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AGRICULTURAL HOUSEHOLDS' ADAPTATION TO WEATHER SHOCKS IN SUB-SAHARAN AFRICA: WHAT IMPLICATIONS FOR LAND-USE CHANGE AND DEFORESTATION?

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Agriculture in Sub-Saharan Africa is regularly threatened by the occurrence of weather shocks due to extreme events as well as inter-annual and intra-seasonal climate variability. In this paper, we wonder whether the way farmers respond to shocks can affect land-use and induce deforestation, a question that has only been marginally studied in the literature. We conduct a review of the impacts of weather shocks on agriculture, and review the strategies used by farmers to cope with and adapt to these threats. We then wonder how these strategies can affect land-use, drawing from the land-use change literature, and reviewing publications that have connected weather shocks, adaptation and land-use change. It appears that weather shocks can induce land-use change both in the short and long-term, with some practices leading to land conversion while others may foster conservation. However, many effects remain ambiguous, and are likely to depend on socioeconomic and geographic factors.

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

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 rainfalls within the season. These weather shocks can range from short events to prolonged episodes lasting several years. With over 95% 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). 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% of Sub-Saharan Africa's population lives in rural areas and around 85% depends on rainfed agriculture and agriculture-based rural activities for their livelihoods (Shah et al., 2008).

Parallely, agriculture and farmers' livelihoods have been shown to be major drivers of land-use change and deforestation in Sub-Saharan Africa through agricultural expansion and the collection of resources such as fuelwood in ecosystems (Angelsen and Kaimowitz, 1999; Geist and Lambin, 2001; Curtis et al., 2018).

Hence, agricultural livelihoods are one of the main direct cause 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 household adaptation and response to weather shocks affect their land-use decisions, and consequently these current land-use change dynamics. In other words, do weather shocks encourage agricultural expansion and deforestation or, conversely, foster conservation?

Numerous publications have studied the impacts of weather shocks on agriculture and examined how farmers in Sub-Saharan Africa adapt and cope with such shocks. Many also explored land-use change dynamics and drivers in the region. However, 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 (e.g. runoff control, 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; Noack et al., 2015; Wunder et al., 2018). Additionally, in a 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.

Therefore, the purpose of this article is to examine the literature across different subjects in order to expose what is known of the effects of farmers' adaptation to weather shocks on land-use in Sub-Saharan Africa and identify questions for future research on this topic. Here, we focus on adaptation at the household level in reaction to climate variability and the occurrence of weather shocks. We do not address adaptation to climate change more broadly.

To this end, the article reviews the impacts of weather shocks on agriculture and farming households (section 2), and the strategies used by households to respond and adapt to weather shocks and climate variability (section 3), to get intuitions on how such shocks could affect land-use. In section 4, we review whether (and how) the effects of weather shocks on land-use have been studied in the literature and expose the mechanisms through which weather shocks can affect land-use in Sub-Saharan Africa, both in the short term and in the long term. Finally, section 5 concludes.

We found that weather shocks can affect farmers' land-use decisions in several ways. Indeed, some practices could foster conservation and reduce land conversion, while others may cause an increase in land-use change and induce deforestation. However, it remains unclear whether some strategies lead to an increase or rather a decrease in land-use change, as it is likely to depend on socioeconomic and geographic factors influencing farmers' decisions. We also confirm that few articles have explicitly connected adaptation to weather shocks with land-use change. Among these publications, studies focusing on Sub-Saharan Africa are scarce. Hence, based on our review of the literatures focusing on farmers' adaptation and land-use change, we identify areas where further research is needed.

2. Impacts of weather shocks on agriculture and farmer livelihoods

Extreme weather events (mainly droughts, heat waves, heavy rainfalls and floods in Sub-Saharan Africa) can be detrimental to agriculture in different ways. Such events might induce a decrease in yields or a complete or partial destruction of crops. Storms, heavy rains and floods, as well as drought-induced fires, can moreover lead to the destruction or degradation of agricultural land and infrastructures necessary to agricultural activities, either through a direct effect or because of induced erosion, landslides and debris deposition (Liswanti et al., 2011; Lobell et al., 2011; Thornton and Cramer, 2012; Fitchett and Grab, 2014). Additionally, it has been shown that weather shocks could lead to a decrease in the nutritional quality of food crops (Hummel et al., 2018). Other types of shocks due to inter-annual and intra-seasonal climate variability may also have adverse impacts on agriculture. For example, a prolonged dry spell after sowing, a delayed onset of the rainy season or a shortened season can affect yields negatively (Rosenzweig et al., 2001; Thornton and Cramer, 2012; Mbilinyi et al., 2013; Guan et al., 2015; Antwi-Agyei et al., 2018).

The severity of the impacts of a shock on crops depends on the type of shock, its intensity and duration, as well as on crop species, as some species or varieties are more resistant than others to drought, heat or flooding. Cassava, for instance, is quite resistant to drought and high temperature conditions, but is sensitive to flooding (Thornton and Cramer, 2012). The moment in which the shock occurs within the growing cycle of the plant is also determinant. Indeed, weather shocks are particularly damaging during the early stages of plant development such as the juvenile and reproductive stages (Rosenzweig et al., 2001; Thornton and Cramer, 2012). At the reproductive stage for instance, four days of moisture stress can lead to a reduction in corn yield up to 50% (Rosenzweig et al., 2001). Noack et al. (2019), studying the impact of droughts on crop income, found that dry shocks are damaging during the plant growing period, and not necessarily around the harvesting period. Positive rainfall shocks, on the other hand, can be beneficial to some crops during the growing season and detrimental during the harvesting period, depending on the intensity of the precipitation.

Several studies have examined the potential effects of climate change on crop yields in Africa but those that quantify the impacts of weather shocks more specifically are few. It appears that while greater temperatures or precipitation (if not excessive) might be beneficial to certain crops in some areas, such changes can become highly detrimental when exceeding a certain level (Rosenzweig et al., 2001; van Asten et al., 2011; Lobell et al., 2011; Blanc, 2012; Thornton and Cramer, 2012). Lobell et al. (2011), using maize cropping trials and daily weather data in Africa, found a decrease in final yield by 1% for each degree day passed above 30°C under optimal rain-fed conditions. This percentage reaches 1.7% under drought conditions, underlying the importance of moisture for maize to cope with heat. Blanc (2012) found that a one standard deviation change from median precipitation lead to an increase in maize yields by 2.9%, while yields during floods are lower by 7.1% compared to normal conditions in Sub-Saharan Africa. Similarly, for sorghum, floods lead to lower yields by 7.5% compared to normal periods. Lobell et al. (2011) found that, under drought stress, all present maize-growing areas observed yield loss, and over 75% of the harvested area had at least a 20% loss of yield for 1°C warming. Groundnut, produced by many smallholders as a food and cash crop in Sub-Saharan Africa, could suffer important yield decrease due to temperature shocks coupled with water stress. Temperatures over 25°C were found to engender significant reduction in the number of subterranean pegs and pods, seed size and seed yield by 30-50% *(*(Ong, 1984) in (Thornton and Cramer, 2012)).

Beyond its effects on crops, weather shocks also impact livestock rearing. Droughts, storms, floods and heat waves can lead to livestock mortality (Thornton and Cramer, 2012). During heat waves, animals are outside of their thermal comfort zone and thus reduce their food intake, which leads to a decrease in productivity (milk production, weight gain). It was found that above 25-30°C (depending on the type of animal), animals reduce their feed intake by 3-5% per additional degree of temperature, thereby leading to a productivity loss of 10-20% per additional degree of temperature (National Research Council, 1981; Thornton and Cramer, 2012). Moreover, heat waves and repeated droughts might impact animal reproduction, hence affecting herd size. Weather shocks might also render livestock more vulnerable to diseases (Herrero et al., 2009; Thornton and Cramer, 2012). In addition, it could affect water resources on which livestock rearing heavily depends, as well as feed sources in quality and quantity by affecting the productivity of feed crops and grazing systems, and the composition of pastures (Herrero et al., 2009; Thornton and Cramer, 2012). For pastoralist and agro-pastoralist households in Africa's drylands, for whom livestock sometimes represents their only assets, or that depend extensively on livestock production for their livelihoods, the effects might be devastating. In the Horn of Africa, the droughts that took place between 1998 and 2011 killed over 50% of cattle in the most heavily impacted regions, affecting millions of livelihoods (De Haan, 2016).

Furthermore, weather shocks might have indirect adverse effects on agriculture by affecting essential natural resources and ecosystem services. Such impacts become apparent later in time rather than immediately after a shock as it can take time for effects on ecosystem services and resources to manifest as agricultural losses. In this regard, weather shocks can affect soils (erosion, soil degradation, loss of absorption capacity, loss of soil moisture), water resources, and the functioning and composition of ecosystems. Important additional impacts include effects on the propagation and repartition of pathogens, plant diseases, pests, and on insects and species essential for crops (e.g. pollinators). For agricultural productions, effects on these overall components can be largely detrimental (Rosenzweig et al., 2001; Thornton and Cramer, 2012).

The impacts of weather shocks on agricultural productions may then reverberate on markets and food prices. Indeed, as yields become lower following a shock, the prices of agricultural products are expected to increase (Jodha, 1978; Roncoli et al., 2001; Araujo Bonjean and Simonet, 2016). The impacts of such market mechanisms on a household depend on whether it is a net buyer or net seller i.e. whether the household produces more than it needs for its subsistence, or needs to buy surplus on the market (de Janvry and Sadoulet, 2011). Households that are net buyers might thus be impacted directly by the weather shock, but also indirectly through the prices of goods they need to buy. Likewise, for livestock products, prices generally increase after a shock, allowing those who were less impacted or with more assets to take advantage of this price increase.

Hence, weather shocks due to extreme events and inter-annual and intra-seasonal variability can have strong repercussions on farmer households, affecting agricultural productions, markets and food prices, and consequently income, food security and even health (Haile, 2005; IPCC, 2014; Kotir, 2011; Thornton and Cramer, 2012; Gautier et al., 2016; Noack et al., 2019). The extent of the impact on a farmer's activities and livelihood varies upon the type, severity and duration of the shock that could range from a short event to an episode lasting several days, months, or even years as it was the case for the prolonged Sahelian droughts that occurred between the end of the 1960s and the 1980s (Dai et al., 2004). In the following section, it is shown that households have implemented diverse strategies to adapt to the risk posed by weather shocks, cope with the effects of those events and maintain their livelihoods.

3. Farmer responses to weather shocks

Several studies have reported that farmers in Africa perceive changes in climate as well as in inter-annual and intra-seasonal variability, including changes in the frequency and intensity of weather extremes. They can also observe the impacts of such phenomena on agricultural activities and livelihoods. Over the years, they have developed many practices and strategies to adapt to and deal with the diverse risks they are facing, including weather-related risks (Maddison, 2007; Thomas et al., 2007; Hassan and Nhemachena, 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). Here, we focus on adaptation and coping practices implemented at the farming household level, as it is assumed that decisions affecting livelihood strategy, production, adaptation and land-use are taken at that scale.

In reaction to the shocks caused by climate variability, agricultural households in Sub-Saharan Africa adopt different approaches. Following (or during) a weather shock, they resort to different coping strategies to deal with the consequences of the event, maintain their productions, and survive. These coping practices are most often temporary but may, in extreme cases, last or become permanent. In the longer-term, households may also implement anticipatory adaptation strategies to deal with the risk induced by climate variability. Some adaptation strategies aim at reducing the household's exposure and sensitivity to the risk by smoothing income fluctuations ex-ante (risk-management practices). For instance, they can decide to diversify their sources of livelihoods. Other strategies (risk-coping practices) seek to prepare for the occurrence of shocks and limit potential impacts on the household through ex-post income or consumption smoothing (Alderman et Paxson, 1994; Dercon, 2002). Households can for instance build asset stocks ex-ante that can be depleted in difficult times. These strategies, in contrast with coping measures, are anticipated, planned, and usually continuous, and not a reaction to a specific shock. The distinction between coping practices (ex-post) and anticipatory adaptation strategies (ex-ante) can, however, sometimes become blurred, as some coping practices may extend in time and become part of broader planned adaptation strategies, and other coping responses require actions and preparation ex-ante in order to be effective in the face of a shock. For instance, households in developing countries often constitute asset stocks during favorable times because they anticipate that they might need to sell assets to get cash and cope with a shock later.

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) 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 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, we have decided to use the term 'adaptation' to refer to strategies implemented ex-ante to deal with climate variability, including strategies usually used by households to deal with diverse risks.

Thereafter, in tables 1, 2 and 3, common strategies found in the literature, and implemented by African farmers and herders in response to climate variability and weather shocks are categorized in accordance with the two distinctions introduced previously: anticipatory adaptation / coping strategies and risk-management / risk-coping practices. By definition, coping practices, which are used by households after a shock to deal with the impact, comprise only risk-coping practices. Finally, we differentiate agricultural from non-agricultural strategies as it does not resort to the same resources and is likely to have different impacts on the environment and land-use. Some of the articles cited below also mention adaptation and coping strategies used in developing countries more broadly, and are not focused only on Africa.

Anticipatory adaptation practices

Table 1. Risk-management strategies

	Practices	Description	References
Off-farm & Non-farm	Diversification of income sources	Diversifying income with non-farm or off-farm activities. It involves changes in labor allocation, and might involve migration. Common off-farm activities include the gathering of non-timber forest products (NTFP), petty trade, etc. In the case of a migration, the emigrated family member(s) can send remittances to the family.	(Pattanayak and Sills, 2001; Ellis, 2008; Osbahr et al., 2008; Paavola, 2008; Liswanti et al., 2011; Angelsen et al., 2014; Wunder et al., 2014)
	Income skewing	Re-allocation of resources to one or several activities with lower returns but lower risks.	(Dercon, 2002)
	Migration	- Permanent migration and resettlement of the entire household, or only of some household members - Regular seasonal migration of household members	(Jodha, 1978; Corbett, 1988; Osbahr et al., 2008; Paavola, 2008; Liswanti et al., 2011)
Agricultural	Agricultural diversification	- Diversification of crops, intercropping, halting of monoculture production, use of crops with different agronomic and physiological characteristics (time to maturity, etc.) - Diversification of agricultural practices (fallow times, rotations…) - Spatial diversification: division of the exploitation in plots with different attributes (crops, practices), taking advantage of landscape diversity (topography, soils, climate…) – this practice requires land and labor - Transition to crop-livestock mixed systems. This can be seen as a diversification strategy but might also be an integration strategy (use of one activity's byproducts as an input for the other activity). - Diversification through the addition of trees. It may provide food, income, and ecosystem services for crop and livestock activities – it might require labor, skills and knowledge, as well as equipment.	(Jodha, 1978; Reenberg and Paarup-Laursen, 1997; Osbahr et al., 2008; Bezabih and Sarr, 2012; Mapfumo et al., 2014; Thornton and Herrero, 2014; Wunder et al., 2014; Yegbemey et al., 2017; Veljanoska, 2018)
	Other agricultural practices	- Use of crops or varieties better adapted to droughts, high temperatures, and even waterlogging. This can lead to a change in the main crop, or to the introduction of new crops. New crops might as well be ancient varieties. - Addition of trees / agroforestry - protection from strong winds, shading, runoff control, fodder source, etc. - Relocation of crops to less exposed and better adapted lands, or even relocation of the farm – it requires access to land - Change in the agricultural calendar (sowing date, etc.), and choice of short-maturing varieties - Soil conservation and water harvesting techniques / climate-smart agriculture - Irrigation – it might be financially costly, but allows dry season farming, and growing fruits and vegetables - Increase in crop spacing to avoid plant competition for water - Seedling covering (plastic or other cover) - Expansion/extensification (decrease in fallow time, conversion of fallow or of new land) - Turning back to / increase of subsistence farming	(Brou, 2005; Thomas et al., 2007 ; Paavola, 2008; Bryan et al., 2009; Mapfumo et al., 2014; Thornton and Herrero, 2014; Elum et al., 2017; Yegbemey et al., 2017; Partey et al., 2018; Antwi-Agyei et al., 2018)

		- Intensification	
	Practices specific to livestock rearing	- Use of breeds better adapted to droughts and high temperatures - Diversification through diversified herd composition, herd splitting in different places, transition to mixed crop-livestock systems - Reduction in herd size, or halting of livestock rearing - Diversification of feed sources, finding more resistant feed sources (to both drought conditions and waterlogging), change in feeding regime - Relocation of herds to less exposed or better adapted zones (in terms of climate, vegetation, feed sources).	(Silvestri et al., 2012; Tibbo and van de Steeg, 2013; Mapfumo et al., 2014; Thornton and Herrero, 2014)

Table 2. Risk-coping strategies

	Practices	Description	References
Off-farm & Non-farm	Participation in / development of kinship networks	Such networks are based on reciprocity, to benefit from donation, lending, help, trading of food, labor, money, or other elements in case of shock (e.g. exchange of labor against food). It is a form of risk pooling, and can be done with family, friends, neighbors, or between communities and villages.	(Corbett, 1988; Dercon, 2002; Osbahr et al., 2008; Wunder et al., 2014)
	Constitution of buffer stocks	Stocks of food, harvest, NTFP. Form of informal insurance.	(Corbett, 1988; Wunder et al., 2014)
	Constitution of asset stocks	Livestock is particularly being used for saving purposes. Most often, it is smallstock (e.g. poultry) as it is less expensive and easier to resell, but it depends on numerous factors among which culture, religion, wealth, and location.	(Jodha, 1978; Corbett, 1988; Dercon, 2002; Wunder et al., 2014)

Coping responses to weather shocks

Table 3. Risk-coping strategies

	Practices	Description	References
Off-farm & Non-farm	Asset sales	Sales of assets acquired for saving purposes in the first place, such as smallstock or jewelry, and sales of productive assets later if the shock is severe, for instance cattle, farm, land (distress sales).	(Jodha, 1978; Corbett, 1988; Osbahr et al., 2008; Smucker and Wisner, 2008; Silvestri et al., 2012; Wunder et al., 2014)
	Search of alternative income sources	Through off-farm work, natural product harvesting, handicraft, etc. Such practice might take the form of temporary migration. The emigrated family member(s) can send remittances. The migration also alleviates pressure on the consumption needs of the family. More generally, this practice implies a reallocation of production factors, notably labor.	(Corbett, 1988; Smucker and Wisner, 2008; Liswanti et al., 2011; Silvestri et al., 2012; Mapfumo et al., 2014; Wunder et al., 2014; Noack et al., 2019)
	Natural products harvesting	For consumption or sale to make up for poor harvest (fuelwood, construction wood, fodder, NTFP, etc.). This practice might already take place in normal times but even more following a shock. Some studies report an increase in charcoal production (for cash income) after a shock.	(Corbett, 1988; Angelsen and Wunder, 2003; Smucker and Wisner, 2008; Liswanti et al., 2011; Woittiez et al., 2013; Gautier et al., 2016; Noack et al., 2019)

	Purchase of food or construction materials	The income from migration (remittances), or from other sources (asset sales, NTFP sales, off-farm work) can be used for this purpose.	(Osbahr et al., 2008; Silvestri et al., 2012)
	Use of kinship networks	To get food, livestock, labor, seeds, or work. However, in the case of severe or lasting shock this solution might be inefficient as the whole community is affected.	(Corbett, 1988; Osbahr et al., 2008; Liswanti et al., 2011; Silvestri et al., 2012 ; Gautier et al., 2016)
	Change in the intensity of use of the labor force	Household members work longer hours, harder, and children might be taken out of school to be used as additional labor.	(Wunder et al., 2014)
	Economical behavior	Reduced expenditures and consumption, rationing. Constitution of food stocks (crops, wild foods) if the shock is thought to last.	(Jodha, 1978; Corbett, 1988; Silvestri et al., 2012 ; Gautier et al., 2016)
	Change in diet	Consumption of different food	(Silvestri et al., 2012)
	Migration	- Temporary migration to look for work - Distress migration (permanent)	(Corbett, 1988; Osbahr et al., 2008; Gautier et al., 2016)
	Taking a loan	Use of credit from merchants or moneylenders. Interest rates might be high.	(Corbett, 1988; Gautier et al., 2016)
Agricultural	Responses for livestock rearing	- Relocation of the herd and/or mobility to find areas with more feed and water resources, or with a more appropriate vegetation and climate. This can lead to grazing in protected areas, common pool resources, government areas. - Buying fodder and water - Selling animals - pastoralists are less inclined to kill or sell their animals after a shock compared to other farmers for whom livestock can be considered more as savings rather than as productive assets.	(Ifejika Speranza, 2010; Mapfumo et al., 2014; Gautier et al., 2016)
	Focus on livestock (rather than crops)	Reduce investment in agriculture / cessation of cropping activities to focus on livestock management.	(Thomas et al., 2007)
	Finding temporary agricultural land	Especially if the land was damaged or flooded.	(Takasaki et al., 2004 ; Liswanti et al., 2011)
	Other practices	Soil conservation and water management conservation practices, delaying planting / replanting.	(Berman et al., 2014)

Among the practices and strategies listed in the above tables, it is important to distinguish those which increase the resilience of households and farmers, for instance soil and water conservation practices, from other practices which may bring advantages and relief in the short-term but also induce environmental degradation. For instance, practices that induce erosion, ecosystem depletion, land conversion, affect water resources or impact biodiversity will, in the long-term, decrease the resilience of households to weather shocks, and may even increase risk (increase greenhouse gases emissions) and lead to vicious cycles. Additionally, practices used by farmers to increase yields may in reality increase risk. For instance, if farmers use more farm inputs to increase yields, their costs increase, and so do the losses in the case of a bad rainy season or year. Hence some practices implemented to deal with weather shocks can aggravate the situation and make farmers more vulnerable.

Market mechanisms

As households adapt to and cope with weather shocks, some market mechanisms might affect their strategy. In this regard, market feedbacks from adaptation and coping practices are particularly interesting. Indeed, if shocks affect a large sample of households and a large geographic perimeter, and if household all undertake similar coping options simultaneously, those options may become less efficient. For instance, if everybody is selling assets to get cash income, asset prices might decrease, which reduces the coping efficiency of the selling (Jodha, 1978; Dercon, 2002). Similarly, if many agents are looking for off-farm work to find alternative income sources, wages might decrease because of the increased labor supply. After a positive year or season, asset prices might spike as many want to acquire assets and (re)build stocks (Dercon, 2002). Hence, the timing in which the household choose to resort to such practices is determinant to its success.

Furthermore, the demand for goods and services in affected communities is reduced following droughts (Sen, 1981), which might limit the possibilities for off-farm employment and the search for alternative sources of revenue such as petty trade or selling crafts. The agricultural failure induced by a weather event can also limit rural employment possibilities (Haile, 2005).

Gradation and sequence of farmer responses to weather shocks

Research on weather shocks and coping practices suggests that agricultural households respond to shocks following a certain logic and sequence of actions. Indeed, they try to satisfy immediate needs and address imminent threats without depleting their means of subsistence (mainly, their productive assets) to maintain their livelihood, which indicates a long-term vision (Corbett, 1988; Smucker and Wisner, 2008). An illustration of the gradation of farmer's responses to a shock is given by Corbett (1988) that studies household coping mechanisms in the midst of drought-induced famines in Africa based on the work of Watts (1983), Cutler (1986), and Rahmato (1991). Even though many factors apart from weather events come into play to explain famine, the reasoning offered by (Corbett, 1988) remains interesting as it can be assumed households would behave similarly when facing shocks threatening their food security.

In the first phase, households try to cope with the crisis while not endangering their long-term survival, through the sale of assets acquired for saving purposes, reduction in consumption, collection of wild foods, or off-farm work. If it turns out not to be sufficient, households might engage in a second phase of response by selling important productive assets, or borrowing from merchants or moneylenders at high interest rates. Finally, in last resort, they might have to sell farmland and migrate permanently to look for land or work opportunities elsewhere and to survive. Depending on their initial endowments, and the severity and duration of the crisis, households engage more or less far in those stages of response. Hence, in severe cases, households might implement strategies that will have long-term effects. If a farmer sold productive assets to buy food for instance, it might be hard for him to reacquire such assets after the crisis, and thus to prepare for the next shock. As Jodha (1978) points out, some farmers and herders might even become tenants or landless laborers at some point. An increase in the frequency and intensity of weather shocks would then exacerbate this phenomenon, increase poverty and vulnerability, while endangering the household's capacity to respond to future threats. Weather shocks might thus create or reinforce poverty traps. First, because of their impacts on income and asset loss in the sense that some households might fall below a minimum asset threshold under which asset accumulation and livelihood growth are difficult (Carter et al., 2007). Second, through the adaptation and coping strategies that are implemented. Indeed, some practices required for the subsistence and insurance of the household keep them from undertaking other more profitable activities while not alleviating poverty either as the activity undertaken does not generate more than their subsistence needs. In this regard, Sunderlin et al. (2001), Angelsen and Wunder (2003) and Delacote (2009) describe how the use of common property resources, and NTFP extraction in particular, can represent both a safety-net and a poverty trap.

Influence of socioeconomic and geographic factors on farmers' choice of adaptation strategies

The literature exploring farmer responses to weather shocks provides evidence showing that several factors can influence a household's choice of adaptation and coping strategies, but also constrain its ability to adapt. Such factors are related to markets conditions (e.g. access to markets, to insurance and credit); household socioeconomic characteristics (e.g. wealth, education or risk aversion); local geographical and biophysical conditions (proximity of woodlands and natural resources, climate); as well as features specific to adaptation practices (e.g. cost). Table 4 gives a list of factors often quoted in the literature.

Table 4: Example of determinants influencing the possibilities and choices of adaptation and coping practices

Type of factors	**Factors**	**References**
Market	Absence/imperfection/lack of access to insurance and credit market	(Maddison, 2007 ; Bryan et al., 2009; Deressa et al., 2009, Deressa et al., 2010; Hisali et al., 2011; Silvestri et al., 2012)
	Conditions of local labor market	(Corbett, 1988)
	Access to input / output markets	(Hassan and Nhemachena, 2008)
Socio-economic	Factor endowments and asset holding	(Deressa et al., 2009, Deressa et al., 2010; Angelsen et al., 2014; Wunder et al., 2014)
	Wealth	(Corbett, 1988; Bryan et al., 2009; Berman et al., 2014)
	Sources of livelihood	(Corbett, 1988)
	Level of risk aversion of the household	(Alderman and Paxson, 1994; Knight et al., 2003; Bezabih and Sarr, 2012)
	Level of education, age and gender of the head of the household	(Knight et al., 2003; Deressa et al., 2009; Deressa et al., 2010; Hisali et al., 2011; Angelsen et al., 2014; Berman et al., 2014; Alemayehu and Bewket, 2017; Antwi-Agyei et al., 2018)
	Household size	(Angelsen et al., 2014)
	Level of income diversification and off-farm employment	(Deressa et al., 2009; Hisali et al., 2011; Silvestri et al., 2012)
Geographical and biophysical	Proximity of forests and woodlands	(Hedge and Bull, 2008; Fisher et al., 2010)
	Available natural resources (water, etc)	(Bryan et al., 2013; Opiyo et al., 2015)
	Agro-ecological zone	(Deressa et al., 2009; Deressa et al., 2010; Hisali et al., 2011; Bryan et al., 2013; Alemayehu and Bewket, 2017)
Features of adaptation practices	Cost	(Bryan et al., 2013; Opiyo et al., 2015)
	Skills or knowledge requirement	(Opiyo et al., 2015)
	Ease / difficulty of access to some practices (irrigation, drought-resistant seeds, agroforestry, etc.)	(Silvestri et al., 2012; Bryan et al., 2013; Opiyo et al., 2015)
Other local conditions	Land availability, access, and tenure	(Corbett, 1988; Bryan et al., 2009; Hisali et al., 2011; Silvestri et al., 2012; Bryan et al., 2013; Alemayehu and Bewket, 2017)
	Distance to the closest center and market	(Hisali et al., 2011; Silvestri et al., 2012; Angelsen et al., 2014; Noack et al., 2015)
	Access to extension services	(Bryan et al. 2009; Deressa et al., 2009; Deressa et al., 2010 ; Hisali et al., 2011; Silvestri et al., 2012 ; Bryan et al., 2013; Alemayehu and Bewket, 2017)

In particular, the climatic context might influence and constrain adaptation and coping possibilities. In the regions where climate variability is intensifying, and where weather shocks are expected to become more severe and frequent, some strategies might turn out to be inefficient or inoperable. In areas facing an increased frequency and intensity of droughts or heavy rains for instance, some insurance mechanisms such as the constitution of asset stocks through the acquisition of livestock may not be resorted to anymore due to a high mortality risk.

4. Effect of weather shocks on land-use

The previous sections have underlined the negative impacts of weather shocks on agricultural activities and livelihoods in Sub-Saharan Africa, and detailed how farmers react and adapt in the short and long-term with climate variability and the occurrence of weather shocks. We now wonder whether the way farmers respond and adapt to such shocks induces land-use changes.

Land-use change can be defined as the transition, either partial or complete, from one utilization of a land to another, for instance natural to agricultural, agricultural to urban or agricultural to natural. In some cases, land-use change can take the form of deforestation. Land-use change, and tropical deforestation more specifically, are caused by a combination of proximate drivers (agriculture, infrastructure, etc.) and underlying forces influencing those drivers (socioeconomic, environmental, political and institutional) (Geist and Lambin, 2001; Lambin et al., 2001). In Sub-Saharan Africa, agriculture, in the form of agricultural expansion, has been shown to be one of the main direct driver of land-use change and deforestation (Geist and Lambin, 2001; Curtis et al., 2018). Furthermore, through practices such as fuelwood extraction, charcoal making and other natural product harvesting, farmer and rural livelihoods contribute to ecosystem degradation and deforestation (Geist and Lambin, 2001; Robledo et al., 2012). We thus wonder if climate variability, and the occurrence of weather shocks, affect farmers' land-use decisions and practices, and play a role in their decisions to expand or reduce farmland area, to exploit or conserve surrounding natural ecosystems i.e. whether climate variability represents an underlying driver of land-use change.

In this section, we first conduct a review of publications that have explicitly connected farmers' adaptation and coping strategies to weather shocks with land-use changes, 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 a second part, and building on this review, we draw from the land-use change literature and the adaptation literature to further connect weather shocks and land-use change and better understand the mechanisms through which such shocks affect land-use. Overall, this review of various literatures allows us to expose what is known about this question, and to identify areas where further research is needed.

4.1. Literature connecting weather shock, adaptation, and effect on land-use

In the literature studying the drivers of land-use change, a few studies have identified climate variability, and more specifically weather shocks, as an underlying force causing land-use change. Indeed, because such variability and shocks affect agricultural productions, it is also likely to influence farmers' land-use decisions. Few studies however detail the mechanisms through which weather shocks lead to a change in land-use. In this regard, interesting papers in 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. The 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). 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 is pastoralism. 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 with more abundant rainfall or possibility of irrigation. In these regions the conversion to cropland did not slow down. They suggest that it could be explained by the fact that farmers in the Rift Valley (a more 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 suggest that climate conditions and variability are considered by farmers when making 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 because they induce migrations. The droughts that occurred in the 70s and 80s, 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 change in areas of destination, mainly because it lead 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, (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' perception (interviews) in these studies. It seems that no statistical analysis has been conducted to correlate the observed land-use changes with the perceived drivers of these changes. Thus, these papers do not allow to quantify the extent of the role of weather shocks in causing these 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 change i.e. if they require land conversion, 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 lands. Some of the reasons cited for this decrease in farmland area were that these lands had performed poorly in the 1997 drought year, or because of the loss of labor due to migrations and the effects of drought on health. This study suggests that weather shocks influence farmers' decisions to expand or reduce farmed area in the short term (adjustment before the next growing season). On this question, we only found two papers in the literature empirically studying whether farmers expand their land following a weather shock. 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 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% country wide compared to years of normal weather, and +14% 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 chose 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 to expand farmland (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) in 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. Thus, further research is needed to understand if similar process take place in other regions, with different environment and farming systems, and to better understand what conditions influence farmers to expand their land after a shock rather than to reduce it.

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 and finds out that diversification based on off-farm jobs or operating provision shops is a conservation-driving strategy, taking pressure off forests, whereas savings, based on cattle-ranching, is rather a deforestation-driving practice. For the two other adaptations 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 land-use change (defined here as the conversion from natural ecosystems into crops, pastures or infrastructures). Out-migration, on the other hand, is positively correlated with increased land-use change. In these two articles however, the mechanisms through which these adaptation practices 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 impact 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 drought on yields, revenues, work load, job opportunities or health; and through the adaptation practices implemented. Households suffering from the consequences of drought 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, may influence farmers' land-use decisions (cropland expansion, farming systems) and push them to take action or implement practices with possible consequences on land-use (collection of natural products in surrounding ecosystems, migration, diversification of activities). However, the mechanisms through which these adaptation and coping practices affect land-use decisions are not always clear, and the effect of weather shocks on land-use is sometimes ambiguous. For instance, it appears that weather shocks can lead to cropland expansion in some cases, and to a reduction in farmed area under other circumstances. 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 rest of this section, we build on the above literature review, and connect our research on weather shocks and farmers' adaptation to the land-use change literature to better understand how weather shocks can impact land-use and deforestation in the short and longer-term, and summarize what is known (and not known) about this question. This allows us to identify topics on which further research is needed.

4.2. Farmers' adaptation and coping strategies to weather shocks and effects on land-use

In the short-term

As detailed in section 3, farmers use diverse coping strategies during or in the aftermath of a shock to maintain their productions, livelihoods, and subsistence. Some of those coping practices could however cause severe degradation in natural ecosystems, which in the long-term may foster land-use change. If their production or land was damaged by a flood, storm or drought-induced fire, and if it happened early enough in the growing season, some farmers may look for alternative agricultural land to replant. Herders may practice herd mobility to address difficult weather conditions and access other feed and water sources, or relocate livestock to graze elsewhere, for instance on common pool resources or government property despite regulations. These practices could cause temporary land-use change, which may be the first step toward more permanent land-use change, for instance if climate variability increases and these practices are more often resorted to. It can also lead to degradations in natural ecosystems.

Additionally, it has been reported that farmers look for alternative income and food sources following a weather shock. To this end, they often go collect natural products (food, forage, fuelwood, etc.) in surrounding ecosystems to consume, sell or trade (Woittiez et al., 2013; Gautier et al., 2016). Depending on the nature, frequency and intensity of the harvest, and the type of items being collected, these 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; Robledo et al., 2012; Antwi-Agyei et al., 2018). If many people in a community go collect these products to cope with a shock, or if shocks occur (more) frequently, it might lead to overexploitation and to an important degradation of surrounding ecosystems, thereby endangering the future coping capabilities of farmers. Once natural ecosystems, and forests in particular, are degraded and depleted of their resources, thereby losing value for local population, there might be less incentives to conserve rather than convert such ecosystems to other land-uses. In the longer-term, it could thus encourage deforestation. The effect of natural product harvesting on land-use will depend on the location of the harvest, whether it takes place in natural ecosystems such as forests or rather in areas already converted and used by farmers (e.g. fallow, farm bush, agroforest) in which case the impact of harvesting might not be as important. Overall, the way farmers cope with a weather shock can, in the short-term, cause degradations in surrounding ecosystems. Further research is needed to understand whether such degradations can encourage land-use change and deforestation in the longer-term.

Furthermore, if the weather shock that occurs is particularly severe, or lasting, or if shocks occur frequently, it might push farmer households to migrate and relocate in another region permanently (Corbett, 1988). As a result, land-use change can occur both in 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).

Beside these coping practices use to maintain livelihood and survival, farmers may decide to make agricultural adjustments following a season of difficult weather conditions to prepare for the next growing season. On the one hand, the decrease in agricultural production induced by a weather shock may push farmers to relocate fields to better adapted or more productive plots, or expand farmed area. On the other hand, the effects of weather shocks on labor resources could lead them to decrease farmed area (Roncoli et al., 2001). Indeed, weather shocks affect food security and thus health and work capacity (Bailey et al., 1992; Wilkie et al., 1999). Indirectly, it also affects labor availability because shocks can induce a reallocation of labor away from agriculture for the search of alternative income and food sources, and can push some household members to migrate to look for a job or alleviate pressure on the household's food needs. If these effects on labor occur at the same time as the decision to expand farmland, expansion might be constrained, because it is a labor-intensive practice. Additionally, farmers' land-use decisions are likely to be influenced by their risk preferences. Indeed, it has been reported that farmers in developing countries tend to be risk averse (Wik et al., 2004; Yesuf and Bluffstone, 2009). Hence, following a period of difficult weather conditions, some might decide to limit risk exposure by reducing farm activities and farmed area, and by switching to non-farm sources of income for instance. As explained precedently, further research is needed to better understand what factors influence or constrain farmers' decision to expand their land after a shock or conversely, to reduce it.

In the long-term

In the longer-term, weather shocks are also likely to influence farmers' land-use decisions, such as the farm size, intensification, the type of farming system and agricultural activities. Indeed, farmers may want to compensate for the direct and indirect effects of weather shocks on their production (land degradation and loss of ecosystem services, loss of productivity), 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. They may also decide to implement strategies to prepare for future shocks and limit the consequences. Farmers may decide to increase landholding to compensate for yield decrease and maintain a certain production level and income. On the other hand, the decline in farm profitability caused by weather shocks, and the increase in risk (if farmers are risk averse), could push some farmers to reduce their farmed area.

Both in the short and long-term, a farmer's decision to expand or reduce farmed area is also likely to depend on the household's degree of integration into markets. Households in near-subsistence systems (i.e. producing mainly for their own consumption) - and these types of farmers remain widespread in Sub-Saharan Africa -, as well as households having few alternative income sources, might need to expand farmland to maintain a certain level of production with little concern over farm profitability. Households more integrated into markets may be more sensitive to the profitability argument. At the same time, if the prices of agricultural products rise in times of crisis, households that can sell a part of their harvest in markets might be incentivized to maintain or even increase production to take advantage of the price increase. In the longer-term, the impact of a weather shock on the prices of agricultural products is also likely to influence farmers' land-use decisions in terms of whether to increase or decrease landholding and diversify income with non-farm activities, as well as the type of crops grown. However, the long-term effects of weather shocks on agricultural prices remains unclear.

Some farmers may also decide to resort to intensification practices to boost yields and production. It is uncertain whether an increase in yield leads to a decrease or an increase in farm area. On one side, the Borlaug hypothesis, or subsistence hypothesis (Angelsen and Kaimowitz, 2001), suggest 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 Jevons paradox) implies that an increase in the efficiency with which a resource is used leads to the 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. Again, numerous factors will determine which of these two outcomes is true, for instance, households' characteristics such as 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's 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 effect of intensification as a response to climate risks on land-use and the influence of contextual factors.

Apart from expansion or intensification strategies, many farming households 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 to crop- or livestock-only exploitation 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 region where pastoralism is the dominant farming system, such a transition could induce a process of sedentarization, with very likely effects on land-use. 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, 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 farm 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 and could thus alleviate pressure on forests through reduced harvest 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 (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 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 those practices can lead to degradation and land conversion is not known.

Beside these land-use-based farm strategies (extensification, intensification, change in farming system and activities), other risk-management practices that are not agricultural may have an effect on land-use and surrounding ecosystems, either directly or because they affect households' resources such as labor and income and thus influence land-use decisions. When households diversify their income and food sources 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 of the money they earn (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 work force available for agriculture and the harvest of natural products will be reduced. In particular, it could constrain expansion that is a labor-intensive practice. 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. Diversification, through the reallocation of production factors and resources away from agricultural activities, could thus alleviate pressure on surrounding ecosystems such as 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). Whether diversification of livelihoods, and diversification through migration in particular, reduce expansion and pressure on land is thus not certain.

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, medicine. Those products can be used for consumption, barter or income. This practice is used by households in normal times for diversifying their production and revenues. It may be increasingly resorted to in times of crisis, thus playing a role of safety-net (Angelsen and Wunder, 2003; Sunderlin et al., 2005; Liswanti et al., 2011; Woittiez et al., 2013; Noack et al., 2019). 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 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, which may reduce deforestation. 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). Yet, evidence of ecosystem degradation suggest 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 use at an unsustainable pace, may lead to severe deterioration of natural ecosystems such as woodlands, depending on the nature, frequency and intensity of the harvest, 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 build NTFP stocks for instance, which could lead to overexploitation. Again, this loss of forest ecosystem services due to over-harvesting can lead to the decrease of the forest value for local population, and can be considered as a first step toward deforestation. Again, the effect of natural product harvesting on land-use depends on the location of the harvest (forest, fallow, etc.) and the way in which common pool resources are managed within the community. The impact of natural product collection on land-use is ambiguous and needs to be further explored.

Finally, one last strategy that is worth mentioning because of its potential impact on land-use is the acquisition of assets during favorable times such as years of good harvest to constitute buffer stocks that can be liquidated in the event of a shock (Corbett, 1988; Dercon, 2002). In Sub-Saharan Africa, livestock if 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 and forests for feeding and grazing purposes (Geist and Lambin, 2001). This strategy could therefore induce changes in land-use. 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 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.

Overall, it appears that weather shocks can induce land-use change in the short and long-term. The way through which farmers cope with the occurrence of a shock can, in the short-term, cause degradations in ecosystems. Such degradation process could, in the longer-term, foster deforestation and land conversion. Moreover, agricultural adjustments following a shock to prepare for the next growing season may cause land-use changes (expansion or reduction of farmland). In the longer-term, farmer households also make transformational changes into farm activities and implement many risk-management and risk-coping strategies. Such practices, that aim at reducing a household’s exposure and sensitivity to risk and to limit the impacts of shocks, may reduce the need for households to cope with shocks and thus the short-term effects of weather shocks on land-use. However, these ex-ante adaptation strategies can also lead of their own to slower and more progressive, but perhaps also more permanent, land-use changes.

Many potential effects of weather shocks on land-use however remain uncertain and ambiguous, and likely to depend on socioeconomic and geographic conditions. Moreover, these effects are also likely to be influenced by the type, severity, intensity, duration, spatial extent and moment of occurrence of shocks, as these characteristics influence the impact of shocks on farmers, their decisions in term of adaptation, and thus the effect on land-use. Indeed, as exposed in section 2, different shocks have different impacts on agricultural activities, and thus call for different response strategies. Moreover, some shocks have slow onsets (e.g. droughts), and thus leave time to farmers to prepare and adjust, while other shocks are more sudden and unpredictable (e.g. floods). Similarly, depending on when the shock occurs within the season (beginning, middle, or close to harvest), farmers will have more or less 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 amid the growing season, such response will not be possible. The spatial extent of a shock also conditions adaptation strategies based on land-use (e.g. search of alternative fields or pastures, relocation of herds). Additionally, the severity, duration and frequency of occurrence of shocks influence farmers' responses. As explained in section 3, there exist a gradation of farmers' responses to shocks, and some practices (selling productive assets, migrating, reallocating production factors) are usually only resorted to when previous responses have not been sufficient (Corbett, 1988; Smucker and Wisner, 2008). More generally, an increase in weather-related risks, for instance an increase in the frequency or intensity of shocks, might push farmers to change their strategy. For example, they could decide to abandon their farm and migrate. Moreover, some strategies such as building food or asset stocks, are implemented during favorable times (years of good harvest) to prepare for hardships and might thus be unavailable in the event of consecutive difficult years due to repeated shocks. Overall, the type, duration, intensity, frequency, and timing of occurrence of shocks affect how farmers cope and adapt, and consequently the impact they may have on land-use. Hence, these different characteristics of weather shocks should be taken into account when assessing how weather shocks impact land-use.

5. 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 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 shocks and adapt to their intensification under climate change. These practices are likely to have feedback effects on the environment.

Our contribution is thus threefold. First, we review in the literature how climate variability and weather shocks impact agriculture in Sub-Saharan Africa. Second, this paper reviews and categorize the adaptation and coping strategies to these shocks. Finally, we relate these strategies to the land-use change literature in order to get some intuitions on possible links between commonly used adaptation practices and effects on land-use change and deforestation dynamics.

It appears that weather shock influence farmers' land-use decisions and pushes them to implement strategies that can have implications on land-use both in the short and long-term (e.g. change in farm area, change in agricultural system, exploitation of nearby woodlands). Some practices might lead to land-use change, while others may rather foster ecosystem conservation. In some cases, the effect on land-use is ambiguous and likely to depend on contextual factors such as household characteristics and local conditions. Yet, studies exploring how adaptation to weather shocks might affect land-use change and deforestation in developing countries have been scarce, especially in Sub-Saharan Africa. Further research work on the linkages between adaptation and land-use change is thus needed, with both theoretical and empirical approaches.

Besides, several further questions have been identified for future research. First, adaptation practices strongly depend on geographic characteristics. Hence, it is very likely that the impacts of shocks and adaptation on land-use change and deforestation also depend on geography. Indeed, there is an immense diversity in climates, ecosystems and agro-ecological zones across the continent, which, along with other factors, influence the different types 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 response and possible adaptations to shocks. Moreover, climate also varies quite a lot across the continent, and different location are subject to different weather shocks. The geographical local context is also likely to influence and constrain adaptation and coping possibilities in response to shocks. The presence of woodlands, waterbodies, or market access for instance will determine whether farmers can go harvest resources in forests, implement irrigation, relocate near water sources, or go look for a job elsewhere. Hence, the way farmers adapt and react, and thus the effects of weather shocks on land-use vary across different landscapes. Studying the effects of weather shock on land-use thus calls for a localized approach. In this regard, it would be particularly interesting to study how different farming systems in different regions react and adapt in the short and long-term to weather shocks. A deeper analysis of local characteristics (e.g. forest cover, agro-ecological zone), and how these characteristics influence the link between weather shocks and land-use change, is also needed.

Second, the socio-economic context also has some strong influence on the practices that may be implemented to respond to weather shocks. Here again, a question that arises is how do the socio-economic context (e.g. market access, factor endowment and wealth, access to energy, etc.) can influence land-use change following the occurrence of a weather shock.

Finally, the difference between ex-ante adaptation and ex-post coping strategies are likely to have diverse impacts on land-use change. Indeed, ex-ante adaptation strategies are more likely to be implemented in the long-run, with possible slow yet permanent land-use change implications. In contrast, coping strategies may have short-run impacts, of which unexpected deforestation implications can reduce long-term adaptation capacities and available strategies for more vulnerable households. Further research is needed to better understand and distinguish short-term from long-term impacts of weather shocks on land-use.

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