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Maize crop residue uses and trade-offs on smallholder crop-livestock farms in Zimbabwe: Economic implications of intensification

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Decisions to use crop residues as soil cover for conservation agriculture create trade-offs for farmers who own cattle in crop-livestock systems. Trade-offs among soil C, crop and animal and crop productivity were analysed using the NUANCES-FARMSIM (FArm-scale Resource Management SIMulator) dynamic model. Retention on the soil surface of 0, 25, 50, 75 and 100% of the maize stover yield produced per farm, and the use of the remainder as animal feed was quantified over a 12 year period for four farm types in Murehwa, Zimbabwe. Retaining 100% maize residues in the field led to an annual loss of on average 68 and 93 kg body weight per animal for cattle on farms of the relatively wealthiest farmers (Resource Group, RG1) who had most land and cattle and RG2 respectively), and is therefore unsustainable for livestock production. There was an increase in grain yield of 1.6 t farm^{-1} and 0.7 t farm^{-1} for RG1 and RG2 respectively. Farmers without cattle (RG3 and RG4) may have a greater incentive for retaining their crop residues but they have to invest labour to keep the residues during the dry season. However, improved crop productivity for these farmers is limited by lack of access to fertiliser. The current practice of allocating all crop residues to animals results in average gross margin of US$7429 and US$4037 for RG1 and RG2 farmers respectively. Our results showed that from an economic perspective, it is logical that farmers prioritise the sustenance of cattle with crop residues over soil fertility management. We conclude that at current productivity levels, farmers who own cattle have limited scope to allocate crop residues for soil cover as it leads to significant loss in animal production and economic value.
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1. Introduction

Conservation agriculture (CA) based on crop residue retention in combination with minimum tillage and crop rotations or intercrops is actively promoted in many parts of the tropics including southern Africa (cf. FAO, 2008). Smallholder agriculture in southern Africa is characterized by mixed crop-livestock systems (Thornton and Herrero, 2001) in which livestock are commonly used for tillage and crop residues are fed to livestock (Erenstein, 2002). Livestock are an important source of food and income, and can be used as an insurance with which food can be bought when crops fail. In particular, cattle support crop production through the provision of draught power and manure, cattle manure is important as fertiliser and in some instances, the only resource to sustain soil fertility (Murwira et al., 1995). These multiple roles imply that the sustenance of livestock (cattle) is critical for whole farm productivity.

In this study, the costs and benefits of feeding livestock with crop residues are assessed for a crop–livestock case study in Zimbabwe. A crop–livestock system is defined as a system in which at least 10% of dry matter fed to livestock comes from crop harvest residues (Steinfeld et al., 2006), and in this specific case study, as much as 30% of cattle feed is derived from crop residues (Rufino et al., 2011). Thus, crop production intensification through CA probably creates the strongest trade-offs in resource use among the intensification options that exist for smallholder farmers in mixed crop-livestock systems despite it being promoted widely in the last decade (Giller et al., 2009). In the case study site, farmers allocate crop harvest residues for cattle feed in the dry season and

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there is no deliberate production of pasture or fodder crops to support livestock production. It is doubtful whether smallholder farmers in general can produce sufficient crop residues to satisfy the dual objectives of improved crop production through CA and of sustained livestock production (Giller et al., 2009; Corbeels et al., 2014). The retention of crop residues in combination with no-till are the pillars of CA (Rusinamhodzi, 2015), and throughout this paper, the acronym CA is used extensively to refer to the two practices. Promotion of CA may reduce the amount of feed and threaten the integration of crop and livestock production on smallholder farms. Yet integration of crop and livestock production is considered to be a key pathway to improve productivity, efficiency and sustainability of smallholder agriculture (Powell et al., 2004).

For example in Zimbabwe, supplementary feed sources in the form of crop residues are needed to feed cattle during the dry season when the availability and quality of the feed in the communal grazing areas is insufficient (De Leeuw, 1996). It is estimated that crop harvest residues (stover) in the dry savanna zones of Sub Saharan Africa contribute to between 40 and 60% of the total dry matter intake of cattle during the dry season (Standford, 1989; De Leeuw, 1996). The use of crop residues as livestock feed combined with uncontrolled grazing during the dry season suggests that maintaining a permanent mulch of crop residues in the field throughout the year is unachievable. Thus the introduction of CA leads to a competition for crop residues, and might result in a trade-off between cattle body weight and crop yield because of reduced feed intake in the dry season after allocating the crop residues for soil cover (Naudin et al., 2014; Baudron et al., 2015)

Competition for the available crop residues also exists across different farms. Cattle-owners often have free access to the crop residues of non-cattle owners, thereby limiting the options available for carbon (C) input into their soils. Denying access to crop residues by livestock would impact negatively on animal productivity and reduces the amount of manure available for crop fertilisation (Rufino et al., 2011).

The poor crop productivity in combination with the importance attached to cattle can intensify the trade-offs for crop harvest residue uses. Quantifications of these trade-offs in terms of crop and livestock production are not reported yet in the literature. Recent studies have quantified the interactive effects of crop residue availability and cattle carrying capacity (Andrieu et al., 2015; Baudron et al., 2015), both at farm and village level, but integrated studies quantifying both crop and livestock production under different crop residue allocation strategies are largely missing for smallholder farming systems. Similarly, Magnan et al. (2013) quantified the shadow economic value of crop residues at the herd level but did not look at aspects such as soil organic matter dynamics and the development trajectories across farm types. The objective of this study was therefore to quantify the farm level benefits related to the allocation of maize crop residues for cattle feed or for soil fertility management. The farming system and cattle management at Murehwa, Zimbabwe was studied. In this farming community, ruminant production depends on natural rangelands and crop harvest residues. Our hypotheses were that under the smallholder crop-livestock systems, non-cattle owners can rebuild soil fertility and crop productivity best by retaining crop residues in the fields, while livestock owners can derive the most benefits if they offer crop residues to livestock and use manure for soil fertility replenishment.

2. Materials and methods

2.1. Study site

Murehwa smallholder farming area is located about 80 km east of Harare and lies between 17° and 18°S latitude, and 31° and 32°E longitude, at an altitude of about 1300 m. The population density is about 104 people km^{-2}. The climate is sub-humid with average annual rainfall of 750 mm distributed in a unimodal pattern between December and April. The soils are mostly granitic sandy soils (Lixisols) of poor fertility with infrequent intrusions of more fertile dolerite-derived clay soils (Luvisols) (Nyamapfene, 1991). The farming system is a mixed crop-livestock system with maize (*Zea mays* L.) as the dominant staple crop, although nearly 60% of the farmers owned no cattle. Other crops commonly cultivated include groundnut (*Arachis hypogaea* L.), sweet potato (*Ipomoea batatas* (L.) Lam.), sunflower (*Helianthus annuus* L.) and a variety of vegetables, mostly brassicas. Cattle are the main livestock and are grazed in a communal system where they are herded (only during cropping otherwise cattle graze freely) in the rangeland during the day and are kept in kraals close to the homesteads at night. In the case study, rangelands (pastures) and crop fields are separate (spatially) from where the food crop production takes place i.e. there is no deliberate management aimed at rangeland improvement. There is no rotation between crops and grasses, these are produced in different parts of the landscape. The only

Table 1
Characteristics of farm types (resource groups, RGs) used in the model simulations classified according to the typology for the communal area of Murehwa.

Resource group	Richest RG1	Medium-rich RG2	Medium-poor RG3	Poor RG4
Number of people	7	5	6	5
Proportion in the village (%)	6	35	26	33
Livestock owned	ca. 10 cattle	<10 cattle	No cattle	No cattle
Farm size (ha)	2.2	1.6	1	0.7
Homefield (ha)	1.2	0.8	0.6	0.4
Outfield (ha)	1	0.8	0.4	0.3
Fertiliser use				
Fertiliser N per farm (kg)	120	60	35	15
Homefields (kg N ha^{-1})	67	50	33	20
Outfields (kg N ha^{-1})	40	25	38	0
Fertiliser P (kg P farm^{-1})	17	10	4	1
Homefields (kg P ha^{-1})	10	10	5	0
Outfields (kg P ha^{-1})	4	2	1	0
Resource exchanges	Hire labour and share draught power	Do not sell or hire labour, share draught power	Sometimes sell labour or exchange it for draught power	Sell labour and/or exchange it for draught power
Food self-sufficiency	Self-sufficient, able to sell grain and vegetables	Self-sufficient, able to sell grain and vegetables	Purchase grain and sell vegetables	Purchase food or receive food aid

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