and application of manure rather than direct application of residues can avoid the short-term N immobilization that often results from direct crop residue application (Powell et al. 2004). Nutrients in manure are generally more plant available than those in crop residues (Powell et al. 1999). However, the benefits of passing crop residues through livestock prior to returning them to fields need to be balanced against the logistical and labour-related challenges of applying bulky manure to fields rather than simply retaining intact residues in the field. In the case of the sites in this study, the feeding of residues to livestock by farmers was more likely to have related to the immediate need to feed livestock rather than indirect benefits to soil properties.

Conclusions

Intensification of livestock production in the developing world is usually regarded as a positive trend for the environment and for farmer livelihoods (Herrero et al. 2010; McDermott et al. 2010). Our results suggest that some caution is needed before accepting this argument; increased intensity of livestock production coupled with greater market orientation of poor livestock producers could have negative impacts on the return of biomass to soils in the form of crop residues with potential long-term implications for soil properties and hence arable crop yields. Competition for biomass for different uses will continue as systems intensify. To allow this intensification to be sustainable, a coupled approach is needed whereby yields of both arable crops and livestock products increase in tandem. This is because the only way to spare sufficient biomass for maintenance of healthy soils is the production of much higher levels of overall biomass production in smallholder systems in Sub-Saharan Africa.

References

Aklilu Mekasha, Gerard,B., Tesfaye,K., Lisanework Nigatu & Duncan,A.J. 2014. Inter-connection between land use/land cover change and herders'/farmers' livestock feed resource management strategies: a case study from three Ethiopian eco-environments. Agriculture Ecosystems & Environment, 188, 150-162.

Baldyga,T.J., Miller,S.N., Driese,K.L. & Gichaba,C.M. 2008. Assessing land cover change in Kenya's Mau Forest region using remotely sensed data. African Journal of Ecology, 46, 46-54.

Bationo,A., Buerkert,A., Sedogo,M.P., Christianson,B.C. & Mokwunye,A.U. 1995. A critical review of crop-residue use as soil amendment in the West African semi-arid tropics. In: International Conference on Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Addis Ababa (Ethiopia). 22-26 Nov 1993. (Ed. by J.M.Powell, S.Fernandez-Rivera, T.O.Williams & C.Renard), pp. 305-322. Addis Ababa: ILCA.

Baudron,F., Jaleta,M., Okitoi,O. & Tegegn,A. 2013. Conservation agriculture in African mixed crop-livestock systems: Expanding the niche. Agriculture, Ecosystems & Environment, 187, 171-182.

Berhe,K. 2004. Land Use and Land Cover Changes in the Central Highlands of Ethiopia: the Case of Yerer Mountain and Its Surroundings. MSc Addis Ababa University.

Castellanos-Navarrete,A., Tittonell,P., Rufino,M.C. & Giller,K.E. 2015. Feeding, crop residue and manure management for integrated soil fertility management. A case study from Kenya. Agricultural Systems, 134, 24-35.

CGIAR Consortium for Spatial Information . Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) pre-processed for Ethiopia. 2014. 10-11-2014.

de Ridder,N. & van Keulen,H. 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid-tropics (SAT). Fertilizer Research, 26, 299-310.

Dessie,G. & Kleman,J. 2007. Pattern and Magnitude of Deforestation in the South Central Rift Valley Region of Ethiopia. Mountain Research And Development, 27, 162-168.

Diwani,T.N., Asch,F., Becker,M. & Mussgnug,F. 2013. Characterizing farming systems around Kakamega Forest, Western Kenya, for targeting soil fertilityΓÇôenhancing technologies. Journal of Plant Nutrition and Soil Science, 176, 585-594.

Eberhardt,M. Cereal production in Ethiopia: a brief historical overview of land under cultivation and yields. Briefing note prepared for the DFID funded study "Understanding the constraints to continued rapid growth in Ethiopia: the role of agriculture". 2008.

Elias,E. & Fantaye,D. 2000. Managing Fragile Soils: a Case Study From North Wollo, Ethiopia. IIED-Drylands Programme.

Ethiopian Agricultural Research Organization 2004. Directory of Released Crop Varieties and Their Recommended Cultural Practices. Addis Ababa: EARO.

Giller,K.E., Witter,E., Corbeels,M. & Tittonell,P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research, 114, 23-34.

Hazell,P. & Wood,S. 2008. Drivers of change in global agriculture. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 363, 495-515.

Herrero,M., Thornton,P.K., Notenbaert,A.M., Wood,S., Msangi,S., Freeman,H.A., Bossio,D., Dixon,J., Peters,M., van de Steeg,J., Lynam,J., Parthasarathy Rao,P., MacMillan,S., Gerard,B., McDermott,J., Sere,C. & Rosegrant,M. 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock production. Science, 327, 822.

Hobbs,P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? Journal Of Agricultural Science, 145, 127.

Jaleta,M., Kassie,M. & Shiferaw,B. 2013. Tradeoffs in crop residue utilization in mixed crop–livestock systems and implications for conservation agriculture. Agricultural Systems, 121, 96-105.

Lambin,E.F., Geist,H.J. & Lepers,E. 2003. Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environmental Resources, 28, 205-241.

Mandefro Nigussie, Anteneh Girma, Chimdo Anchala & Abebe Kirub 2009. Improved Technologies and Resource Management for Ethiopian Agriculture. A Training Manual. Addis Ababa: Government of Ethiopia Ministry of Agriculture and Rural Development; Rural Capacity Building Project.

Masters,W.A., Djurfeldt,A.A., De Haan,C., Hazell,P., Jayne,T., Jirstr+¦m,M. & Reardon,T. 2013. Urbanization and farm size in Asia and Africa: Implications for food security and agricultural research. Global Food Security, 2, 156-165.

McDermott,J.J., Staal,S.J., Freeman,H.A., Herrero,M. & Van de Steeg,J.A. 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science, 130, 95-109.

Pearson,R.A. 1993. Resource requirements for draught animal power. Occasional Publication - British Society of Animal Production, 57-67.

Powell,J.M., Ikpe,F.N. & Somda,Z.C. 1999. Crop yield and the fate of nitrogen and phosphorus following application of plant material and feces to soil. Nutrient Cycling in Agroecosystems, 54, 215-226.

Powell,J.M., Pearson,R.A. & Hiernaux,P.H. 2004. Crop-livestock interactions in the west African drylands. Agronomy Journal, 96, 469-483.

Pretty,J., Toulmin,C. & Williams,S. 2011. Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability, 9, 5-24.

Rufino,M.C., Tittonell,P., van Wijk,M.T., Castellanos-Navarrete,A., Delve,R.J., de Ridder,N. & Giller,K.E. 2007. Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science, 112, 273-287.

Ruthenberg,H. 1980. Farming Systems in the Tropics. London: Oxford University Press.

Shepherd,K.D. & Soule,M.J. 1998. Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems & Environment, 71, 131-145.

Thornton,P.K., Jones,P.G., Owiyo,T., Kruska,R.L., Herrero,M., Kristjanson,P., Notenbaert,A., Bekele,N. & Omolo,A. Mapping climate vulnerability and poverty in Africa. 2006. Nairobi, International Livestock Research Institute.

Tittonell,P., Muriuki,A., Shepherd,K.D., Mugendi,D., Kaizzi,K.C., Okeyo,J., Verchot,L., Coe,R. & Vanlauwe,B. 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. Agricultural Systems, 103, 83-97.

Turmel,M.S., Speratti,A., Baudron,F.d.r., Verhulst,N. & Govaerts,B. 2015. Crop residue management and soil health: A systems analysis. Agricultural Systems, 134, 6-16.

Valbuena,D., Homann-Kee Tui,S., Erenstein,O., Teufel,N., Duncan,A.J., Abdoulaye,T., Swain,B., Mekonnen,K., Germaine,I. & Gerard,B. 2014. Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. Agricultural Systems, 134, 107-118.

Vanlauwe,B., Wendt,J., Giller,K.E., Corbeels,M., Gerard,B. & Nolte,C. 2014. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. Field Crops Research, 155, 10-13.

Table 1 – Agro-ecological and socio-economic indicators at zonal/district level

Indicator	North Wello (Kobo)	East Welega (Nekemte)	Western Kenya (Kakamega)
Mean annual rainfall (mm) [1]	768	1037	2009
Soil type [2]	Vertisol	Nitisol	Acrisols, Ferralsols, Alisols
Landscape	Hilly and valley bottoms	Hilly and flat	Flat land dominated (undulating peneplain)
Altitude (masl) [3]	1112 - 3293	961 – 2342	1250 – 2000
Length of growing period (days) [4]	136	210	292
Human population density (persons/km^2) [5]	81	101	821
Cattle densities (head/km^2)[6]	33	48	104
Proportion of land under crop cultivation (%) [7]	80.9	76.6	82
Market development [8]	++	+	+++
Resource use property rights [9]	+	+	+++
Extension support [10]	+++	+++	+

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[1] Sirinka, Bako and Kakamega Agricultural Research Centres Meteorological station data (2011, personal communication)

[2] Authors' expert knowledge, (Elias & Fantaye 2000), (Diwani et al. 2013)

[3] (CGIAR Consortium for Spatial Information 2014), (Diwani et al. 2013)

[4] Data generation described in (Thornton et al. 2006)

[5] Global Rural-Urban Mapping Project (GRUMP)

[6] FAO Gridded Livestock of the World

[7] EIAR GIS (2011, personal communication); Kenya population and housing census (2009).

[8] Authors' own expert assessment

[9] Authors' own expert assessment

[10] Authors' own expert assessment

Table 2 – Crop production: land allocated to different crops, indicators of input use, and indicators of output production-using crop level data

		Kobo		Nekemte		Kakamega	
Land allocation to different crops[a]		Mean	SE mean	Mean	SE mean	Mean	SE mean
Average potentially cultivated land (ha/hh)		1.6	0.09	1.4	0.08	0.4	0.03
of which							
Large grain cereals (%)[b]							
Maize		11.4		12.8		14.1	
Sorghum		32.4		8.6		0.0	
Total		43.7		21.4		14.1	
Small grain cereals (%)							
Teff		33.4		17.7		0.0	
Wheat		0.0		19.2		0.0	
Others		0.0		11.6		21.4	
Total		33.4		48.5		21.4	
Other crops (%)							
Legumes		0.0		7.9		14.3	
Horticultural crops		17.9		8.1		31.1	
Others		4.8		12.2		17.0	
Total		22.7		28.2		62.4	
Fallow (%)		0.2		1.9		2.1	
Indicators of input use							
Fertilizer (kg /ha)							
Manure	Whole sample	34.5	6.6	36.5	4.2	221.4	28.0
-	For those using	270.6	32.0	177.2	12.9	423	48.8
Urea	Whole sample	1.1	0.7	13.3	1.5	67.7	7.3
	For those using	41.1	20.7	54.8	4.7	136.3	12.6
DAP	Whole sample	0.5	0.3	24	2.3	88.6	5.3
	For those using	29.2	9.2	52.1	4.3	121.9	6.0
Use of improved and hybrid seeds (% hh)		27.8	3.7	12.3	2.6	84.1	2.9
Improved and hybrid seeds applied area (%)		13.8	2.3	5.4	1.3	57.6	3.0
Irrigation (% of hh)		8.3	2.3	16.8	3.0	9.6	2.4
Irrigation (% of area)		3.5	1.2	4.6	1.0	5.2	1.4
Manual tillage (% of hh)[c]		0.7	0.7	2.5	1.2	55.8	3.6
Reported use of herbicide or fungicide							
Proportion of hhs (%)		36.8	4.0	70.3	3.7	1.3	0.9
Proportion of area (%)		22.2	2.7	38.4	2.7	0.6	0.5
Spending on herbicides or fungicides							
For an average HH ($/per applied ha)		1.6	0.2	2.9	0.3	0.1	0.1
Among users ($/per applied ha)		4.4	0.4	4.1	0.4	5.9	1.5
Among an average HH ($/per ha)		1.0	0.1	1.4	0.2	0.04	0.0
Among users ($/per ha)		2.6	0.3	2.0	0.2	3.2	1.8
Indicators of market orientation							
% of crop production marketed							
Large cereal		30.8	1.7	12.6	1.9	28.6	1.5
Small cereal		39.4	2.2	15.8	1.7	53.7	11.2
Other crops		61.7	14.8	38.3	4.0	45.1	2.7

Note: a) Where more than 1 crop was grown per year on the same parcel of land, the denominator was increased to account for this. Where fields were intercropped both crops were treated as if mono-crops. b) Allocations to different crops are calculated at site level to avoid distortions that would arise from calculating at household level related to variable farm size and the fact that not all households grew each crop. c) The remaining percentage in Kobo and Nekemte is animal traction; in Kakamega the remaining comprises 26% animal traction and 14% tractors.

Table 3 – Livestock production: livestock holdings, feed composition, production indicators

	Kobo		Nekemte		Kakamega	
Livestock holdings	Mean	SE mean	Mean	SE mean	Mean	SE mean
Proportion of HHs with livestock (%)	93	2.2	84	3.0	89	2.5
Mean TLU per HH (TLU/HH)						
Whole sample	3.7	0.2	4.7	0.4	2.9	0.2
For those having	4	0.2	5.6	0.4	3.3	0.2
Of which (% of TLU herd)[a]						
Cattle, local	82.6		91.9		67	
Cattle, cross	0.2		0		24.4	
Goat	3.3		1.3		2.3	
Sheep	2.3		2.7		3.6	
Equines	11		3.8		0	
Poultry	0.5		0.4		2.2	
Other	0		0		0.6	
Livestock pressure						
Livestock density (TLU/ha total area)	3.9	0.5	4.6	0.4	18.8	2.5
Feed composition (%)						
Grazing grass	23.8	1.4	63.3	1.3	67.4	1.1
Grazing stubbles	21.2	1.1	12.5	1.0	10.3	0.9
Stall fed						
Dry fodder	28.4	1.0	12.4	0.7	8.0	0.7
Green fodder	28.3	1.5	9.4	0.7	12.7	0.7
Concentrate	0.0	0.0	3.3	0.7	2.0	0.3
Production and market orientation indicators						
Average milk yield (l/d)						
Local cows	0.9	0.1	1.6	0.2	3	0.2
Cross-bred cows	_	_	_	_	4.1	0.3
Animals sold or bartered (% of total holding)						
Cattle	26.4	3.1	5.9	1.3	10.2	1.8
Goats	37.6	6.6	20.1	7.8	19.2	6.4
Sheep	17	8.5	23.8	5.3	25.6	5.4

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[a] Percentage shares of different livestock species are calculated at site level to avoid distortions that would arise from calculating at household level related to variable herd compositions of different farm sizes and the fact that not all households kept each livestock species.

Table 4 – Descriptive statistics of variables included in the econometric model (only maize and/or sorghum producing households)

	Kobo		Nekemte		Kakamega		All households		
Variables	Mean	SE mean	Mean	SE mean	Mean	SE mean	Mean	SE mean	Max
Household head education (in years)	1.1	0.2	3.4	0.3	7.6	0.4	4.1	0.2	18
On farm income out of total income (%)	86.0	1.5	80.3	2.5	39.9	1.6	67.8	1.5	100
Total cultivated land (hectares)	1.6	0.1	1.5	0.1	0.4	0.0	1.1	0.0	7
Livestock pressure (TLU/ha total area)	3.7	0.5	4.4	0.5	18.6	2.6	9.2	1.0	264
Labor availability (working members/ha total area)	3.1	0.2	3.8	0.3	22.7	1.7	10.3	0.8	67
Food self-sufficiency index[a]	0.7	0.0	0.7	0.0	0.3	0.0	0.6	0.01	1
Access to information[b]	0.35	0.0	0.4	0.0	0.5	0.0	0.4	0.01	1
Livestock output marketed (%)[c]	0.2	0.0	0.2	0.0	0.3	0.0	0.2	0.02	1
Crop output marketed (%)	30.8	1.7	12.6	1.9	28.5	1.5	24.5	1.0	100
Importance of crop (crop area/total cultivated area)	0.6	0.02	0.4	0.02	0.5	0.0	0.5	0.01	1
Improved seed variety (dummy, 0 if local and 1 if improved)	0.2	0.03	0.1	0.03	0.8	0.0	0.4	0.02	1
Travelling time to crop outputs market (hour)	1.1	0.04	1.1	0.1	0.8	0.2	1.0	0.1	20
Alternative feed source[d]	0.97	0.01	0.8	0.03	0.7	0.04	0.8	0.02	1
Association membership[e]	0.002	0.002	0.03	0.01	0.1	0.02	0.1	0.01	1
Access to credit (dummy, 0 if no, 1 if yes)	0.4	0.04	0.3	0.04	0.7	0.04	0.5	0.02	1

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[a] Food sufficiency is defined as the proportion of months per year during which farm grown produce fulfils household food requirements.

[b] Access to information is the proportion of affirmative responses out of 16 questions on whether households obtain different information from governmental or non-governmental organizations. The information pertain to crop variety, price, and technology, and livestock breed, feed, health, technology, and marketing.

[c] Processed and unprocessed milk sold as a percentage of milk produced.

[d] Alternative feed source takes a value of 1 if households have access to open communal land, communal grass reserves, or private grazing land in any season and 0 otherwise.

[e] Association membership assigns a value of 1 if households are members of all 3 organizations of crop, livestock, and dairy producers' association/cooperative. Members of any 1 or 2 organizations are assigned a value 1/3 and 2/3, respectively.

Table 5 – Three stage least-squares estimates of factors affecting combined maize/sorghum crop residue use

Explanatory variable	Estimated coefficients			Calculated elasticities		
	Soil	Feed	All other uses	Soil	Feed	All other uses
Household head education (in years)	0.306	-0.061	-0.201			
On farm income out of total income (%)	-0.033	0.038	-0.008			
Total cultivated land (hectares)	3.43***	3.005**	-2.117**	19.84	7.50	-15.31
Livestock pressure (TLU/ha total area)	-0.142**	0.20***	-0.007	-6.62	3.96	
Labor availability (working members/ha total area)	0.094*	-0.036	-0.042	6.04		
Food self-sufficiency index	-13.5***	24.5***	-0.541	-39.69	31.03	
Access to information	-0.749	3.405	0.113			
Livestock output marketed (%)	-6.8**	16.0**	-5.992**	-8.29	8.43	-9.13
Crop output marketed (%)	-0.020	-0.076	0.056			
Importance of crop (crop area/total cultivated area)	5.742	-8.719*	7.296**		-9.02	21.88
Improved seed variety (dummy)	-0.116	4.878*	-1.375		3.97	
Travelling time to crop outputs market (hour)	-0.460	2.04***	-0.861		4.49	
Alternative feed source	0.825	-4.616	4.870**			26.04
Association membership	22.9***	-11.378	-4.656	6.92		
Access to credit (dummy)	-3.969**	0.996	0.707	-0.98		
Nekemte (dummy)	15.2***	-37.1***	12.5***			
Kakamega (dummy)	28***	-27***	14.6***			
Constant	10.369*	46.4***	5.302			
R2	0.450	0.475	0.174			
Chi-squared statistics	342	377	88			
Number of observations	417					

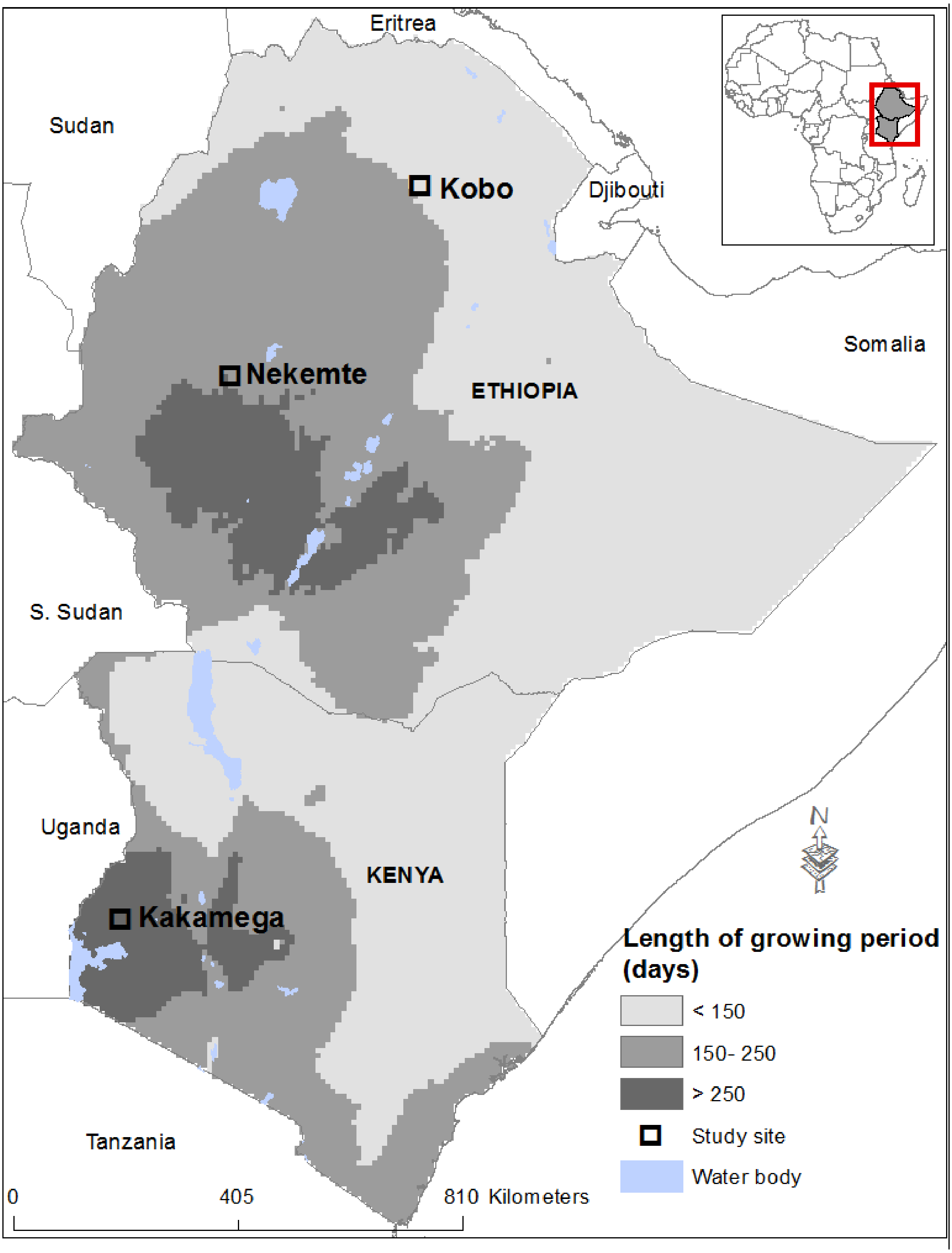
Asterisks denote level of significance: * P<0.05, ** P< 0.01, *** P< 0.001

Figure captions

Figure 1 **–** Location map of the three study sites in eastern Africa showing location in different zones of productivity indicated by length of growing period

Figure 2 **–** Maize/sorghum residue allocation patterns at 3 study sites in Eastern Africa moving up a gradient of productivity from Kobo → Nekemte → Kakamega

Figure 1 – Location map of the three study sites in Eastern Africa showing location in different zones of productivity indicated by length of growing period[a]



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[a] Date source: IIASA-FAO Global Agro-ecological Zone (GAEZ v3.0).

http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/

Figure 2 – Maize/sorghum residue allocation patterns at 3 study sites in Eastern Africa moving up a gradient of productivity from Kobo → Nekemte → Kakamega