Determinants of Crop Residue Use Along an Intensification Gradient in West Africa's Savannah Zones

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Summary

The study compares and contrasts crop residue uses in 3 case study sites along an agricultural intensification gradient in the Sahel-Sudano zone of Niger and Nigeria. It draws on data collected from 24 villages involving 480 households and employs a Tobit model to analyse the determinants of crop residue uses for cereals and legumes. The study uses an innovative classification of crop residue uses as an internal and external service to the farming system. Survey results indicate that internal service as livestock feed constituted the largest share across sites and crop types. Sale of crop residues is the largest external use identified for legumes. The study found that the internal use of cereal crop residue decreases along an intensification gradient. However, legume biomass redistribution within the system (internal service) did not follow a clear intensification gradient. The result of Tobit analyses indicates internal service use was positively influenced by livestock ownership ($p<0.01$), age ($p<0.1$), education ($p<0.01$), training by extension agent on crop-livestock interaction ($p<0.05$) and crop residue management ($p<0.01$). However, as household size ($p<0.01$) increased the probability of enhancing internal services to agricultural systems declined. This suggests that larger households with more pressing demands for cash tend to sell their crop residues at the expense of more sustainable uses such as mulching. The overall pressure on crop residue use was also especially high in the more intensive system of the Kano region.

Résumé

Déterminants de l'utilisation des résidus de cultures selon un gradient d'intensification dans les zones de savanes de l'Afrique de l'Ouest

Cette étude compare et met en perspective l'utilisation des résidus des cultures dans 3 sites selon un gradient d'intensification dans la zone sahélienne et soudano-sahélienne du Niger et du Nigeria. Elle est basée sur des données collectées dans 480 exploitations réparties dans 24 villages et utilise un model Tobit pour analyser les déterminants de l'utilisation des résidus des céréales et des légumineuses. L'étude utilise une approche innovante de classification des résidus de culture selon leur utilisation interne ou externe au système de production agricole. Les résultats de l'enquête indiquent qu'une utilisation interne au système, telle que l'alimentation du bétail, représente la plus grande proportion de l'utilisation des résidus de céréales. La vente représente la plus grande utilisation externe pour les légumineuses. L'étude a montré que l'utilisation interne des résidus des céréales décroît selon le gradient d'intensification. Cependant, pour les légumineuses, aucune tendance claire en fonction du gradient n'a pu être identifiée. Les résultats de l'analyse de régression basée sur le model TOBIT indiquent que l'utilisation interne est positivement influencée par la possession du bétail ($p<0,01$), l'âge du chef de ménage ($p<0,1$), son niveau d'éducation ($p<0,01$), la participation à une formation sur l'intégration agriculture-élevage ($p<0,05$) et la gestion des résidus ($p<0,01$).

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Therefore, given the importance of crop residue for livestock feed and soil cover in these fragile savannah system and the high pressure for competing uses of crop residues, there is need to develop and promote potential substitute to ensure sustainability.

Cependant la probabilité d'une utilisation interne diminue avec l'augmentation de la taille de l'exploitation. Ceci suggère que les grandes exploitations, avec les besoins en liquidités les plus élévées, vendent plus leur résidus aux dépend des utilisations plus durables comme l'amendement du sol. En général la pression pour l'utilisation des résidus de culture est plus forte dans le site de Kano où la production est la plus intensive. En conséquence, étant donné l'importance des résidus de culture pour l'alimentation bétail, la fragilité deszones de savane et la forte pression pour l'utilisation alternative des résidus de culture, il est nécessaire de développer et de promouvoir des produits de substitution pour garantir un système plus durable.

Introduction

Crop–livestock systems and associated crop residue use in sub-Saharan Africa are socially, economically, and technologically diverse (1, 25, 28, 29, 35). The retention of crop residues for soil enhancement and particularly as mulch to reduce surface run-off, improve rain water infiltration, suppress weed growth and enhance soil health is being advocated in the context of conservation agriculture (16, 17, 20). However, in mixed crop-livestock systems, crop residues have several other purposes among which its use as livestock feed exerts a particular challenge for eventual alternative uses. Households also use crop residues as fuel, roofing and house construction, and as a source of income through sales (5, 12, 13, 14, 15). Famers may also prefer to burn crop residue in plots to ease land preparation/tillage and control pests and insects. Crop residue management can be linked to population density and associated effects on crop-livestock integration and agricultural intensification (23, 35). For instance, along a population density gradient, crop-livestock interactions are first set to increase and may reach a maximum at an intermediate level of population density, after which crop and livestock specialization sets in, resulting in lower crop-livestock interaction levels (14, 28). It has also been suggested that intensification is an endogenous process in response to increased population pressure (9, 10).

Population growth has historically led societies to invest in land improvements and to adopt technologies that resulted in higher agricultural production per unit of land. As population density increases, changes occur in cropping techniques that at first involve expanding the area under cultivation or, when that is no longer feasible, shortening fallow periods and increasing the labor input to satisfy the higher demand for food (9). In direct contrast to the Malthusian perspective, Boserup's hypothesis was that the problem of population pressure gives rise to its own solution. The scarcity of land, by altering factor prices, results in its more intensive use (9). This view of intensification, with its central tenets of factor substitution and technological change, is also consistent with the "induced innovation" model (18). This model contends that changes in factor proportions will lead to the conservation of the more scarce resource (in this case, land) and to increased use of the abundant resource in production (in this case, labor). As the ratio of land to population decreases, farmers are thus induced to adopt technologies that raise return to land – which potentially could include using crop residues as soil enhancing and mulching.

Crop-livestock systems are diverse and not only associated with population density, but also with differences in agro-ecology and economic opportunities, including the varied nature of the institutions that govern production relations in different agricultural systems. Agro-ecology for instance influences crop diversity and productivity and availability of alternative feed sources. Crop residues thereby provide an interface among crop, livestock and the environment, and its allocation and use likely involves trade-offs in terms of immediate livelihood interests and long term environmental sustainability (4, 22). One would thus expect crop residue management to have evolved in response to the system context – including crop residue types, farming systems, agro-ecology and market opportunity. Crop residues can provide internal services to the agricultural system when they are used as mulch, or for feeding own livestock. They can also be providers of external services to agricultural systems when devoted to off-farm uses such as sale, *ex-situ* stall feeding etc.

Existence of trade-offs in agricultural systems, between agricultural and broad environmental or socio-cultural objectives had long been established (36). The limited availability of fodder in crop-livestock systems had been associated with internal competition for the use of crop residues (12). How farmers use crop residues depends on individual preferences and the biophysical and socio-economic conditions (15). In the face of competing demands for crop residues and to address the critical need to improve current on-farm productivity and efficiency without jeopardizing long-term environmental sustainability, better understanding of farmers' decision-making with respect to the use of biomass becomes imperative. The decision made by farmers at any time will favour short time on-farm productivity and efficiency or long-term economic benefits or both. However, immediate need for cash and the current discount rate could necessitate farmers' decisions to be detrimental to long-term environmental sustainability and benefits when full knowledge of long time benefits is lacking.

It therefore becomes imperative to investigate drivers of farmers' decisions to use crop residues for internal services in order to guarantee both short term and long term benefits of productivity, efficiency and environmental sustainability.

This study investigates crop residue use in the Sahelian and Sudan savannah zones of West Africa. In this zone crop-livestock systems predominate and crop residues are an important feed source, used both in situ and ex situ (19, 22).

Specifically, the paper quantifies crop residue uses in three case study sites along an intensification gradient, and assesses the determinants of their use as internal service/input to the agricultural production system or as an external service/output. The remainder of this paper will first discuss methods and then present the results. Study findings are then discussed before some conclusions are drawn.

Methodology

Data collection

This study purposely selected three case study areas in the semiarid Sahel and Sudan savannas along a gradient of population density and associated crop-livestock integration and agricultural intensification (Kano–Nigeria; Maradi-Niger; Fakara–Niger) following (35).

The study sites can be ordered in terms of their crop production intensity as high for Kano, average for Maradi and low for Fakara (Table 1).

The gradient reflects decreasing rainfall – from a high in Kano (the most Southern site) to a low in Fakara (in western Niger) – as well decreasing market access. In Kano sorghum, millet, cowpea and groundnut are the predominant crops, with millet increasingly replacing sorghum proceeding along the gradient. In Fakara, sorrel (Rumex acetosa, a perennial herb and leaf vegetable) is also an important crop. The cereals and cowpea are primarily grown for home consumption, whereas groundnut and sorrel are primarily grown for the market. Cattle, sheep and goats are the predominant livestock across the sites.

The study applied a multi-stage sampling technique to draw a sample from 24 villages and 480 households surveyed Fakara and Maradi in Niger as well as Kano in Nigeria.. Each study site was first stratified based on market access reflecting distance to market centres and major roads from which a total of 8 villages were selected randomly.

In each village a census was first conducted to list

Table 1
Selected characteristics of research sites, savannah zone West Africa.

Fakara (western Niger)	Maradi (south-central Niger)	Kano (northern Nigeria)
Low	Medium	High
500	600	700
2.0	2.7	3.3
0.3	0.5	0.6

Source: Adapted from Valbuena *et al.*, (35).

all household before 20 households were randomly selected (see 35 for more details).

Data analysis

Descriptive statistics, such as mean, standard deviation and frequency distributions were computed and used for household characterization. A Tobit model was used to determine factors associated with crop residue use in the study areas.

Crop residue use can be categorized as an internal service/input to the agricultural production system or as external:

1. Internal service/input to agricultural production system (crop and/or livestock): primarily revolves around the use of crop residues as soil enhancing (including mulching) and as livestock feed – either through in situ stubble grazing or ex situ through stall feeding.
2. External service/output to agricultural production system – i.e. uses other than those associated with the internal agricultural production system within the farm, including any off-farm uses and non-agricultural on-farm uses. This primarily revolves around crop residue sales and gifts, in situ burning, household fuel and construction.

The internal *vs* external service of crop residues corresponds to a large extend with the associated biomass and nutrient flows within or out of the agricultural production system. For instance, most crop residues fed to livestock on the farm will be converted to manure, most of which is eventually returned to the crop field – either during stubble grazing or collected from stall feeding. However some of the external services may partially remain within or return to the agricultural system – for instance in case of ashes from in situ or *ex situ* burning and re-cycling of construction material.

Theoretical model

Households are faced with decisions to export crop residues from the agricultural systems in order to meet immediate exigencies or internal services such as mulching that favour long time sustainability of resources. The theoretical model of the household's decision to utilize crop residues for internal services that promotes long time sustainability of land, productivity or efficiency is assumed as the adoption of a new technology and treated as a continuous but discrete choice following (2).

It is assumed that the household makes the decision to use residues for internal services that promotes sustainable use of land based on the utility that is derived from the chosen agricultural technique. The household chooses between those defined as internal services or external services decision is made based on the farming technique(s) that delivers the maximum utility.

Household utility maximization is modelled to explain farmers' adoption behaviour following (11) because households are both consumers and producers of goods. And since the farmers often operate under various market imperfections characterized limited by transportation, imperfection of information availability to consumers and, erratic production methods, an expected utility maximization framework could be used to represent choices made under such market uncertainty. An expected utility maximization model is developed based on the assumption that farmers' decision making is conditioned by resources available, knowledge they possess, and constraints which limit these activities. The household utility maximization model is based on the expected value of the non-observable underlying utility function that ranks the preference of the ith household according to the chosen crop residue' use.

The non-observable utility function, U, is represented by Equation I:

$$E\,[U_iB\,(C_i\,(H_i,\,A_i),\,Z_i)] \qquad \text{(I)}$$

where *C* represents the household goods consumed, *Z*, is a group of other factors (including leisure), *E* is the expectations operator, *B* represents the crop residue choice (*B*=1 when internal services are on the lot and *B*=2 when external services are employed), *i* indicates the individual household. Consumption of farmers is derived from observable socio-economic characteristics, *H*, (such as farm size, and age and education level of the household heads), and from observable crop residue characteristics where the technology refers to the crop residue usage chosen by the household. The choice of technology therefore determines farm yield and household income, which are influenced by the labour limitations of the family.

Input and output levels of agricultural production will differ according to the farm technique. Although the utility is unobservable, the relation between the utility derived from a specific technology is a function of the vector of the observed farm and technology characteristics included in the utility measurement. The family chooses between $E[U_{i1}]$ and $E[U_{i2}]$ depending upon which agricultural technology yields the greatest expected utility. The utility ranking of the chosen technology is therefore estimated from the vector of observable farm and technology characteristics as indicated in the equation II.

$$E\left[U_{\mathrm{itT}}\right]=\alpha_{\mathrm{i}}F_{\mathrm{i}}\left(X_{\mathrm{i}}\right)+e_{\mathrm{i}}\,T=1{,}2\,i=1,\ldots\ldots\ldots\ldots,n \qquad \text{II}$$

where e_i is a normally distributed disturbance term. The *ith* family will choose to export biomass (external services) from the farm if $U_{it1}<U_{it2}$ (although, a minor limitation of this study), or if the latent variable $Y^*= U_{i1}-U_{i2}<0$ and will choose using the biomass as an internal system when $U_{i1}>U_{i2}$, or if the non-observable latent variable $Y^* =U_{i1}-U_{i2}>0$ (Equation III).

$$Y_i=\begin{cases} 1\, if\; U_{i1}>U_{i2,} & \text{Internal services are adopted} \\ 0\, if\; U_{i1}<U_{i2,} & \text{External services are adopted} \end{cases} \qquad \text{III}$$

The probability that the i*th* household use crop residue for internal services (the probability that Y_{it} equals one), is a function of the independent variables as indicated in the Equation IV.

$$P_{\mathrm{it}}=\Pr\left(Y_{\mathrm{i}}\right)=1=\Pr\left(U_{\mathrm{i}1}>U_{\mathrm{t}2}\right) \qquad \text{(IV)}$$
$$\Pr\left[\alpha_1F_{\mathrm{i}}\left(X_{\mathrm{i}}\right)+e_{\mathrm{i}1}>\alpha_2F_{\mathrm{i}}\left(X_{\mathrm{i}}\right)+e_{\mathrm{i}2}\right]$$
$$\alpha_2-\alpha_1$$
$$\left(e_{\mathrm{i}1}-e_{\mathrm{i}2}\right)>F_{\mathrm{i}}\left(X_{\mathrm{i}}\right)$$
$$\Pr\left[\mu_{\mathrm{i}}>\alpha_2F_{\mathrm{i}}\left(X_{\mathrm{i}}\right)\beta\right]$$
$$\Pr$$

where *X* is an *n* x *k* matrix of explanatory variables, and *β* is a *k* x *1* vector of coefficients to be estimated. The probability that the i*th* household use crop residue for the internal system is therefore the probability that the utility gained from external system' use less than the utility gained from the adoption of sustainable activities of internal system (the accumulation distribution function of F for $_i$ evaluated at X_i). If μ_{ij} is normal, *F* will have a cumulative normal distribution, and if μ_{it} is uniform then F is triangular. For the purpose of this analysis, μ_{it} is assumed to be normal, thereby necessitating the use of Tobit model.

The stochastic model underlying Tobit as suggested by Tobin (34) can be expressed by the following the Equation V.

$$y_i=X_i\beta+u_i \quad \text{if} \quad X_i\beta+u_i>0 \quad \text{and} \qquad \text{(V)}$$
$$0 \quad \text{if} \quad X_i\beta+u_i\leq 0$$
$$i=\ ,2,\ldots,N,$$

Where is the *N* is the number of observations, y_i is the dependent variable, X_t is a vector of independent variables, *β* is a vector of unknown coefficients, and u_t is an independently distributed error term assumed to be normal with zero mean and constant variance σ^2. Thus the model assumes that there is an underlying, stochastic index equal to $X_t\beta+u_t$) which is observed only when it is positive, and hence qualifies as an observed, latent variable.

The total change in *y* can be disaggregated into two very intuitive parts: (1) the change in y of those above the limit, weighted by the probability of being above the limit; and (2) the change in probability of being above the limit, weighted by the expected value of y if above. The value of dependent variable is in proportions. Invariably, tobit could be used instead of logit or probit where the dependent variable assumes the value of 1 and zero.

The estimates of the disaggregated variables as well as their marginal effects can then be obtained as stated by Amemiya (4) and, McDolnald and Moffit (27).

Empirical model

The theoretical Tobit model was fitted with the collected data. The dependent variable is the proportion of crop residue used for internal services/input within the agricultural production system - which by definition mirrors and complements the proportion of crop residue external to the agricultural production system. In order to justify the use of tobit model, an OLS estimates of the model was done and results presented. The empirical model was specified in the Equation VI.

$$Y_i=\beta_0+\beta_1 HHAGE+\beta_2 HHEDU+\beta_3 HHGENDER+\beta_4 HHSIZE+\beta_5 TLU+\beta_6 CREDITAC+\beta_7 PLOTMANU+\beta_8 FERTPHA+\beta_9 OUTPUTPH+\beta_{10} CROEXT+\beta_{11} EXTLIVST+\beta_{12} KANOAR+\beta_{13} FAKARVAR+\mu \quad \text{VI}$$

The multidisciplinary explanatory / independent variables included farmer, farm and institutional factors postulated to influence adoption of technologies. These variables include age of the household head in years (*HHAGE*), years of education of the household head (*HHEDU*), household size (*HHSIZE*), aggregate livestock ownership (Tropical Livestock Units, *TLU*), access to credit (*CREDITAC*), distance of the field from the house measured in kilometres (*FIELDDIST*), total asset of the farmers in Nigeria Naira (*ASSET*). Others include training received on importance of crop residue use (*CROPEXT*) and training on crop-livestock integration (*EXTLIVST*). Moreover, variations associated with gradients of population density and associated crop-livestock integration and agricultural intensification are captured by the two region dummies of Fakara and Kano, *FAKARVAR* and *MARADVAR*, respectively (See Table 2).

The rationale for inclusion of these factors was based on previous agricultural technology adoption literature and the analysis of these systems (8, 30, 31). The expected effect of age (*HHAGE*) on the use of crop residue is ambivalent and likely location- and technology-specific. Previous studies show that the age affect mental attitude to new ideas and influences adoption in several ways.

Younger farmers have been found to be more knowledgeable about new practices and may be more willing to bear risk and adopt innovations because of their longer planning horizons. On the other hand, older farmers even though might be risk averse may have more experience, resources, or authority that may give them more possibilities for trying a new technology.

Education (*HHEDU*) was hypothesized to positively influence the internal service use of crop residue. Education increases the ability of farmers to use their resources efficiently and the allocative effect of education enhances the farmer’s ability to obtain, analyze and interpret information (3, 6).

Similarly, effect of education is expected to increase along the intensification gradient from Fakaya to Kano.

Household size (*HHSIZE*) has been identified to have either positive or negative influence on adoption (6, 24, 26, 37). However, in this study larger family size could be associated with a greater labor force being available to the household for the timely operation of farm activities including crop residue use. More labor hours could be used on collecting and transporting crop residue away from the farm. The study hypothesizes that increased household size could favour external service use. Moreover, since population increases along the intensification gradient, external service use is expected to increase across the intensification gradient. Institutional factors of prior farmer training on crop residue use (*CROPEXT*) and crop-livestock integration (*EXTLIVST*) as well as access to credit (*CREDITAC*) are hypothesized to positively influence the internal service use.

The training variable incorporates the information that the farmers obtain on their production activities on the importance and application of innovations through counselling and demonstrations by extension agents on regular bases. The effect of this information on adoption varies depending on channel, source, content, motivation, and frequency. The present study hypothesized that the respondents who frequently receive training have higher probability of adoption than those that do not (6, 33). We also expect access to training to increase along the intensification gradient.

Table 2

Description of key variables for regression.

Variable	Variable descriptions	Units
HHAGE	Age of the household head in years	Years
HHEDU	Years of formal education completed by the household head.	Years
GENDER	Gender of the household head. 1 if male, 0 if not.	
HHSIZE	Household size, i.e., number of people living together under the same roof and eating from the same pot.	
CROPEXT	An ordinal measure of farmer's having received training on crop residue use. 1 if training was received, 0 if not.	
EXTLIVST	An ordinal measure of farmer's having received training on crop-livestock integration. 1 if training was received, 0 if not.	
CREDITAC	Access to credit measured by farmer's access to a source of credit, such as co-operative society, at a reasonable cost. 1 if there was access, 0 if not.	
PLOTMANU	Quantity/ha of manure applied.	Kg/ha
FERTPHA	Quantity/ha of fertilizer applied.	Kg/ha
OUTPUTPH	Quantity/ha of major output produced.	Kg/ha
TLU	Aggregate livestock holding of the household, as probable source of wealth.	Tropical Livestock Units
FAKARVAR	Fakara dummy; Fakara 1, Kano and Maradi 0	
KANOVAR	Kano dummy, Kano 1, Fakara and Maradi 0	

The variable, *CREDITAC*, takes cognizance of farmers' access to sources of credit to finance the agricultural activities and thereby boosts farmers' readiness to adopt technological innovations. It is hypothesized that the variable has a positive influence on the probability of the adoption and use of improved technologies (37). It is measured as a dichotomous variable with access being one, and zero for no access. It is expected to reduce the need to sell crop residues and thereby enhance the internal service use and increase along the intensification gradient.

Measures of wealth, livestock ownership (*TLU*), and *ASSET* are hypothesized t enhance the internal service use of crop residue and to increase along the intensification gradient (33). They represent capital that could be used either in the production process or be exchanged for cash or other productive assets.

Livestock and assets increase the availability of capital which makes investment in production activities feasible. The livestock holding possessed by the households (*TLU*) is expected to positively relate to the internal service use given increased feed demand. Livestock type affects feed demand (14) and larger animals such as cattle are expected to enhance the internal service use. Farmers in the area own different types of livestock. To have a common unit of measurement for different types, we converted all into Tropical Livestock Unit. Cropping patterns, population and livestock density, residue use, and availability of resources potentially differ by agroecology. Based on this, it is hypothesized that in the region specific variables - *FAKARVAR* and *MARADVAR* could be positive or negatively related to crop residue use.

Results and Discussions

Demographic and socio-economic characteristics of the sampled households

The characteristics of the sampled households were variously associated with the intensification gradient (Table 3). The average respondent was young (45) and with a household of 10-12 – being consistent across the gradient. This relatively young age might influence the availability of labor for agricultural activities, for testing of agricultural innovations, and production of biomass (6). The average educational level increased along the intensification gradient – from about 3 years in Fakara to 9 years in Kano. Most previous studies have found a positive relationship between literacy and the ability to process information on agricultural innovations (2). Land ownership increases along the intensification gradient – being near universal in Kano – although farm size tends to decrease along the same, with the largest average farm size in Fakara (Table 4). In Kano about 12% for farm households were also involved in shared cropping, while only 2% rented in; whereas in the less intensive Fakara, renting was 23% while shared cropping was negligible. Livestock ownership was common throughout the study area reflecting the prevalence of mixed crop-livestock systems. Livestock holding per farm household decreases along the intensification gradient (Table 4): i.e. the largest herds (in terms of *TLU*) were observed in Fakara, the lowest in Kano, the latter with a large proportion of small ruminants, in line with Mortimore (29).

However, given lower population density and larger farm sizes in Fakara, livestock density actually increases along the intensification gradient (Table 1). In spite of the important role that livestock play in the household economy and capital accumulation, purposive forage or pasture cultivation was negligible throughout the study areas. Livestock were primarily fed with biomass from crop residues and communal lands like few grasslands, roads and weeds.

The cropping system across the gradient is dominated by cereals (58-72% of the cropped area, primarily sorghum, millet) followed by legumes (17-38% of the cropped area, primarily cowpea, groundnut – Table 4). In line with the intensification gradient, crop intensification indicators– including fertilizer use, manure application and yields –were increasing from Fakara to Kano. However, average rates of fertilizer and manure use remain low throughout.

The institutional characteristics were increasing with the intensification gradient. These include agricultural training, savings and access to credit (Table 3) – albeit the latter mainly from the informal sector. The provision of credit is increasingly regarded as an important tool for raising the incomes of rural populations, mainly by mobilizing resources for more productive uses (21).

Crop residue use in the Sudano-Sahelian zone

Crop residue uses varied across crop types and study regions (Table 5), comprising both internal and external services. Internal service as livestock feed constituted the largest share across sites and crops–averaging 34-59% for cereal stover biomass (millet and sorghum) and 70-80% for legume haulms (cowpea and groundnut). In line with their feed value, legume haulms were consistently preferred over cereal stovers. Across sites, there was no marked difference between cowpea and groundnut haulms, notwithstanding increased research interest in cowpea haulms as feed (32). Sorghum stover was generally preferred as feed over millet stover across sites. Internal service as soil amendment/mulching was largely limited to the most extensive systems (Fakara) and millet stover, and to a lesser extent sorghum and sorrel. Sales of crop residues were the main external service/output and more common for legume haulms biomass (15-24%) compared to cereal stover (5-6%). Crop residue sales were positively associated with the intensification gradient – with highest average shares in Kano both for legume haulms (31-41%) and cereal stover (21%). Sale of cowpea biomass was somewhat higher than for groundnut across sites, off-setting the somewhat higher feed use of groundnut. Gifts of legume haulms were equally common for the two legumes.

Table 3

Demographic and institutional characteristics surveyed households by research site, Savannah zone West Africa.

Variables	Fakara (n =156)	Maradi (n=160)	Kano (n =159)
Demographic Characteristics			
Age of the household head	46(14)	45(16)	45(14)
Years of education household head	2.6(3.6)	5.8(7.4)	8.8(4.2)
Male headed household (% of respondents)	98.7	98.7	99.4
Household size	11.9(22.5)	9.7(18.9)	11.1 (24.6)
Institutional characteristics			
With credit (% of respondents)	33	54	76
With savings (% of respondents)	16	42	95
Received training (% of respondents):			
- on crop residue management	72	0	100
- on crop livestock integration	61	37	100

Figures in parentheses represent standard error. Source: Data analysis, 2012.

Table 4

Farm characteristics surveyed households by research site, savannah zone West Africa.

Variables	Fakara (n =156)	Maradi (n=160)	Kano (n =159)
Land ownership (% of respondents)	76	85	96
Farm size (ha hh^{-1})	11.9(23.7)	3.7(15.6)	4.8(19.5)
Livestock holding (TLU hh^{-1})	4.9(10.4)	4.4(4.8)	2.9(4.5)
Crop area (% cultivated area)			
- Cereals	58	72	65
- Legumes	38	17	27
- Other	4	11	8
Livestock composition (% TLU)			
- Large ruminants	80	59	12
- Small ruminants	15	34	63
- Other stock	5	7	25

Figures in parentheses represent standard error. Source: Data analysis, 2012.

Table 5

Crop residue uses (% of biomass) reported by surveyed households by crop and research site, savannah zone West Africa.

	Internal service		External Service				
	Mulch	Feed	Sold	Gift	Burnt (*in situ*)	Fuel	Construction
All							
Millet	24	34	5	5	2	22	8
Sorghum	8	59	6	2	2	18	5
Cowpea	3	70	24	4	0	0	0
Groundnut	0	80	15	5	0	0	0
Fakara							
Millet	49	39	5	1	0	1	5
Sorghum	28	57	8	1	0	2	4
Cowpea	7	68	21	4	0	0	0
Groundnut	0	87	13	0	0	0	0
Sorrel	32	50	11	0	1	2	4
Maradi							
Millet	13	65	8	1	0	10	3
Sorghum	7	81	6	1	0	4	0
Cowpea	2	90	7	1	0	0	0
Groundnut	0	90	5	6	0	0	0
Kano							
Millet	0	31	21	4	3	28	13
Sorghum	1	39	21	4	3	18	14
Cowpea	0	67	31	3	0	0	0
Groundnut	2	57	41	1	0	0	0

Source: Data analysis, 2012

Taken together, legume biomass was used solely as internal feed or for external sales/gifts – reiterating their higher value compared to cereal stover. The cereal stover use was more diverse – including internal services as soil mulch (8-24%) and external services such as household fuel (18-22%), construction (5-8%) and *in situ* burning (2%). These other services were associated with the intensification gradient – with internal soil enhancing/mulch being largely absent in Kano with the reverse being true for the other external services (Table 5).

The more intensive systems in Kano thereby showed considerable pressure on biomass given their intensive use for feed, sales, fuel and construction with limited surplus remaining for alternative uses. In the more extensive systems in Fakara, crop residue use centres basically on livestock feeding with limited sales and substantial surplus cereal residues remaining as soil amendment/mulch in the field.

The diversity in crop residue use intensity along the intensification gradient and particularly in the more intensive systems raises concerns on systems sustainability and livelihood security. Further capacity building of farmers could help promote internal services and recycling to enhance system sustainability in these fragile and stressed agro-ecologies. However, this also calls for appropriate innovations to facilitate sustainable intensification. The grouping of crop residue use in terms of internal and external services to the agricultural production system reinforces the important roles played by crop residues along the intensification gradient (Table 6). Cereal biomass redistribution within the farming system was highest in Fakara (76 percent %), and followed by Maradi (66 percent %). The figure was lowest in Kano (61 percent). On the other hand, export of cereal residue from the system was highest in Kano (39 percent). The result indicates that the use of cereal crop residue for internal services that favour long time sustainability decreased along the intensification gradients. This might be connected to reduced access to fertilizers and other intensification inputs that increase along the intensification gradients. Increasing availability of alternative land enhancing inputs could be a driving force making farmers to use less of the available cereal crop residues along the intensification gradient. However, there was substantial legume biomass export (>82 percent in all the sites) out of the system. Maradi had highest legume biomass redistribution within the system. Generally, there was more legume biomass export out of the system in Kano followed by Fakara. The high export of legume biomass out of the systems could be traced to high sales of legume crop residues for cash in both sites. The proximity of these sites to urban markets and/or availability of few cash crops to generate cash earnings could necessitate better exchange of legume haulms for cash in both Kano and Fakara compared to Maradi.

Determinants of crop residue uses

Tobit model was run alongside with multiple regression model. However, Tobit model was preferred based on theoretical a priori expectation and statistical significance of the variables as well as better fitness of fit of regression equation. The results of the Tobit model are summarized in Table 7. Based on the size of sigma and log-likelihood, the model has an overall good fit. The log-likelihood was -2169.02 and was significant at 1 percent. Similarly, the sigma was 28.78 and was also significant at 1 percent.

The variables of age (*HHAGE*), education (*HHEDU*), household size (*HHSIZE*), training received on the use of crop residue (*CROPEXT*), training in livestock (*EXTLIVST*), livestock ownership (*TLU*) and region specific variables (*FAKARVAR* and *KANOVAR*) were the significant factors influencing the probability and intensity of internal services to the agricultural system (Table 7). One year increase in age of farmer increased the probability of enhancing internal service by 0.01%. The results indicated that the probability of redistributing biomass within the system (internal service) increases as farmers grow older. This is related to due fact that older farmers tend to have better experience that reinforces their understanding of enhancing internal services to the agricultural system.

Education was positively and significantly related to the probability and intensity of enhancing internal services to agricultural system. This is also in agreement with our expectation that trained farmers have better insights of the importance of biomass as soil enhancing technology An additional one year of formal education obtained increased the probability and intensity of boosting internal service of agricultural system by about 0.6 percent. This was further substantiated by the findings that training of farmers via extension services on crop residue use also positively influenced internal services of agricultural system. An average farmer that received the training had 14 percent increase in the probability of enhancing internal services of agricultural system compared to those who have not

Table 6

Aggregate crop residue use (% of biomass) for internal and external services to agricultural system by crop type and research site, savannah zone West Africa.

	Kano		Maradi		Fakara	
	Cereal Stover	Legumes haulms	Cereal Stover	Legumes haulms	Cereal Stover	Legumes haulms
Service	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
External	39 (19)	99 (21)	34 (24)	81 (23)	24 (16)	93 (19)
Internal	61 (21)	1 (4)	66 (24)	19 (9)	76 (26.7)	7 (7)

Figures in parentheses represent standard error.

Source: Data analysis, 2012.

Table 7

Determinants of crop residue use for internal crop services to agricultural production system across research sites, savannah zone West Africa (Tobit model).

	Tobit regression estimates			Multiple regression estimates	
Variable	Coefficient	P[|Z|>z	Marginal effect	Coefficient	P[|Z|>z
CONSTANT	26.971***	0.0000	2697	-3352	0.7197
HHAGE	0.013*	0.0575	1	59	0.7803
HHEDU	0.580**	0.0193	58	509	0.7010
HHSIZE	-0.559**	0.0117	-6	-1328	0.0561
FIELDDIST	6	0.8283	1	2	0.9816
CROPEXT	14.126***	0.0002	1,413	2727	0.7754
EXTLIVST	6.198**	0.0347	620	11299	0.2263
FAKARVAR	38.209***	0.0000	3821	-2361	0.7546
MARADVAR	45.852***	0.0000	4583	-13498	0.1207
CREDITAC	-1505	0.5826	-151	2902	0.7366
TLU	0.9499***	0.0000	95	740	0.2468
ASSET	-15	0.3524	-2	1	0.9923
Log likelihood function	-2169.02				
Number of observations	476				
Sigma	28.78				

Significant at 1%, 5% and 10%, respectively.

Source: Data analysis, 2012.

received any training. Similarly, exposure to training about crop-livestock integration increased internal services to agricultural system. One unit increase in education on crop-livestock integration increased the probability of enhancing internal services to agricultural systems by about 6 percent.

Livestock ownership also increased the probability of enhancing internal services to agricultural systems. An increase in livestock ownership of farming households by 1 tropical livestock unit increased the probability of enhancing internal services to agricultural systems by about 1 percent. Farmers possessing livestock took the advantage of using manure from the animals for greater biomass production and redistributed the biomass within the system by feeding the crop residues to their livestock thereby boosting the internal services to agricultural systems.

However, as household size increased the probability of enhancing internal services to agricultural systems declined. One unit increase in household size decreased the probability of boosting internal services to agricultural systems by 0.6 percent. This suggests that larger households tend to sell their crop residues to supplement their income through sales in market or other places. Therefore, crop residues are being exported out of the system not allowing more sustainable internal uses such as soil cover or mulching to be done. Our findings on the location-specific variables agree with the a priori expectation that probability of redistributing biomass within the farm (internal service) increased along the gradient of intensification from Fakara to Maradi. Compared to Kano, the two location specific variables were positively related to probability of enhancing internal service. Agro-ecological attributes associated with living in Fakara had the tendency of increasing the probability of redistributing crop residue within the system by about 38 percent but agro-ecological characteristics in Maradi increased probability of reallocating by about 46 percent (Table 7).

Conclusion and recommendations

The study confirms widespread crop residue use both as internal service to agricultural production (particularly livestock) and as external service/output in West Africa’s savannah zones. Cereal biomass redistribution within the farming system (internal service) was highest in Fakara and followed by Maradi and lowest in Kano. This supports that cereal crop residue uses as internal decreases along an intensification gradient. However, Maradi had highest legume biomass redistribution within the system (internal service). Generally, there was more legume biomass export out of the system in Kano followed by Fakara. Therefore, internal uses of legume uses do not follow a clear intensification gradient.

The Tobit regression results also showed that age of the farmer, education, and training by extension agent on crop-livestock interaction and crop residue management were positively and significantly related to probability and intensity of use for internal services. Similarly, livestock ownership and region specific variables were positively significant in influencing the probability and intensity of use of crop residue for internal service. However, as household size increased the probability of enhancing internal service to agricultural systems declined. Therefore, given the importance of crop residue for livestock feed and soil cover in these fragile savannah system and the high pressure for competing uses of crop residues, there is need to develop and promote potential substitute to ensure sustainability.

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