SECHERESSE

Research Article

Sécheresse 2013 ; 24 : 330–9

Biomass in crop-livestock systems in the context of the livestock revolution

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Reprints : M. Blümmel

Abstract

Mixed crop-livestock systems are the dominant source of livelihood supporting more than 80% of people living in the developing world and producing 50% of world cereals, around 34% of the global beef production and about 30% of global milk production. However, mixed systems are coming under increasing pressure with their human population predicted to increase from 1,099 million in 2000 to 1,670 million people in 2030 and their cattle population to increase from 230 million to 317 million from 2000 to 2030. Coupled with this increase in human and livestock populations, cereal yields have been stagnating in sub-Saharan Africa (SSA) for the last 40 years (in contrast to growth rates of 1.5-2% per year for the rest of the developing world), with most increase in overall cereal production arising from expansion of arable land. Such trends cannot be maintained as land suitable for cropping is scarce, and additional cropland might also be more marginal and subject to greater climatic risks. There is increasing pressure on biomass in mixed systems and there are strong needs to find ways out of this "biomass trap" through increasing overall biomass yield and fodder quality and through increasing the efficiency of livestock production. Biomass from crop residues (CR) is used as a feed resource and as mulch to improve crop yields. Biomass is becoming scarcer and competition for CR is becoming more severe. This is reflected in changes of CR use from grazing to harvesting and storage, longer distances across which CR are transported and transacted and decreasing CR to grain ratios. The predicted increase in demand for livestock products, the so-called *livestock revolution*, will further fuel feed demand and increase the usage of CR for livestock feeding. Use of CR for mulch and conservation agriculture demands about 2 to 3 tons of CR per hectare which is often equal to their total yield under rain-fed conditions in the semi-arid tropics. Multidimensional crop improvement can mitigate competition for biomass by increasing CR quantity and by improving fodder quality. Increased CR yield will facilitate partitioning of CR between livestock and soil improvement and improved CR fodder quality will support intensification of livestock production where more animal sourced foods (ASF) can be produced with less feed. It is important to realize that feed biomass requirement is very context specific and decreases with increasing per unit animal productivity.

Key words : biomass, crop residues, feed resources, livestock revolution, mixed crop-livestock systems.

Résumé

La biomasse dans les systèmes culture-élevage dans le contexte de l'explosion démographique du bétail

Les systèmes agraires mixtes cultures-élevage constituent la principale activité économique pour plus de 80 % de la population des pays en développement (PED),

To cite this article: Blümmel M, Homann-Kee Tui S, Valbuena D, Duncan AJ, Herrero M, 2013. Biomass in crop-livestock systems in the context of the livestock revolution. *Sécheresse* 24: 330-9. doi: 10.1684/sec.2013.0403

doi: 10.1684/sec.2013.0403

produisant 50 % de la production mondiale de céréales, environ 34% de la production bovine mondiale et environ 30 % de la production laitière mondiale. Cependant, ces systèmes agraires sont remis en question par la croissance projetée de la population humaine dans les PED qui devrait passer de 1 099 millions de personnes en 2000 à 1 670 millions en 2030, et par l'augmentation du cheptel animal qui devrait passer de 230 millions à 317 millions de têtes de l'an 2000 à 2030. Les rendements des cultures céréalières ont de plus stagné en Afrique subsaharienne ces 40 dernières années (en contraste avec l'augmentation des rendements de 1,5 à 2 % par an pour le reste des régions en développement), et l'augmentation de la production globale céréalière est principalement due à l'exploitation de nouvelles terres arables, et non à un accroissement de la productivité agricole. De telles projections ne sont pas viables à long terme car les terres propres à la culture deviennent rares, et les éventuelles nouvelles terres à cultiver risquent d'être plus marginales et plus vulnérables aux aléas climatiques. La pression est de plus en plus grande sur l'utilisation de la biomasse dans les systèmes agraires mixtes, et il y a un besoin urgent d'innover pour contrer cette « pénurie de biomasse » en augmentant le rendement global de la production de biomasse et la qualité des fourrages tout en accroissant l'efficacité de la production animale. La biomasse venant des résidus de culture (RC) est utilisée comme ressource alimentaire et comme paillis pour augmenter les rendements de culture. La biomasse devient plus rare et la compétition pour les RC devient de plus en plus critique en raison de son utilisation soit comme aliment du bétail soit pour le renouvellement de la fertilité du sol. Cette compétition s'illustre dans les changements d'utilisation des RC du pâturage à la récolte et au stockage, dans l'augmentation des distances de transport des CR entre les lieux de récolte et de vente, et la diminution du ratio de RC par rapport à la production de grains. L'augmentation projetée de la demande en produits animaux, dénommée *révolution de l'élevage*, va stimuler encore plus la demande en fourrage et par conséquent augmenter l'utilisation des RC pour l'alimentation du bétail. L'utilisation des RC comme paillis et dans l'agriculture de conservation nécessite environ 2 à 3 tonnes de RC par hectare, ce qui est souvent égal au rendement total en RC dans le cas de l'agriculture pluviale dans les tropiques semi-arides. L'amélioration multidimensionnelle des plantes peut réduire la compétition pour la biomasse en augmentant la quantité des RC et en améliorant leur qualité fourragère. Augmenter les rendements en RC facilitera leur répartition entre l'alimentation du bétail et l'amélioration de la fertilité du sol. Augmenter la qualité fourragère des RC soutiendra l'intensification de l'élevage où plus de produits animaux pourront être obtenus avec moins d'aliments pour le bétail. Il est important de comprendre que les besoins en biomasse fourragère dépendent du contexte local et diminuent avec l'augmentation de la productivité par unité animale.

Mots clés : biomasse, demande en fourrage, résidus de cultures, révolution de l'élevage, systèmes agraires mixtes cultures-élevage.

Importance of crop-livestock systems

Mixed crop livestock farming systems represent an integrated system in which resource flows between crop and livestock production are essential within a single enterprise. Seré *et al.* (1996) defined the mixed systems as being those in which at least 10% of dry matter fed to livestock comes from crop residues or at least 10% of the total value of production comes from non-livestock sources. Much of the feed for livestock in these systems comes from crop residues (Parthasarathy Rao and Hall, 2003; NIANP, 2003; Valbuena *et al.*, 2012). In turn, livestock contribute to crop production through provision of manure for soil fertility and through draft power for cultivation (Powell *et al.*, 2004). Furthermore, livestock provide a buffer against shocks and can sustain livelihoods through dry years when crops might fail (Bosman *et al.*, 1997). A schematic figure of the main interactions in these systems is presented in *figure 1* (Herrero *et al.*, 2010). Mixed systems are diverse and can be further subdivided on the basis of their production potential and access to market into "mixed intensive systems" and "mixed extensive systems" (Herrero *et al.*, 2009).

Mixed systems are the dominant source of livelihood for the bulk of the world's poor and on a global scale they provide much of the world's food. In a study commissioned by the Consultative Group on International Agricultural Research (CGIAR) Systemwide Livestock Programme, Herrero *et al.* (2009) calculated that in 2000 more than 80% of people living in the developing world were living in mixed systems (24% in mixed extensive systems and 59% in mixed intensive systems). On a global scale, 50% of world cereal production is derived from mixed systems in the developing world with 14% of total production coming from mixed extensive systems. Around 34% of global beef production comes from mixed systems (15% in mixed extensive and 19% in mixed intensive systems). Similarly 30% of global milk production comes from mixed systems in the developing world (13% from mixed extensive and 17% from mixed extensive systems). Clearly mixed crop-livestock systems are central to global food production. With much of world population growth occurring in developing countries in the coming decades, these systems will remain crucial for livelihoods and food production.

However, mixed crop livestock systems are experiencing increasing pressure.

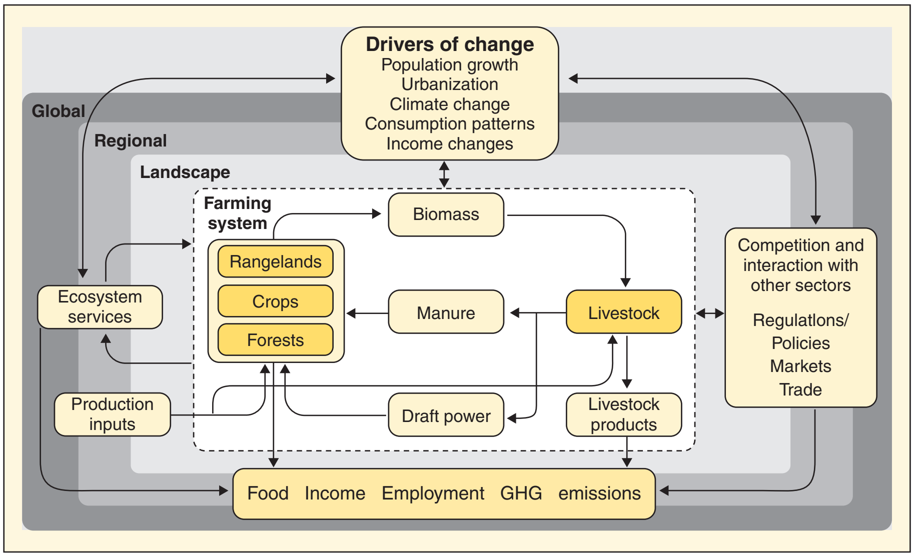

Figure 1. Main interactions in crop-livestock systems (from Herrero *et al.*, 2010).

Thus, the population of mixed extensive systems is predicted to increase from 1,099 million in 2000 to 1,670 million people in 2030. This increase in human population will be accompanied by an increase in livestock population. For example even under conservative estimates the cattle population of mixed extensive systems is set to increase from 230 million to 317 million from 2000 to 2030 (Herrero *et al.*, 2009). Furthermore while human and livestock populations increase, cereal yields have been stagnating in sub-Saharan Africa (SSA) for the past 40 years (in contrast to growth rates of 1.5-2% per year for the rest of the developing world), with most increase in overall cereal production arising from expansion of arable land. Such trends cannot be maintained since land suitable for cropping is scarce, and additional cropland might also be more marginal and subject to greater climatic risks. There is increasing pressure on biomass in mixed systems and there are strong needs to find ways out of this "biomass trap" either through increasing overall biomass yields or by increasing the efficiency of livestock production (Blümmel *et al.*, 2010a; Valbuena *et al.*, 2012). Crop yield development will play a significant role in future land use dynamics and in the provision of food and fodder in mixed systems to avoid this "biomass trap". It will determine the requirements for additional cropland area and will also influence grassland area expansion if current livestock product demand trends are maintained.

The livestock evolution and revolution and their implications for mixed crop-livestock systems

Livestock production is a major livelihood strategy for smallholder farmers to cope with the low and fluctuating crop production given the semi-arid conditions and limited access to irrigation water in large parts of SSA (McDermott *et al.*, 2010, Tarawali *et al.*, 2011). Much has been made in the last decade of the phenomenon known as the *livestock revolution* (Delgado *et al.*, 1999). Delgado and colleagues used a global trade model, IMPACT, to predict demand for livestock products to 2020 and came up with some startling projections. The basis of their projections was the tendency for consumption of animal source foods ([ASF], mainly meat and milk) to increase with rising incomes and urbanization. As well as this change in diet, the effects of population growth on overall ASF consumption were taken into account. The results showed major increases in demand, particularly in China and South East Asia. The *livestock revolution* concept has been influential and has been used to justify the increasing role of livestock in the livelihoods of the world's poor. The reason was that increasing demand for livestock products represents an opportunity for the poor to profit from increased marketing of livestock products. However, the *livestock revolution* effect in SSA has perhaps been overplayed. Comparatively little change in the make-up of diets has transpired and in some cases *per capita* consumption of ASF has declined (Pica-Ciamarra and Otte, 2011). Still, the simple phenomenon of population growth (leading to more overall demand for food) coupled with urbanization (proportionately less people to produce food) will inevitably place more pressure on mixed systems to produce more livestock products while increasing the demand for feed resources and the risk of further degradation of natural resources by increasing livestock populations (FAO, 2006). This relates to the inability of producers in developing countries to feed animals adequately throughout the year, which remains the major technical constraint in most smallholder livestock systems to more fully utilize the market opportunities from the increasing demand for livestock products (Ayantunde *et al.*, 2005). In this context, crop residues (CR) become fundamental resources in the overall productivity of mixed systems, particularly as livestock feed but also as soil amendment.

Importance of crop residues in mixed systems

Livestock feeding and overall productivity in mixed crop livestock systems

Along with the use of manure as organic fertilizer and of animals for ploughing and threshing, CR represent one of the pillars of crop and livestock integration in mixed systems (McIntire *et al.*, 1992). In these systems, with scarcity of arable land and increasing shortage of water, CR such as straws, stover and haulms are major feed resources. For example, in a survey of 12 locations in 9 countries across SSA and South Asia, Valbuena *et al.* (2013) report that CR accounts for up to 60% of the total livestock diet in mixed systems. Feed inventories in India (NIANP, 2003) have also systematically quantified fodder resources and found that CR were the single most important feed resource providing more than 44% of the total feed resource in 2000. More recently Ramachandra *et al.* (2007) have estimated that CR will provide more than 70% of the feed resources for Indian livestock by the year 2020. While few such country-wide structured feed resource data bases exist for SSA, localized evidence suggests similar current and future importance and contributions of CR to livestock feeding as observed in India (Berhanu *et al.*, 2009; Grings *et al.*, 2013).

The increasing importance and demand for CR as fodder is reflected in four major trends: increasing labour investment in collecting and storing CR in more extensive systems (Valbuena *et al.*, 2012); farmers' preferences for dual-purpose crop varieties; higher market price for CR with a higher feed quality; and higher livestock productivity with CR with a higher feed quality. Evidence for cultivar preferences based on feed traits comes from farmers rejection of new sorghum and pearl millet cultivars that had been improved only for grain yields, because of low stover quantity and quality (Kelley *et al.*, 1996). More recently, farmers ranked maize stover traits highly when assessing cultivars in East Africa (de Groote *et al.*, 2013).

The price of CR is high and increasing as biomass scarcity increases, trading of CR is expanding in volume and distances and CR: grain price ratios during the past two decades have been getting narrower (Kelley *et al.*, 1993; Blümmel and Rao 2006; Berhanu *et al.*, 2009). For example in India sorghum stover is now sold at 50 to 60% of the grain price on an equal dry matter weight basis (Sharma *et al.*, 2010). Also, CR fodders from different crops are not considered the same by farmers and traders. Surveys of CR fodder trading in SSA and India showed that – traded at the same time and place – CR from groundnut *versus* cow pea haulms (Grings *et al.*, 2013), barley *versus* tef straw (Berhanu *et al.*, 2009) and wheat *versus* rice straw (Teufel *et al.*, 2010) were differently priced. In other words fodder traders and customers were well aware of differing fodder quality from CR of different crops. In wheat and rice straw and in sorghum stover trading supplying urban and periurban dairy production in India, traders and customers also recognize CR fodder quality differences within a crop, for example between CR from different cultivars. For sorghum stover, a difference of 5% units (47 *versus* 52%) in *in vitro* digestibility (IVOMD) – which was highly correlated with stover pricing – was associated with a price premium of 20% and higher (*figure 2*). In rice straw trading differences in IVOMD as small as 2 to 3% units were associated with similar price premiums (Teufel *et al.*, 2010).

Soil amendment and overall farm productivity

CR are also key resources to improve the soil quality of mixed systems. Soils in the SAT are of inherently poor quality, often at an advanced state of erosion and nutrient depletion, following permanent cropping, low fertilizer application under conditions of poor access to inputs and limited return of manure (van Keulen and Breman, 1990; Breman *et al.*, 2001; Haileslassie *et al.*, 2005). Retaining crop residues on soils is expected to restore soil condition and increase crop production while improving the overall sustainability of farming (Wall, 2007; FAO, 2009; Kassam *et al.*, 2010). Crop residues as soil amendments have been shown to contribute to control of water run-off and soil erosion, weed suppression and a build up carbon stocks. Related to the percentage of retained crop residues as soil cover, immediate benefits were seen in higher infiltration rates and thus a potential for more efficient water use (Thierfelder *et al.*, 2012). Reduction of soil erosion as the most severe form of soil degradation is the most substantial effect of mulching (Erenstein, 2002; Erenstein, 2003). Coverage with mulch has an effect on weed suppression, but is often restricted by biomass in the smallholder farming sector (Mashingaidze *et al.*, 2012). More related to the volumes and quality of retained crop residues are the effects on increasing soil carbon contents and nitrogen for subsequent crop growth (Naudin *et al.*, 2012). These benefits can be measured in visible long-term benefits such as crop yield growth (Rusinamhodzi *et al.*, 2011). These benefits have a potential to increase over time, and thus greater benefits from continuous soil cover application can be expected (Thierfelder *et al.*, 2012).

Mulching can result in significant increases in crop production provided it is accompanied by favorable agro-ecological conditions to produce sufficient biomass (Giller *et al.*, 2009) and minimum levels of intensification (Valbuena *et al.*, 2012; Baudron *et al.*, 2012). The success of the mulching effect is strongly dependent on the amount of residues retained, the quality of biomass as well as the length of time the CA system has been implemented. Naudin *et al.* (2012) infer 30% soil cover to reduce soil erosion, and 90% soil cover for good weed control. For maintaining soil productivity this translates into a critical amount of about 2-3 t residue mulch/ha. In mixed farming systems with biomass limitations retaining the required volumes of crop residues is difficult, especially when compared to the function of crop residues as feed for livestock (Govaerts et al., 2009; Valbuena *et al.*, 2012). Furthermore, substantial fertilizer application is required to prevent N immobilization under residues with large C/N ratio (Rusinamhodzi *et al.*, 2011). Access to fertilizer and the lack for immediate yield differences are major constraints for the uptake of Conservation Agricultural (CA) practices in these

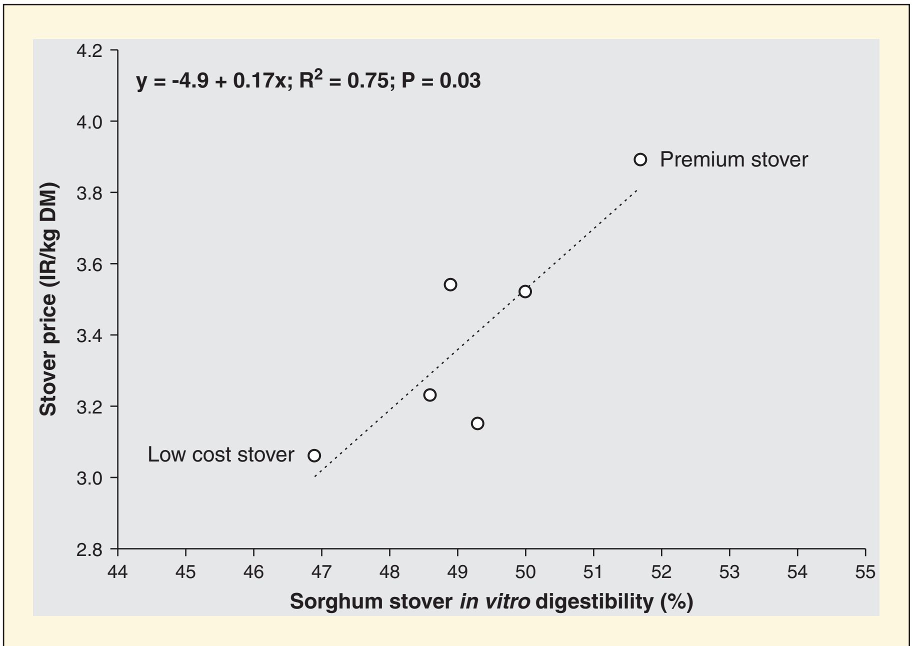

Figure 2. Relations between sorghum stover digestibility and prices in stover collected monthly in Hyderabad from 2004 to 2005.

areas. Nevertheless, given the low availability of CR in these mixed systems, CR pressures and trade-offs are often common. Specifically, proponents of CA packages promote the use of CR as a mulch to enhance medium-term crop production while understating the direct and short-term benefits of selling or using CR to feed the livestock (Wall, 2007; Giller *et al.*, 2011).

Trade-offs of crop residue use – How and where

Trade-offs in CR use are common across mixed crop-livestock farms and agro-ecosystems in the developing world. Particularly, trade-offs are evident between short-term (e.g. animal feed, households fuel and construction) and longer term benefits (e.g. soil fertility). The nature and intensity of these trade-offs varies across locations and farms. Still, a comparison between 12 locations across sub-Saharan Africa and South Asia showed that smallholder farmers in the selected locations tend to favour the use of CR for short term benefits, specifically as animal feed over mulching for soil fertility management (Valbuena *et al.*, 2011). This current pattern has favoured a further degradation of soil properties, a stagnation or lowering of crop productivity and an overall increase in pressures and trade-offs in CR use (Owen and Jayasuriya, 1989; Williams *et al.*, 1997). CR use, trade-offs and dynamics can be better understood by looking at four major interacting and evolving factors: farmers' preferences, CR availability, CR demand, and access to alternative resources (Erenstein *et al.*, 2011; Valbuena *et al.*, 2013). Firstly, farmers' preferences determine the overall strategy of agricultural production, including allocation of CR (e.g. burning *versus* mulching CR), given the specific resource endowment and biophysical and socio-economic context of the farming system (Tittonell *et al.*, 2010; Valbuena *et al.*, 2012). Secondly, CR availability and quality largely depend on the crop type and the overall crop production of the farm, which is notoriously below potential in parts of Africa and South Asia. With a poor institutional context, limited access to inputs and lack of irrigation, most crop production is limited by the agro-ecological conditions of low rainfall and depleted soil fertility. This creates considerable yield gaps and low CR availability in mixed farming systems (Koning and Smaling, 2005; Kuyvenhoven, 2008, Nin-Pratt *et al.*, 2011). Thirdly, CR demand can include demand for animal feed, household fuel and construction material, market products and mulching depending on the farm structure and agro-ecological context (de Leeuw, 1997; Erenstein *et al.*, 2011). As human populations continue to increase and food preferences change, larger demand for livestock products and biomass resources for fuel, livestock feed and construction materials may occur. Finally, access to and affordability of alternative resources determines CR demand, influencing the opportunity costs for households to sell, use or replace CR. Specifically, access to alternative resources in communal lands can reduce the need to collect and use CR as livestock feed or fuel. However, communal lands such as grasslands and woodlands are often degraded and/or shrinking reducing availability of alternative biomass resources (Anderson, 1992; Tiffen, 2003; Kuyvenhoven, 2008; Satterthwaite *et al.*, 2010).

In general, trade-offs are particularly important on those mixed farms where crop production does not meet CR demand and alternative resources are not accessible or affordable (Latham, 1997; Tittonell *et al.*, 2007; Rufino *et al.*, 2011). For instance, Valbuena *et al.* (2013) describe how farmers' use and potential trade-offs in CR use relate to CR availability, demand and access to alternative resources in 12 locations across sub-Saharan Africa and South Asia. Potential trade-offs between short and longer term benefits are highest in agro-ecosystems with poor access to alternative resources, and low levels of irrigation. Furthermore such trade-offs are important at intermediate levels of crop intensification and high demand for animal feed and household fuel located in sites in Ethiopia and India and in those agro-ecosystems with low-level crop intensification located in sites in West Africa. Similarly, potential trade-offs are high in agro-ecosystems with low-level of crop intensification and access to alternative resources, where the livestock demand for CR is high (e.g. sites in Zimbabwe and Mozambique). This demand is specifically high during the dry season and the beginning of the rainy season when other feed resources are not available. In contrast, potential trade-offs tend to be lower in agro-ecologies with either: adequate irrigation, high levels of inputs, mechanisation and high levels of crop production allowing a sufficient amount of CR for different uses (e.g. sites in India and Bangladesh); or fertilizer use and low demand for animal feed (e.g. site in Malawi).

Opportunities to limit trade-offs of crop residue use

Given the diversity of preferences, CR availability, demand and access to alternative resources, promising opportunities to cope with pressures and trade-offs of CR use are needed to understand and account for the specific context of the mixed crop-livestock farms and the agro-ecosystems (Giller *et al.*, 2009; Valbuena *et al.*, 2012; Tittonell *et al.*, 2012). For instance, Valbuena *et al.* (2012) suggest that in locations with high pressures and potential high trade-offs of CR use, CR availability needs to increase through intensification of crop and fodder production (e.g. better input use or dual-purpose varieties); a decrease in number of animals by intensifying livestock production (e.g. more productive animals, lower mortality rates) and improving the management of communal lands while producing additional dual-purpose or fodder crops could reduce demand for CR. Of course, these opportunities should include working with farmers, institutions (e.g. agricultural and labour markets) and sets of flexible and viable technologies targeted to improve the overall resource efficiency and agricultural productivity of mixed crop-livestock systems (Clute, 1982; van Keulen and Breman, 1990; Anderson, 1992). Appropriate policies are instrumental for encouraging better extension systems, incentives, and access to irrigation, markets, subsidies and inputs that will lead to higher levels of CR production and management targeting both short and longer term benefits. Hereby, we focus on two major intensification pathways to reduce major trade-offs of CR use by: improving CR quality and quantity; and livestock intensification.

Opportunities for improving quantity and fodder quality of crop residues

The widespread availability of CR and increasing importance and demand for livestock fodder marks them as a strategic feed resource of the highest order. Given the limited availability of feed resources in these mixed systems, improving the quantity and quality of CR is a plausible pathway to improve the overall farm productivity. This has long being recognized and in the 1980s and 1990s livestock nutritionists focused on post harvest interventions with considerable efforts expended on technologies for improving the nutritive quality of CR by chemical, physical or biological treatments. Except for chopping in some intensive mixed systems, comparative little uptake of these technologies was observed (see for example Singh and Schiere [1993]) in part because of the labour and input costs of chemical treatments. This failure of wide spread adoption of CR treatment by chemical, physical or biological methods has provided the ground for new research on targeted improvements of CR quantity and fodder value by cultivar selection and genetic enhancement of dual-purpose varieties (Reed *et al.,* 1988; Kristjanson and Zerbini, 1999).

• Exploiting existing variations among cultivars

Increasing the quantity of available crop residues would be a simple way to reduce this competition. While crop improvement institutes such as the *Centro Internacional de Mejoramiento de Maiz Y Trigo* (CIMMYT, International Maize and Wheat Improvement Centre) strongly advocated CR use for CA, they neglected stover and straw aspects in their breeding work until very recently (Berhanu *et al.,* 2012; Blümmel *et al.,* 2012). Straw and stover yields were not considered in new cultivar development and release. As shown for several key crops such as maize (Berhanu *et al.,* 2013, Zaidi *et al.,* 2013), sorghum (Blümmel *et al.,* 2010b), wheat (Blümmel *et al.,* 2012), groundnut (Nigam and Blümmel, 2010) and cow pea (Grings *et al.,* 2013) considerable variation exists in harvest indices (HI) in these crops. In other words, grain and CR yields exhibit a considerable degree of independence. In all those crops, CR yields of the 5 to 10 highest grain yielders easily varied by 2 to 3 tons per hectare on research fields.

In addition in all these crops different cultivars varied in their fodder quality of stover/straws/haulms. In sorghum stover IVOMD in top grain yielding *Rabi* (off season) and *Kharif* (monsoon) cultivars varied by 5 to 10% units between cultivars (Blümmel *et al.,* 2010b). Berhanu *et al.* (2013) estimated, based on investigations of a wide range of experimental maize hybrids grown over several years and locations in Ethiopia and Tanzania, that 4 to 8 units in stover IVOMD can be gained through choice of cultivar. Similar observations have been made for CR from fine cereals such as rice. Among most rice cultivar types variations for example in IVOMD varied close to 10% with a minimum of 6.9% units observed in New Planting Types (NPT). Interestingly, rice hybrids with on average the highest grain yields had also the highest mean straw IVOMD; variations in rice straw IVOMD came with little or no penalty to grain yields (Blümmel *et al.,* 2007). Variations in CR fodder quality of importance to livestock nutrition were also observed in leguminous crops such as groundnut and cowpea. In a wide range of groundnut cultivars (>800) haulm nitrogen content varied by almost twofold, and IVOMD varied by almost 10% units (Nigam and Blümmel, 2010). Variations of a very similar order were observed in haulms of cowpea from a core collection of the International Institute of Tropical Agriculture (IITA) (Grings *et al.,* 2013). There were generally no, or at worst manageable, trade-offs observed between CR fodder quality and grain/pod yield (Sharma *et al.,* 2010)

Crop productivity in smallholder crop-livestock systems is generally low relative to the genetic potential of the crops. In most national crop improvement programs new cultivars fulfil the releasing criteria if they outperform grain/pod yields of check cultivars by 10%. A mere 10% increase in grain/pod productivity may offer too little incentive for such cultivars to be widely promoted, multiplied and lastly to be adopted. As recently shown with a dual-purpose groundnut cultivar in India, a concomitant increase of about 10% in each of pod yield, haulm yield and haulm fodder quality (as reflected in higher milk yield) provided sufficient incentives for fast and large scale adoption of the new cultivar (Pande *et al.,* 2006). Release criteria for new cultivars intended for crop-livestock systems should therefore be revised and augmented to include CR fodder traits.

• Targeted further genetic enhancement towards dual purpose traits

Till recently targeted genetic enhancement towards higher fodder quality was mainly aimed at mono-usage forages such as grasses, silage maize and so on. Little attention was given to targeted improvement of fodder value of crop byproducts such as CR. In pearl millet within two recurrent selection cycles digestible organic matter intake of stover fed in sheep increased from 12.9 to 15.1 g/kg live weight (LW), an increase of 17%, and with the nitrogen balance in feeding trials with sheep changing from negative (-0.016 g/kg LW/d) to positive (0.05 g/kg LW/d). The improvement in stover fodder quality did not come at any penalty for grain or stover yield (Bidinger *et al.,* 2010). Berhanu *et al.* (2013) and Zaidi *et al.* (2013) included stover traits of parental lines into maize hybrid productions and produced variations in IVOMD of 7 to 9% units in F1 cultivars. Rao *et al.* (2012) developed experimental Brown Mid Rib (BMR) sorghum varieties through degree methods and improved sorghum stover IVOMD by about 3 to 4 units but varieties with higher stover IVOMD were penalized by lower grain and stover yields. Nepolean *et al.* (2009) used Quantitative Trait Locus (QTL) to concurrently improve stover quality and grain yield in pearl millet hybrid.

Opportunities from intensification of mixed crop livestock systems

Intensification in mixed crop livestock systems results in more food produced per unit land or more animal sourced food (ASF) per animal. The effect of intensification on feed demand and therefore biomass requirement is potentially enormous. With low producing animals most of the feed is used for maintaining the animal and not for production of ASF. Using dairy production and productivity in India in 2005-2006 as an example, only about 32% of the feed metabolizable energy was used for milk production. If per animal daily milk yield would increase from the 2005-2006 across herd (buffalo, crossbred and indigenous cattle) average of 3.61 kg to 15 kg total feed metabolizable energy requirement would be reduced by over 50% (*table 1*) resulting from fewer animals needed to produce the same amount of milk. In other words more than 50% less feed biomass would be required to produce the same amount of ASF.

Encouragingly, these levels of productivity could be achieved on largely CR and agro-by-product based feeds as demonstrated by Anandan *et al.* (2010) in collaboration with private feed manufacturers Miracle Fodder and Feeds PVT Ltd. in India (Shah, 2007). Miracle Fodder and Feeds PVT Ltd. (Shah, 2007) designed so-called densified total mixed ration (DTMR) feed blocks that consist largely of by-products such as sorghum stover (about 50%), bran/husks/hulls (18%), oilcakes (18%) with the rest contributed by molasses

Table 1. Actual across herd average daily milk yields (3.61 kg) and scenario-dependent (6 to 15 kg) metabolizable feed energy requirements to support total Indian milk production of 81.8 million tons in 2005.

Milk (kg/d)	Metabolizable energy required (MJ * 10^9^		
	Maintenance	Production	Total
3.61	1,247.6	573.9	1,821.5
6	749.9	573.9	1,323.8
9	499.9	573.9	1,073.8
12	374.9	573.9	948.8
15	299.9	573.9	873.9

Table 2. Milk potential in Indian dairy buffalo fed two densified total mixed ration (DTMR; in form of feed blocks) based on premium and low cost sorghum stover (*figure 2*).

	Block Low Cost Stover	Block Premium Stover
Protein (%)	17.1	17.2
Metabolizable energy (MJ/kg)	7.37	8.46
Voluntary intake of feed block (kg/d)	18.0	19.7
Voluntary intake of feed block (%/kg LW)	3.6	3.8
Milk potential (kg/d)	9.9	15.5

Data recalculated from Anandan *et al.* (2010) based on actual milk fat contents.
Note milk potential in cross-bred cattle with lower milk fat content than found in dairy buffalo would be 3 to 5 litres higher.

Table 3. Milk demand in India in 2005/2006 and in 2020 and dairy population and feed demand under across herd yields of 3.61 kg/d in 2005/2006, an estimated compounded annual growth rate in 2020 of 5.24 kg/d and a needed average daily milk yield of 6.76 kg/d if the milk demand in 2020 is to be provided by the dairy livestock population of 2005-2006.

	2005-2006	2020	2020 (fixed DLP)
Milk (tons)	81, 800,000	172,000,000	172,000,000
Yield/day (kg)	3.61	5.24	6.76
Dairy livestock population (DLP)	69,759,000	89,920,000*	69,759,000
Feed metabolizable energy requirements (MJ x 10^9^)			
Maintenance	1,247.64	1,608.22	1,247.6
Production	573.94	,1075.00	1,075.00
Total	1,821.58	2,683.22	2,3266.6
Feed requirements (tons)	247,500,000	364,570,000	315,600,000

(8%), maize grain (4%) and a urea, minerals, vitamins mix (2%). In a series of trials with commercial dairy producers, Anandan *et al.* (2010) varied the quality of the sorghum stover in the DTMR by purchasing and incorporating low cost (IVOMD=47%) and premium sorghum stover (IVOMD=52%) described in *figure 2* into the DTMR. The key findings of these trials are presented in *table 2*.

Differences in stover quality translate into significant differences in animal productivity. Anandan *et al.* (2010) used the lower (IVOMD=47%) and higher (IVOMD=52%) quality sorghum stover as basal diet ingredient (50% of total diet) in complete total mixed rations and tested the two diets with commercial dairy buffalo producers. The potential daily milk production was about was about 5 litres higher per buffalo (15 *versus* 10 litre) in the group fed the complete diets based on the higher quality sorghum stover (Anandan *et al.,* 2010). This increased milk potential was due to the additive effect of higher energy content of the diet with the superior sorghum stover and higher feed intake. Thus differences in CR fodder quality as low as 3 to 5% units in IVOMD can have significant effect on livestock productivity and leading to substantial price premiums for higher quality CR (see also *figure 2*) is economically sound.

It is highly improbable that the so called livestock revolution can materialize without significant intensification in the production of ASF. These considerations are exemplified in *table 3* table 3 based on the dairy scenario in India which in 2005 had a dairy livestock population of 69,759,000 producing about 82 million tons of milk. By the year 2020 the demand for milk is predicted to increase to about 172,000,000 million tons. If per animal milk yield were to increase at the Compound Annual Growth Rate (AGR) average daily milk yield would be 5.2 kg and about 20 million more dairy animals would be required to meet the demand for milk. Given the already severe feed shortage and the mounting concerns about negative environmental effects from livestock this is clearly not a viable strategy. In contrast increasing per animal productivity as conceptualized in *table 2* and pilot tested as described in *table 3* would result in a significant reduction in numbers animals (*figure 3*).

Conclusion

Crop residues represent a fundamental resource in the integration and intensification of smallholder mixed farming systems. Especially at low levels of agricultural intensification, crop livestock interactions are the main means to bring farmers to higher levels of production. Feeding crop residues to livestock provides immediate benefits, when other feed resources are scarce and external inputs not accessible. This review has pointed to two major pathways to avoid a "biomass trap" in mixed farming systems: the considerable potential to improve both the quality and

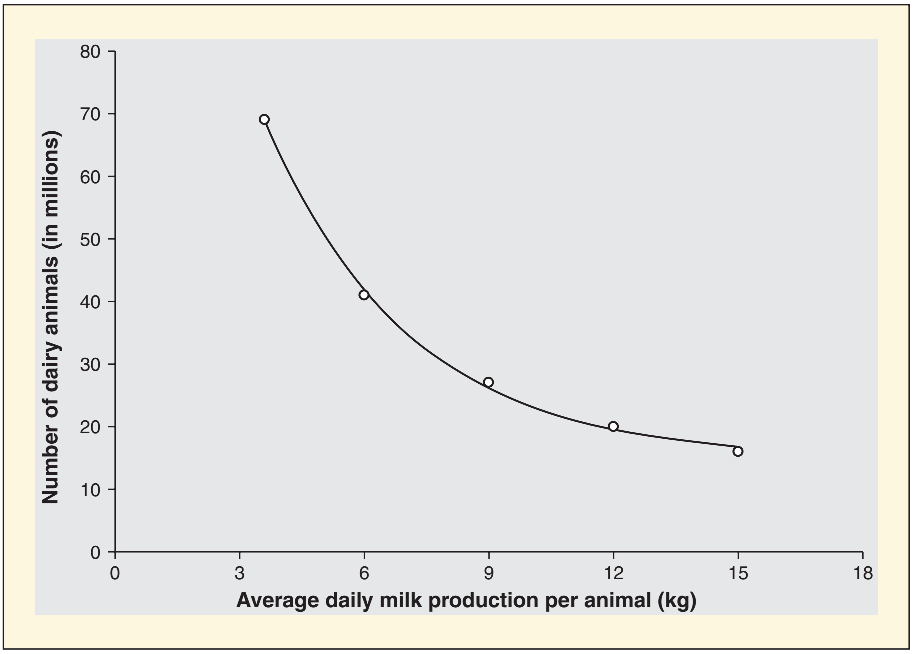

Figure 3. Effect of per animal dairy milk production on total numbers of dairy animals required to meet the 2005 milk demand of India of 82 million tons.

quantity of crop residues available to small scale farmers though appropriate selection of cultivars; and the intensification of livestock production improving the energy use efficiency in these systems. More attention to the livestock feed characteristics of cereal crop residues could have major benefits in facilitating intensification and limiting some of the negative environmental effects of livestock production.

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