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Introduction

Crop Residues (CR) are an important, internally produced by-product from crop production with several uses on smallholder, mixed crop-livestock farms. CR includes straw from small grains such as rice and wheat, stover from large grains such as maize, and residual plant material from other crops. Traditionally and currently in much of the developing world, CR are used for livestock feed, mulch, fuel, and construction material (Erenstein et al., 2015; Rao and Hall, 2003). CR are sometimes exchanged or traded, potentially providing additional income. In many areas, surplus CR are removed or burned so planting can be done in soil traditionally seen as clean and ready for planting.[1] Recent interest in Conservation Agriculture (CA) increases the pressure for retaining CR as mulch (i.e., soil cover) instead of other uses. In CA, CR are left in the field as mulch on the soil surface to improve soil productivity as measured by nutrient balance, water retention, erosion control, and soil health (Giller et al., 2009; Valbuena et al., 2012; Erenstein, 2002; Jat et al., 2020). These competing uses create internal tradeoffs for households: the short-term benefits of using CR to feed livestock, sell in the market, and use at home for fuel and construction material versus the long-term benefits of leaving CR in

[1] Burning clears the field quickly before the next crop is planted and releases some of the nutrients in the residue for use by the next crop.

the field as mulch (Tittonell et al, 2015). This study develops a method for estimating the internal value for these uses of residues.

Increasing global demand for meat and milk products due to population growth and rising incomes (especially in developing countries) has increased the interest in and calls for attention to the mixed crop-livestock systems prevalent in developing countries (Herrero, et al., 2010; McDermott et al., 2010; Thornton, Herrero, and Ericksen, 2011; Wright et al., 2011; Tarawali et al., 2011; Delgado et al., 1999a, 1999b). In such work, livestock is seen as a critical source of food both for the immediate household and for many others connected by local and distant markets. Even with the development and growth of larger intensive livestock operations, these authors and proponents contend that smallholder livestock operations will continue to be an important part of the meat and milk supply chain and contribute significantly to the supply of food in the developing world. Thus, these authors contend, the demand for CR as feed will continue.

In an early study, Owen and Jayasuriya (1989) show the benefits of CR as livestock feed and the need to utilize CR more fully in developing countries to meet food needs. More recently, Herrero et al. (2010) discuss the need for investment in mixed crop-livestock systems in general and specifically more research for the livestock side of that mix and the need to improve dual-purpose crops for both grains for humans and CR for feed. The potential for such dual-purpose crops has been variously analyzed – e.g. in the case of maize (Blummel et al, 2013; Erenstein et al., 2011) and sorghum and millets (Hall et al., 2004).

Some crop research has focused on the benefits of using CR as mulch in CA and on the promotion of CA to smallholder, mixed crop-livestock farms (Derpsch et al., 2010; Kassam et al., 2009; Hobbs, 2007; Lal, 2006; Larbi et al., 2002; Thiombiano and Meshack, 2009). Other crop research has identified the potential benefits of adopting CA as well as the problems and constraints slowing the widespread adoption of CA (Duncan at al., 2016; Akinola et al., 2016; Homann-Kee Tui et al., 2015; Valbueno et al., 2015; Erenstein et al., 2012; Jat et al., 2012; Valbuena et al., 2012; Umar et al., 2011; Erenstein et al., 2011; Erenstein and Thorpe, 2010; Giller et al., 2009, 2011; Gowing and Palmer, 2008; Erenstein, 1999, 2002, 2003). While early studies concentrated on the comparison of CA management systems relative to traditional crop management without including livestock in their analyses, others describe the complexity of and the need to understand the use and allocation of CR within the mixed crop-livestock system (Erenstein and Thorpe, 2010; Herrero et al, 2010; Moritz, 2010; and the more recent studies cited above). Giller et al. (2011) identify a research agenda needed to develop a fuller understanding of the smallholder, mixed crop-livestock system in Africa. Tittonell et al. (2015) synthesize some of the tradeoffs around crop residue biomass use in smallholder crop-livestock systems. The production and use of livestock manure in smallholder crop-livestock system has also received attention (Wang et al., 2020 and Castellanos-Navrrete, 2015).

These two uses of CR (i.e., as feed and as mulch) are competing uses also for researchers and development agencies promoting either livestock production or CA. Those interested in livestock production promote the need for CR as feed for livestock to produce food and improved nutrition and livelihood for households over CR as mulch. Those interested in crop production, soil productivity, environmental quality, and CA, promote CR as mulch over CR as feed.

Even though positive economic and environmental benefits of CA have been variously reported and CA has been variously promoted, the uptake of CA particularly by smallholder farmers in the Global South has been relatively modest. CA benefits may not have been obvious and large enough and farmers still predominantly use CR as feed versus as mulch in many areas (Giller et al., 2009). The reasons for this lack of change include tradition, culture, and the value of livestock for the family, and thus, CR as feed (Erenstein et al., 2012; Jat et al., 2012; Umar et al., 2011; Giller et al., 2009; Gowing and Palmer, 2008; Erenstein, 2002, 2003). The presence of free grazing may affect the ability to leave and retain CR in situ. This is an important constraint in many rainfed mixed systems, but less relevant in irrigated systems (like those that prevail in 2 of our study sites, Karnal and Dinajpur), since irrigation allows multiple cropping with free grazing limited to the off-season. In addition, the limited grazing window and productivity means that even when grazed, abundant CR will remain in the field. In instances where CR have recognized (monetary) value and can be traded, active CR markets and trading can develop. Such an increasing (monetary) value of stover and associated markets may increase the removal of crop residue from the field. Duncan, Samaddar and Blümmel (2020) surveyed rice and wheat straw traders in northern India and found market price differences based on quality. Earlier work had surveyed CR trade in southern India (Blummel and Rao, 2006). The findings of increased CR value has increased the attention of plant breeders on stover as well as grain. Erenstein and Thorpe (2010) note that the complexity of CA management and the need for in situ adjustments versus simple, common recommended practices also inhibit the adoption of CA and conclude that traditional research on straw feeding “neglected farmers’ perceptions of their agro-ecosystems” (p.687).

A few studies have searched for socio-economic and agro-ecological determinants that explain farmers allocation of CR (Jaleta, Kassie, and Shiferaw, 2013; Valbuena et al. 2012; Moritz, 2010). Using survey data from Kenya, Jaleta, Kassie, and Shiferaw (2013) found that more intensive farming led to higher use of CR as feed while extensive management was associated with higher use of CR as mulch; larger livestock holdings and higher numbers of cross-bred and exotic dairy animals led to higher use of CR as feed; and better knowledge about alternative uses of CR and plot steepness were associated with higher use of CR as mulch.

Little work has been done to estimate the economic value that individual households perceive in their use and allocation of CR as feed or as mulch. Magnan, Larson, and Taylor (2012) is one study that values stubble (leftover CR in the field) and found it to be a substantial part of a farm's total value of (rainfed) cereal production. This was especially true in a drought year when grain production was very low. While they did not estimate the benefits of switching to alternative production methods, they were concerned about efforts to encourage farmers to move away from methods that would use stubble as feed.

The objective for this study was to develop a method to estimate the internal shadow value of CR as feed and as mulch for smallholder households—as measured by the shadow prices of CR in these uses. Since both casual observation and, as will be shown, the data in this study show higher use of CR as feed than as mulch, the null hypothesis is that the internal shadow value of CR as feed is higher than as mulch.

Methods

Although we cannot directly measure the value the household places on CR for internal uses, we can estimate these internal values or shadow prices following the methods for estimating the value of labor in agricultural households (Jacoby 1993, Skoufias 1994, Shively and Fisher 2004), of stubble (Magnan, Larson, Taylor, 2012), and of farmyard manure (Teklewold, 2012). In these methods, the first step is to estimate Cobb-Douglas agricultural production functions for the sub-sample of households using a given CR as an input. The general specification of the production functions for crops and livestock are:

$Q_M = g^M(R_L, L_L, X_L, A_L)$ (1a)

$Q_C = g^C(R_C, L_C, X_C, A_C)$ (1b)

Q_M and Q_C are the household's physical production of milk and crops (rice, wheat, and maize in this study) which are described as a function of CR used as livestock feed (R_L) and as mulch for crops (R_C), (household and hired) labor allocated to livestock (L_L) and to crops (L_C), inputs purchased off the farm for livestock (X_L) and crops (X_C), and fixed assets represented by livestock (A_L) and land (A_C).

The functions are estimated in log-linearized representations of a Cobb-Douglas function, written generally as:

$\ln Q_M = \beta_{RL} \ln R_L + \beta_{LL} \ln L_L + \beta_{XL} \ln X_L + \beta_C \ln A_L + \varepsilon_L$ (2a)

$\ln Q_C = \beta_{RC} \ln R_C + \beta_{LC} \ln L_C + \beta_{XC} \ln X_C + \beta_A \ln A_C + \varepsilon_C$ (2b)

From (2a) and (2b) we can calculate the marginal value product for each CR use in the sub-sample of households engaging in given CR uses, based on the estimated coefficients, the predicted value of production for each household in the sub-sample, and the actual amount of CR used. Making use of the fact that the estimates of β_{RL} and β_{RC} in (2a) and (2b) are the CR's elasticities of production in the log-linear form of the Cobb-Douglas function, the elasticity formula can be rewritten and the marginal value products for CR use are defined as:

$p_M^* = (\hat{Q}_M / R_L) * \beta_{RL}$ (3a)

$p_C^* = (\hat{Q}_C / R_C) * \beta_{RC}$ (3b)

where $\hat{Q}_M$ and $\hat{Q}_C$ are, respectively, the livestock and crop outputs estimated using the estimated production function, R_L and R_C are household CR uses available in the data set, and β_{RL} and β_{RC} are estimated coefficients.

In this analysis, these methods are used to estimate the shadow price of CR in the production of a single product (i.e., milk, rice, wheat, and maize) in South Asia.

Data

The data were obtained from a set of village and household surveys performed in South Asia in 2010 and 2011 from three survey sites: Karnal, in the state of Haryana, north of New Delhi in India; Dinajpur in northern Bangladesh; and Udaipur in the state of Rajasthan in western India. This selection accounts for sites with contrasting agro-ecologies and levels of agricultural intensification (Valbuena et al., 2012; Table 1).

Quantitative household level surveys were conducted in a total of 480 households in 48 villages in 2011. Since the survey was cross-sectional for one production year, the CR production and allocation was assumed to be indicative of previous production and allocation decisions and thus used as explanatory variables in the estimated production functions. In South Asia, the limited number of crops, the common production of one (sole) crop per season and only two (irrigated) growing seasons per year in this dataset allowed the allocation of CR to specific crops.

CR uses in the survey were aggregated for analysis in this study. CR grazed by the household's animals, grazed by others, and collected for stall feeding were combined into livestock feeding. CR used as mulch was not aggregated with any other use. CR sold in the market was the total of CR sold to village members and others, stored for sale later, and given as payment in kind. Household consumption of CR was the total used for household fuel and for roofing and construction material. Burning and collecting by others for free, and other uses were not aggregated.

Results

Descriptive Statistics of Survey Data

The allocation of each CR to different purposes varied among the three main cereal crops in the South Asia study sites (Table 2). The overall importance of CR as feed, especially stall feeding, was obvious with 75% of wheat residue, 59% of maize residue and 51% of rice residue being used for stall feeding; whereas *in situ* stubble grazing was very limited. Rice residue was more likely used for mulch or burnt compared to maize and wheat. More maize and wheat residue was marketed. More maize residue was used for household fuel compared to rice residue and especially wheat residue.

CR used for feed and mulch were the dominant uses of CR at all sites measured by the estimated[2] kg per household and the number of households reporting each use (Table 3). The

[2] CR amounts are farmer estimates and indicative. CR are byproducts and in contrast to main products are not often marketed or measured.

highest level of CR as feed in South Asia was at Karnal with an estimated average of 23.7 ton per year for the 155 households that fed CR. The highest level of CR used as mulch was also at Karnal with an estimated average of 7.7 ton per household using CR as mulch per year; the lowest level was at Udaipur with 48 kg. CR sold per household was the highest at Karnal with an average of 17.2 ton per household selling CR per year, but only 27 households sold CR in the market (out of 160 surveyed at Karnal). Household CR consumption was highest at Dinajpur estimated at 3.2 ton per household consuming CR per year and considerably lower at other sites. Sixty-three households in Karnal reported burning an estimated average of 39.2 ton of CR per year. Burning, collecting by others for free, and other uses of CR were relatively small uses at other sites. The high absolute CR quantities per household for Karnal reflect a combination of intensive irrigated agriculture (typically double cropped, rice-wheat) and substantially larger farm sizes (2.9 ha) compared to the other 2 study sites (0.3-0.5 ha, Table 3).

The value of livestock and crop production varied considerably across sites (Table 4). The highest values were in Dinajpur and Karnal which are closer to markets and have irrigated water available in contrast to the drier, rainfed, and more distant site of Udaipur. The average value of livestock production per household was highest at Dinajpur with US$1,982 per household per year followed closely by Karnal at US$1,567. The highest average value of crop production per household was at Karnal, a major irrigated intensive system producing rice and wheat near major transportation routes, with an average of US$4,509 per household per year. The average value of crop production per household was considerably lower at other sites, in part reflecting the small farm sizes. The intensity and importance of livestock versus crop production can be seen in the share of the household's total value of agricultural production coming from livestock - being highest in the drier production site at Udaipur with an average of 58%.

Based on the households' estimates of labor used for livestock production, Udaipur had the highest average livestock labor hours with an average of 2,594 hours per year per household reporting. Crop labor costs included the value of household labor (based on the households' estimates of labor used in crop production and the reported village wage rates) as well as the cost of hired cropping operations (e.g., planting and harvesting) which were very common in South Asia. Crop labor costs were the highest at Karnal with US$800 per household per year and affected inter alia by farm size and labor rates.

Farm size proxies included total land cultivated and herd size (in tropical livestock units, TLUs). Total land cultivated included the land owned by the household and rented from others but not land rented to others. The amount of land cultivated per household ranges from an average of 0.3 ha per household in Udaipur, 0.5 ha in Dinajpur to 2.9 ha in Karnal. TLUs per household ranged from 1.5 in Udaipur to 1.7 in Dinajpur and 3.0 in Karnal.

Almost all the surveyed households in Karnal produced milk, totaling 1,883 kg per household per year. Only some 40% produced milk in Dinajpur and Udaipur, and at substantially lower production levels (316 and 345 kg, respectively - Table 5). Karnal households fed considerably more CR, green forage, and concentrates than the other two sites, but the Karnal households did not feed grass to their cattle and buffalo while the animals did graze for some of their feed in the other two sites. The average labor for milking was similar across the three sites, but it was much more variable in Karnal. (Milking hours was used as an indicator for total livestock labor since it was entered more reliably than estimates for other labor needs for livestock.)

In crop production, the major crop for Dinajpur was rice which was produced in each of the two growing seasons (Tables 6 and 7). The major crop in Karnal was rice in the first (monsoon) season and wheat in the second (winter) season. Udaipur planted mainly maize in the first (monsoon) season and wheat in the second (winter). Average production per household in Karnal was much higher reflecting higher input use and more than quadruple the amount of land planted to the crop. Average production per household in Udaipur was particularly low, associated with the small farm size, limited irrigation and rainfall, and lower input use. Karnal households used more CR as mulch than the households at Dinajpur and Udaipur.

Estimated Production Functions

Separate production functions for milk, rice, wheat, and maize were first estimated for each of the South Asia study sites, with the estimated coefficients then used to calculate the shadow prices of CR.

In South Asia, milk production per household was described as a function of feed (CR, grass, green forage, and concentrate); labor (with milking labor used as an indicator of total labor); and herd size (adult TLUs; Table 8). Grass was dropped from the estimation in Dinajpur and Karnal, green forage in Udaipur, and concentrate in Dinajpur and Udaipur because of limited use of these inputs.

The (positive) coefficient for CR as feed for milk was not statistically significant ($p>0.10$) in any of the functions for the three sites in South Asia (Table 8). The amount of concentrate fed had a positive impact in Karnal. The amount of milking labor had a positive impact in Dinajpur. Herd size had a positive impact in Karnal and Udaipur. Explanatory power as indicated by R^2 was low at all three sites. The milk function in Karnal was most robust, inter alia reflecting the prevalence of milk production and the highest number of useable observations.

Crop production per household for each crop and South Asian site was described as a function of CR used as mulch, the amount of land planted to each crop, and the level of seed and urea (except for Udaipur) inputs (Table 9). Other inputs such as manure, di-ammonium phosphate (DAP) fertilizer, herbicide, and fungicide had very few households using them and were dropped.

The coefficient for CR as mulch in crop production in South Asia was positive in most sites, except for boro rice (second season) in Dinajpur (Table 9). The amount of land had a positive impact for all crops and sites. The level of seed had an impact only for rice in season 1 at Dinajpur and for wheat in season 2 at Udaipur. The amount of urea did not have a significant impact at any site. Explanatory power, as indicated by R^2, was high for these crops and sites with the lowest R^2 being 0.75 for wheat in season 2 at Udaipur.

Estimated shadow prices

Using the methods developed in this study, estimated shadow prices were found to be higher for CR as mulch than for CR as feed at all three sites (Table 10). At Dinajpur, the estimated shadow price for CR as mulch was greater than the reported market price which was, in turn, greater that the estimated shadow price for CR as feed. At Karnal, the reported market price was greater than the estimated shadow price of CR as mulch which was, as seen in

Dinajpur, greater that the estimated shadow price for CR as feed. In Udaipur, the estimated shadow price of CR as mulch was much higher than for CR as feed. (Market prices were not reported for Udaipur.)

Discussion and Conclusions

The internal values that a household places on intermediate products and resources influence how those products and resources are used within the household. This study adapted a method to estimate the internal values of resources provided by the household. This paper estimated the internal values that households place on CR in alternative uses. As an example of using this method and the survey data from South Asia, the observed deviations from this expectation indicate that farmers are including more information in their decision process.

At all three sites, the estimated shadow prices (as our estimate of the internal value) of using CR as mulch were greater than the estimated shadow prices for CR as feed for livestock. At Dinajpur, the shadow values of CR as mulch and as feed were both higher than the reported market price for CR. At Karnal, the reverse was found; the reported market price was greater than the estimated shadow prices of CR used as mulch and as feed. This difference in relative rankings of market prices and shadow prices for CR between Dinajpur and Karnal indicate that farmers may be making rational economic decisions since, as shown in Table 3, Karnal had the highest level of CR sold in the market as farmers have better market access and high alternative uses. The relative shadow prices of feed and mulch reflect that crops generally responded positively to CR as mulch in our study sites whereas milk production was not significantly affected by CR as feed. The weak relationship between CR feeding and milk yield is not wholly surprising. CR is a basal feed needed to maintain animals rather than necessarily boosting yield. We would expect a much stronger relationship between concentrate use and milk yield. However, the weak relationship does not mean CR are not important. They are needed for maintenance of livestock, to ensure they survive into the next season. Their role is therefore more like a fixed cost than a variable cost. An additional contributing factor to the divergent shadow valuation may well be the robustness of the estimated production functions, which were found to be substantially more robust for the studied crops than for milk. Further empirical research is needed to confirm the robustness of crop and milk production response to CR use with even more detailed and robust production functions.

These results reject the null hypothesis that the estimated shadow price for CR as feed is greater than the shadow price for CR as mulch. However, the predominant use of CR was still as feed for livestock. Farmers (especially poor farmers) often focus on short term gains at the expense of long-term objectives. They would rather ensure their livestock (and family) survive the next season than think about increased crop yields in some unknown future Since the null hypothesis was formed based on observing household behavior, the rejection of the null hypothesis implies that other reasons explain why more households use CR as feed versus as mulch. Another reason may be that the data and the quantitative model used need to be improved to reflect the household decision process more accurately by incorporating more information. As noted earlier, the reasons for the lack of adoption of CA and CR as mulch have been associated with tradition, culture, value of livestock for the family, and thus, CR as feed to maintain livestock, and the complexity of CA management. Smallholders' continued reliance on livestock as part of their farming system can also be a reason for continued use of CR as feed. Jaleta, Kassie, and Shiferaw (2013) found that more intensive farming led to higher use of CR as feed while extensive management was associated with higher use of CR as mulch. Due to the lack of livestock availability from other sources, farmers may feed more CR even though the shadow price is lower as feed. Magnan, Larson, and Taylor (2012) showed the value of stubble was substantial in a drought year when grain production was very low, so stubble (and other forms of CR) was likely a form of insurance for obtaining a stable feed supply. Tradition may also play a large part; as Moritz (2010) observed, the peri-urban pastoralists were not considering only the economic or business side of their decisions because "livestock, production is privileged in their decision making" (p. 127).

The continued use of CR as feed versus the apparent higher value of CR as mulch illustrates the general problem that a large portion of research so far has considered only part of the households' decision framework (i.e., CR only as feed or only as mulch) while the households consider a much larger framework or system that extends beyond the borders of the fields and pastures. Erenstein and Thorpe (2010) also point this out in their conclusion that traditional research on straw feeding "neglected farmers' perceptions of their agro-ecosystems" (p.687). We concur with Giller et al. (2011) and Tittonell et al. (2015): we see a need for a much broader, multidisciplinary study of the households' decisions. The rejection of the null hypothesis of the value of CR as feed being greater than the value of CR as mulch in this study should encourage researchers to push forward to help households improve their knowledge and well-being. Alternatively, future researchers could improve the model through a more expansive understanding of the household decision process and a more expansive set of data (e.g. including farm yard manure, now left out for lack of consistent data).

Until households begin to place a higher value on CR as mulch, they should not be expected to change their traditional use of CR as feed. Changing a household's internal value structure to give a higher value to CR as mulch may need to be done in ways other than showing the long-term value of mulch since this has been done before with households not making large shifts in CR use. Increasing the use of demonstration plots for CR as mulch across broader geographical areas may increase farmers' knowledge of the yield response to mulch. Providing alternative methods for insurance and wealth holding (such as financial insurance instruments and access to banking) may decrease the need for and value of livestock for insurance and holding wealth and allow a household to switch to using CR as mulch. Providing better access to feed sources better than CR (and credit access so households could purchase these sources) could help animal productivity and household income as well as increase the amount of CR available for use as mulch. Increasing our multidisciplinary understanding of the households' decision-making process may enhance the use of internal farm resources and the well-being of smallholder crop-livestock farmers in South Asia and beyond.

References

Akinola A, Abdoulaye T, Valbuena D, Erenstein O, Haileslasie A, Germaine I, Shehu M, and Ayedun B (2016) Determinants of crop residue use along an intensification gradient in West Africa's savannah zones. Tropicultura 34, 396-410. https://hdl.handle.net/10568/78825

Blümmel M, Grings E, and Erenstein O (2013) Potential for dual-purpose maize varieties to meet changing maize demands: Synthesis. Field Crops Research 153, 107-112. http://dx.doi.org/10.1016/j.fcr.2013.10.006

Blummel M, Rao PP (2006) Economic Value of Sorghum Stover Traded as Fodder for Urban and Peri-urban Dairy Production in Hyderabad, India. International Sorghum and Millets Newsletter. 47: 97-100.

Castellanos-Navarrete, A., Tittonell, P., Rufino, M.C., Giller, K.E., 2015. Feeding, crop residue and manure management for integrated soil fertility management – A case study from Kenya. Agricultural Systems 134, 24-35. http://dx.doi.org/10.1016/j.agsy.2014.03.001

Chilonda P, and Otte J (2006) Indicators to monitor trends in livestock production at national, regional, and international levels. Livestock Research for Rural Development, 18(8): 117.

Delgado C, Rosegrant M, Steinfeld H, Ehui S, and Courbois C (1999a) Livestock to 2020: The next food revolution. Food, Agriculture, and the Environment Discussion Paper 28. Washington, D.C.: International Food Policy Research Institute.

Delgado CL, Rosegrant MW, Steinfeld H, Ehui S, and Courbois C (1999b) The coming livestock revolution. Choices, Fourth Quarter: 40-44.

Derpsch R, Friedrich T, Kassam A, and Hongwen L (2010) Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric & Biol Eng., 3(1): 1-25.

Duncan AJ, Bachewe F, Mekonnen K, Valbuena D, Rachier G, Lule D, Bahta M, and Erenstein O (2016) Crop residue allocation to livestock feed, soil improvement and other uses along a productivity gradient in Eastern Africa. Agriculture, Ecosystems & Environment 228, 101-110. http://dx.doi.org/10.1016/j.agee.2016.05.011

Duncan, A.J., Samaddar, A., Blümmel, M., 2020. Rice and wheat straw fodder trading in India: Possible lessons for rice and wheat improvement. Field Crops Research 246, 107680. https://doi.org/10.1016/j.fcr.2019.107680

Erenstein OCA (1999) The economics of soil conservation in developing countries: The case of crop residue mulching. Thesis. Wageningen, The Netherlands: Wageningen University.

Erenstein O (2002) Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil & Tillage Research, 67: 115-133. https://doi.org/10.1016/S0167-1987(02)00062-4

Erenstein O (2003) Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. Agriculture Ecosystems and Environment, 100: 17-37. https://doi.org/10.1016/S0167-8809(03)00150-6

Erenstein, O., 2011. Cropping systems and crop residue management in the Trans-Gangetic Plains: Issues and challenges for conservation agriculture from village surveys. Agricultural Systems 104, 54-62. https://doi.org/10.1016/j.agsy.2010.09.005

Erenstein, O., Samaddar, A., Teufel, N., Blummel, M., 2011. The paradox of limited maize stover use in India's smallholder crop-livestock systems. Experimental Agriculture 47, 677-704. DOI: 10.1017/S0014479711000433

Erenstein O and Thorpe W (2010) Crop-livestock interactions along agro-ecological gradients: a meso-level analysis in the Indo-Gangetic Plains, India. Environ. Dev. Sustain., 12: 669-689. https://doi.org/10.1007/s10668-009-9218-z

Erenstein O, Gérard B, and Tittonell P (2015) Biomass use trade-offs in cereal cropping systems in the developing world: Overview. Agricultural Systems 134, 1-5. http://dx.doi.org/10.1016/j.agsy.2014.12.001

Erenstein O, Sayre K, Wall P, Hellin J, and Dixon J (2012) Conservation agriculture in maize- and wheat-based systems in the (sub)tropics: Lessons from adaptation initiatives in South Asia, Mexico, and Southern Africa. J. of Sustainable Agriculture, 36:180-206. http://dx.doi.org/10.1080/10440046.2011.620230

Giller KE, Witter E, Corbeels M, and Tittonell P (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research, 114(1), 23–34.

Giller KE, Corbeels M, Nyamangara J, Triomphe B, Affholder F, Scopel E, and Tittonell P (2011) A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crop Research, 124: 468-472.

Gowing JW and Palmer M (2008) Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. Soil Use and Management, 24: 92-99.

Hall A, Blummel M, Thorpe W, Bidinger FR, Hash CT (2004) Sorghum and Pearl Millet as food-feed-crops in India. Animal Nutrition and Feed Technology. 4: 1-15.

Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasarathy Rao P, Macmillan S, Gerard B, McDermott J, Seré C and Rosegrant M (2010). Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems. Science, 327 (5967), 822–825.

Hobbs PR (2007) Conservation agriculture: what is it and why is it important for future sustainable food production. J. of Agricultural Science, 145:127-137.

Homann-Kee Tui S, Valbuena D, Masikati P, Descheemaeker K, Nyamangara J, Claessens L, Erenstein O, van Rooyen A, Nkomboni D (2015) Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe. Agricultural Systems 134, 48-60. http://dx.doi.org/10.1016/j.agsy.2014.06.009

Jacoby H (1993) Shadow wages and peasant family labor supply: An econometric application to the Peruvian Sierra. Rev. Econ. Studies 60(October): 903-922.

Jaleta M, Kassie M and Shiferaw B (2013) Tradeoffs in crop residue utilization in mixed crop-livestock systems and implications for conservation agriculture. Agricultural Systems 121, 96-105.

Jat HS, Jat RD, Nanwal RK, Lohan Shiv Kumar, Yadav AK, Poonia T, Sharma PC and Jat ML, (2020) Energy use efficiency of crop residue management for sustainable energy and agriculture conservation in NW India. Renewable Energy 155: 1372-1382.

Jat RA, Wani SP and Sahrawat KL (2012) Conservation agriculture in the semi-arid tropics: Prospects and problems. Advances in Agronomy, 117: 191-273.

Kassam A, Friedrich T. Shaxson F and Pretty J (2009) The spread of conservation agriculture: Justification, sustainability and uptake. International J. of Agricultural Sustainability, 7(4): 292-320.

Knowler D and Bradshaw B (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy, 32(1), 25–48.

Larbi A, Smith JW, Adekunle IO, Agyare WA, Gbaraneh LD, Tanko RJ, Akinlade J, Omokaye AT, Karbo N and Aboh A (2002) Crop residues for mulch and feed in crop-;livestock systems: Impact on maize grain yield and soil properties in the West African humid forest and savanna zones. Expl. Agric., 38: 253-264.

Lal R (2006) Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degrad. Develop., 17: 197-209.

Magnan N, Larson DM and Taylor JE (2012) Stuck on stubble? The non-market value of agricultural byproducts for diversified farmers in Morocco. American Journal of Agricultural Economics. 94(5): 1055-1069.

McDermott JJ, Staal SJ, Freeman HA, Herrero M and Van de Steeg JA (2010) Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science, 130(1):95-109.

McIntire J, Bourzat D and Pingali P (1992). Crop-Livestock Interactions in Sub-Saharan Africa (p. 246). Washington D.C.: World Bank.

Moritz M (2010) Crop-livestock interactions in agricultural and pastoral systems in West Africa. Agric. Hum. Values, 27:119-128.

Owen E and Jayasuriya MCN (1989) Use of crop residues as animal feeds in developing countries. Research and Development in Agriculture, 6(3): 129-138.

Rao P Parthasarathy and Hall AJ (2003) Importance of crop residues in crop–livestock systems in India and farmers' perceptions of fodder quality in coarse cereals. Field Crop Research 84: 189-198.

Shively G and Fisher M (2004) Smallholder labor and deforestation: A systems approach. Amer. J. Agr. Econ, 86(5):1361-1366.

Skoufias E (1994) Using shadow wages to estimate labor supply of agricultural households. Amer. J. Agr. Econ. 76 (May): 215-227.

Tarawali S, Herreo M, Descheemaeker K, Grings E and Blümmel M (2011) Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. Livestock Science, 139: 11-21.

Teklewold H (2012) The impact of shadow prices and farmers' impatience on the allocation of a multipurpose renewable resource in Ethiopia. *Environment and Development Economics*, 17(4): 479-505.

Thiombiano L and Meshack M (2009) Scaling up Conservation Agriculture in Africa: strategy and approaches. Addis Ababa, Ethiopia: FAO.

Thornton P, Herrero M and Ericksen P (2011) Livestock and climate change. Livestock Exchange Issue Brief 3, Nairobi, Kenya: International Livestock Research Institute.

Tittonell P, Gérard B and Erenstein O (2015) Tradeoffs around crop residue biomass in smallholder crop-livestock systems – What's next? Agricultural Systems 134, 119-128. http://dx.doi.org/10.1016/j.agsy.2015.02.003

Umar BB, Aune JB, Johnsen FH and Lungu OI (2011) Options for improving smallholder conservation agriculture in Zambia. J. of Agricultural Science, 3(3): 50-62.

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC, Teufel N, van Rooyen A and van Wijk MT (2012). Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Research, 132: 175–184. https://doi.org/10.1016/j.fcr.2012.02.022

Valbuena D, Homann-Kee Tui S, Erenstein O, Teufel N, Duncan A, Abdoulaye T, Swain B, Mekonnen K, Germaine I and Gérard B (2015) Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. Agricultural Systems 134, 107-118. http://dx.doi.org/10.1016/j.agsy.2014.05.013

Wang, B., Li, M., Wen, X., Yang, Y., Zhu, J., Belzile, N., Chen, Y.W., Liu, M., Chen, S., 2020. Distribution characteristics, potential contribution, and management strategy of crop straw and livestock-poultry manure in multi-ethnic regions of China: A critical evaluation. Journal of Cleaner Production, 274:1-10. https://doi.org/10.1016/j.jclepro.2020.123174

Wang, B., Shen, X., Chen, S., Bai, Y.C., Yang, G., Zhu, J.P., Shu, J.C., and Xue, Z.Y. (2018) Distribution characteristics, resource utilization and popularizing demonstration of crop straw in southwest China: a comprehensive evaluation. Ecological Indicators, 93:998-1004.

Wright IA, Tarawali S, Blümmel M, Gerard B, Teufel N and Herrero M (2012) Integrating crops and livestock in subtropical agricultural systems. J. Sci. Food Agric., 92: 1010-1015.

Table 1. Main bio-physical and socio-economic characteristics of the research sites, South Asia

Location	Dinajpur, Bangladesh	Karnal, India	Udaipur, India
Agro-ecology[a]	Humid (irrigated)	Semi-arid (irrigated)	Semi-arid (rainfed)
Rainfall (mm/yr)	2000	750	650
Main crops	Rice	Wheat, rice	Maize
Livestock	Cattle, goat	Buffalo, cattle	Cattle, buffalo, goat
Market access	++	+++	++
Agricultural intensification[b]	++	+++	+

[a] Agro-ecology primarily reflects aridity for predominantly rainfed agriculture, unless otherwise indicated.

[b] Relative indicator, low (+), medium (++), high (+++).

Source: Valbuena et al., 2012.

Table 2. Crop residue use by major crop in South Asia study sites, average % allocated.

	Maize	Rice	Wheat
Feed	60.9	50.9	75.5
– graze own	1.6	.1	.7
– graze others	.3	.1	.1
– stall feeding	59.0	50.7	74.7
Mulch	6.2	20.8	8.4
Market	16.0	4.1	11.6
– sold village	9.4	1.7	6.5
– sold other people	2.4	.0	2.2
– given as	1.7	.4	.9
– selling later	2.5	2.0	2.0
Consumption	14.8	13.2	4.1
– household fuel	14.5	9.8	2.0
– roofing/construct	.3	3.4	2.1
Collected by others free	1.3	0.9	0.3
Burned	0.9	10.1	0.3
Other	0.0	0.0	0.0

Source: project survey

Table 3. Summary statistics of CR use by site (farmer reported values per household per year, across crops).†

Variable	Dinajpur, Bangladesh	Karnal, India	Udaipur, India
CR fed to livestock (kg pa)	4,428 (4,866) n = 146	23,667 (34,717) n = 155	1,085 (1,639) n = 137
CR used as mulch (kg pa)	3,197 (5,483)	7,665 (13,935) n = 158	48 (77) n = 129
CR sold in the market (kg pa)	2,312 (3,903) n = 38	17,240 (22,280) n = 27	605 (779) n = 37
CR consumed by HH (kg pa)	3,148 (6,909) n = 144	1,255 (1,607) n = 77	36 (79) n = 24
CR burned in field (kg pa)	none	39,223 (156,091) n = 63	50 (80) n = 56
CR collected and used by others for free (kg pa)	3,143 (5,622) n = 11	13,797 (17,972) n = 11	43 (57) n = 8

†Averages are per household per year (pa), based on those households reporting a value for each variable. Standard errors in parentheses. The number of observations per site is reported if different from 160.

Table 4. Summary statistics of variables used in the analysis by site (values per household).†

Variable	Dinajpur, Bangladesh	Karnal, India	Udaipur, India
Value of livestock production (US$ pa)	1,982 (4,286) n=152	1,567 (1,102) n=156	216 (209) n=137
Value of crop production (US$ pa)	851 (832) n = 159	4,509 (5,057) n = 159	157 (236) n = 159
Total value of agricultural production (US$ pa)	2,729 (4,420)	6,009 (5,423)	340 (378)
Value of livestock production as a percentage of total value of agricultural production (%)	44.2 (30.0) n =152	36.7 (21.5) n =156	57.5 (22.2) n =137
Livestock labor (hours pa)	2,044 (1,459) n = 151	2,251 (2,542) n = 156	2,594 (1,754) n = 133
Crop labor cost (US$ pa)	144 (52)	800 (1,464)	83 (99) n = 159
Crop family labor (hours pa)	982 (1,329)	67 (369)	55 (60) n = 159
Total land cultivated (ha)	0.5 (0.5)	2.9 (3.7)	0.3 (0.3) n = 159
Tropical Livestock Units (TLUs)	1.7 (1.0) n=152	3.1 (2.3) n=154	1.6 (1.0) n=131

†Averages are per household, generally per year (pa), based on those households reporting a value for each variable. Standard errors in parentheses. The number of observations per site is reported if different from 160. All local currencies were converted to U.S. dollars using the exchange rates on October 1, 2010, which was during the time of the household survey.

Table 5. Summary statistics for milk production by site in South Asia (annual values per household).†

Variable	Dinajpur, Bangladesh[1]	Karnal, India[2]	Udaipur, India[2]
Milk production (liters)	316 (212) n = 66	1,883 (1,374) n = 150	345 (308) n = 59
CR fed (kg)	2,090 (787) n = 142	5,193 (2,208) n = 155	2,746 (3,218) n = 88
Grass fed (kg)	1,138 (1,040) n = 126	none	1,804 (2,327) n = 84
Green forage fed (kg)	1,447 (542) n = 138	6,534 (3,067) n = 155	1,823 (2,267) n = 33
Concentrate fed (kg)	347 (251) n = 104	1,452 (953) n = 150	648 (283) n = 6
Milking labor (hours)	346 (301) n = 69	334 (1,315) n = 151	338 (286) n = 100

Dairy Tropical Livestock Units (TLUs)	1.5 (0.9) n = 143	3.0 (2.1) n = 153	1.3 (0.8) n = 99

† Averages are per household per year based on non-zero observations. Standard errors in parentheses.

[1] Includes only cattle (local and cross). No buffalo milk reported in Dinajpur.

[2] Includes both cattle (local and cross) and buffalo in Karnal and Udaipur.

Table 6. Summary statistics for crop production in Season 1 by site in South Asia (annual values per household).†

Season, crop, and input variable	Dinajpur, Bangladesh	Karnal, India	Udaipur, India
SEASON 1	rice	rice	maize
Crop production (kg)	2,045 (2,034) n = 158	11,253 (12,744) n = 135	332 (416) n = 159
CR in field as mulch (kg)	1,565 (1,763) n = 101	2,717 (4,487) n = 157	31 (52) n = 98
Land planted to this crop in this season (ha)	0.5 (0.5) n = 158	2.3 (2.4) n = 135	0.3 (0.2) n = 159
Seed (kg)	23 (22) n = 158	29 (31) n = 135	11 (12) n = 159
Manure (kg)	21 (26) n = 139	1,019 (1,068) n = 75	12 (18) n = 136

Urea (kg)	62 (59) n = 158	874 (944) n = 135	30 (48) n = 99
DAP (kg)	37 (39) n = 115	285 (347) n = 123	30 (39) n = 50
Other fertilizer (kg)	48 (57) n = 126	83 (121) n = 110	††
Herbicide (US$)	10 (10) n = 26	57 (69) n = 134	9 (8) n = 5
Fungicide (US$)	11 (14) n = 129	175 (222) n = 135	13 (14) n = 10

† Averages are per household per year based on non-zero observations. Standard errors in parentheses.

†† No non-zero values reported for this variable at this site.

Table 7. Summary statistics for crop production in Season 2 by site in South Asia (annual values per household).†

Season, crop, and input variable	Dinajpur, Bangladesh	Karnal, India	Udaipur, India
SEASON 2	(boro) rice	wheat	wheat
Crop production (kg)	2,885 (2,727) n = 101	10,596 (11,119) n = 158	440 (669) n = 129
CR in field as mulch (kg)	566 (619) n = 157	6,064 (12,382) n = 114	23 (34) n = 120
Land planted to this crop in this season (ha)	0.5 (0.4) n = 101	2.4 (2.4) n = 158	0.3 (0.2) n = 129
Seed (kg)	24 (24) n = 101	254 (263) n = 157	38 (53) n = 129
Manure (kg)	23 (28) n = 96	390 (297) n = 2	11 (19) n = 55
Urea (kg)	95 (93)	927 (988)	35 (51)

	n = 101	n = 158	n = 106
DAP (kg)	52 (57) n = 95	314 (367) n = 157	28 (32) n = 59
Other fertilizer (kg)	61 (63) n = 101	178 (232) n = 10	9 (-) n = 1
Herbicide (US$)	6 (5) n = 47	69 (83) n = 156	5 (2) n = 5
Fungicide (US$)	10 (11) n = 87	64 (75) n = 68	9 (7) n = 7

† Averages are per household per year based on non-zero observations. Standard errors in parentheses.

†† No non-zero values reported for this variable at this site.

Table 8. Milk production function by site in South Asia.†

Variable	Dinajpur, Bangladesh	Karnal, India	Udaipur, India

CR fed (kg), log	0.13 (0.15)	0.14 (0.15)	0.42 (0.25)
Grass fed (kg), log	††	††	-0.13 (0.19)
Green forage fed (kg), log	0.17 (0.13)	0.15 (0.14)	††
Concentrate fed (kg), log	††	0.41*** (0.09)	††
Milking labor (hours per HH), log	0.24*** (0.06)	0.06 (0.06)	0.04 (0.14)
Tropical Livestock Units per HH, log	0.046 (0.065)	0.06** (0.03)	0.49* (0.26)
constant	2.07 (1.50)	1.45 (1.18)	2.87* (1.51)
R-squared	0.27	0.32	0.15
n	64	146	49

† Standard errors in parentheses.

***denotes p<0.01, **denotes p<0.05, *denotes p<0.10

†† Variable deleted from regression due to missing or small number of observations.

Table 9. Crop production function by crop, season and site in South Asia.†

Variable	Dinajpur, Bangladesh		Karnal, India		Udaipur, India	
Crop and Season:	Rice, S1	Rice, S2	Rice, S1	Wheat, S2	Maize, S1	Wheat, S2
CR as mulch (kg/ha), log	0.085**	0.061	0.085**	0.054***	0.33***	0.43***
	(0.039)	(0.049)	(0.035)	(0.017)	(0.06)	(0.07)
Cultivated land in this crop	0.52***	0.94***	0.78***	1.00***	0.87***	0.56***
and season (ha), log	(0.13)	(0.10)	(0.29)	(0.23)	(0.13)	(0.14)
Seed (kg/ha), log	0.33***	-0.01	0.075	0.06	0.10	0.20**
	(0.12)	(0.05)	(0.26)	(0.21)	(0.08)	(0.08)
Urea (kg/ha), log	0.089	-0.01	0.13	-0.08	††	††
	(0.055)	(0.08)	(0.13)	(0.10)		
constant	5.99***	8.35***	6.83***	8.16***	5.34***	4.46***
	(0.59)	(0.51)	(1.04)	(1.14)	(0.39)	(0.44)
R-squared	0.96	0.95	0.93	0.98	0.79	0.75
n	100	99	134	114	98	95

† Standard errors in parentheses. S1 = season 1 (monsoon). S2 = season 2 (winter).

***denotes p<0.01, **denotes p<0.05, *denotes p<0.10

†† Variable deleted from regression due to missing or small number of observations.

Table 10. Reported market prices and estimated shadow prices of crop residues by site (U.S.$/kg)†

	Average	Std. Dev.	n
Dinajpur, Bangladesh			
Reported market prices	0.02	0.00	
Residue as feed for milk, shadow price	0.009	0.004	67
Residue as mulch for rice, season 1, shadow price	0.025	0.011	100
Residue as mulch for rice, season 2, shadow price	0.059	0.024	99
Karnal, India			
Reported market prices	0.42	0.43	
Residue as feed for milk, shadow price	0.021	0.010	147
Residue as mulch for rice, season 1, shadow price	0.120	0.066	134
Residue as mulch for wheat, season 2, shadow price	0.07	0.11	114
Udaipur, India			
No reported market prices			
Residue as feed for milk, shadow price	0.023	0.010	67
Residue as mulch for maize, season 1, shadow price	0.78	0.43	98
Residue as mulch for wheat, season 2, shadow price	1.90	0.04	129

† These shadow prices are estimated using the models and the procedures described in this paper.