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Land degradation along a climatic gradient in Mali: Farmers' perceptions of causes and impacts

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Abstract

Land degradation (LD) in Mali is prevalent and leads to an enduring environmental and humanitarian crisis. Farmers' ecological knowledge has proven to be a valuable tool in addressing its challenges. How farmers perceive LD affects how they deal with induced risks, and their responses to these perceptions will shape restoration options and outcomes. Therefore, this study assessed farmers' perceptions of LD along a climatic gradient in three regions of Mali. We interviewed 270 farmers, and we analyzed their responses using descriptive statistics and Spearman rank-order correlation. We found that the respondents were aware of LD and have identified its key indicators and its impacts on their livelihoods. Moreover, we found that farmers' perceptions are not influenced by gender, age, or education level, but rather by agricultural training, participation in agricultural labor, the practice of fallowing, shortage of firewood, livestock, household size, appearance of some plant species and famine. Additionally, farmers' perceptions of LD vary along the climatic gradient as they correlate to different variables in each agro-ecological zone. LD's impacts, however, decrease in severity along the north–south gradient, although they are linked to the same variables. As LD is seen through a reduction of ecosystem services provisioning capacity because of the local communities' heavy dependence on natural resources, actions should be geared towards agronomic and vegetative land management options. Such actions should prioritize context-specific soil and water conservation techniques and proven indigenous practices.

KEYWORDS
agro-ecological zone, dryland, environmental-change, natural resource management, restoration, WestAfrica

1 | INTRODUCTION

The land is essential to human subsistence on Earth. It provides the ecosystem services our livelihood depends on (Intergovernmental Panel on Climate Change [IPCC], 2019). Land degradation (LD) is defined as the degradation of the services provided by the land or its productive capacity (United Nations Convention to Combat Desertification [UNCCD], 2017). LD also results from natural biophysical evolutions, it affects ecosystem services, and it is generally induced and exacerbated by human activities (Brabant, Bied-charreton, &

Schnepf, 2010; Lal & Stewart, 2010; UNCCD, 2017; Zougmoré, Jalloh, & Tioro, 2014). LD is aggravated by climate change (CC), and it could, in turn worsen CC effects (IPCC, 2019; Olsson et al., 2019; Yirdaw, Tigabu, & Monge, 2017). In the Intergovernmental Panel on Climate Change's Special Report on Climate Change and Land, scientists stated with very high confidence that "...land degradation represents—along with climate change—one of the biggest and most urgent challenges for humanity" (Olsson et al., 2019, p. 348). It affects 3.2 billion people worldwide and represents an economic loss of about 10% of annual global gross product; inhabitants of drylands regions such as the Sahel are the most affected (Hountondji, Ozer, & Nicolas, 2004; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2018; UNCCD, 2019).

The Sahel is a transition Zone between the drier Sahara Desert in the north and the moist savanna in the south (Sissoko, van Keulen, Verhagen, Tekken, & Battaglini, 2011; United Nations Environment Programme [UNEP], 2012). Average rainfalls in the Sahel vary from 100 to 600 mm in an increasing gradient southwards along with increased vegetation and biodiversity towards its southern border (Mbow, 2017; UNEP, 2012). LD increases the vulnerability of all Sahel communities through degraded vegetation and declined soil fertility leading to decreased crop yields and food insecurity (Sissoko et al., 2011; UNEP, 2011). Thus, threatening the means of livelihood of millions of farmers dependent on rain-fed agriculture and pastoralism (Funk, Rowland, Adoum, Eilerts, & White, 2012; Ingram, Roncoli, & Kirshen, 2002; Kandji, Verchot, & Mackensen, 2006; Zhou & Staatz, 2016). In a Sahel country, such as Mali, the agro-pastoral production is mostly concentrated in the regions starting south of the Sahara Desert, characterized by distinct climatic zones, the Sahelian, Sudanian and Guinean zones. Situated in the western part of the Sahel Zone, Mali is seriously affected by LD which is causing an agricultural GDP loss estimated at 2–4% per year, with reduced crop yields (Monitoring African Food and Agricultural Policies [MAFAP], 2013) and subsequent degradation of ecosystem services (Millennium Ecosystem Assessment [MEA], 2007; Sidibé, 2013; UNCCD, 2017). LD also drives an average annual deforestation of 500,000 ha per year (MEA, 2007; UNCCD, 2019). Furthermore, erosion affects soil fertility and crop production; it directly impacts the livelihood of local communities. LD increases food insecurity, and it forces farmers to shorten the fallow time, to expand to marginal lands, and to adopt non-sustainable practices (Spiekermann, Brandt, & Samimi, 2014). Rainfall variability, erosion and human activities, such as agricultural expansion, overgrazing, overharvesting of fuelwood and charcoal production are considered to be the key characteristics of LD in Mali (Mbow, Brandt, Ouedraogo, de Leeuw, & Marshall, 2015; MEA, 2007). To cope with LD at the local scale, farmers have been using their ancestral ecological knowledge and practices, such as fallowing, use of stone bunds and planting pits (traditionally known as *zai* or *towalen*) in an attempt to reverse LD and increase crop production (Saïdou, Kuyper, Kossou, Tossou, & Richards, 2004). At the national scale, since 1960, the government of Mali has made sustainable land management and soil fertility improvement programs a priority (MEA, 2007; Sidibé, 2013). Additionally, more than 1,000 local non-governmental organizations (NGOs) are implementing various land restoration projects throughout the Country (MEA, 2007).

The involvement of NGOs and other global initiatives in combatting LD certainly underlines the urgency of the matter. Despite all these initiatives, Mali's ability to feed itself is still challenged nowadays, almost 50 years after the droughts and famines of the 1970s (Sacande & Berrahmouni, 2016; UNCCD, 2017). This situation is exacerbated by a socio-economic context driven by population pressure (Institut National de la Statistique [INSTAT],- 2019; World Bank, 2016) and the absence of adequate policies addressing land tenure (Lal & Stewart, 2010; MEA, 2007; United States Agency for International Development [USAID], 2010).

However, in addressing LD, many of the adopted approaches have failed to take into account the context and the perceptions of local farmers (Olsson et al., 2019; Pulido & Bocco, 2014). According to Gray and Morant (2003), a contextual approach that takes into account farmers ecological knowledge could complement the predominant remote sensing methodologies. Assefa and Hans-Rudolf (2016) further noted that farmers that perceived soil degradation were more inclined to adopt management practices that reduced its impacts on their livelihood. Therefore, their opinions should not be ignored (IPBES, 2018; Mairura et al., 2008; Odendo, Obare, & Salasya, 2010; Olsson et al., 2019). Also, the literature suggests that farmers' perceptions are influenced by variables related to their socio-economic and demographic context, such as age, education, and household size (Barbier & Hochard, 2018; Davies, Pollard, & Mwenda, 2010; Hasan & Kumar, 2020; Tesfahunegn, 2018). Additionally, variables related to their agricultural practices, such as fallowing, use of fertilizers, tree planting (Biratu & Asmamaw, 2016; Gashu & Muchie, 2018; Sanogo et al., 2017) and other environmental and climatic factors (Lal, 2001; Orchard, Stringer, & Manyatsi, 2017), also influence them as well. Pulido and Bocco (2014) found that farmers tend to adopt mitigation options based on their agro-ecological conditions and prioritize the strategies that fulfill their basic needs. Similarly, the perceptions of Malian farmers living along a north–south climatic gradient, exposed to different agro-ecological conditions and experiencing different rates of LD, are essential in designing any successful mitigation strategy for their particular context (Davies et al., 2010; Dembele, 2006; Odendo et al., 2010). Such approaches are also necessary for undertaking actions in the framework of any land restoration initiatives, whether they are local, regional or global initiatives, such as the United Nations Sustainable Development Goal 15 (SDG 15), the Bonn Challenge, Land Degradation Neutrality (LDN) of UNCCD, and so forth. As LD is exacerbated by CC, previous studies on farmers' perceptions of CC in Mali, have suggested that farmers are aware of its adverse effects, and they consequently adopt adaptation measures (Sanogo et al., 2017; Traore et al., 2015). Concerning LD, until now, there are still considerable research gaps about farmers' perceptions in the Sahel in general, as evidenced by the paucity of published information. This study is the first addressing farmers' perceptions of LD within a local context in Mali. Considering the many challenges in the SahelZone that are attributed to the depletion of natural resources (Organisation for Economic Co-operation and Development [OECD/

SWAC], 2014; Ouedraogo et al., 2010; Perry, 2013), understanding the perceptions of local communities at the heartland of the region is therefore relevant for the rest of the region and is a necessary step towards addressing LD in the Sahel.

The present study, therefore, sought to address these knowledge gaps. We focus on understanding the variables that contribute to raising farmers' awareness of LD at the local context in Mali, in three separate regions belonging to different agro-ecological zones, characterized by a north–south increasing rainfall gradient which affects vegetation growth. LD impacts are different in drier versus wetter zones, and so are the mitigation options adopted by the communities living along a latitudinal climatic gradient (MEA, 2007; UNCCD, 2019; UNEP, 2012). As the mitigation options are based on their perceptions (Pulido & Bocco, 2014), we assumed that farmers' perceptions vary along the rainfall gradient according to the agro-ecological conditions and that it is important to capture the variations therein; this led us to conduct our study along a climatic gradient (Dawoe, Quashie-Sam, Isaac, & Oppong, 2012; Duguma & Hager, 2011; Pawluk, Sandor, & Tabor, 1992; Rist & Dahdouh-Guebas, 2006; Sternberg et al., 2011). We aimed to: (a) assess farmers' perceptions of LD in selected agro-ecological areass and determine the key factors that influence their perceptions; and (b) elucidate the impacts of LD on the livelihoods of the communities of these regions.

2 | MATERIALS AND METHODS

2.1 | Study sites

Mali is a landlocked country in the heart of West Africa; it covers 1,241,238 km^2 and is administratively divided into eight regions (Plan d'Action National d'Adaptation au changement climatique [PANA], 2007; World Bank, 2016). The study sites are located in the regions of Mopti, Segou, and Sikasso, along a north–south climatic gradient from the Sahelian Zone southwards towards the Sudano-Guinean Zone (Figure 1).

The population in the three regions has considerably increased in the past decades, Sikasso has a population of 3,148,819 inhabitants, followed by Segou (2,785,676) and Mopti (2,425,735) (INSTAT, 2015). Agriculture and agropastoral activities are dominant. The mean annual temperature is 28.0°C for Mopti, 27.6°C for Segou, and 27.0°C for Sikasso region. Mali has four agro-ecological zones, characterized by a unimodal rainfall, with increasing averages from North to South. The rainy season lasts for about 3–6 months, May to October in the South and July to September in the North, August being the peak (MEA, 2007), and the remaining months are dry (PANA, 2007). Rainfall is more abundant in Sikasso with an annual average of 1,121 mm; this yearly average decreases as we move north towards the drier Sudanian and Sahelian Zones (Observatoire du Sahara et du Sahel

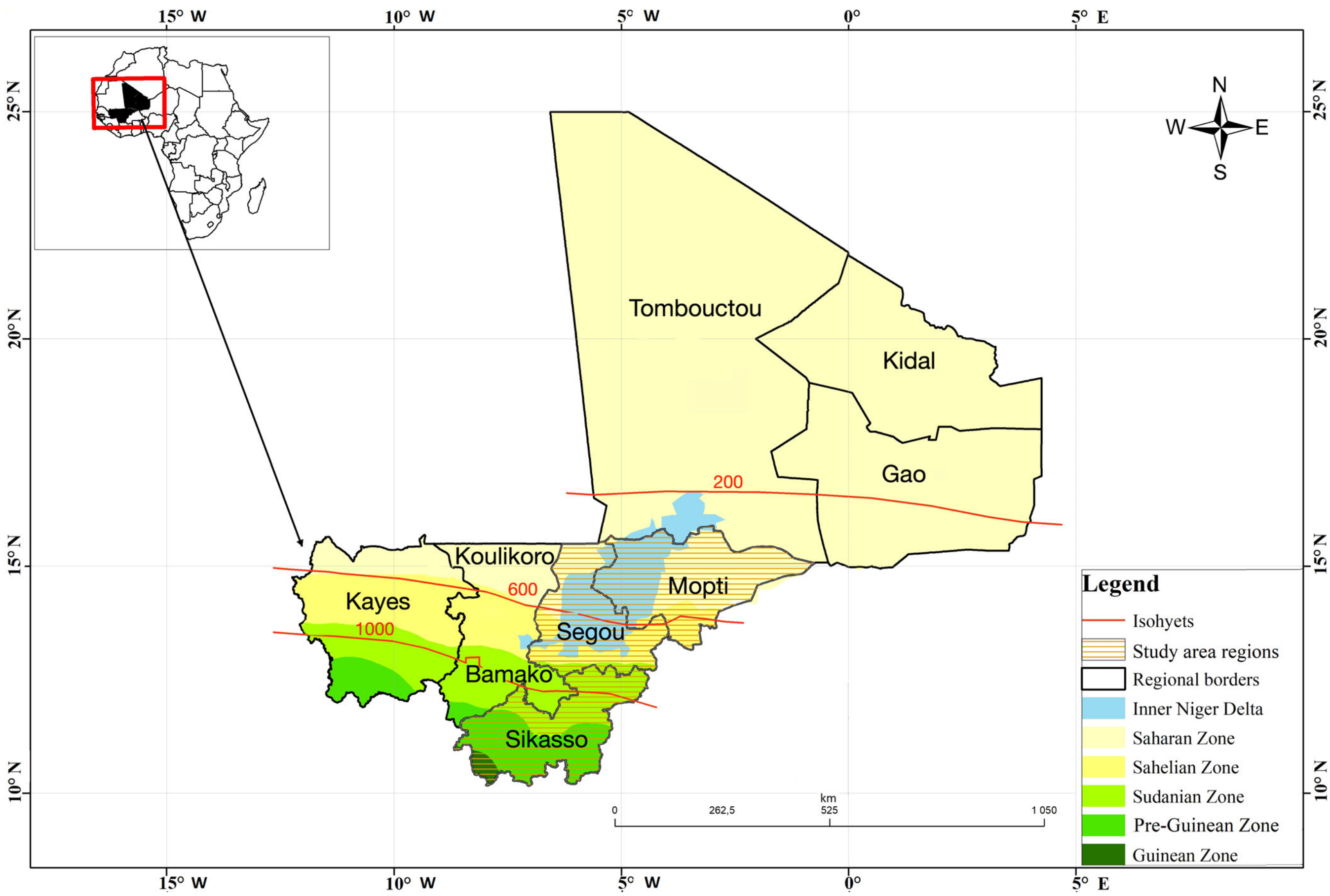

FIGURE 1 Isohyets through the main agroecological entities in Mali [Colour figure can be viewed at wileyonlinelibrary.com]

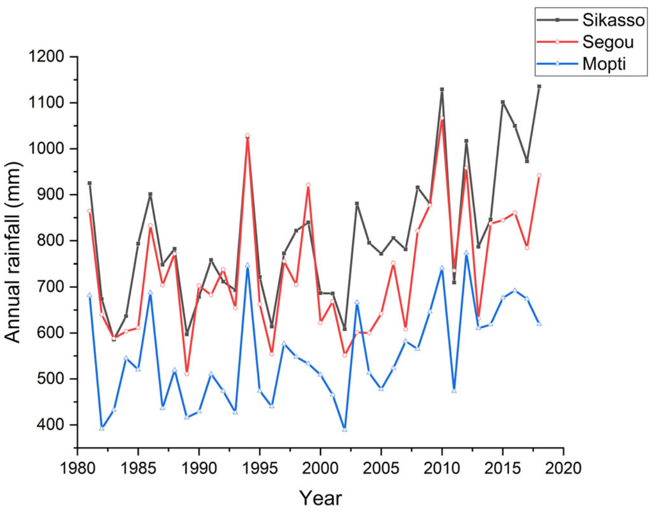

FIGURE 2 Average annual precipitation (mm yr^{-1}) for the past 37 years in the regions of Mopti, Segou and Sikasso in Mali (data from the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) POWER Project, NASA, 2018) [Colour figure can be viewed at wileyonlinelibrary.com]

[OSS], 2014). Hence, Segou receives 746 mm, while Mopti receives 495 mm of precipitations per year (Figure 2). Despite aridity, farmers manage to produce millet, rice, and sorghum, which are generally the dominant staple crops; additionally, Sikasso extensively cultivates cotton and maize as cash crops. Livestock rearing is practiced across the three regions but more predominantly in the Mopti region, which hosts 28% of the Country's cattle population (Direction Nationale des Productions et Industries Animales [DNPIA], 2016).

2.2 | Data collection

We have used a survey to assess farmers' perceptions about LD; this methodology is frequently used in LD research to inquire about land users' opinions (Kapalanga, 2008; Tesfahunegn, 2018). In the current study, we interviewed 270 farmers, using a combination of questionnaires, focus group discussions (FGD), and field observations to collect the primary data. We conducted surveys in May 2017; we purposively selected the nine villages that participated in the Drylands Development Program (drydev.org), which envisions to empower farmers to transition from subsistence farming to sustainable rural development, through improved soil and watershed management practices. In each village, we randomly selected 30 farmers from a list of the program beneficiaries, due to budget and time constraints. To administer the questionnaire, we recruited three enumerators for data collection based on their social data collection experience and familiarity with the study area. We conducted the interviews in the local dialects and recorded the translated responses using tablet computers loaded with the Open data toolkit application (Hartung et al., 2010). The questionnaire aimed at understanding the factors that would affect farmers' perceptions of LD in different agro-ecological zones. We assumed, based on the reviewed literature, that the variables affecting farmers' perceptions would belong to three main categories, socio-economic and demographic variables (age, education level, household size, plot size, livestock, off-farm employment), agricultural variables (level or participation in labor, land percentage under cultivation, fallowing, tree planting, crop yield, changes in plot size, soil and water conservation) and variables linked to the environmental context farmers live-in (appearance of new species, deforestation, rainfall regime, drought frequencies, erosion) (Doso, 2014; Geist & Lambin, 2002; Pulido & Bocco, 2014; Sanogo et al., 2017). Additionally, questions specifically related to erosion, deforestation, and soil fertility were also added to measure farmers' awareness of LD on a three-point Likert scale (no LD, moderate LD, Severe LD).

In each of the villages, we also set up FGD for adult women, adult males, and one for the youths. Their ages ranged from 16 to 19 years old for the youths and from 25 to 70 years old for the adults. In some cultures it is unusual for women and youth to express their opinions in the presence of elder members of the community; to avoid that any group would dominate the discussions, we proceeded to separate them in order to encourage members to freely express their opinions (Stewart, Shamdasani, & Rook, 2007). Each FGD had 6–10 persons purposively selected from youth associations, women organizations, and male elders. FGDs were followed by field visits with local farmers to assess signs of LD in situ and to have a better understanding of the status of the natural resources (vegetation cover). In the fields, we also identified and documented land-use types, management practices, and farmers' on-going initiatives to mitigate LD. Through this exercise, we understood the scale of erosion and better contextualized farmers' opinions from one village to another along the climatic gradient.

In order to characterize the climatic gradient of our study zones, we have also acquired secondary data on monthly precipitations and temperatures for the period 2000–2018 from the global NASA-Power climate database (National Aeronautics and Space Administration [NASA], 2018).

2.3 | Data analysis

2.3.1 | Interview data

We used Spearman rank-order correlation to determine the strength and the direction of the relationship between selected independent variables (Table 1) and the dependent variable representing LD's perception. The Spearman correlation is less restrictive in that it does not require data to be linearly related or bivariate normally distributed (Salkind, 2012).

We formulated hypotheses on selected variables based on existing literature, the FGD, and our own field experience. Table 1 below presents our hypothesis on each of the selected variables; positive (+) means the variable increases farmers' perceptions of LD, and negative (–) the contrary. For some variables, we did not hypothesize their effects on farmers' perceptions, which could be either positive or negative (+/–). We analyzed the data using IBM SPSS statistical software (International Business Machines Corp, 2017).

TABLE 1 Hypothesis on selected independent variables, '+' and '–' represent the direction of the impact on farmers' perceptions

Variables description	H_1	Justifications based on authors opinions and from sources in the literature
Age	+	We hypothesize that age pairs with experience; older farmers could have seen different land uses covers. Therefore, their capacity to identify LD is higher (Shiferaw & Holden, 1998; Tesfahunegn, 2018).
Education level	+	Educated farmers are expected to have more contacts with extension workers, thus they are more aware of risks (Asrat et al., 2004). Furthermore, lack of formal education has been linked to higher deforestation (Davies et al., 2010; Geist & Lambin, 2002; Hasan & Kumar, 2020; Shiferaw & Holden, 1998).
Participation to labour	+	Degraded lands usually require more labour and labour availability is a condition for both agricultural expansion and intensification. Therefore, this variable would have a positive impact (Gashu & Muchie, 2018; Reenberg et al., 1998).
Household size	–	We hypothesize a negative effect on perception as larger households could be less aware of LD and more concerned with increasing yields by all means and maximizing the use of available natural resources because of poverty (Barbier & Hochard, 2018; Gashu & Muchie, 2018; Qasim et al., 2011).
Land under cultivation (%)	+	Farmers with larger exploitation are more involved in soil and water conservation activities (SWC) and more aware of climate factors, (Biratu & Asmamaw, 2016; Sanogo et al., 2017).
Agricultural training	+	We hypothesize that trained farmers have been exposed to different SWC techniques, hence increasing their capacity to recognize LD (Assefa & Hans-Rudolf, 2016; Qasim et al., 2011; Tesfaye, 2017)
Plots combined in one unit	+	Farmers with multiple units tend to abandon least productive units in favour of productive ones. Besides, applying management practices across several units requires additional labor with financial implications (Teshome et al., 2014)
Practice of fallowing	+/–	Farmers are familiar with fallowing and its benefit for soil fertility (Dawoe et al., 2012; Gray, 1999). We do not propose a specific hypothesis for fallowing, those who practice it and those who have abandoned it use similar reasons.
Famine as a result of drought	+	We hypothesize this variable would have a positive impact on farmers' perception. Famine is sometimes perceived as a consequence of drought (Gautier et al., 2016)
Use of chemical fertilizer	+	It is reported that farmers utilizing fertilizer would do so to compensate for soil fertility as a result of the shortened fallow period and LD (Gray, 1999; Saïdou et al., 2004; Thapa & Yila, 2012).
Growing trees on your farm	+	Trees on farms not only tend to improve fertility, but they also protect crops against wind erosion (Gray, 1999; Sterk, 2003). We assume farmers plant trees to mitigate LD amongst other benefits. .
Appearance of new species	+	Appearance of species that farmers relate to LD, would positively impact their perceptions (Tesfahunegn, 2018).
Firewood shortage	+	Excessive firewood extraction has in many cases lead to vegetation degradation and deforestation (Doso, 2014). We hypothesize that shortage of firewood, would positively affect farmers' perceptions on LD. Less firewood means fewer trees, consequently higher exposure to LD
Use of marginal lands	+	We hypothesize this variable would have positive effect on farmers' perceptions (Lal, 2001; Reenberg et al., 1998)
Livestock	+	Livestock grazing and trampling have been identified as cause of vegetation and soil degradation in the Sahel (Hiernaux et al., 1999; Savadogo, Sawadogo, & Tiveau, 2007). We hypothesize a positive a positive impact on farmers' perceptions of LD

2.3.2 | Climate data

Mann-Kendall (MK) test and Sen's slope method

To test for the existence of a monotonic upward or downward trend for the precipitation variable over time, we applied the widely used Mann-Kendall (MK) non-parametric statistical test (Ahmad et al., 2015; Fahmi et al., 2015; Mallik, Chowdhury, Ahasan, Akhter, & Hasan, 2016). In this test, the null hypothesis H_0 is that there are no trends; the alternative hypothesis is that there is a trend that could either be negative, positive, or non-null (Mann, 1945). The MK test uses the following formula based on the *S* statistics to calculate the sum of differences:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(x_j-x_i)\text{ and }\operatorname{sgn}(x_j-x_i)=\begin{cases}1\text{ if }(x_j-x_i)>0\\0\text{ if }(x_j-x_i)=0\\-1\text{ if }(x_j-x_i)<0\end{cases},\quad(1)$$

where n represents the number of data points, x_j and x_i are the annual observations. The variance of S is calculated as follows for $n < 10$:

$$\text{var}(S)=\frac{1}{18}[n(n-1)(2n+5)].\quad(2)$$

For $n > 10$, the variance of S is calculated as:

$$\text{var}(S)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{p-1}^{q}t_p(t_p-1)(2t_p+5)\right],\quad(3)$$

where q represents the number of repeated sets or tied groups, t_p represents the number of data values in the pth group. The Z statistics tests the null hypothesis. H_0 is rejected if $|Z| > Z_{1-\alpha/2}$, which is 1.96 at $\alpha = 0.05$ from the standard cumulative distribution table. The Z value is:

$$z=\begin{cases}\dfrac{S-1}{\sqrt{\text{var}(S)}}\text{ if }S>0\\0\quad\text{ if }S=0\\\dfrac{S+1}{\sqrt{\text{var}(S)}}\text{ if }S<0\end{cases}.\quad(4)$$

In a positive (upward) trend, Z is positive, and a negative Z value indicates a downward trend. Assuming there is a linear trend, we use Sen's non-parametric method to assess its magnitude (Mallik et al., 2016). The slope estimates of the data points are:

$$Qi=\frac{x_j-x_k}{j-k}\quad(5)$$

where x_j and x_k are data points, with $j > k$. For n values of x_j in the time-series, the median of $N = n(n - 1)/2$ is Sen's estimator of slope. The Sen's estimator is:

$$Q=Q_{[(N+1)/2]}\quad\text{if }N\text{ is odd or}$$
$$Q=\frac{1}{2}\left(Q_{[N/2]}+Q_{[(N+2)/2]}\right)\quad\text{if }N\text{ is even}\quad(6)$$

We used the MAKESENS software to apply the MK test and to perform the Sen's method to estimate the slope (Salmi, Maatta, Anttila, Ruoho-Airola, & Amnell, 2002).

Standardized precipitation evapotranspiration index (SPEI)

The Standardized Precipitation Index (SPI) is a precipitation-based universal meteorological drought index developed by Mckee, Doesken, and Kleist (1993) and adopted by the World Meteorological Organization (WMO). The SPI is extensively used to identify dry and wet conditions and their intensities; it produces positive values to indicate rainfall surplus, drought events, and their intensity are reflected with negative values. However, because it relies only on precipitations data, the SPI fails to account for changes in drought conditions (Vicente-Serrano, Beguería, & López-Moreno, 2010). Temperature rise has been proven to affect the intensity of droughts (Carré et al., 2019; Ndehedehe, Agutu, Ferreira, & Getirana, 2020); it is therefore, crucial to account for temperature and potential evapotranspiration (PET) in assessing drought conditions. To remedy this situation, we used the SPEI, which is a drought index based on temperature and PET (Vicente-Serrano et al., 2010), for a better assessment of drought events. SPEI is calculated as:

$$\text{SPEI}=W-\frac{C_0+C_1W+C_2W^2}{1+d_1W+d_2W^2+d_3W^3},\quad\text{where }W=\sqrt{-2\ln(P)}\text{ for }p\le .5,\quad(7)$$

C_0, C_1… C_i, and d_1, d_2…d_i are constants, P represents the probability of exceeding a determined D value (Vicente-Serrano et al., 2010). For PET calculation we have used the Thornthwaite equation (Thornthwaite, 1948), SPEI statistics were calculated using package SPEI (*v1.7*; Begueria, Serrano, & Sawasawa, 2017), on R 3.5.0 (R Core team, 2015).

3 | RESULTS

3.1 | Socio-economic and demographic characteristics

Out of the 270 heads of household interviewed, 64% of them were male, and 92% of them were residents of their respective villages and established there for many generations (Table 2). Farmland is generally acquired through inheritance for the majority of the respondents (93%) or through the village chief, through a leasing agreement. The vast majority of the respondents (94%) were married. The age of the respondents averaged at 45 years with 21 as minimum and 69 the maximum. Most of the respondents (81%) were illiterate. However, in over half of the households (144), there was at least one member who could read and write in French (the official language). All respondents possessed farmlands, and the average farmland size was 8.0 ha, with the minimum size being 0.5 ha and a maximum of 51.0 ha, and 70% of respondents had farmland larger than 5.0 ha. Cropping was the only source of livelihood for 93% of respondents, and 80% of them considered it a fulltime activity, followed by livestock rearing; others relied on trading activities for their livelihood. It came out from our FGDs that famine and hunger represented their main hardship. Due to population growth, 70% of farmers in Mopti believed croplands were insufficient. Millet was abundantly cultivated in Mopti (72%) and Segou (81%), while in Sikasso maize (28%) and cotton (30%) were favored. During periods of droughts and hardship, the youth migrate to nearby cities, and the villagers depend on money sent from relatives working in urban areas. Women used to engage in gardening and livestock rearing activities during the dry season to

TABLE 2 Socio-economic characteristics of the regions of Mopti, Segou and Sikasso in Mali

Characteristics	Mopti (%) (*n* = 90)	Segou (%) (*n* = 90)	Sikasso (%) (*n* = 90)	Total (%) (*n* = 270)
Gender				
Female	32.40	41.11	27.78	36.30
Male	67.60	58.89	72.22	63.70
Age class				
<25	7.80	3.30	7.80	6.30
25–45	51.10	48.90	51.10	50.40
46–65	40.00	47.78	41.11	43.00
>65	1.10	0.00	0.00	0.40
Household size (number of persons)				
<5	27.80	20.00	17.78	21.90
6–10	52.20	62.22	46.67	53.70
11–15	16.68	17.78	17.78	17.40
16–20	2.17	0.00	12.22	4.80
>20	1.10	0.00	5.56	2.20
Education level				
Primary	94.38	95.55	96.68	95.60
Secondary	5.57	4.44	3.33	4.40
Illiterate	85.50	79.83	78.55	81.00
Farmland under cultivation				
26 to 50%	1.10	0.00	0.00	0.36
51 to 75%	5.60	2.22	2.22	3.30
76 to 99%	36.71	40.00	53.33	43.30
100%	56.67	57.78	44.44	53.00
Main source of livelihood				
Cropping only	88.87	94.44	95.56	92.96
Both cropping and livestock	8.88	3.33	1.11	4.44
Others (trading, therapist, seasonal jobs)	2.25	2.22	3.33	2.60

generate income, but now most of the wells dry-out and water availability is scarce.

3.2 | Agricultural and livelihood characteristics

3.2.1 | Agricultural practices

Variables related to agricultural practices usually constitute the second set of factors that influence farmers' perceptions. As cropping is the main activity across the study sites, 45% of respondents declared the size of their farms remained unchanged for the past 10 years, 39% said they increased, and the remaining 16% have seen a decrease. The main crops cultivated across the climatic gradient are millet by 63% of the respondents, then sorghum by 15% of the respondents; cotton and maize are predominantly grown in the Sikasso region, by 7% of the respondents. Only 2% of the respondents cultivated peanut, usually as a secondary crop. In Mopti and Segou regions, 64% of the farmers practiced intercropping. As for their agricultural practices, soil tillage was standard across the climatic gradient, and 90% of the farmers use draught animal power. The use of tractor concerned only 11% of the respondents of Sikasso.

Regarding yield, 45% of the respondents perceived that it declined, while 40% said it somewhat increased. Famers attributed yield increase to the use of sustainable practices such as agroforestry parklands, reduced tillage, use of soil and water conservation infrastructure (*zaï* pits), increased use of mineral fertilizers and compost, and the use of improved seeds. On the contrary, they attributed decreased yield to the reduced amount of rainfall, the lack of fertilizers, the removal of trees and inherent low fertility of some of the soils. Our survey results suggested that in the three regions, 83% of the farmers use mineral fertilizers on their farms, the highest usage is in Sikasso (95%), then Mopti (80%) and Segou (67.8%). Additionally, preserving and nurturing trees on their farms along with crops is a practice adopted by 90% of the farmers. However, our results revealed that the majority of the farmers do not yet use

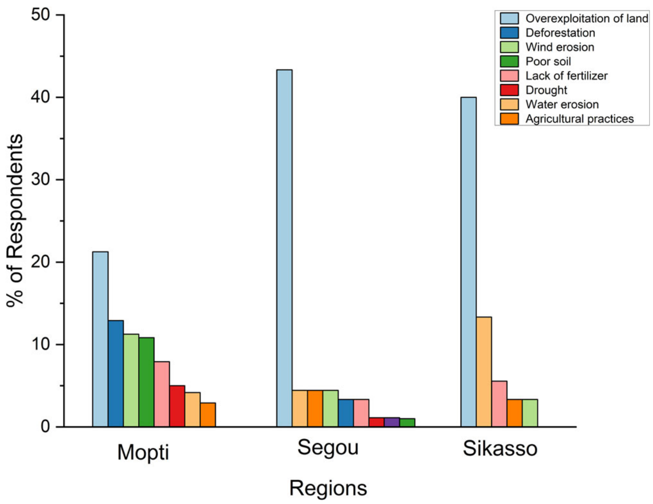

FIGURE 3 Causes of soil fertility decline according to the farmers' perceptions in three study regions of Mali [Colour figure can be viewed at wileyonlinelibrary.com]

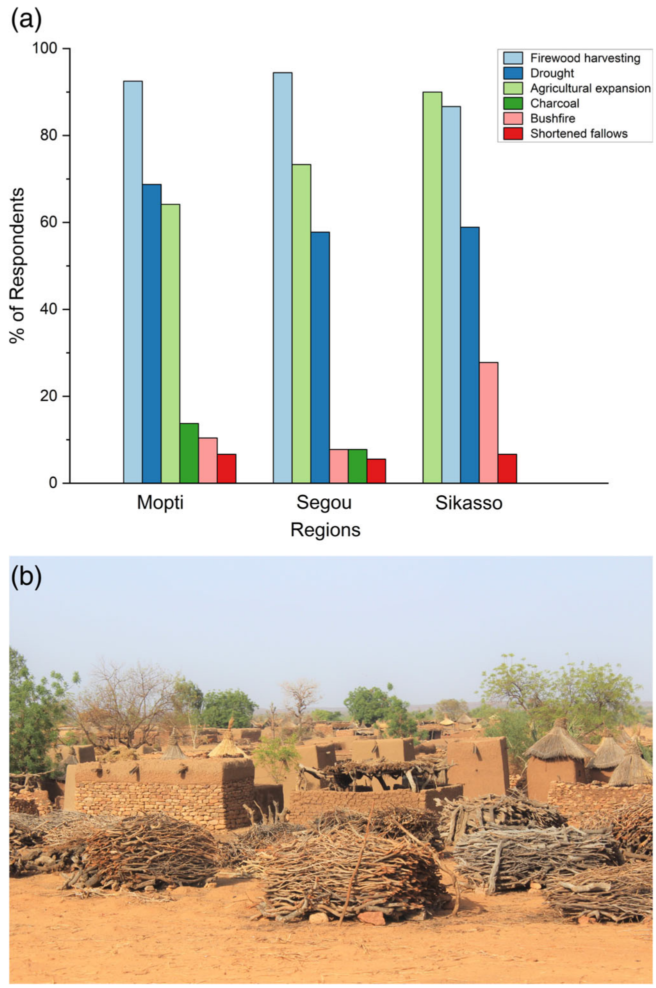

FIGURE 4 (a) Farmers' perceptions of the causes of deforestation in three study regions of Mali. (b) Piles of collected firewood in the village of Kogo, Mopti region [Colour figure can be viewed at wileyonlinelibrary.com]

improved seeds (65.5%), and only 37% of them practiced fallowing. Amongst the perceived causes of LD and soil fertility decline, farmers have identified the overexploitation of land resources for agriculture as the leading cause across all three regions (Figure 3). Of course, this cause appeared less critical in the Mopti region than the two others. Except for water erosion, which is more critical in Sikasso; other causes appear to decrease in percentages going from the north to the south. In the Mopti region, wind erosion and deforestation are perceived by many as the leading causes of soil fertility decline.

3.3 | Deforestation and its impacts

Farmers acknowledged the importance of trees and forests in their communities, 90% of them believed forests are essential for their livelihood. For instance, trees provide firewood, fodder, medicine, shade, and other non-timber forest products, to the benefits of farmers and their livestock. Tree species such as *Adansonia digitata*, *Faidherbia albida*, *Parkia biglobosa*, *Tamarindus indica* and *Vitellaria paradoxa*, several other species are preserved by the communities in parklands throughout the climatic gradient because of the many benefits they provide. According to farmers' perceptions, firewood extraction, agricultural expansion, and drought are the leading causes of deforestation across the climatic gradient (Figure 4). Firewood harvesting remains a key cause of deforestation in farmers' views across the regions; however, when asked about its shortage, 85.6% of farmers perceived it as abundantly available in Sikasso, 74.4% in Segou, only in Mopti did this perception lower to 46.7%. Public forested areas constituted the main sources for firewood extraction for 76.3% of the respondents, and the harvesting distance has increased in the past years to reach 4.3 km for Mopti, 1.7 km for Segou and 2.8 km for Sikasso. As firewood harvesting is generally performed by the women (Figure 4b), we compared the overall responses of male versus female respondents concerning the average distance and average time for firewood harvest. While the female respondents provided an average 4 km as the distance and 90 min as the time, the distance was underestimated by 60%, and the time overestimated by 5% by the male respondents. We further found a significant positive correlation ($r = 0.324$, $p < .01$) between the shortage of firewood and the distance traveled to harvest it.

Drought is another cause of deforestation; its importance is slightly higher in Mopti than in the two remaining regions. Farmers are divided concerning how often they experience drought and famine, those who perceived it (57%) are split between every year (28.5%) and every 3-years (28.5%). Agricultural expansion increases from the north to the south following a gradient of increased availability of more fertile soils. Other causes mentioned by the respondents are bushfire, charcoal production, and shorter fallow cycles. Concerning fallowing, the majority of the farmers do not practice it: 38.9% in Mopti, 37.8% in Segou, and only 35.6% in Sikasso. Income-

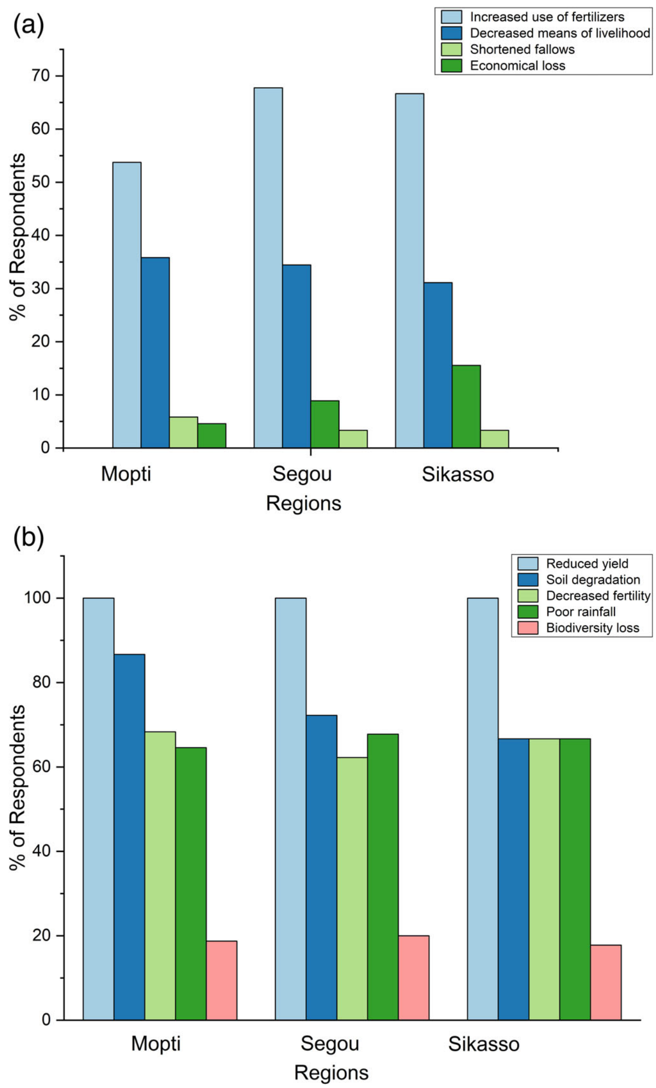

FIGURE 5 (a) Farmers' perceptions of deforestation indirect impacts in the three study regions of Mali. (b) Farmers' perceptions of deforestation direct impacts in the three study regions of Mali [Colour figure can be viewed at wileyonlinelibrary.com]

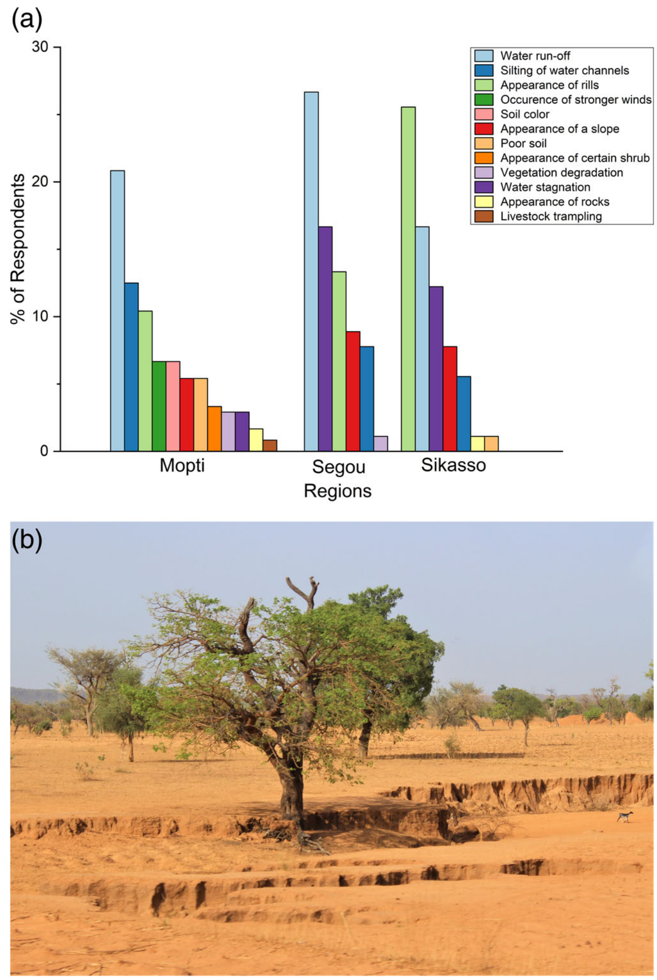

FIGURE 6 (a) Farmers' perceptions of indicators of erosion in three study regions of Mali. (b) Evidence of erosion found during field visit. Large gullies cutting through farmland in Kogo, Mopti region [Colour figure can be viewed at wileyonlinelibrary.com]

generating activities like charcoal production are not perceived to be a cause of deforestation in the wettest Sikasso region, contrary to the situation in Mopti and Segou.

Farmers identified the impacts of deforestation on their communities; we classified them as indirect and direct impacts. For instance, the impact on livelihood, which remained constant across the climatic gradient, or 'economic loss' which was higher towards Segou and Sikasso (Figure 5). 'Increased use of fertilizers', is another indirect impact of deforestation perceived across our study sites; it is, however, more accentuated in the regions of Segou and Sikasso. Concerning direct impacts, farmers consistently perceived 'Reduced yields' across the climatic gradient (Figure 5b). They also perceived 'soil degradation', which decreased in importance progressively across the climatic gradient towards the south. 'Poor rainfall' and 'decreased fertility' were similarly perceived regardless of the region (Figure 5b).

3.4 | Environmental and climatic factors

3.4.1 | Erosion indicators and its causes

Concerning erosion, the majority of farmers have observed it in their farms, in Mopti (87%), Sikasso (80%), and Segou (83%). Farmers have, throughout their practices and experiences, identified several processes that they attribute to erosion. Their perceptions yielded 12 different indicators across the climatic gradient from Mopti to Sikasso (Figure 6). A higher number of indicators are perceived in Mopti. Stronger winds, soil color, the appearance of certain shrub species, and livestock trampling were cited only in Mopti. Four amongst the perceived indicators are rainfall-related and found across the three regions, silting of water channels, appearance of rills (Figure 6b), water stagnation spots in their farms and water run-off. However, 'Water run-off' was more cited in Segou and Mopti, whereas the appearance of rills and gullies were higher in Sikasso. Water stagnation was found more critical in Segou and Sikasso regions.

3.4.2 | Trends in climatic data

The SPEI revealed the existence of droughts and their severity (Figure 7a). Although drought events occurred in the three regions, they ranged from moderate dry (−1 to −1.49) to severe dry (−1.5 to −1.99). However, for the specified period, only Mopti experienced extreme dryness (−2 and less). Using the rainfall data, the MK test and Sen's slope method produced significant Z score values for Mopti (2.87), Segou (2.94), and Sikasso (3.15), hence confirming the existence of a positive trend for rainfall in the three regions (Figure 7b).

3.5 | Spearman rank-order correlations

3.5.1 | Spearman rank-order

The Spearman rank-order correlation was run to determine the relationships between farmers' perceptions of 'Land degradation' and 15 independent variables. The directions and strengths of the relationships are given in Table 3. Across all three regions, farmers' perceptions of LD positively correlated with agricultural training received from technical partners and the appearance of plant species as low soil fertility indicators; this matched our initial hypotheses on these two variables. However, contrary to our initial hypothesis, farmers' perceptions of LD negatively correlated with firewood shortage with a decreasing gradient from southern to northern regions. In the Mopti region, as hypothesized, livestock and its associated effects had a positive correlation with the perceptions of LD. In Segou, participation in agricultural labour, the practice of fallowing, and famine negatively impacted perceptions of LD, while the percentage of land under cultivation had a positive correlation. In Sikasso, participation in agricultural labour negatively varied with perceptions of LD. Household size and percentage of land under cultivation positively contributed to increasing farmers' perceptions of LD in Sikasso. As for the directions of the correlations, agricultural training, growing trees on farm, the appearance of plant species that signify low soil fertility, and livestock were all identified to have a positive impact on farmers' perceptions of LD across all regions as initially hypothesized. Contrary to our initial hypothesis, participation in agricultural labor, famine resulting from drought, and firewood shortage were found to have negative impacts on perceptions across all regions. The directions of the impacts of the remaining variables could either be positive or negative, as it depends on the specific local context of each region.

4 | DISCUSSION

4.1 | Farmers' perceptions of land degradation and key factors that influence their perceptions

Through this study, we assessed farmers' perceptions of LD along a climate gradient in three different regions. The existence of a climate gradient between the three distinct regions was confirmed by

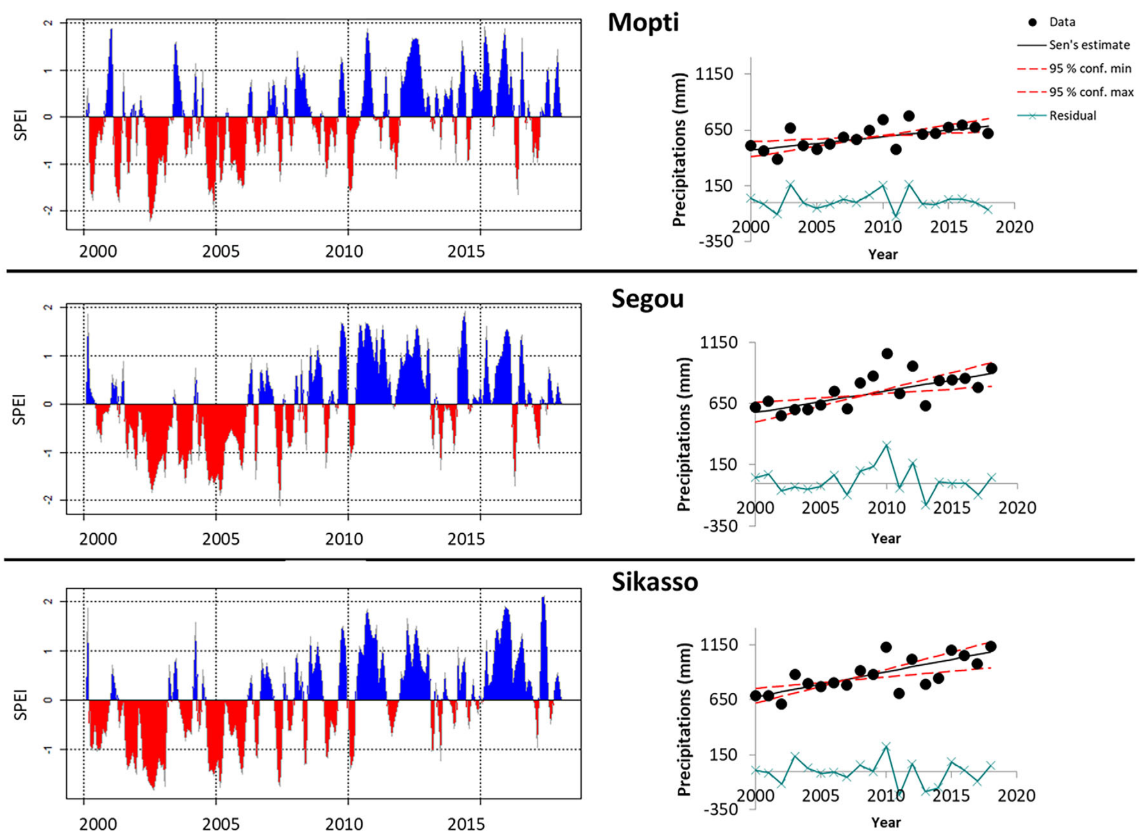

FIGURE 7 Standardized precipitation evapotranspiration indices and Mann-Kendall test and Sen's slope estimates for 19 years, for the regions of Mopti, Segou and Sikasso in Mali. (a) Standardized precipitation evapotranspiration index. (b) Mann-Kendal test [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Spearman rank-order correlations between selected variables (Table 1) and farmers' perception of land degradation (LD) in three study regions (Mopti, Segou and Sikasso) of Mali

		Mopti	Segou	Sikasso
Variables description	H_1	LD	LD	LD
Age	+	0.089	−0.069	0.081
Education level	+	0.059	0.000	−0.116
Participation to agricultural labour	+	−0.141	−0.346**	−0.232*
Household size	–	0.166	−0.003	0.228*
Land under cultivation (%)	+	−0.006	0.469**	0.272**
Agricultural training	+	0.228*	0.233*	0.233*
Plots combined in one unit	+	−0.038	0.000	−0.054
Practice of fallowing	+/−	−0.145	−0.258*	−0.051
Famine resulting from drought	+	−0.032	−0.266*	−0.377
Use of chemical fertilizer	+	−0.080	0.067	−0.198
Growing trees on farm	+	0.163	0.000	0.042
Appearance of plant species that signify soil fertility decline	+	0.250*	0.210*	0.341**
Firewood shortage	+	−0.232*	−0.383**	−0.414**
Expansion of cultivation to marginal lands	+	0.053	−0.071	0.098
Livestock (as cause of degradation)	+	0.314**	0.105	0.094

Note: * and ** represent significance at 5 and 1% level of probability. H_1 represents the initial hypothesis emitted on the direction of the impact of the variable on farmers' perceptions of LD (Table 1).

analyzing climate data and assessing drought severity in each region. We used descriptive statistics to highlight the socio-economic and demographic contexts of the farmers in each of the regions, the causes of fertility decline, and the impacts of deforestation. Our study confirms that farmers across the three regions are aware of LD and they perceive it through a set of variables belonging to their socio-economic and demographic context, their agricultural practices, and the environmental and climatic factors they live under.

Although the three regions belonged to separate agro-ecological zones, the farmers nevertheless shared the same socio-economic and demographic contexts. As most smallholder farmers, their primary concern is to produce enough food to sustain the household needs. Thus, cropping is usually their main activity and sole source of income; this is the case for the majority of our respondents. With insufficient land, they find it challenging to produce enough food for the growing number of household members; at the same time, soil fertility of existing farmlands is decreasing. As an alternate means of livelihood, some engage in trading activities or animal rearing or migrate to urban areas in search of employment. Due to low literacy rates, options to diversify income are very limited. This socio-economic context the farmers live-in, is made-up of many concurring factors that together strongly determine their perceptions of LD and constitute an underlying driver for the eventual practices and measures they would adopt to improve their livelihood.

Farmers' agricultural practices certainly have an impact on the current conditions of their lands. In the three regions, farmers' perceptions of LD correlated with their participation in agricultural trainings. This was similarly found by Nigussie et al. (2017), who suggested that farmers who received training through extension agents were more susceptible to perceive LD; this corroborates with our findings for all regions. Independently of age and education level, training did increase farmers' perceptions of LD. In addition, in Mopti, livestock was perceived as a cause of LD. The role of livestock in relation to vegetation and soil degradation has been debated in the literature (Hosonuma et al., 2012; Orchard et al., 2017), but our results are comforted by findings of Savadogo et al. (2007), that livestock grazing has detrimental effects on vegetation and the soil by reducing its water infiltration rate, thus contributing to water-runoff and erosion. Participation in agricultural labor negatively influenced farmers' perceptions of LD in Segou and Sikasso; households that were more active in labor activities were less inclined to perceive LD. This could be due to the fact that additional labor effort could allow farmers to compensate for the decreasing productivity attributed to LD. Gashu and Muchie (2018) suggest that to meet their income needs, farmers increase labor participation as a means to increase productivity. The shortage of firewood is negatively correlated with farmers' perceptions in the three regions, and the correlation strength increases along the increasing rainfall gradient. This could be explained by the fact that as firewood is an indispensable component of their livelihood, farmers do not concede to its shortage, as it is used daily and multiple times per day. Firewood is their primary source of energy, and its harvesting constitutes one of their main use of the forest. However, we have noted that the collection distance has increased; women in Mopti walk an average of 4.3 km to collect it compared to those in wetter regions of Segou and Sikasso. Alternatively, the lack of firewood shortage could be considered as a perceived abundance; hence, preventing farmers from perceiving LD. However, with the exception of trees such as *A. digitata*, *F. albida*, *P. biglobosa*, *T. indica* and *V. paradoxa*, not many trees were visible in the vicinity of the villages in our study sites. As an example, in the village of Soroly in the Mopti region, trees are sparsely distributed, wind and water erosion are prevalent, farmers have to carry soil materials uphill and surround it with stone blocks in squares to prevent its erosion, they then crop in between the squares.

The environmental and climatic factors contain variables that are clearly perceived by farmers. According to Lal (Lal, 2001), the majority of farmers perceive LD through soil erosion, which is one of its main manifestations, and they consider it severe. This view is persistent across the three regions, regardless of socio-economic or agricultural practices. Davies et al. (2010), Assefa and Hans-Rudolf (2016) further found that farmers are aware of erosion through more apparent signs such as rills and gullies that appear in their farms. This is consistent with our findings, were farmers cite the appearance of rills, water stagnation, and silting of water channels as indicators of erosion. Those signs are generally linked to the biophysical and climatic conditions of the area. Our analysis of the climate data indicated that dryness is common along the gradient and more so in the Mopti region than the other regions. Agricultural drought reduces the amount of water available to crops and is usually caused by soil erosion and poor agricultural practices (Agnew & Warren, 1996). The rainfall pattern is erratic, but the overall rainfall is on an increasing trend. Increased precipitations (Mahé & Paturel, 2009) onto degraded soils without much vegetation cover, leads to water run-off, soil erosion, evaporation, and reduced water availability for optimal crop production (Stroosnijder, 2012).

4.2 | Impacts of LD on farmers' livelihoods

LD primarily affects farmers' livelihoods through decreased productivity, as they principally depend on agriculture. Overexploitation through the shortening of fallow time, inadequate and intensive tilling, and deforestation are putting unsustainable pressure on fragile lands; and on already depleted natural resources. Reduced yields, soil degradation, decreased fertility, poor rainfall, and biodiversity loss are perceived by farmers as LD's direct impact on their livelihood through deforestation. However, farmers' perceptions of deforestation as a driver of LD through erosion and decreased fertility declines progressively along the gradient from drier areas towards the wetter south. We attribute this to increased soil organic matter in the south, which improves soil fertility, structure, water infiltration, and it reduces soil erosion from water-run-off (Bayala & Ouedraogo, 2008; Kusimi, 2008; Lal, 2001; Mortimore & Turner, 2005; Neupane & Thapa, 2001). The results also highlight farmers' perceptions of indirect impact resulting from LD via deforestation. They drive the increased use of fertilizers, the shortening of fallow times, economic loss, and a reduction in the means of livelihood of the communities.

This study provides evidence that farmers perceive LD in the three studied regions across the climatic gradient. The results also suggest that farmers perceive LD differently across the climatic gradient. Their perceptions are correlated to separate variables even though they could be classified into three main categories. LD also impacts communities across the gradient through reduced productivity, deforestation, and erosion. However, as limitations of this study, we acknowledge the subjectivity of studying perceptions, and the seasonality could also have an effect on farmers' perceptions as many of the indicators are rainfall related, conducting the study at the onset of the rainy season may have affected their responses.

5 | CONCLUSIONS

The findings of this study reveal that farmers across a longitudinal climate gradient from the Sahelian region, south to the Sudanian regions of Mali, are well aware of LD. The farmers have also constructed their perceptions of the indicators based on their experiences and ecological knowledge of their local environment. Our results confirm the influence of the climatic gradient on farmers' perceptions through the difference in the number and types of indicators used. We understand that receiving agricultural training, shortage of firewood, perceiving fertility decline through the appearance of plant species are significantly affecting farmers' perceptions of LD in the Mopti region. Farmers in the Segou region are rather being influenced by their level of participation in agricultural labour, the percentage of their land under cultivation, receiving agricultural training, the practice of fallowing, the shortage of firewood, and perceiving fertility decline through the appearance of some particular plant species. In the Sikasso region, farmers' perceptions are affected by their level of participation in agricultural labor, the percentage of their land under cultivation, receiving agricultural training, the size of the household, the shortage of firewood, and perceiving fertility decline through the appearance of some particular plant species.

Across the climatic gradient, all communities have experienced the consequences of LD, regardless of what affects their perceptions. Meeting the growing demand for food products and other natural resources has certainly led many communities, on-the-one-hand, to engage in intensive agricultural practices, leading to shortened fallow times, and on-the-other-hand, to adopt extensive practices that could lead to deforestation and LD. All those paths lead to reduced fertility and lower crop production. Farmers should invest more in sustainable agricultural practices and soil and water conservation techniques they already know, such as agroforestry, stone bunds, *zaï* pits, and tie ridges that have proven their efficiency. All these existing practices should be scaled up through incentives on agricultural investment and policy enforcement. This would result in more resilient landscapes, more productive fields, and an improved livelihood for all the communities living along the climatic gradient.

The outcomes of this study could further be contextualized to serve many of the countries of the Sahelian Zone. As many of the ambitious global initiatives struggle to meet their targets, understanding farmers' perceptions of LD at the local level across the Sahel could facilitate the adoption of better-contextualized restoration strategies.

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