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Conservation agriculture in African mixed crop-livestock systems: Expanding the niche

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ABSTRACT

Competition for crop residues between livestock feeding and soil mulching is a major cause of the low and slow adoption of conservation agriculture (CA) in sub-Saharan Africa. Retaining crop residues in the field is not only a prerequisite for CA but may also be the most viable option for African farmers to retain their fields in a productive state. In this paper, (1) we explore the possibility of increasing the quantity of crop residue available by closing the maize yield, (2) we propose interventions that can reduce crop residue demand for livestock feed, and (3) we quantify the optimum amount of crop residues required as mulch, using empirical, secondary and modeling data from Western Kenya and the Ethiopian Rift Valley. Residue retention can also be increased by reducing livestock demand. Closing the maize yield gap–i.e. achieve 90% of the water-limited yield potential–and intensifying dairy production–which would promote the use of rations that are more energy-dense than cereal residue-based rations–would increase the estimated proportion of farmers retaining at least 1 t ha^{-1} of crop residues from the current 36% to 97% in Western Kenya. In the Ethiopian Rift Valley, closing the maize yield gap and substituting mechanization to animal draught power would increase the estimated proportion of farmers retaining at least 1 t ha^{-1} of crop residues from the current 3% to 83%. We conclude that the question is not 'if', but 'how' cereal residues can fulfill the demand of both the soil and the livestock.

1. Introduction

Retaining crop residues as surface mulch, together with minimum soil disturbance and crop rotation and association, forms the basis of conservation agriculture (CA, Kassam et al., 2009). The environmental benefits of CA in terms of soil and water conservation are well documented (e.g., Lal, 1998; Scopel et al., 2004). CA may also generate a number of short-term benefits for farmers (Knowler and Bradshaw, 2007; Rusinamhodzi et al., 2011). Reduction in machinery and fuel costs has been one of the major incentives for the large-scale adoption of CA in North America, South America and Australia (Kassam et al., 2009). In the less mechanized systems in developing countries, CA may enable early planting, as the number of operations required to prepare the land are reduced (Haggblade and Tembo, 2003). Moreover, reduced soil water loss from runoff and evaporation (Rockström et al., 2009; Thierfelder and Wall, 2009) may result in more efficient use of rainfall by the crop and yield stabilization, particularly in dry areas (Friedrich, 2008; Erenstein, 2002, 2003).

Feeding crop residues to livestock is an alternative use particularly common in the developing world, where 75% of the milk and 60% of the meat are produced in mixed crop-livestock systems (Herrero et al., 2010; Valbuena et al., 2012). The crop residue demand by the livestock sector is unlikely to decrease in this part of the world, as meat and milk consumptions are projected to more than double by 2050 from their values in 2010 (Thornton, 2010). A trade-off arises when a particular stakeholder faces more than one objective towards a resource that cannot simultaneously be achieved (Grimble and Wellard, 1997). Due to the multiple benefits livestock generates (Schiere et al., 2002; Powell et al., 2004; Rufino et al., 2006; Herrero et al., 2010; McDermott et al., 2010), mixed crop-livestock African farmers generally feed the bulk of their crop residues to livestock and sacrifice on soil mulching i.e. they trade soil mulching for livestock feeding (Valbuena et al., 2012). When insufficient quantities of crop residues are retained as surface mulch, minimum tillage alone may lead to lower yields compared with the current farm practices, particularly on soils that are prone to crusting and compaction (Baudron et al., 2012). Based on those observations, some authors have concluded that CA would only fit in a limited set of socio-ecological niches in Africa, which is dominated by mixed crop-livestock systems (Giller et al., 2009, 2011; Andersson and Giller, 2012).

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Table 1
Sub-objectives and methods used in the study.

Sub-objectives	Methods
Quantifying current crop residue use	Calculations from farm survey data
Exploring alternatives to increase cereal grain and residue yield	Yield gap analysis from farm survey data
Exploring alternatives to reduce livestock demand for crop residues	
By stimulating livestock productivity	Feeding trial to establish the relationship between cereal residue feeding and livestock productivity
By providing substitute to the main functions livestock plays	Calculations from farm survey data to quantify livestock functions
Quantifying the short-term benefits of soil mulching on crop productivity	On-station trial to establish the relationship between mulching rate and grain yield

Several studies have quantified and explained crop residue trade-offs in mixed crop-livestock systems (e.g. Erenstein, 2002, 2003; Valbuena et al., 2012) but few have explored alternatives to feed both the livestock and the soil, and thus expand the niche in which CA would fit. Retaining part of the crop residues in African fields is not only a prerequisite to CA adoption: it may also be the most viable option to maintain them in a productive state, whether they are ploughed in or retained as surface mulch. It is widely acknowledged that increasing the use of mineral fertilizer, currently estimated at an average 8 kg ha^{-1} (Groot, 2009), is necessary to improve crop productivity in Africa (e.g. Vitousek et al., 2009). Soils with a low soil organic carbon content, however, generally respond poorly or not at all to mineral fertilizers (Lal, 2010; Vanlauwe et al., 2010). An adequate annual input of organic material is crucial to maintain soil organic carbon, especially in coarse-textured soils (Chivenge et al., 2006; Stewart et al., 2007; Luo et al., 2010). The quantity of manure and plant biomass (other than crop residues) available to African farmers as organic input is generally low (Vanlauwe and Giller, 2006; Tittonell and Giller, 2012). Manure and plant biomass, when available, are also bulky materials: their collection, transport and application are labour-intensive, and they are only applied to a minority of fields (Tittonell et al., 2005). On the other hand, crop residues represent the most abundant organic material available to farmers (Lal, 2005) and their retention *in situ* does not require any labour. Thus, retaining part of the crop residues produced in African fields is a priority to sustain agricultural intensification in the continent. In circumstances where the retention of these residues as surface mulch leads to short-term benefits for farmers, it may also expand the adoption of CA.

The objective of this study was to quantify crop residue trade-offs and explore alternatives to overcome them in two study sites known for their high livestock densities: Western Kenya and the Ethiopian Rift Valley. Both sites are part of the maize mixed farming system as defined by FAO (http://www.fao.org/DOCREP/003/Y1860E). Western Kenya corresponds to the wetter part of this domain, and the Ethiopian Rift Valley to the drier part.

2. Materials and methods

2.1. General approach

A range of methods were used in this study, to fulfill four inter-related sub-objectives (Table 1). First, current crop residue uses were quantified, using farm survey data. Second, alternatives were explored to increase the quantity of crop residues retained in the field by (1) increasing the quantity produced and (2) reducing livestock demand. These explorations were made using farm survey data and feed trial data. Third, the impact of crop residue mulching on crop productivity was established using on-station trial data.

2.2. Study areas

2.2.1. Western Kenya

In Western Kenya, the study was conducted in the District of Bungoma, located between 34°22 and 34°03 East and 0°25 and 1°08 North, and the District of Siaya, located between 33°57 and 34°33 East and 0°18 and 0°26 North. Bungoma lies between 1,300 and 3,100 m above sea level, whilst Siaya lies between 1,100 and 1,500 m above sea level. Bungoma receives bimodal rainfall ranging from 1,200 mm to 1,800 mm per year, with the long rains falling between March and July and the short rains between August and November. Higher regions of Siaya receive 1,800 mm to 2,000 mm of rainfall per annum, while the lower regions receive 800 mm to 1,600 mm per annum. Average temperatures in Bungoma range from 16 °C to 30 °C with an average of 23 °C. In the two districts, maize (*Zea mays* L.), common bean (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz), sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.), sweet potatoes (*Ipomoea batatas* (L.) Lam.), and bananas (*Musa sp.* L.) are the main food crops grown, whilst sugarcane (*Saccharum sp.* L.), tea (*Camellia sinensis* (L.) Kuntze), cotton (*Gossypium hirsutum* L.) and tobacco (*Nicotina sp.* L.) are the main cash crops. The major livestock enterprises are dairy cattle and poultry. This study area is referred to as 'Western Kenya' in the rest of the paper.

On-station research trials in Western Kenya were conducted at Kakamega Agricultural Research Center. The station is located at 34°45 East, and 00°16 North, at an altitude of 1,585 m above sea level, receives between 1,890 and 1,920 mm of annual rainfall, and is characterized by a mean minimum temperature of 14 °C, and a mean maximum temperature of 27 °C. Soils are dominated by mollic Nitosols.

2.2.2. Ethiopian Rift Valley

In Ethiopia, the study was conducted in four districts of the Ethiopian Rift Valley: Adama, Adami Tulu, Boset, and Dodota Sire, located between 38°40 and 39°30 East and 7°50 and 8°40 North. The area lies between 1,500 and 1,950 m above sea level, and is characterized by low and erratic rainfalls comprised between 500 and 800 mm and high evapo-transpiration rates. Mean minimum temperatures range from 7.8 to 14.4 °C and mean maximum temperatures from 27.2 to 28.6 °C. The study area is characterized by two clearly defined seasons: a main rainy season from June to October, and a long dry season from November to May. Tef (*Eragrostis tef* (Zucc.) Trotter), maize, wheat (*Triticum sp.* L.) and common bean are the main crops grown. Cattle, goats, horses and donkeys are the main livestock types farmers keep. This study area is referred to as the 'Ethiopian Rift Valley' in the rest of the paper.

On-station research trials in the Ethiopian Rift Valley were conducted at Melkassa Agricultural Research Center. The station is located at 39°12′ East, and 8°24′ North, at an altitude of 1,550 m above sea level, receives 763 mm of average rainfall annually, and is characterized by a mean minimum temperature of 28.6 °C, and a mean maximum temperature of 13.8 °C. Soil is dominantly loamy and clay loamy.

2.3. Farm survey

A sample of farms was randomly selected in the two study areas: 299 in Western Kenya and 344 farms in the Ethiopian Rift Valley. The head of each farm was interviewed using a standardized questionnaire addressing size and composition of the household,