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REVIEW ARTICLE

Agricultural households' adaptation to weather shocks in Sub-Saharan Africa: implications for land-use change and deforestation

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Abstract
Agriculture in Sub-Saharan Africa is regularly threatened by the occurrence of weather shocks. We wonder whether the way farmers respond to shocks can affect land use and induce deforestation. Reviewing the existing literature, we found that this question has only been marginally studied. Drawing from the adaptation and land-use change literatures, we then expose the mechanisms through which weather shocks can push farmers to induce land-use change, or conversely to foster conservation. As farmers cope with shocks, their responses can cause degradations in ecosystems which could, in the long term, encourage deforestation and land-use change. To prepare for the next growing season, or adapt to climate variability and risk in the longer term, farmers also make structural adjustments in their farm and land-use decisions, which may lead to changes in land holding. They also resort to adaptation strategies that can indirectly affect land-use decisions by affecting households' resources (labor, income).

Keywords: adaptation; agriculture; coping; deforestation; land use; weather shocks

JEL classification: Q15; Q24; Q54; Q57; R14

1. Introduction

Climate in Sub-Saharan Africa is highly variable both across space and time, with a variability across different timescales: multi-decadal, decadal, inter-annual and intra-annual (Hulme *et al*., 2005). Extreme weather events such as droughts, floods and storms regularly threaten the region. Additionally, inter-annual and intra-seasonal variations in temperatures and rainfall amounts and patterns can translate into a delayed or premature onset, or a shortening of the rainy season, and into an erratic distribution of rainfall within the season. These weather shocks can range from short events to prolonged episodes lasting several years. With over 95 per cent of total cropland being rainfed (International Water Management Institute, 2010), African agriculture is heavily dependent on weather conditions. As a consequence, agriculture and agricultural-based livelihoods are regularly suffering from the occurrence of weather shocks induced by climate variability (Rosenzweig *et al*., 2001; Haile, 2005; Kotir, 2011; Thornton and Cramer, 2012; Guan *et al*., 2015). Effects on crops can range from a yield decrease to the destruction of crops and lands, as well as of infrastructures necessary to agriculture (Rosenzweig *et al*., 2001; Lobell *et al*., 2011; van Asten *et al*., 2011; Blanc, 2012; Thornton and Cramer, 2012; Mbilinyi *et al*., 2013; Fitchett and Grab, 2014; Guan *et al*., 2015). Livestock rearing can similarly be severely affected, with an increased mortality, decreased productivity and reproduction, and an increased vulnerability to diseases (National Research Council, 1981; Herrero *et al*., 2009; Thornton and Cramer, 2012).

More broadly, and in the longer term, weather shocks can affect natural resources and ecosystem services essential to agriculture, inducing erosion, a loss of soil moisture, the propagation of pests and crop diseases or pollination issues. For agricultural production, effects on these overall components can be largely detrimental (Rosenzweig *et al*., 2001; Thornton and Cramer, 2012). The severity and extent of the impacts will depend on the type of crop and livestock, the shock type and on the timing of occurrence of the shock within the growing season. The impacts of shocks on agriculture may reverberate on markets and food prices, as lower yields tend to lead to an increase in the prices of agricultural products (Jodha, 1978; Roncoli *et al*., 2001; Araujo Bonjean and Simonet, 2016). Hence, as a consequence of weather shocks, agricultural households' income, food security and even health may be affected (Haile, 2005; Kotir, 2011; Thornton and Cramer, 2012; IPCC, 2014; Gautier *et al*., 2016; Noack *et al*., 2019). Because of its low adaptive capacity constrained by widespread poverty and its dependence on natural resources, ecosystems and agriculture, Sub-Saharan Africa is particularly vulnerable to such shocks (Sokona and Denton, 2001; Somorin, 2010; IPCC, 2014). Indeed, over 70 per cent of Sub-Saharan Africa's population live in rural areas and around 85 per cent depend on rainfed agriculture and agriculture-based rural activities for their livelihoods (Shah *et al*., 2008).

Many studies have shown that farmers in the region are aware of climate risks, and implementing diverse adaptation strategies (in anticipation) and coping practices (ex-post) to deal with shocks and try to maintain their production, livelihoods and get through the crisis. (Corbett, 1988; Dercon, 2002; Maddison, 2007; Thomas *et al*., 2007; Dinar *et al*., 2008; Mertz *et al*., 2009; Bezabih and Sarr, 2012; Silvestri *et al*., 2012; Bryan *et al*., 2013; Kosmowski *et al*., 2016; Elum *et al*., 2017). These practices may be temporary or permanent, agricultural (e.g., expanding farms, replanting, managing soils) or not (e.g., selling assets, diversifying activities).

In parallel, agriculture and farmers' livelihoods have been shown to be important drivers of land-use change and deforestation in Sub-Saharan Africa. Land-use change can be understood as the transition (total or partial) from one utilization of a land to another, for instance natural to agricultural or urban use. Deforestation is one form of land-use and land-cover change. Agriculture, in the form of agricultural expansion, has been shown to be one of the main direct drivers of land-use change and deforestation in Sub-Saharan Africa (Angelsen and Kaimowitz, 1999; Geist and Lambin, 2001; Curtis *et al*., 2018). Furthermore, through practices such as fuelwood extraction, charcoal making and other natural product harvesting, farmers and rural livelihoods contribute to ecosystem degradation and deforestation (Geist and Lambin, 2001; Robledo *et al*., 2012).

Hence, agricultural livelihoods are one of the main direct causes of land-use change in Sub-Saharan Africa, while at the same time farmers are threatened by recurrent weather shocks, pushing them to react and adapt. This raises the question of whether, and how, agricultural households' adaptation and responses to weather shocks affect land-use decisions, and consequently the current land-use change dynamics. In other words, do weather shocks encourage agricultural expansion and deforestation or, conversely, foster conservation and spare land?

The effects of weather shock adaptation on land-use change seem to have only been marginally studied in Sub-Saharan Africa, and in developing countries more broadly. Understanding these effects is, however, critical. Indeed, the conversion and degradation of natural ecosystems such as forests induced by land-use change are responsible for emitting important amounts of greenhouse gases, and cause the destruction of carbon sinks that are essential to mitigate climate change. The impacts on biodiversity and many other ecosystem services such as runoff control or soil quality are not negligible either (IPCC, 2019). These ecosystems are also essential to the livelihoods of a large part of the population in Sub-Saharan Africa (Angelsen *et al*., 2014; Wunder *et al*., 2014, 2018; Noack *et al*., 2015). Additionally, in the context of climate change, weather conditions might become even more variable than they already are in Africa, and weather shocks could become more frequent and intense. Studies and observations of past climate data in Sub-Saharan Africa tend to show an increase in climate variability in the last decades, and some project an increased variability in the 21st century (Usman and Reason, 2004; Cook and Vizy, 2006; Kotir, 2011; IPCC, 2014; Panthou *et al*., 2014). The effects of weather shocks on land use could thus be amplified in the future. Moreover, if it turns out that weather shocks lead to an increase in land-use change, the feedback effects, through a change in the albedo, may further contribute to climate change and fuel a vicious cycle. Hence, understanding how weather shocks – through adaptation and farmers' responses – affect land use, is crucial.

Therefore, the purpose of this article is threefold: (i) to examine the literatures on adaptation and land-use change in order to expose what is known of the effects of farmer adaptation and responses to weather shocks on land-use change in Sub-Saharan Africa, (ii) to study the economic mechanisms leading from a shock to a change in land use, and finally, (iii) to identify questions for future research on this topic. In this paper, we focus on adaptation at the household level in reaction to climate variability and the occurrence of weather shocks, and on the impact on land use. We do not address adaptation to climate change more broadly, and we focus on the household level, and do not explore what happens at a larger scale (e.g., macro-scale effects involving markets).

The rest of the paper is structured as follows. Section 2 reviews the literature having explicitly studied the effects of weather shocks on land use in Sub-Saharan Africa, and in developing countries more generally, to get some additional insights. In section 3, we connect the literature focusing on land-use change drivers with the literature studying weather shock impacts and farmers' adaptations and reactions. Our goal is to expose the economic mechanisms through which weather shocks can affect land use in Sub-Saharan Africa, both in the short and long term. This allows us to identify future research questions. Finally, section 4 concludes.

2. Literature connecting weather shocks, adaptation and effects on land use

In this section, we conduct a review of publications that have explicitly connected farmers' coping and adaptation strategies to weather shocks with land-use change, with a focus on Sub-Saharan Africa. We also review papers studying this question in developing countries more broadly as it may give interesting insights on how weather shocks and land use are connected in our region of interest.

Only a few studies have identified climate variability, and more specifically weather shocks, as an underlying force causing land-use change. Yet, because such variability and shocks affect agricultural production, it is also likely to influence farmers' land-use decisions. In this regard, interesting papers on Sub-Saharan Africa are those of Reid *et al.* (2000), Tsegaye *et al.* (2010), Biazin and Sterk (2013) and Kindu *et al.* (2015), that use remote sensing techniques to identify land-use change dynamics in different regions of Ethiopia over the past decades, as well as socioeconomic and historical data and interviews to pinpoint the direct and underlying drivers of those dynamics. Along with other factors such as land reforms and demographic dynamics, rainfall variability and recurring droughts were perceived to have played a part in farmers' decisions to settle down and start with mixed-farming systems. Indeed, Biazin and Sterk (2013) show that mixed-farming systems are less vulnerable to dry spells than pastoralism. This sedentarization of a large part of the pastoral population and their transition from pastoral to mixed-farming systems account for a significant proportion of the observed land-use changes in the region (shift from woodland and grassland to cultivated land). In Kenya, Campbell *et al.* (2005) found a similar land-use change pattern.

Biazin and Sterk (2013) also observed that the land conversion rate in the Rift Valley of Ethiopia in the last decade was slower than in other regions having more abundant rainfall or the possibility of irrigation. In these regions, the conversion to cropland did not slow down. The authors suggest that it could be explained by the fact that farmers in the Rift Valley (a drought-prone area) want to retain as much grazing land as possible to be able to continue with the mixed-farming system in the future, a system that allows them to be less vulnerable to dry spells. Again, this suggests that climate conditions and variability are considered by farmers when making long-term land-use decisions.

Additionally, the harvest, production and selling of fuelwood and charcoal was also perceived to be an important driver of land-use and land-cover changes in these studies. This activity is increasingly practiced during droughts as households look for additional sources of revenue in times of crisis. In this sense, droughts can indirectly contribute to land-use and land-cover changes.

Finally, these studies found that weather shocks can affect land use by inducing migration. The droughts that occurred in the 1970s and 1980s, in combination with other factors, triggered population movements, heavily-used land was abandoned, and farmers migrated to maintain their livelihoods. Southern parts of Ethiopia, in particular, welcomed a lot of migrants because land was available and rainfall quite reliable in this part of the country (Reid *et al.*, 2000). Such migrations triggered land-use changes in areas of destination, mainly because it led to agricultural expansion (Tsegaye *et al.*, 2010).

Overall, these four studies underline several channels through which climate variability and weather shock occurrence can impact land use: (i) it influences farmers' decisions in terms of farming systems, (ii) it pushes farmers to collect resources in natural ecosystems which can lead to degradation, and (iii) it pushes farmers to migrate, abandon land and establish themselves elsewhere, which can lead to new land clearing. However, the identification of the underlying forces explaining land-use change is mostly based on local populations' perceptions (interviews) in these studies. It seems that no statistical analysis has been conducted to correlate, and establish causality, between the observed land-use changes and the perceived drivers of these changes. Hence, these papers do not make it possible to quantify the extent of the role of weather shocks in causing the observed land-use changes.

Focusing on the determinants of farmers' land-use strategies in drought-prone areas such as the Sahelian region, Reenberg (1994), Reenberg and Paarup-Laursen (1997) and

Reenberg *et al*. (1998) also found that climate and rainfall parameters influence land use. To adapt to droughts in such areas, farmers relocate fields to better adapted soils (e.g., land with a better absorption capacity) and use spatial diversification. It is not uncommon for farmers to cultivate different types of land (with different soils and slopes for instance) to harvest only some and abandon the others if the amount and timing of rainfall are good in the end. These articles are rather descriptive, based on field observations, and do not investigate if such practices cause land-use changes, i.e., if they require land conversion, farm expansion, or cause degradation.

Roncoli *et al*. (2001), studying the coping practices of Burkinabe farmers in response to the drought of 1997, noted that some households had increased their cultivated area (notably in the lowlands) in 1998, while others had abandoned their lands. Some of the reasons cited for this decrease in farmland area were the poor performance of some fields in the 1997 drought year, and the loss of labor due to migration and the effects of drought on health. This study suggests that weather shocks influence farmers' decisions to expand or reduce agricultural areas in the short term (adjustment following a shock, before the next growing season), and that the availability of labor resources may play a role in this decision.

On this question, we found only two papers in the literature empirically studying whether farmers expand farmed areas following a weather shock. The results of Damania *et al*. (2017) suggest that dry shocks lead to an important expansion of cropland, whereas wet rainfall shocks are apparently not correlated with land-use change. This expansion would be explained by what the authors name the 'safety-first' response of farmers to shocks: when facing repeated years of difficult weather conditions and lower yields, farmers realize that yields in the coming years might continue to be depressed and thus decide to expand farmed areas as they have limited options to maintain production and income. When studying the relation between droughts and deforestation in Madagascar, Desbureaux and Damania (2018) found that droughts trigger an increase in deforestation due to agricultural expansion (+7.6 per cent country-wide compared to years of normal weather, and +14 per cent in areas with communities living nearby). However, while moderate droughts are correlated with an increase in deforestation, severe or consecutive droughts seem to have the opposite effect, reducing deforestation compared to years of normal weather. The authors suggest that this reverse effect could be explained by the risk-aversion behavior of farmers. As the risk becomes too high, farmers realize it, and choose to resort to different strategies rather than expand cultivated areas which would increase risk exposure. This hypothesis has not been tested by the authors, and other explanations are possible. After a period of severe, long or repeated shocks, households perhaps no longer have the resources necessary to expand farmland, which is a labor-intensive practice, due to the impact of weather shocks on the food security, health and work capacity of the household (Bailey *et al*., 1992; Wilkie *et al*., 1999; Roncoli *et al*., 2001). Moreover, the study of Desbureaux and Damania (2018) is centered on Madagascar where shifting agriculture is the dominant agricultural system, a system that has been pointed out as being an important source of deforestation. Hence, further research is needed to understand if similar processes take place in other regions with different environments and farming systems, and to better understand what conditions influence farmers to expand their land after a shock rather than to reduce it, and in particular the role of risk aversion and perception in the decision process.

Outside of Sub-Saharan Africa, one author stands out for having explicitly connected adaptation to climate variability with land-use change in two empirical studies focusing on protected areas in the Americas. Rodriguez-Solorzano (2014) investigates the impacts of some adaptation practices to climate variability on deforestation in Calakmul and Maya biosphere reserves in Mexico and Guatemala. It is found that diversification based on off-farm jobs or operating provision shops is a conservation-driving strategy, taking pressure off forests. Savings, based on cattle-ranching, is found to be a deforestation-driving practice. For the two other strategies studied, migration and pooling (a form of risk sharing used by households by working together as a productive group), no pattern arises. In a second article, this time focusing on internationally adjoining protected areas (IAPAs) in the Americas, Rodriguez-Solorzano (2016) shows that diversification and pooling have no statistically significant relationship with natural land conversion (defined as the conversion of land from natural ecosystems into crops, pastures or infrastructures). Out-migration, on the other hand, is positively correlated with an increase in natural land conversion. In these two articles, however, the mechanisms through which adaptation strategies lead to an increase (or a decrease) in land-use change are not investigated.

Lastly, Azadi *et al.* (2018) review the interactions between droughts and agricultural land conversion, defined as the conversion of agricultural land to an urban use. This paper is descriptive, and not quantitative, and it does not focus solely on Africa or developing countries. Nevertheless, it proposes interesting insights on how droughts might affect land use. The first pathway through which a drought impacts land-use change is because of its direct biophysical effects on lands, resources and ecosystems that affect the available agricultural surface and agricultural possibilities. The second pathway is through socioeconomic processes triggered by the impacts of droughts on yields, revenues, work load, job opportunities or health, and through the adaptation practices implemented. Households suffering from the consequences of droughts could abandon agriculture, convert farmland to other uses, and migrate temporarily or permanently. Practices such as diversification and looking for off-farm sources of income could also favor agricultural land conversion as they induce a shift away from agricultural activities. On the other hand, practices aiming at enhancing farm productivity and reducing climate risk (irrigation, rainwater management, agricultural diversification, improvement of soil quality, etc.) would discourage agricultural land conversion because the impacts of droughts on households' activities and income are reduced.

What comes out of this literature review is that weather shocks – because they affect agricultural production, food security and health – can affect land use, either because they directly influence farmers' land-use decisions (cropland expansion, change in farming system, relocation of fields) or because it pushes them to take action and implement practices with possible consequences for land use (collection of natural products in surrounding ecosystems, migration, diversification of activities). Weather shocks, depending on which adaptation and coping practices are implemented, can induce land conversion or discourage land-use change. However, the mechanisms through which these adaptation and coping practices affect land-use decisions are not always clear, and the effects on land use are sometimes ambiguous, as several overlapping mechanisms are at work. For instance, out-migration is associated both with increased and decreased land-use change, because of land abandonment due to population migration and decreased labor force (Reid *et al.*, 2000; Roncoli *et al.*, 2001; Rodriguez-Solorzano, 2014, 2016). In some cases, weather shocks push farmers to increase their farmed areas, and in others to reduce them (Roncoli *et al.*, 2001; Damania *et al.*, 2017; Desbureaux and Damania, 2018). The effect on land use is likely to depend on some contextual factors (socioeconomic, geographical, institutional) such as the level of risk, market integration and access, presence of forests and tenure systems, but these factors are rarely analyzed or mentioned in these studies.

Overall, only a few studies have explicitly connected weather shocks, farmers' adaptation and land-use change, whether we look in Sub-Saharan Africa or in developing countries more broadly. Many insights we have on how weather shocks may affect land use remain theoretical and have rarely been tested in Sub-Saharan Africa. From a methodological perspective, most of these studies are descriptive, and do not quantify the extent to which weather shocks can induce land-use change. More empirical studies are needed to confirm the effect of weather shocks on land use and deforestation. Theoretical approaches and models could also be helpful to explain farmers' behavior in reaction to weather shocks and possible effects of shocks on land use.

In the following section, we build on the above literature review, and draw from both the land-use change literature and the literature on farmers' adaptation to explore the mechanisms through which weather shocks can impact land use in the short and long term. We summarize what is known and not known about this question. We also discuss the effects of a few contextual factors that we think play an important role in determining the effects of farmers' adaptation and strategies on land use: the level of risk, market access and integration, and the proximity to forests and woodlands. This allows us to identify questions for future research.

3. From weather shocks to land-use changes through agricultural adaptation: what are the underlying mechanisms?

There is a vast literature investigating the strategies and practices used by agricultural households in Sub-Saharan Africa to adapt to climate variability and cope with weather shocks (Corbett, 1988; Dercon, 2002; Dinar *et al.*, 2008). The purpose of this section is not to review all these strategies, but to focus on those that may induce land-use changes and on the underlying mechanisms. Note that we have summarized the main practices mobilized by farmers when facing climate variability and weather shock impacts in online appendix A.

One distinction that appears clearly in the literature and that is relevant to our discussion is the one between anticipatory (ex-ante) adaptation strategies, and ex-post coping practices. Coping practices are used by households following or during a shock to deal with the consequences of the event, maintain their production, and survive. Looking for off-farm work, selling assets for seasonal consumption smoothing or collecting natural products in forests for consumption or trade are some examples of common coping practices (Corbett, 1988; Dercon, 2002; Kazianga and Udry, 2006; Dillon *et al.*, 2011; Silvestri *et al.*, 2012; Noack *et al.*, 2019). These practices are most often short term and temporary but may, in extreme cases, last or become permanent. Anticipatory adaptations[1] are not implemented in reaction to a specific shock, but rather to deal with the

[1]The use of the term 'adaptation' may seem inappropriate here, in the sense that adaptation is usually used in response to a situation that is changing (for instance, adaptation to climate change – a change in the climate trend) and many of the practices studied here are not solely implemented in response to weather events, but to deal with the many risks and shocks that households in Sub-Saharan Africa face. Such practices may thus be a part of their usual livelihood strategy. The distinction between adaptation strategies and strategies used to deal with risk is not always clear in the literature. However, considering that climate change is likely to affect climate variability, and thus the severity and frequency of occurrence of weather shocks,

risk induced by climate variability, prepare and protect for the possible occurrence of a weather shock and its consequences. They are thus most often a planned strategy, used in the long run. Such strategies can for instance aim at diversifying sources of livelihood to smooth income fluctuations ex-ante and thereby reduce the household's exposure and sensitivity to risk, for example reducing its dependence on agricultural income (Dercon, 2002; Ellis, 2008). Other strategies seek to prepare for the occurrence of shocks and limit potential impacts on the household through ex-post income or consumption smoothing (Alderman and Paxson, 1994; Dercon, 2002). Households can for instance build buffer stocks ex-ante that can be depleted in difficult times, for example by acquiring assets. The timescale of implementation of coping and adaptation practices is different and, consequently, so is the timing of the effect on land use: in the short term following a shock, or in the longer term.

What we mean here by 'short term' is the period following a weather shock during which household decisional factors are rigid, and production structures fixed, thereby limiting the capacity of households to react. It is thus closely related to the concept of coping. In the long term, households can adapt, make changes and investments in their production systems and activities. However, this distinction is not always clear in practice: some adaptation strategies, such as converting and planting new fields following a bad rainy season to insure next season's harvest, may be implemented in the months following a shock (i.e., in the short term). There is thus not a perfect overlap between coping and short term, and adaptation and long term. In this section, we will discuss this double distinction and try to disentangle how farmers' coping and adaptation strategies may affect land use in the short and long term.

The structure of this section is as follows. First, we expose how coping practices can affect land use in the short term after the occurrence of a shock. Second, we discuss how farmers can decide to make structural changes to their land-use decisions, through changes in farm size, farming systems and activities, both in the short and long term. Third, we show that long-term adaptations of farmers can also have important consequences on land use. In particular, some strategies can indirectly affect land-use decisions because of their effects on households' key resources such as labor and income.

3.1 In the short term, what effect does coping with a shock have on land use?

Farmers use diverse coping strategies during or in the aftermath of a shock to maintain their production, livelihoods, and subsistence. Some coping practices could induce land-use changes through several mechanisms:

(i) *Coping with a weather shock can induce environmental degradations and temporary land-use changes in the short term, and possibly permanent land-use changes in the longer term.* If their production or fields were damaged by a flood, storm or drought-induced fire, and if it happened early enough in the growing season, some farmers might look for alternative agricultural land to replant (Osbahr *et al.*, 2008). Herders might practice herd mobility to address difficult weather conditions and access other feed and water sources (Ifejika Speranza, 2010; Tibbo and van de Steeg, 2013; Mapfumo *et al.*, 2014; Gautier *et al.*, 2016). They might also relocate livestock to graze elsewhere, for instance on common pool resources

we have decided to use the term 'adaptation' to refer to strategies implemented ex-ante to deal with climate variability, including strategies that are commonly used by households to deal with other risks.

or government property despite regulations. These practices could cause temporary land-use changes, which might be the first step toward more permanent land-use changes, for instance if climate variability increases, shocks occur more frequently, and these practices are more often resorted to. It can also lead to degradations in ecosystems.

Additionally, it has been reported that farmers look for alternative income and food sources following a weather shock. To this end, they often collect natural products (food, forage, fuelwood, etc.) in surrounding ecosystems to consume, sell or trade (Corbett, 1988; Angelsen and Wunder, 2003; Woittiez *et al*., 2013; Gautier *et al*., 2016). Noack *et al*. (2019) for instance found that if crop income is reduced following a drought, this fall is partially offset by an increase in income from forest extractions. Depending on the nature, frequency and intensity of the harvest, and the type of items being collected, harvests could lead to the deterioration of natural ecosystems in the short term (cutting or damaging of trees and plants) and in the longer term (change in ecosystem composition, disappearance of species) (Peters, 1994; Tsegaye *et al*., 2010; Robledo *et al*., 2012; Biazin and Sterk, 2013; Antwi-Agyei *et al*., 2018). If many people in a community collect natural products to cope with a shock, or if shocks occur (more) frequently, it might lead to the overexploitation and to a significant degradation of surrounding ecosystems, thereby endangering the future coping capabilities of farmers, and preventing natural regeneration (Delacote, 2009). Once natural ecosystems, and forests in particular, are degraded and depleted of their resources, thereby losing value for the local population, there might be fewer incentives to conserve rather than convert such ecosystems to other land uses. Degradation may reduce the perceived land value by agricultural households, which can indirectly incentivize land-use changes. In the longer term, the degradation of the natural ecosystem related to resource overharvesting could thus encourage deforestation. However, the effect of natural product harvesting on land use will depend on the location of the harvest. The dynamics may be a bit different if harvesting occurs on fallow lands, farm bushes or agroforests. Further research is needed to understand whether such degradations in the short term can encourage land-use change and deforestation in the longer term. Indeed, some work has been done to analyze the harvesting decision of forest products (Robinson *et al*., 2002, 2013; Albers and Robinson, 2013), but the dynamic link between forest degradation and deforestation has, to our knowledge, been overlooked by the literature so far.

(ii) *Coping with a weather shock can induce land-use change indirectly, by affecting labor availability in the short term.* Common coping practices involve looking for off-farm work and alternative income sources, which can involve temporary migration of some household members, as well as collecting natural products in surrounding areas (foods, materials, etc.) for consumption or trade. Labor resources are thus reallocated away from agriculture. If labor resources are reallocated to land-sparing activities (off-farm work, handicraft, etc.), this coping strategy is likely to decrease the pressure on land, at least in the short term. The results of Noack *et al*. (2019) mentioned earlier (e.g., the fall in crop income following a drought is partially offset by an increase in forest income) suggest that labor resources are reallocated from agricultural activities to forest extraction activities. This activity is not land-intensive. It can, however, as mentioned previously, lead to the degradation of forests. Overall, households' integration in labor markets is a key parameter here. If the only labor used on the household's fields is that of the household itself, and if the coping strategy consists of land-saving activities (e.g., off-farm work or non timber forest product harvesting), then this coping strategy is likely to decrease the pressure on forests, because of a labor transfer from one activity to another (Delacote and Angelsen, 2015). However, this mechanism is less likely when households hire part of the labor allocated to the agricultural activity.

(iii) *Coping with a weather shock can induce land-use change by directly involving a change in land use triggered by a migration.* Households can decide to migrate and relocate in another region permanently to look for land or work opportunities elsewhere and to survive. This is however reported to be a solution of last resort, if the weather shock that occurs is particularly severe or lasting, or if shocks occur frequently, and there is no other option (Corbett, 1988). As a result, land-use change can occur in both the area of origin (farm abandonment) and of destination (conversion of land to establish a new farm, contribution to the process of urbanization in the case of rural-urban migration) (Reid *et al.*, 2000; Tsegaye *et al.*, 2010). Displacement of deforestation and land-use change may be observed here.

3.2 In the short and long term: land-used based adaptation strategies

To adapt to climate variability, because for instance farmers notice an increase in the severity or frequency of shocks, they may decide to make structural changes in land use and farm activities: adjusting farm size, field locations and spatial diversification, intensification practices, farming system and activities. Such changes could occur in the short term following a shock to prepare for the next season, but also in the longer term as part of a broader adaptation or preparation strategy. Indeed, farmers may want to compensate for the effects of weather shocks on their production as they realize that their yields might continue to be depressed in the coming years, or that the risk associated with climate variability is increasing, and implement strategies to prepare for future shocks and limit the consequences. Moreover some long-term effects of shocks, such as land degradation and loss of ecosystem services, translate into agricultural losses later in time. It may thus take some time for farmers to observe and adapt their practices to these delayed effects.

Hence, the decrease in agricultural production induced by a weather shock may push farmers to relocate fields to better adapted or more productive plots (Reenberg, 1994; Reenberg and Paarup-Laursen, 1997). Farmers could also expand farmed areas, with the idea of maintaining a certain production and income level. Such adaptation strategies may require converting new plots of land for agriculture. Roncoli *et al.* (2001), Damania *et al.* (2017) and Desbureaux and Damania (2018) found that some farmers have increased cultivated areas following droughts, which can result in an increase in deforestation.

As part of their adaptation strategies, some farmers may also decide to resort to intensification practices to boost yields and production (Paavola, 2008; Bozzola *et al.*, 2016; Ngoma *et al.*, 2018). It is uncertain whether an increase in yield leads to a decrease or an increase in farm areas. On the one side, the Borlaug hypothesis, or subsistence hypothesis (Angelsen and Kaimowitz, 2001), suggests that if farmers manage to produce more with the amount of land they already have, there is no reason for them to increase landholding. On the other side, the Jevons hypothesis (also called the Jevons paradox) implies that an increase in the efficiency with which a resource is used leads to an increase in the use or consumption of the resource itself. If this thesis holds, intensification could lead to agricultural expansion as yields and farm profitability are improved. Moreover, if the intensification process frees labor resources, it could further stimulate production and consequently expansion. Numerous factors will determine which of these two outcomes is true, for instance, a household's labor and capital resources, its degree of integration into markets, the type of intensification practice or technology that is used and whether it is labor-intensive or -saving, and the scale of adoption of the intensification process (Angelsen and Kaimowitz, 2001; Ngoma *et al*., 2018). If many farmers in an area resort to intensification, it could lead to an increase in supply and a decrease in prices in consequence (depending on demand elasticity), and this could discourage further expansion of farmland (Ewers *et al*., 2009; Rudel *et al*., 2009). Research work at a local scale in Sub-Saharan Africa would be useful to understand the effects of intensification as a response to climate risks on land use and the influence of contextual factors.

Apart from expansion or intensification strategies, farming households can adapt to climate risks by making changes in their portfolio of farm activities, sometimes for diversification purposes. Some decide to quit (or reduce) either crop or livestock activities, which may result in land abandonment, and then nature regrowth or conversion to another land use. Others choose to transition from crop- or livestock-only exploitations to mixed crop-livestock systems. Depending on whether there is addition or substitution of crop and livestock activities, and if more space is needed for grazing for instance, this transformation could lead to land-use change. In some regions where pastoralism is the dominant farming system, such a transition could induce a process of sedentarization, with very likely effects on land use, as observed in Ethiopia by Tsegaye *et al*. (2010) and Biazin and Sterk (2013) following severe droughts in the 1970s and 1980s.

Some farmers also use agroforestry because it can be beneficial to adapt to climate variability as it can protect crops, enhance soil structure and fertility, and provide food, wood and other resources. It can also be a way to diversify production (Gautier *et al*., 2016; Partey *et al*., 2018). Thanks to the ecosystem services it provides, the plantation of trees on farms can boost agricultural yields, and thus constitute a form of intensification which, as described above, has ambiguous effects on land use. In addition, agroforestry trees can be used for the collection of fruits, wood, fodder and other products. Hence, agroforestry could alleviate pressure on forests through reduced harvests of natural products in nearby ecosystems, thereby fostering conservation. The positive effects of agroforestry on forests are even more important when it is implemented close to the forest margins (Minang *et al*., 2011).

Farmers also use spatial diversification to manage climate risks, as a form of insurance (Tibbo and van de Steeg, 2013; Veljanoska, 2018). For instance, they spread fields in different places and take advantage of landscape diversity to use lands with different slopes, soils or vegetation. Some split their herds in several sites as well. It is not uncommon for farmers to cultivate different types of land and to harvest only some and abandon the others if rainfall amounts and timing are good in the end (Reenberg and Paarup-Laursen, 1997). These practices could thus require cultivating or using more land, and lead to land conversion or degradation. More generally, the relocation of fields or even of the whole farm in search of land less exposed or better adapted to adverse climatic conditions can lead farmers to abandon some lands and convert new plots. The extent to which these practices can lead to degradation and land conversion is not known.

Several factors may influence the decision of a household to implement the land-use-based strategies described above, and consequently the effect on land use. They are:

(i) *Labor availability.* Weather shocks affect food security and thus health and work capacity (Bailey *et al.*, 1992; Wilkie *et al.*, 1999). Indirectly, they also affect labor availability because shocks can induce a reallocation of labor away from agriculture in the search of alternative income and food sources, and can push some household members to migrate to look for a job, or to alleviate pressure on the household's food needs (Gray and Mueller, 2012; Delacote and Angelsen, 2015; Noack *et al.*, 2019). If these effects on labor occur at the same time as the decision to expand farmland, relocate fields, intensify or change agricultural activities, these actions might be constrained if they are labor intensive. In this case we would expect no land-use change or even a reduction in farm size and activities, as observed by Roncoli *et al.* (2001), because there is no longer enough labor to exploit the whole farm.

(ii) *The level of risk, determined by the frequency and severity of weather shocks, in relation to risk aversion.* Farmers in developing countries tend to be risk averse (Wik *et al.*, 2004; Yesuf and Bluffstone, 2009), and their land-use decisions are likely to be influenced by their risk preferences. Thus, when households perceive that risks related to weather events increase, they are likely to implement strategies to reduce their exposure to risk. For instance, some might decide to limit their exposure by reducing farm activities and farmed areas, and by switching to non-farm sources of income (not exposed to weather risk). Further, they might modify their portfolio of agricultural activities in order to reduce aggregate risk. If safer agricultural practices (i.e., the ones less impacted by weather shocks) are also the ones less (resp. more) land-intensive, then these adaptation practices are likely to decrease (resp. increase) land-use change and deforestation. In this regard, one future research question could be to study, theoretically and empirically, how the levels of risk, and risk aversion, affect the land-intensity of agricultural adaptation strategies.

(iii) *The integration of households into the market.* Farmers in Sub-Saharan Africa are often in near-subsistence systems, producing mainly for their own consumption. Additionally, households often lack access to credit, insurance and other financial services that could help them in times of crisis (Binswanger, 1986; Besley, 1995; Dercon, 1996). Such farmers, as well as those having few other income sources aside from agriculture, might have to make land-use changes (e.g., farmland expansion or intensification) to maintain a certain level of production and their livelihoods. Households more integrated into markets and less dependent on agriculture for their livelihoods have more options to mitigate the decrease in farm production caused by weather shocks. In this case, increasing farm area or intensifying production may not be the best or most profitable option for those households, who may turn toward off-farm labor or credit markets to mitigate risk impacts. At the same time, prices of agricultural products tend to rise in times of crisis (Jodha, 1978; Araujo Bonjean and Simonet, 2016). Households more integrated into markets and less impacted by shocks may be incentivized to increase production to take advantage of future price increases. Hence, the degree of integration of households into markets can be an important element influencing households' land-use decisions in the context of weather shocks.

(iv) *Land availability and accessibility.* The availability of cultivable land, the right of access to land, and customary law as well as tenure systems are likely to be important factors making expansion of farmland possible or difficult. Questions of access to land and tenure systems are really complex in Sub-Saharan Africa, and beyond the scope of this paper, but may determine whether putting additional plots of land into farming is feasible in reality. This may explain, in part, why farmers in some regions expand farmland following a weather shock and why farmers in other areas do not.

3.3 In the long term: adaptations affecting land use

Beside land-use-based farm strategies (extensification, intensification, diversification and change in farming system and activities), which are direct land-use changes, other adaptation practices implemented in the long term may have an effect on land use. In particular, some strategies affect households' resources such as labor and income, and consequently influence the decisions of farmers related to land use.

When households diversify their income and food sources to mitigate risks**,** they engage in several occupations (if possible with low covariance in revenue) both on- and off-farm (Dercon, 2002). Some household members could migrate to look for opportunities elsewhere, either permanently or just seasonally, and send back some remittances to their family. For a given endowment in resources and production factors, less is available for farm activities. In particular, labor resources are divided among different activities or locations, and if the diversification process implies migration or labor-intensive activities, the workforce available for agriculture (especially labor-intensive activities such as expansion or field relocation) and the harvest of natural products will be reduced. Through this labor effect, it can thus take pressure off forests and natural ecosystems. Angelsen and Kaimowitz (1999), reviewing numerous economic models analyzing the causes of tropical deforestation, found that greater off-farm employment opportunities tend to reduce deforestation by competing with agricultural and forestry activities for labor at the household level. Moreover, households that diversify generate higher off-farm income and are thus less dependent on farm activities, less vulnerable to weather shocks, and do not need to produce as much, which reduces potential incentives to clear land. Araujo *et al.* (2014), focusing on Brazil and the Amazon, found that a higher off-farm income tends to reduce deforestation and suggest that this could be explained by an increase in the opportunity cost of farm activities. Rodriguez-Solorzano (2014) found that diversification based on off-farm jobs or operating provision shops was a conservation-driving strategy (as opposed to deforestation-driving) in reserves in Mexico and Guatemala.

Diversification, through the reallocation of production factors and resources away from agricultural activities, could thus alleviate pressure on land and forests. That being said, many farmers in Sub-Saharan Africa remain in near-subsistence systems and may decide to still allocate an important amount of time and labor to agricultural activities. Moreover, the income generated by off-farm activities, and in particular the remittances sent by emigrated household members, could be invested to make up for the loss of labor or allow farmers to engage in riskier activities and investments (e.g., expansion, intensification, high value crops, livestock acquisition) that are not neutral in terms of land use and have a priori ambiguous impacts (de Sherbinin *et al.*, 2008; Radel and Schmook, 2008; Greiner and Sakdapolrak, 2013; Romankiewicz *et al.*, 2016). This income, or remittances, can also allow households to be less dependent on agriculture, and decrease the need for agricultural production, thereby substituting for agriculture and reducing pressure on land and forests.

Hence, diversification of livelihoods seems to be associated with decreased pressure on land and forests. However, some ambiguity remains about whether migration and remittances reduce or increase expansion and pressure on land. In Central America, Davis and Lopez-Carr (2014) found that economic migration is positively correlated with an increase in land and pasture purchases. In Mexico, Ervin *et al.* (2020) found that forest cover change between 2001 and 2010 is positively associated with migration. Some underlying mechanisms mentioned are the undersupply of labor and the use of intensification practices. In El Salvador, remittances are associated with forest resurgence and a decrease in forest clearing (Hecht, 2010). In Nepal, migration and remittances would have a positive impact on forests, reducing deforestation (Oldekop *et al.*, 2018; Fox *et al.*, 2019). The effect of migration on land use is however likely to depend on the local context. The extent and local causes of migration, the farming structures and contexts, as well as the local drivers and dynamics of land-use change in South America (importance of cattle ranching and commercial crops) or in Nepal (poor forest governance, forest encroachment, illegal timber exploitation and trade) differ from those in Sub-Saharan Africa. Additionally, changes in labor allocation and activities induced by migration and remittances may differ in the context of weather shocks as some activities, especially in agriculture, are more subject to climate risks. Further research is needed to better identify the effects of migration and remittances on land use in the context of weather variability and shocks in Sub-Saharan Africa.

As part of their diversification strategy, many farmers in Sub-Saharan Africa (and in rural communities more generally) collect natural products in various ecosystems such as food, forage, construction materials, fuelwood and medicine. Those products can be used for consumption, barter or income. This practice is used by households in normal times to diversify their production and revenues. It may be increasingly resorted to in times of crisis, thus playing the role of safety-net (Pattanayak and Sills, 2001; Angelsen and Wunder, 2003; Sunderlin *et al.*, 2005; Liswanti *et al.*, 2011; Woittiez *et al.*, 2013; Noack *et al.*, 2019). As explained previously, this strategy of forest product extraction following a shock could lead to degradations in the short term. It could be assumed that households relying on natural product collection for their livelihoods value and want to protect and conserve the ecosystems in which they harvest, so they can continue using this strategy to diversify their income and food sources and to cope with shocks when necessary. Providing a theoretical perspective, Delacote (2007) describes how the use of non-timber forest products (NTFP) collection as a safety net against (not only climate) agricultural risk may impact deforestation. It is shown that an increase in agricultural risk, for instance an increase in weather shock occurrence, may decrease the pressure on forests, by increasing the value of the safety-net activity. Furthermore, some communities have designed rules, management and monitoring systems, sometimes with fines and sanctions, to restrict and preserve the access to and the use of common pool resources such as forests, thereby showing that local populations value ecosystem services (Ostrom, 1990; Agrawal, 1994; Libois, 2016). Hence, in the long term, households may be incentivized to protect and conserve these ecosystems. Yet, evidence of ecosystem degradation suggests that it is not because people can benefit from ecosystem services that they necessarily practice conservation. Moreover, as detailed previously, the collection of natural products (if extraction is too heavy or used at an unsustainable pace) may lead to severe deterioration of natural ecosystems such as woodlands, depending on the nature, frequency and intensity of the harvests, and the type of species being exploited. If the risk induced by climate variability becomes more important, rural households might rely more heavily on natural products for diversifying their revenues and building NTFP stocks for instance, which could lead to overexploitation. This loss of forest ecosystem services due to over-harvesting can lead to the decrease in the forest value as perceived by the local population, and can be considered as a first step toward deforestation. Overall, the safety-net use of natural product collection may have two opposite effects on land-use change: (i) more risk of weather shocks is an incentive for forest conservation; but (ii) more risk also means more harvesting and potential degradation which can be a first step toward deforestation.

Several factors may influence whether households resort a lot to this option and whether it causes degradation. First, households that are poorer and lack access to credit, insurance and financial services are more likely to collect natural products in woodlands. Indeed they have fewer alternative options to deal with risks, and collecting natural products to diversify activities and build buffer stocks represent an alternative form of insurance. More generally, households that have few other alternatives to smooth income and consumption and insure (livestock, children off-farm sending money) are more likely to resort to that option (Pattanayak and Sills, 2001). Second, households located closer to woodlands are more likely to collect products and use woodlands in their livelihood strategies (Hegde and Bull, 2008; Fisher *et al*., 2010). Third, the effect of natural product harvesting on land use depends on the location of the harvest (in forests or in already managed lands such as fallow lands or agroforests) and the way in which common pool resources are managed within the community.

Another important strategy that is worth mentioning because of its potential impact on land use is the acquisition of assets during favorable times (e.g., years of good harvests) to constitute buffer stocks that can be liquidated in the event of a shock (Corbett, 1988; Dercon, 2002). In Sub-Saharan Africa, livestock is often bought for such purposes. Yet livestock rearing has been identified as an important driver of land-use change and deforestation because it induces degradation and conversion of natural areas for feeding and grazing purposes (Geist and Lambin, 2001). This strategy could therefore induce land-use changes. Rodriguez-Solorzano (2014) investigates the impacts of some adaptation practices to climate variability on deforestation in Calakmul and Maya biosphere reserves in Mexico and Guatemala and finds out that savings, based on cattle-ranching, is a strategy that has encouraged deforestation. However, in places where weather shocks (and droughts in particular) are projected to become more frequent or intense, this strategy might be challenged as the livestock acquired as a buffer stock will be severely impacted and might not be able to play its role of insurance. The effect of this strategy on land use also depends on the type of livestock acquired (cattle or rather smallstock such as poultry, goat or sheep) as the surface required is likely to differ. The type of animals acquired varies depending upon location, financial resources, but also religion and cultural considerations. Once again, the extent to which asset stock building through livestock acquisition might induce land-use change has not been explored in Sub-Saharan Africa, to our knowledge.

Finally, diverse agricultural practices can be implemented in the long term to maintain yields and deal with some of the long-term impacts of weather shocks on agriculture, such as soil degradation. This includes water and soil conservation practices, changing or associating crop varieties, or agroforestry, to cite only a few practices (Bryan *et al*., 2009; Gautier *et al*., 2016; Yegbemey *et al*., 2017; Ngoma *et al*., 2018; Partey *et al*., 2018). Such practices help maintain resource and ecosystem quality, and agricultural performance. They can allow farmers to maintain or even increase production and income (Aker, 2017), especially if several practices are used in combination (Di Falco and Veronesi, 2013). They thus favor a durable use of already available and used lands. They also make farmers potentially less sensitive to future weather shocks, thus diminishing their future coping response, and resulting land-use changes. Hence, these sorts of agricultural adaptation practices are encouraging land conservation rather than land-use change.

3.4 The type, severity and timing of a shock will influence the impact on land use

The type, severity, intensity, duration, spatial extent and moment of occurrence of shocks influence the impacts on farmers and their decisions in terms of adaptation. Hence, it is likely to have different effects on land use. Indeed, different shocks have different impacts on agricultural activities, and thus call for different response strategies. Additionally, some shocks have slow onsets (e.g., droughts), and thus leave time for farmers to prepare and adjust, while other shocks are more sudden and unpredictable (e.g., floods). Depending on when the shock occurs within the season (beginning, middle, or close to harvest), farmers will have more or fewer possibilities to adjust. Following a flood in the beginning of the rainy season, farmers may look for alternative fields, and perhaps replant. During a drought in the middle of the growing season, such a response will not be possible. The spatial extent of a shock also conditions adaptation strategies based on land use: for instance, finding alternative fields or pastures, or relocating herds, will be more difficult in the case of a drought covering a large region.

Additionally, the severity, duration and frequency of occurrence of shocks influence farmers' responses. Indeed, research on weather shocks and coping practices suggests that agricultural households respond to shocks following a certain logic and sequence of actions. They try to satisfy immediate needs and address imminent threats without depleting their means of subsistence (mainly, their productive assets) to maintain their livelihoods. There exists a gradation of farmers' responses to shocks, and some practices (selling productive assets, migrating, reallocating production factors, selling farmland) are usually resorted to only when previous responses have not been sufficient (Corbett, 1988; Smucker and Wisner, 2008).

Overall, the type, duration, intensity, frequency, and timing of occurrence of shocks affect how farmers cope and adapt, and consequently the impact farmers may have on land use. These different characteristics of shocks should be taken into account when assessing how weather shocks impact land use.

4. Conclusion

Agriculture in Sub-Saharan Africa faces numerous risks. In particular, the important variability that characterizes the climate of the region translates into the regular occurrence of weather shocks that, in a context of climate change, could become more frequent and intense. Such shocks already have important impacts on agriculture, and threaten farmers' income, food security and health and, more generally, their livelihoods. In response, they have developed many practices to deal with weather-related risks, cope with the occurrence of weather shocks and adapt to their intensification under climate change. These practices are likely to have feedback effects on the environment and, in particular, on land use.

In this paper, we first review the literature that has explicitly studied the effects of farmers' adaptations and responses to weather shocks on land-use change and deforestation. We only found a few papers that have treated this question in developing countries, and in Sub-Saharan Africa more specifically. In a second step, and building on this literature review, we study, in the literature, how farmers cope with and adapt to weather shocks and relate these strategies to the land-use change literature in order to get some intuitions on possible links between commonly-used strategies and effects on land-use change dynamics.

Overall, it appears that weather shocks can induce land-use change in the short and long term. The way in which farmers cope with the occurrence of a shock can, in the short term, cause degradations in ecosystems and induce temporary land-use changes. These processes could, in the longer term, encourage deforestation and land conversion. Additionally, severe shocks can trigger households' migration and lead to land abandonment in the region of origin and land conversion in the region of destination. In the short term following a shock to prepare for the next growing season, or in the long term to adapt to climate variability and risk, farmers make structural adjustments in their farm and land-use decisions: expansion or reduction of farmland, intensification, change in field locations or in farm activities. These represent direct land-use changes. In the longer term, farmers also resort to adaptation strategies that can have important effects on land use. In particular, some strategies indirectly affect land use through their effects on households' resources such as labor and income. Additionally, we have identified and discussed how some contextual factors (market access and integration; proximity of woodlands; risk level and aversion; type, severity and timing of a shock) could influence how farmers adapt and respond to shocks and how they impact land use. Surely, additional socioeconomic and geographic factors are likely to influence how farmers' adaptation to weather shocks impact land use, but there is a lack of studies on this topic.

Further research work on the linkages between adaptation and coping strategies, and land-use change, is thus needed. There is a need to explore and test, theoretically and empirically, the mechanisms through which farmers' coping practices and adaptations to weather shocks can lead to land-use change in Sub-Saharan Africa, and how contextual factors come into play. To what extent do weather shocks lead to an increase in farm areas, and how does this evolve with the level of risk? Does the degradation of forests in the short term to cope with a shock increase deforestation in the long term? Are woodlands preserved by local populations in the long term so as to serve as insurance in the face of increasing climate risks? Do migrations caused by weather shocks decrease the pressure on land and forests? Does an increase in climate risk change farmers' strategies towards less land-intensive practices? How does the type, intensity and timing of shocks affect the impact on land use? Finally, there is a wide variety of climates, ecosystems and agro-ecological zones across Sub-Saharan Africa which, along with other factors, influence the type of farming systems and crops grown that can be found in Africa. Differences in farming systems and practices imply different sensitivity to weather shocks, but also very diverse responses and possible adaptations to shocks. The end effect on land use is thus likely to depend on these geographic characteristics. In this regard, it would be particularly interesting to study how different farming systems in different regions cope with and are adapted in the short and long term to weather shocks, and the effect on land use.

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