The potential for adoption of climate smart agricultural practices in Sub-Saharan livestock systems

Garcia de Jalon, S; Silvestri, S; Barnes, AP

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Assessing potential for adoption of '*win-win (-win)'* agricultural practices in Sub-Saharan livestock systems

Abstract

Livestock systems play an important role in the livelihoods of many rural communities in Sub-Saharan Africa while being responsible for an important share of anthropogenic greenhouse gas emissions. This study aims to evaluate potential of adoption of agricultural practices in Sub-Saharan livestock systems, related to the improvement of feed, animal husbandry and grassland management. These agricultural practices present productivity and mitigation benefits and in some cases, may also contribute to enhance resilience and therefore to achieve a triple win. In this study we used a dataset of 1538 farm-households across nine Sub-Saharan countries. A mixed Logit model was used to assess the influence on adoption and estimate probability of adoption. Our results show that there seems to be a stronger influence of physical capital on adoption than the other capitals. Different types of capitals influence the uptake of different agricultural practices. Yet the probability of adoption would change across countries. The results of this study could help to refine adoption estimates calculated through global or regional modelling approaches and to inform the design of policy to better target investments in order to foster adoption.

Keywords: Adoption, Mitigation, 'win-win (-win)', Livestock, Capitals, Climate change, Mixed Logit, Sub-Saharan Africa

1. Introduction

The Fifth Assessment Report of the IPCC (AR5) (Niang and Ruppel 2014) foresees with a high level of confidence that climate change will exacerbate the vulnerability of livestock systems in Sub-Saharan Africa. There is particular concern around the impact that the increase in greenhouse gas concentration will have on exacerbating drought conditions in subtropical agriculture (Tubiello et al., 2007; Thornton et al., 2009). Total greenhouse gas emissions from livestock supply chain represent 14.5 percent of all human-induced emissions from which almost 7% of emissions are attributed to Sub-Saharan livestock production (Gerber et al. 2013). Nevertheless, Sub-Saharan livestock production has the highest greenhouse gas emissions intensities due to low animal productivity across large arid areas, use of low-quality feeds, feed scarcity, and animals with low productive potential (Herrero et al. 2013). Livestock systems play an important role in the livelihoods of many rural communities in Sub-Saharan Africa and numerous studies have identified a multitude of agricultural practices which have the potential to reduce greenhouse gas emissions and therefore tackle climate change (Soussana et al. 2010; Smith et al. 2013; Herrero et al. 2010).

Climate change policies often target smallholder farmers with the purpose of intensifying production by improving efficiency in a sustainable way (Herrero et al. 2010). Nevertheless, the development of climate change policies which target rural communities is hampered by the complexity of the drivers behind adoption of mitigation measures and, conversely, the associated barriers to full adoption of these techniques and technologies (Bryan et al. 2013a; Parry et al. 2004; Lobell et al. 2008; Ngigi 2009).

Public and private institutions have the potential to enhance adoption of farm-level actions against climate change. In this context, national governments are initiating governance systems and developing numerous policies and programmes in Africa (e.g. Niang and Ruppel 2014; AAP 2013; Beddington et al. 2012; Dixon et al. 2003; IFAD 2013) which are aimed at integrating climate change actions into policies related to sustainable development, food security and poverty (Nzuma et al. 2010; Downing et al. 1997). The AR5 highlights the need for enhancing and scaling up actions against climate change at farm and local level including principles for good practice and integrated approaches to mitigation and adaptation (Niang and Ruppel 2014). Therefore, evaluating farm-level adoption can be very helpful in developing policies to enhance capacity for both reducing greenhouse gas emissions and coping with climate change risks and impacts (Nhemachena and Hassan 2007).

In the last decade, a growing interest in the literature focused on understanding the drivers of adoption of agricultural practices at the farm level, paying particular attention to the socio-economic determinants that influence adoption. Reviews of previous studies that assess farm-level adoption of recommended agricultural practices have been conducted to explore those factors that regularly explain adoption (e.g. Prokopy et al. 2008; Knowler and Bradshaw 2007; Baumgart-Getz et al. 2012; García de Jalón et al. 2014a). These studies examine the coefficients of the independent variables estimated by econometric approaches in order to establish common baselines by synthesising the results of numerous studies. In Sub-Saharan Africa, a large body of research has been devoted to analysing the effects of socio-demographics factors in the adoption of actions against climate change (e.g. Gbetibouo 2009; Deressa et al. 2009; Bryan et al. 2009; García de Jalón et al. 2014b; Silvestri et al. 2012). These determinants can act as biophysical, economic or social factors to the adoption of recommended agricultural practices.

One important thing to consider when assessing adoption of new or innovative practices is the diffusion or dissemination of adoption. The theory of Diffusion of Innovations defines the different steps in the process of diffusing adoption of an innovative practice in which a logistic curve was used to describe how adoption could evolve throughout time (Rogers 2003). Agricultural practices with mitigation benefits often represent innovative measures and consequently, adoption might follow a similar evolution throughout time. This implies that adoption estimates calculated through econometric or optimization approaches may not evolve as expected, i.e. the peer-effect or farmer-to-farmer effect could play a key role not expected in the most commonly used models to predict adoption.

Determinants of adoption can be aligned into five types of capital, namely natural, social, physical, financial, and human. These have been found to contribute to the adoption of mitigation and adaptation strategies among farm-households in Sub-Saharan Africa (Wheeler et al. 2013; Below et al. 2012; Gebrehiwot and van der Veen 2013; Deressa et al. 2009; Silvestri et al. 2012). The study of Wheeler et al. (2013) estimated the effect of proxies of the five capitals on the adoption of several adaptation measures among farmers in Australia. It showed that in general, the five capitals had a positive effect on the adoption of adaptation practices. However, their results depicted that for some practices, indicators of the same capital could have both positive and negative effects on adoption. The study of Below et al. (2012) showed that physical and financial capitals were the greatest predictors influencing the uptake of adaptation measures in Tanzania.

A large number of agricultural management practices that target livestock exist. They may present productivity and mitigation benefits (win-win) and may also in some cases contribute to enhance resilience and therefore to achieve a triple win (Moran et al. 2013; Gerber et al. 2013; Lipper et al. 2014). Accordingly, this study aims to assess the potential for adoption of five agricultural practices which can reduce greenhouse gas emissions while either improving soil fertility, increasing resilience to extreme climatic events, alleviating feed shortages, increasing income to resource poor farmers, and increasing milk and meat production in Sub-Saharan livestock systems.

2. Data and Methods

2.1. Data collection

Data used in this study were collected from the survey of the CGIAR Research program on Climate Change, Agriculture and Food Security (CCAFS), conducted between 2010 and 2011. The survey was carried out by face-to-face interviews at the farm-household level and was implemented in eleven case studies across nine different countries of SSA (Burkina Faso (BF), Ghana (GH), Mali (ML), Niger (NE), Senegal (SN), Ethiopia (ET), Kenya (KE), Tanzania (TZ), and Uganda (UG)). In total the sample include 1538 farm-households. Figure 1 shows the location of the eleven case studies.

The questionnaire was designed with the objective of developing some comparable cross-site household-level indicators for which changes in agricultural practices could be assessed throughout time (see Kristjanson, et al. (2011) and Kristjanson, et al. (2012) for more information). The questionnaire presented items on crop and livestock production and sales, adoption of changes in their farm-management practices in the last ten years, food security, farm-household assets, accessibility to climate information, and socio-demographic traits.

< Insert Figure 1 >

2.2. Data analysis

The methodological process aims to provide an approach to estimate potential for adoption of agricultural practices with mitigation and productivity benefits in Sub-Saharan Africa. This approach can be very helpful when assessing potential for adoption of agricultural practices that are not currently being implemented or when optimization models cannot be applied due to lack of information.

From expert discussions in the AnimalChange project the following five agricultural practices that target livestock production systems in Sub-Saharan Africa were identified (see ILRI (2014) for more information): *i*) improving feed quality by processing crop residues and adding maize to the ration, *ii*) improving animal husbandry and health by enhancing fertility and reducing mortality rate, *iii*) improving grassland and grazing management, *iv*) improving grassland management by increasing the use of legumes, and *v*) improving grassland management by introducing Brachiaria genotypes (*Brachiaria spp.*). This approach can be described in the following four methodological steps:

1) Selection of proxies

The first step of the methodological process was to select proxies of the five mitigation practices through other practices in which adoption has been previously evaluated, and consequently, there is available data to assess their drivers of adoption. As there is no available data of determinants of adoption of the five mitigation practices, the estimation was based on the adoption of similar practices. Following the OECD (2008), the selection was based on the analytical soundness, measurability, and the relationship between the selected agricultural practices and the mitigation practices.

2) Selection of determinants of adoption

The second step was to select drivers of adoption of the five agricultural practices. The adoption of innovative practices in agriculture has been widely assessed by numerous approaches by evaluating the influence of natural and socio-economic characteristics on the probability of adoption. We classified the determinants of adoption according to the five types of capital: natural, physical, financial, human, and social. Thereby proxies of the five types of capital were selected to assess their influence on adoption.

Natural, physical, financial, human, and social capitals are stocks or flows that have the capacity to produce flows of economically desired outputs (Goodwin 2003). Natural capital represents the resources and ecosystem services of the natural world which yields a valuable flow of goods and services into the future (Costanza and Daily 1992). Physical capital is defined as physical assets generated by applying human productive activities that are used to provide a flow of goods or services (Goodwin 2003). Financial capital is the capital stock that facilitates economic production. Indicators of this capital could be sources of cash income such as cash crops, off-farm employment, access to credit and bank accounts, etc. Human capital refers to the productive capacities, knowledge, and personal attributes and values that make an individual more productive (Pindyck and Rubifeld 2013). Social capital consists of trust, understanding, and cooperation between individuals and groups (Goodwin 2003). In this study, the selection of the proxies of the five types of capital was based on the relationship between the proxies and the adoption of mitigation practices.

3) Assessing the influence of the five types of capital on adoption

In this step, the influence of the five types of capital on the adoption of the selected proxies of practices was assessed by a generalised linear mixed model (GLMM). In the logistic regressions of the GLMM, the adoption of the practices is treated as a binary dependent variable (with the value of 1 indicating adoption) and the five types of capital as predictors. In this way, a random intercept Logit model was developed, having random effects for each village where the survey had been implemented (the survey was implemented in 80 villages across the nine countries).

Eq. (4) describes the random intercept Logit model in terms of a latent linear response, where only $y_{ij} = I(y_{ij}^* > 0)$ is observed for the latent

$$y_{ij}^* = X_{ij}\beta + Z_{ij}U_j + \varepsilon_{ij} \quad (4)$$

Where X_{ij} are the covariates for the fixed effects (i.e. five capitals) of farm-household *i* in village *j*, with regression coefficients (fixed effects) β. Z_{ij} are the covariates corresponding to the random effects and can be used to represent both random intercepts and random coefficients. As our case is a random intercept model, Z_{ij} equals the scalar 1. U_j represents the error term for the random effects of the 80 villages which are estimated as variance components. ε_{ij} are the errors distributed as logistic with mean 0 and variance $\pi^2/3$ and are independent of U_j.

Defining $\pi_{ij} = Prob(adoption_{ij} = 1)$, equation (5) shows the final random intercept Logit model,

$$logit(\pi_{ij}) = \beta_0 + \beta_1 Human_{ij} + \beta_2 Natural_{ij} + \beta_3 Physical_{ij} + \beta_4 Social_{ij} + \beta_5 Financial_{ij} + U_j \quad (5)$$

for *j* = 1,…,80, with *i* = 1,…,n_j farm-households in village *j*.

4) Evaluating potential for adoption of the agricultural practices

The last step of the methodological process aimed to evaluate the potential for adoption of the five agricultural practices with mitigation and productivity benefits. In this way, the estimated coefficients of the mixed Logit model were used to calculate the likelihood of adoption of each agricultural practice similar to the five mitigation practices. Subsequently, the likelihood of adoption of each mitigation practice was calculated as the average of the probabilities of the similar practices. Finally, the potential for adoption of each practice was analysed on the basis of the estimated probability of adoption.

3. Results

3.1. Selection of proxies for ’win-win (-win)’ strategies

The first step of the methodological process was to select agricultural practices which i) have similar drivers of adoption to our five selected practices, and for which ii) there are available data to assess the influence of their drivers on adoption. Table 1 presents the selected proxies for the five agricultural practices used in this study and describes their adoption estimates.

‘Improving feed by processing crop residues and adding maize to the ration (*Maize*)’ implies implementing some changes and improvements in the farm-management practices related to mechanized farming, using pre-treated seeds or introducing improvements in the feed storage. Thereby the selected proxies with similar drivers of adoption were: ‘introduced mechanized farming’, ‘planting pre-treated/improved seed’, ‘improving fodder storage (e.g. hay, silage)’ and ‘growing fodder crops’.

‘Improving animal husbandry and health (*Herd*)’ aims to increase fertility rates and decrease mortality rates. The objective of this practice can be achieved by enhancing the farm-management practices related to animal husbandry and health. Therefore the associated proxies were: introducing stall keeping, fencing for livestock and mechanized farming.

'Improving grassland management (*Grazing*)' focuses on the enhancement of the current management of grasslands and grazing. The selected proxies for this practice included: improving pastures, and introducing rotations and micro-catchments.

'Improving grassland management (*Legumes*)' deals with the introduction or the increase in the use of legumes in grasslands. As the introduction of legumes in grasslands implies the introduction of new crop-varieties, the practice of planting pre-treated or improved seeds was used as a proxy. In addition, improving pastures and introducing rotations were considered to have similar drivers of adoption.

'Introducing *Brachiaria* to improve grasslands management (*Brachiaria*)' is basically driven by the need to introduce a new crop variety in order to improve grasslands quality. Therefore the selected proxies of this practice were planting pre-treated/improved seeds and improving pastures.

The adoption of the selected proxies was measured as a binary variable in which 1 means that the practice was adopted and 0 that the practice was not adopted. Thereby the mean in Table 1 shows the percentage of farmers who adopted each practice. The practices of introducing crop rotation, planting pre-treated or improved seeds and introducing fodder storage were the practices more frequently adopted. Around thirty percent of farmers adopted these practices. Conversely, improving pastures, introducing stall keeping, mechanized farming, fencing, micro-catchments and growing fodder crops were the practices least frequently adopted. Their adoption rate was around ten percent.

< Insert Table 1 >

3.2. Selection of proxies of the five kinds of capital

Table 2 presents the selected proxies of the five types of capital identified in the CCAFS survey. Since 'physical capital' specifies human productive activities, its selected proxies attempted to cover farm and household assets such as: livestock and land holdings, irrigation systems, electronic assets, mechanical plough and used agricultural inputs.

‘Social capital’ indicates trust, understanding, and cooperation between individuals and groups or institutions. The selected proxies for social capital were: membership of agricultural associations, gender of the head of the household, and various variables that attempted to capture access and ability to use climate information and extreme weather events through social networks.

For ‘financial capital’, the selected proxies were: access to credit, having a bank account, remittances, off-farm and on-farm income.

‘Human capital’ refers to productive capacities, knowledge, and personal attributes. The selected proxies included: size of the household, level of education, as well as attitudes and values towards climate change measured through questions about why farmers had adopted changes recently in their farm-management practices.

In terms of agriculture, natural capital represents climate and soil characteristics which predetermine the suitability for agriculture. Those kind of bio-physical data were not included in the survey and therefore their proxies were derived for each site at a pixel level based on other sources to include: annual precipitation, length of growing period and the difference between precipitation and potential evapotranspiration. The proxies for annual precipitation and the difference between precipitation and evaporation were obtained from WorldClim database (www.worldclim.org/). The selected values were the average between 1950 and 2000. The indicators of length of growing period were obtained from FAO (www.fao.org/geonetwork/). The time period used to calculate the length growing period was from 1963 to 2000 and the grid resolution provided by FAO database was used to locate the case studies.

< Insert Table 2 >

3.3. Influence of the five types of capital on adoption

The influence of the five types of capital on the uptake of the selected proxies for the ‘*win-win (-win)’* practices was evaluated by a mixed Logit approach. Table 3 presents the estimated coefficients of the mixed logistic regressions. Overall, all types of capitals have a positive and significant effect on the uptake of the practices. This confirms the findings of previous studies that highlight the importance of all types of capital on adoption of innovative or recommended agricultural practices (e.g. Wheeler et al. 2013; Thornton et al. 2006; Nelson et al. 2005; Below et al. 2012). However, there seems to be a stronger influence of physical capital on adoption than the other capitals. Also different types of capitals influence the uptake of different practices, with improved pastures, for example, predicted by physical and financial capital and introduced rotations as determined by human, physical and social capital. Indeed some straightforward policy implications to these findings would be to invest in enhancing farm-household assets such as infrastructure, quality inputs for crop production, and household asset such as domestic access to water, electricity and animal shelter in order to enhance the uptake of the selected practices.

Natural capital is the only capital that presents a significantly negative effect on adoption. In this study, the proxies used to form the natural capital mainly indicated the aridity and humidity of the climate in the location of the case studies (i.e. annual rainfall, potential evapotranspiration, and length of growing period, see Table 2). Thus a positive coefficient of natural capital indicates that farm-households located in a humid climate are more likely to adopt. In the practice 'introducing fodder storage', natural capital negatively correlates with adoption ($\beta = -2.62, p < .001$), this may indicate that households in arid areas store more fodder as result of the high variability in fodder provision due to the arid climate.

< Insert Table 3 >

3.4. Assessing potential for adoption

The last step of the methodological process of the study was to evaluate the potential for adoption of each '*win-win (-win)*' agricultural practice targeting livestock. The estimated coefficients of the mixed logistic regressions were used to calculate the likelihood of adoption for each proxy. Subsequently the probability of adoption of the five mitigation practices was calculated as the average of the probability of the proxies for each agricultural practice. Figure 2 shows the distribution of the predicted probabilities of adoption of the five mitigation practices. Considering the median values, the estimated probability of adoption of the five practices range from approximately 3% to 21%. The mitigation practice 'improving grassland management through introducing or increasing the use of legumes' (*Legumes*) presents the highest likelihood of adoption *(median = 0.21)*. The selected proxies of this practice were improving pastures, introducing rotations and planting pre-treated/improved seeds. The CCAFS survey shows that introducing rotations and planting pre-treated/improved seeds are practices frequently adopted among Sub-Saharan farmers, which explains the relatively high probability of introducing legumes to improve grasslands. The elevated rate of adoption of these two practices in comparison with the others could be explained due to their low cost of investment and the economic and soil quality benefits obtained in the short term. The probability of improving feed quality, through processing crop residues and adding maize to the ration (*Maize*), improving grassland management (*Grazing*) and introducing Brachiaria genotypes (*Brachiaria*) is not extremely low (*median values around 0.17*). Improving animal husbandry and health through increasing fertility rate and reducing mortality rate (*Herd*) emerges as the practice least likely to be adopted *(median = 0.03)*. These practices present elevated costs for the household and this may explain their low level of adoption.

< Insert Figure 2 >

Figure 3 shows the estimated probability of adoption of the five agricultural practices by country. The results seem to indicate that the highest probability of adoption is in the case studies regions of Kenya, Tanzania and Burkina Faso. On the contrary, Mali and Niger present the lowest likelihood of adoption of the five agricultural practices The practice improving feed quality through processing crop residues and adding maize to the ration (*Maize*) seems to have a higher likelihood of adoption in Kenya, Tanzania, Ghana, Senegal and Burkina Faso. The practice improving animal husbandry and health through increasing fertility rate and reducing mortality rate (*Herd*) presents probability values close to zero in Mali, Niger and Ethiopia. Improving grassland management (*Grazing*) has the highest probability of adoption in Kenya and Tanzania. Improving grassland management through introducing or increasing the use of legumes (*Legumes*) has the highest likelihood of adoption in Ghana, Senegal, Kenya and Tanzania. Ghana, Tanzania and Kenya seem to be the countries with the highest likelihood of introducing Bracharia genotypes (*Bracharia*). These results could be explained by either biophysical factors, such as for example the type of natural habitat required for the growth of Brachiaria and legumes (Miles et al. 1996), the type of climate which would be more or less suitable for agriculture as well as economic and technological capacity to adopt farm-management changes

(Ayele and Wield 2005). It is noteworthy to highlight that the estimated probability of adoption only determines the potential for adoption and does determine actual adoption. Actual adoption is ultimately driven by specific characteristics and farm-decisions made at the farm level.

< Insert Figure 3 >

4. Limitations, implications and conclusions

This study presents an innovative approach to evaluating smallholders' uptake of agricultural practices with both mitigation and productivity benefits in Sub-Saharan livestock systems. Nevertheless, there are two limitations which need to be addressed. Firstly, to derive the uptake of the five selected practices of this study, we had to select agricultural practices in which adoption is driven by similar determinants. Consequently, this needs to be based on proxies or indicators. The other limitation is that this study aims to encompass adoption for all Sub-Saharan Africa. As adoption of mitigation practices will ultimately proceed on the farm-level decision-making process and this complexity increases as the scales increase then, generalizing adoption and farmer behavior at higher scales may not be precise (Jones and Boyd 2011; Adger et al. 2009; García de Jalón et al. 2014b). Nevertheless, this approach can be utilised as a first step to evaluate potential for adoption of innovative agricultural practices as well as to refine adoption estimates calculated through, for example, global modelling approaches (e.g. Havlík et al. 2014)

Results from the mixed Logit model seem to indicate that overall physical capital is the most powerful predictor on the adoption of the selected mitigation practices. Thus the policy implications to improve implementation of mitigation could be to invest in farm-household assets such as infrastructure, mechanical plough or quality inputs for crop production. All capitals except natural capital have a positive effect on adoption. Hence this seems to indicate that adoption can be fostered in a number of ways, i.e. by enhancing indicators of the different types of capital. The next step for policy makers would be to evaluate the most cost-effective way to improve adoption. For instance, although social capital was not the most powerful capital that determines adoption, investing in factors which enhance social capital, such as extension services or agricultural associations, can provide a cost-effectiveness ratio in terms of adoption improvement which is much lower than investing in infrastructure. The negative correlation between natural capital and some agricultural practices suggests that climate will also play an important role on the probability of adoption. Hence, increasing volatility and warming within these regions could entrench resistance to these practices in the short-term.

The predicted probabilities show that the distribution of the likelihood of adoption can vary among farm-households in Sub-Saharan Africa. This finding seems reasonable as this study assesses farm-level adoption in nine different countries with different natural conditions and socio-economic contexts. The distribution of the probabilities seems to depict that it is very likely that a large number of farm-households in Sub-Saharan Africa will not adopt any of these agricultural practices in the coming years. Thus policy makers need to develop effective programs and policies to really achieve adoption of agricultural practices with mitigation benefits in Sub-Saharan livestock systems. Our results align with those of Herrero et al. (2010), who claims that policies targeting adoption of climate change actions among smallholder farmers should invest in intensive production by carefully manage inputs of fertilizer, water, and feed to minimize waste and environmental impact, supported by improved access to markets, new varieties, and technologies.

Improving grassland management through introducing or increasing the use of legumes (*Legumes*) seems to be the mitigation practice most likely to be implemented in Sub-Saharan Africa. Notably, the estimated probability of adoption can also be used to roughly estimate the cost-effectiveness of a policy with the purpose of improving adoption, as higher levels of predicted uptake will generate economic benefits relative to similar costs of adopting these technologies. Thus the results of this study suggests that investing in the introduction or increase of the use of legumes can be the straightforward way to reduce greenhouse gas emissions in Sub-Saharan livestock systems. Accordingly, it is noteworthy to highlight that a combination of the approach of this study with marginal abatement cost curves (MACCs) of each agricultural practice should provide estimates which are much more accurate than MAC curves themselves, which assume 100% adoption.

This study has evaluated potential for adoption of five mitigation practices in Sub-Saharan livestock systems and implemented a methodological approach to assess adoption across rural communities. This approach is useful for assessing the potential for adoption of agricultural practices that are not currently being implemented or because of lack of data, adoption cannot be estimated directly through other approaches. Finally, since the results were based on farm-level adoption they can be used to predict future adoption of innovative agricultural practices as well as to refine adoption estimates calculated through optimising modelling approaches. Thus the results can represent a first step to more accurately estimate potential for mitigation of greenhouse gas emissions in Sub-Saharan livestock systems.

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Figure

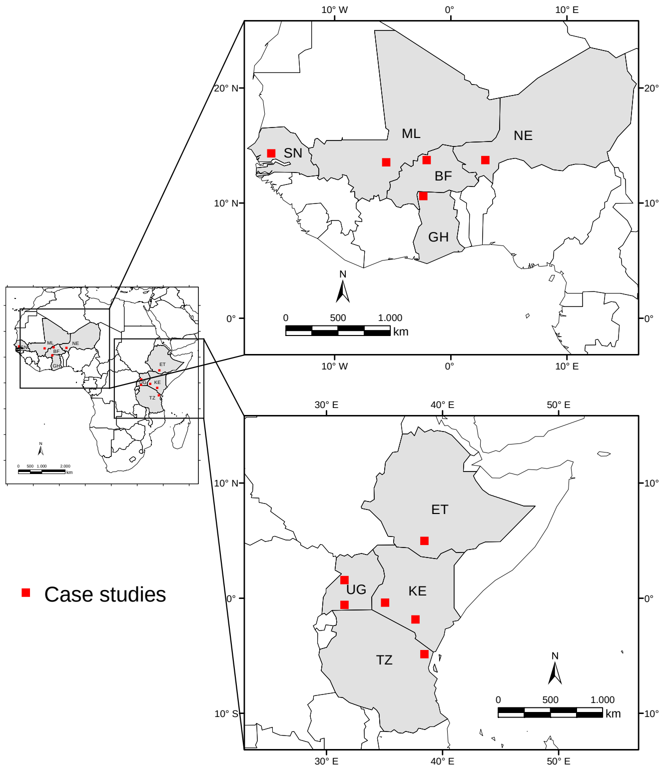

Figure 1. Location of the case studies of CCAFS survey.

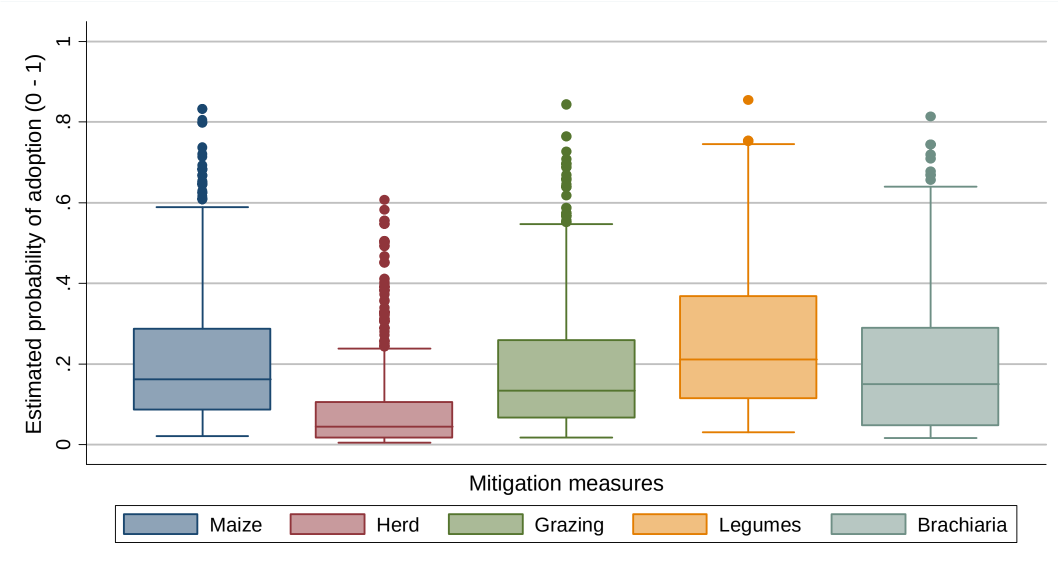

Figure 2. Estimated probability of adoption of the agricultural practices for the livestock sector in Sub-Saharan Africa. Middle horizontal lines within each box indicate the median, boxes extend from the 25th to 75th percentile and vertical lines extend from 5th to 95th percentile of estimations.

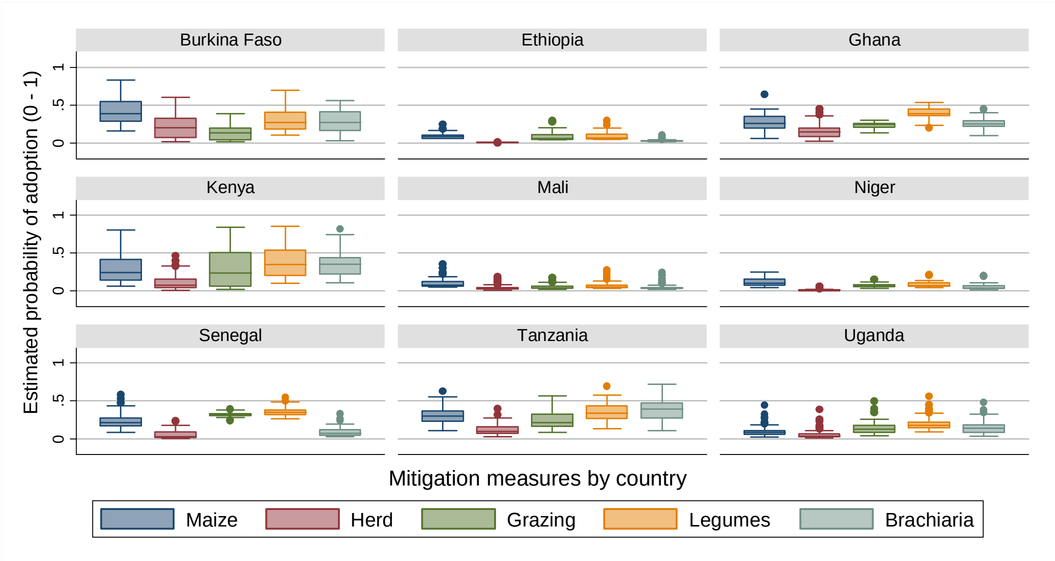

Figure 3. Estimated probability of adoption of the agricultural practices for the livestock sector in the case studies of CCAFS survey. Middle horizontal lines within each box indicate the median, boxes extend from the 25th to 75th percentile and vertical lines extend from 5th to 95th percentile of estimations.

Table 1. Selected proxies of the studied mitigation practices in Sub-Saharan livestock sector

Agricultural practices with mitigation and production benefits	Selected proxies	Mean	Std. Dev.
Maize: Improved feed quality ('processing crop residues and adding maize to the ration)	Improving fodder storage (e.g. hay, silage)	0.30	0.46
	Growing fodder crops	0.12	0.33
	Introduced mechanized farming	0.09	0.28
	Planting pre-treated/improved seed	0.33	0.47
Herd: Improved animal husbandry and health (improve fertility, reduce mortality rate)	Stall keeping introduced	0.08	0.27
	Fencing introduced	0.10	0.30
	Introduced mechanized farming	0.09	0.28
Grazing: Improved grassland management ('improved grazing management')	Improved pastures	0.07	0.25
	Introduced rotations	0.37	0.48
	Introduced micro-catchments	0.11	0.31
Legumes: Improved grassland management ('increase legumes in grasslands')	Improved pastures	0.07	0.25
	Introduced rotations	0.37	0.48
	Planting pre-treated/improved seed	0.33	0.47
Brachiaria: Improved grassland management ('introduce Brachiaria')	Improved pastures	0.07	0.25
	Planting pre-treated/improved seed	0.33	0.47

Table 2. Selected proxies of the five kinds of capital used to assess the adoption of agricultural practices in Sub-Saharan Africa

Capital	Proxies of capital	Units and Scale	Mean	Std. Dev.	Min	Max
Physical	Owned acreage	Hectares	7.09	15.50	0	300
	Large owned livestock	1 = Yes, 0 = Otherwise	0.56	0.50	0	1
	Having mechanical plough	Ditto	0.23	0.42	0	1
	Average of having electronic assets in the household (e.g. TV, radio, phone, Internet, computer)	Ditto	0.29	0.17	0	1
	Average of irrigation systems	Ditto	0.06	0.12	0	0.67
	Average of household structures (e.g. crop storage facility, concrete and bricks, tap water, etc.)	Ditto	0.18	0.18	0	1
	Inputs used (fertilizer, pesticides, herbicides, certified seeds)	Ditto	0.42	0.35	0	1
Social	Membership in an agricultural group	Ditto	0.32	0.47	0	1
	Access to information about climate extreme events (drought, floods, etc.)	Ditto	0.58	0.50	0	3
	Gender of the household headed	1 = Female headed, 0 = Otherwise	0.16	0.37	0	1
	Ability to use weather forecast 2-3 days	1 = Yes, 0 = Otherwise	0.16	0.37	0	1
	Ability to use information about rain forecast	Ditto	0.41	0.49	0	1
	Ability to use weather forecast 2-3 months	Ditto	0.23	0.42	0	1
	Ability to use information about climate extreme events (drought, floods, etc.)	Ditto	0.34	0.47	0	1
Financial	Having a bank account	Ditto	0.09	0.29	0	1
	Access to credit/loan	Ditto	0.13	0.34	0	1
	Receiving remittances	Ditto	0.32	0.47	0	1
	Receiving off-farm paid employment	Ditto	0.19	0.39	0	1
	Receiving cash from fruits	Ditto	0.26	0.44	0	1
	Receiving cash from vegetables	Ditto	0.24	0.43	0	1
	Receiving cash from wood	Ditto	0.08	0.28	0	1
Human	Education	0 = No formal education, 1 = Primary, 2 = Secondary, 3 = Post Secondary	1.23	0.79	0	3
	Household size (number of people)	1 = Yes, 0 = Otherwise	9.12	7.70	1	85
	Changes adopted because less rainfall	Ditto	0.61	0.49	0	1
	Changes adopted because more droughts	Ditto	0.53	0.50	0	1
	Changes adopted because later start of rains	Ditto	0.54	0.50	0	1
Natural	Annual precipitation	Millimeters	851.7	315.3	438	1384
	Difference between annual precipitation and evapotranspiration	Millimeters	-903.3	494.2	-1962	-216
	Length of growing period	Days	113.6	56.9	50	210

Table 3. Estimated coefficients of mixed logistic regressions assessing adoption of the agricultural practices.

	Fencing introduced	Fodder storage (e.g. hay, silage)	Growing fodder crops	Improved pastures	Introduced mechanized farming	Introduced micro-catchments	Introduced rotations	Planting pre-treated/improved seed	Stall keeping introduced
Human	1.01***	1.07***	0.69***	0.23	1.61***	0.69*	0.80***	1.03***	0.33
Natural	-0.39	-2.62***	0.89*	-0.32	-0.60	0.61	-0.44	1.60***	2.79***
Physical	1.31***	0.87***	0.98***	0.77**	1.07***	0.51	0.58**	1.01***	1.41***
Social	0.40*	0.37**	0.58***	0.11	-0.33	0.84***	0.41**	0.47***	0.96***
Financial	0.52	0.61**	1.19***	0.83**	1.22***	0.28	0.22	0.85***	0.88***
Constant	-3.80***	-0.96***	-4.08***	-3.46***	-5.58***	-5.74***	-1.10***	-2.86***	-5.94***
Random-effects Parameters									
Estimate	1.47	1.28	1.64	1.23	2.58	2.99	1.72	1.61	1.39
Std. Error	0.22	0.16	0.23	0.21	0.41	0.46	0.18	0.19	0.26
Number of obs.	1538	1538	1538	1538	1538	1538	1538	1538	1538
Number of groups	80	80	80	80	80	80	80	80	80
Log likelihood	-400.5	-719.3	-457.4	-340.9	-292.0	-328.5	-788.8	-727.1	-308.6
Wald $chi^2(5)$	48.4***	94.1***	54.4***	17.1***	35.6***	23.6***	33.7***	77.2***	60.6***
$Chibar^2(01)$	106.5***	153.7***	153.2***	45.0***	211.7***	264.1***	358.8***	273.5***	57.3***

* = p<0.1; ** = p<0.05; *** = p<0.01.