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Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe

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A B S T R A C T

In complex mixed crop-livestock systems with limited resources and biomass scarcity, crop residues play an important but increasingly contested role. This paper focuses on farming systems in the semi-arid areas of Zimbabwe, where biomass production is limited and farmers integrate crop and livestock activities. Conservation Agriculture (CA) is promoted to intensify crop production, emphasizing the retention of surface mulch with crop residues (CR). This paper quantifies the associated potential economic trade-offs and profitability of using residues for soil amendment or as livestock feed, and explores alternative biomass production options. We draw on household surveys, stakeholder feedback, crop, livestock and economic modeling tools. We use the Trade-Off Analysis Model for Multi Dimensional Impact Assessment (TOA-MD) to compare different CR use scenarios at community level and for different farm types: particularly the current base system (cattle grazing of maize residues) and sustainable intensification alternatives based on a CA option (mulching using maize residues ± inorganic fertilizer) and a maize–mucuna (*Mucuna pruriens*) rotation. Our results indicate that a maize–mucuna rotation can reduce trade-offs between CR uses for feed and mulch, providing locally available organic soil enhancement, supplementary feed and a potential source of income. Conservation Agriculture without fertilizer application and at non-subsidized fertilizer prices is not financially viable; whereas with subsidized fertilizer it can benefit half the farm population. The poverty effects of all considered alternative biomass options are however limited; they do not raise income sufficiently to lift farmers out of poverty. Further research is needed to establish the competitiveness of alternative biomass enhancing technologies and the socio-economic processes that can facilitate sustainable intensification of mixed crop-livestock systems, particularly in semi-arid environments.

1. Introduction

Smallholder farmers in the semi-arid tropics combine farm and off-farm activities to achieve food security, and preserve or improve their livelihoods. Diversified systems, using the complementarities of crop production and livestock husbandry, appear to be robust opportunities for farmers to reduce vulnerability to climatic shocks and improve adaptive capacity to continuous changes in the social–ecological context (Ellis and Freeman, 2004; Lemaire et al., 2013). In particular, where external inputs are relatively inaccessible, animal manure provides essential nutrients for crop growth, while crop residues (CR) provide essential animal feed (McIntire et al., 1992). Using animal draught power farmers can prepare land in time, which improves water and nutrient use efficiency and increases crop yields (Tittonell et al., 2007). In addition to crop input functions, livestock serve as the most important on-farm capital and insurance in times of drought (Moll, 2005), equating livestock to an asset that can be converted to cash. The cash from livestock can be used to buy food and cover shortfalls in crop production. Livestock also make an important contribution to quality of life as the cash from livestock sales can

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be used for educational purposes and also to pay for medical expenses (van Rooyen and Homann-Kee, 2009).

Resources for conducting the different farm activities, including crop production, soil conservation and livestock husbandry are often limited. Limited access to biomass, nutrients, water, and labor creates short and long-term trade-offs in resource allocation (Erenstein, 2002; Giller et al., 2009; Thierfelder et al., 2012). Within a community, farm households are diverse in terms of resource endowments; their level of resource access determines how they will be affected by the trade-offs and what options they have to reduce the trade-offs (Dorward et al., 2009). The trade-offs on biomass use are increasingly contested, particularly on CR allocation for feed and soil amendment in sub-Saharan Africa (e.g. Giller et al., 2009). Crop residues play an important yet often underestimated economic role as the link between crop and livestock activities (McIntire et al., 1992; FAO, 2001a). Crop residues are mostly used as animal feed (Valbuena et al., 2012). Semi-arid Zimbabwe illustrates a case where rangeland feed resources are increasingly being converted into cropland, and CR therefore increasingly serves the important function of supplementing livestock feed, especially during the dry season from May until October (Rufino et al., 2011). Even though the nutritive value of cereal residues is relatively low, feeding CR to livestock during dry periods and droughts sustains survival when little alternative feed is available (Holness, 1999; Masikati, 2011). It also sustains body condition of draught animals, for early preparation of fields after the first rains.

The consequence of feeding most of the CR to livestock is that there are few alternatives to return biomass to the fields, limiting the replenishment of organic material and protection of the soils (e.g. against wind or water erosion). Although animal manure provides important nutrients for crop growth, recommended volumes of 8–10 t/ha are rarely achieved (Mapfumo and Giller, 2001). Investing land and labor in biomass producing cover crops has largely failed because smallholder farmers prefer using their land for food production or would prefer feeding the biomass to livestock (Mazvimavi and Twomlow, 2009). Therefore, the design of more sustainable farming systems needs to account for the limited access to resources, potential trade-offs on resource allocation and the diversity of smallholder households. This design should go beyond describing potential trade-offs of biomass allocation (Baudron et al., 2014), and should offer feasible and more sustainable pathways to overcome the biomass production gap (Keating et al., 2010; Power, 2010).

One option to improve the sustainable intensification of these farming systems is the use of CR as mulch, thereby recycling biomass and improving fertility and water management of inherently infertile and often depleted soils. In Zimbabwe mulching has been promoted since 2004 as one of the Conservation Agriculture (CA) components, providing crop-based food security (FAO, 2001b; Hobbs et al., 2008; Kassam et al., 2010). Even though CA has a high potential for improving crop productivity it faces several challenges particularly in semi-arid areas (Erenstein, 2002, 2003). Naudin et al. (2011) infer a critical amount of about 2–3 t residue mulch/ha to maintain soil fertility. Retaining these volumes of CR is difficult in areas with low residue production, where farmers prefer feeding the CR to livestock and where open grazing is a traditional practice (Giller et al., 2009; Valbuena et al., 2012). Furthermore, substantial fertilizer application is required to prevent N immobilization when mulching CR with high C:N ratios (Rusinamhodzi et al., 2011; Nyamangara et al., 2013b). The soil health effects of mulching also depend on the length of consistent mulching and build up over time (Thierfelder et al., 2012). Apart from limited biomass in areas like semi-arid Zimbabwe, the access to fertilizer and the lack of immediate yield benefits are major constraints for the uptake of CA practices.

An alternative option is to diversify the cropping system by producing fodder legumes, low cost/input technologies that can address soil fertility amendment and provide quality livestock feed at the same time (Maasdorp and Titterton 1997; FAO, 2011). Mucuna (*mucuna pruriens*) has been identified as one possibly attractive option for smallholder mixed farming systems. It was originally introduced and promoted as a cover crop in commercial farming systems to improve crop productivity (Buckles et al., 1998). It was later recognized for maintaining soil fertility, also under low soil fertility conditions and for its drought tolerance (Cook et al., 2005). Experiments in Zimbabwe confirmed high mucuna biomass production (2–6 t/ha) and feed quality (12.5% Crude Protein) under smallholder conditions in sub-humid and semi-arid areas, on poor quality soils and without P-fertilizer application (Maasdorp et al., 2004; Masikati, 2011). In on-farm experiments farmers choose mucuna over other legume crops for its high seed and biomass yield, low susceptibility to pests and diseases, and also for its insecticidal effects and ability to suppress weeds such as *imperata cylindrica* and *striga* species (dito). Despite its advantages, mucuna has not been widely adopted by smallholder farmers in southern Africa (Homann-Kee Tui et al., 2013). With government and development agents focussing on staple food production, attention on feed and fodder technologies has been limited and is only recently regaining interest.

The objective of this paper is twofold: (i) to make explicit the economic value and trade-offs of biomass allocation options for different types of smallholder crop-livestock farming systems in semi-arid Zimbabwe; and (ii) to analyse how alternative options could reduce such trade-offs, reducing the biomass trap for these smallholder households. This study combines household questionnaires, crop and livestock modeling tools, secondary data from on-farm experiments and an economic model to calculate the net returns and economic trade-offs of biomass use.

2. Material and methods

2.1. Study area: Nkayi District

This study was implemented in Nkayi District in semi-arid Zimbabwe (Fig. 1), characterized by low and variable rainfall (Natural region III and IV; Vincent and Thomas, 1957). Soils are mostly deep Kalahari sands (Arenosols), with pockets of clay and clay loams, inherently infertile, with N, P and S deficits. These soils have suffered degradation due to extended periods of crop production under limited fertility management. Human population growth and expansion of households has led to an increase of croplands by 13% against a reduction of rangelands and forests by 14% in the past 20 years (ICRISAT, 2010). Similar livestock densities on smaller rangeland areas aggravate degradation processes and increase feed shortages (Powell et al., 2004). Land use is relatively extensive (Rockstrom et al., 2003), but with a strong integration of crops and livestock (Homann-Kee Tui et al., 2013).

In Nkayi District crop productivity is currently very low, around 650 kg/ha of maize (Mazvimavi et al., 2010; Masikati, 2011). During the 1990s, however, when maize production was promoted along with improved seed and fertilizer, yields were commonly around 1500 kg/ha (Government of Zimbabwe, 2002). Currently, crop input use is low and largely limited to maize production. Only one fifth of the farming households apply inorganic fertilizer with an average fertilizer rate of 54 kg/ha, whereas only a third apply manure at an average rate of 1.5 t/ha (Homann-Kee Tui et al., 2013). Animal traction is used to prepare 96% of the cropland. Conservation Agriculture, although widely promoted, is practiced by less than 10% of the households. Planting basins are the most common CA option, but these are associated with higher labor

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