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Tradeoffs around crop residue biomass in smallholder crop-livestock systems – What's next?

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ABSTRACT

Much has been written on the tradeoffs that smallholder farmers face when having to allocate their biomass resources among competing objectives such as feed, fuel, mulch, compost or the market. This paper summarises yet a new body of evidence from 10 studies on tradeoffs in the allocation of cereal crop residue biomass between soil management and livestock feeding in developing regions, published in the special issue of Agricultural Systems 'Biomass use tradeoffs in cereal cropping systems: Lessons and implications from the developing world'. The studies cover a diversity of socio-ecological contexts, farming system types and scales of analysis. We reflect on their main findings and methodological progress, and on the new and not-so-new implications of these findings for research and action in the development agenda. We propose stylised graphical models to portray tradeoffs and plausible trajectories towards synergies, in the hope that such generalisations would prevent further efforts to 'reinvent the wheel' in the realm of tradeoffs analysis. We advocate an ex-post impact assessment of recent investments in systems research to help focus such research further and clearly define its future role in prioritizing and targeting development interventions.

1. Introduction

The analysis of tradeoffs between competing uses for crop residue biomass has occupied a large volume of the specialized literature over the last two decades (e.g., Powell et al., 1995; Powell and Williams, 1995; Sain and Barreto, 1996; Renard, 1997; Dugué et al., 1998; Erenstein, 2002; Powell et al., 2004; Baudron et al., 2014). Much insight has been gained into their drivers, their magnitude and their consequences. Yet, such knowledge has seldom been translated into generalizable concepts or used to inform practical recommendations for management or policies. A possible explanation for this is the location-, system-, farm type- and scale-specificity, and intrinsic complexity of crop residue tradeoffs (Erenstein et al., 2015). The literature indicates that crop residue biomass is a valuable resource for smallholder farmers, often in short supply, that can be alternatively used to feed livestock, as domestic fuel, as building material or as soil amendment, either through composting, direct incorporation or mulching. The relative importance of these various uses differs across farming system types, as determined by their agro-ecological potential, population density/farm sizes, and markets (Valbuena et al., 2012).

Different authors tend to analyse these tradeoffs from the perspective of their own discipline, e.g., by assessing their potential as feed for livestock intensification (Lenne et al., 2003; Blummel et al., 2009; Herrero et al., 2010; Thornton, 2010; Tarawali et al., 2011), their availability as mulching material for conservation agriculture (Scopel et al., 2004), or their contribution to nutrient cycling in agroecosystems at different scales (Powell et al., 1996; Buerkert and Hiernaux, 1998; Ikpe and Powell, 2002; Zingore et al., 2011). Recent developments in the bioenergy sector (Wilhelm et al., 2007; Service, 2014) prompted the use of crop residue biomass as feedstock for this industry to be included in tradeoffs analysis, notably in regional to global assessments (e.g., Lal, 2008; Dixon et al., 2010). The methods used to assess – and increasingly to quantify – tradeoffs have evolved significantly over the last decades: from participatory assessments of tradeoffs (Defoer et al., 1998; Dougill et al., 2002), to direct measurements of biomass flows in the field, surveying and collection of large datasets across contrasting environments and/or the use of sophisticated modelling techniques at different spatio-temporal scales (e.g. Thornton and Herrero, 2001; Thornton et al., 2003; Stoorvogel et al., 2004; Claessens et al., 2009; Mekasha et al., 2014). Recent examples of an array of methods to analyse tradeoffs across diverse farming systems were compiled in this special issue of Agricultural Systems (cf. Table 1 in Erenstein et al., 2015).

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The analysis of these studies and of the previous literature on tradeoffs around crop residue biomass allocation, particularly to soil amendment vs. livestock feeding, points to a need to (i) distil generalizable patterns to categorise and describe tradeoffs in contrasting socio-ecological contexts, (ii) use these insights to inform the development of management strategies, desirable system trajectories and policies. In other words, and in view of all the knowledge, quantitative and qualitative evidence available, what should be the next step? Is it possible to summarise the various patterns observed into a generic conceptual framework to inform recommendations? Are there knowledge gaps that require further research? We are aware of the challenge posed by these questions, and of the somewhat partial geographical coverage from which we will draw our conclusions. Yet, we feel that further investments in tradeoffs analysis without a framework to translate them into policies and actions to overcome such tradeoffs would be rather futile. The objective of this paper is to summarise the main findings of the studies on tradeoffs in the allocation of crop residue biomass particularly between soil management and livestock feeding published in this special issue to contribute some answers to the questions aforementioned.

2. Theoretical framework

Tradeoffs between any two competing objectives can be depicted as in Fig. 1. In this example, they are generically termed as 'utility of use as feed' (F) vs. 'utility of use as soil amendment' (S), referring to the utility derived from crop residue biomass allocated to either use, without specifying units. In this simplified model there is no other possible use for crop residues, so that the crop residue biomass is partitioned between objectives F and S. This is obviously not the case in most farming systems, as residues are subject to multiple uses. But for illustrative purposes we focus our analysis on these two competing objectives that were also the key tradeoffs analysed in most of the studies in this special issue (cf. Table 1 in Erenstein et al., 2015). The tradeoffs between these two competing objectives, which draw on mutually exclusive crop residue uses at a single point in time, may be best described by one of the three curves proposed in Fig. 1, termed *Regime A*, *B* and *C* (cf. Tittonell, 2013). *Regime A* corresponds to a situation of strong competition between objectives F and S. *Regime B* corresponds to a situation of substitutability in which the rate of

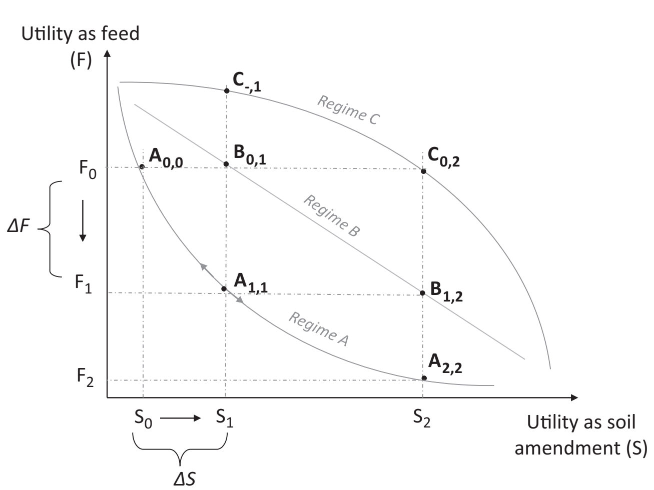

Fig. 1. Conceptual tradeoff curves between crop residue uses as soil amendment vs. livestock feeding. The three regimes describe situations of strong competition (A), substitutability through exact inverse proportionality (B) and possible complementarities (C). See text for further explanation.

replacement or conversion from S to F or vice versa is inversely proportional. *Regime C* describes a situation in which complementarities are possible within a wide range of fulfilment of both F and S. Synergies between both objectives may also be possible when different time horizons are considered; for example, if soil amendments would allow for subsequent increases in feed productivity, then the effect of soil amendment on feed utility might be potentially positive in the longer term.

Let us first assume a competition scenario where the farmer uses most crop residues for F and little for S – i.e. a utility of residue biomass F_0 and S_0 in Fig. 1 represents a current allocation pattern, and that the rate of conversion is described by *Regime A*. Increasing the allocation of crop residues to soil amendment (i.e. to increase the utility of soil amendment by an amount ΔS to a level S_1) will entail a strong reduction in the utility as feed (ΔF) down to a level F_1. The system experienced a shift from point $A_{0,0}$ to $A_{1,1}$. The utility S_1 could indicate, for example, a minimum target level of crop residue amendment necessary to maintain soil fertility in the medium term. The utility F_1 would then indicate the new level of livestock utility, that underwent a substantial reduction due to e.g. having reduced herd size and/or substantially lower herd productivity due to insufficient feeding. Within *Regime A*, conservationists may advocate S_1 to be insufficient for soil fertility maintenance in the long term and the corresponding need to further shift from point $A_{1,1}$ to $A_{2,2}$ to achieve a soil amendment target S_2 that is deemed preferable to target S_1 but further reducing utility of feed to F_2. The level F_2 could indicate, for example, a curtailed livestock utility because livestock productivity is now so low it barely provides any livestock functions.

Regime A depicts a high degree of competition between the utility derived from feed and soil amendment and correspondingly severe tradeoffs. *Regime B* provides for substitutability and *Regime C* for complementarities – which imply increasingly favourable tradeoff scenarios. In Fig. 1 the current (S_0) and minimum target (S_1) levels of allocation of crop residues to soil amendment would correspond with higher levels of feed utility when the tradeoffs are described by *Regimes B* or *C*. The initial feed utility target level F_0 can be achieved only with negligible utility for soil amendment under regime A (point $A_{0,0}$) but substantially higher utility levels within *Regime B* (point $B_{0,1}$, meeting the minimum soil fertility needs) and within *Regime C* (point $C_{0,2}$, meeting longer term soil fertility needs). A noteworthy assumption in this simplified model is that the quality of crop residue biomass does not change across system regimes. In reality, however, inclusion of legume intercrops together with cereals may lead to greater biomass production and feed quality improvements (e.g., Naudin et al., 2011), thereby resulting in greater livestock productivity and potentially allowing regime shifts. If, instead, legumes are included in rotation with cereals this might eventually result in lower total annual biomass productivity (e.g. Thierfelder et al., 2012a,b), increased feed use and faster decomposition of legume residues or weathering losses (Erenstein, 2002: 120–2), aggravating biomass tradeoffs.

The utility maximizing position for any regime – and the associated tradeoffs by moving along any regime – are based on preferences, perceived benefits and risks, or sheer costs and constraints imposed by endogenous (e.g. resources) or exogenous factors (e.g. relative prices). New technologies, new agroecosystem designs, policies and/or development interventions may provoke (i) changes that result in system shifts within a certain regime, (ii) changes that allow system jumps from one regime to the next or (iii) changes that create new regimes. Based on this set of heuristics, it is possible to recognise cases in which the three regimes may represent, either:

1. Different socio-ecological contexts, being observed or proposed as scenarios;