Farmers’ Perception and Adaptation Strategies to Climate Change in Central Mali

Traoré Amadou, a, b Gatién N. Falconnier, a Koureßy Mamoutou, a Serpantié Georges, c B. A. Alassane, a Affholder François, b Giner Michel, b and Sultan Benjamin c

a Institut d’Économie Rurale, Bamako, Mali
b AIDA, Université Montpellier, CIRAD, Montpellier, France
c ESPACE-DEV, Université Montpellier, IRD, Université Guyane, Université Réunion, Université Antilles, Université Avignon, Avignon, France

(Manuscript received 12 January 2021, in final form 13 September 2021)

ABSTRACT: Adaptation of the agricultural sector to climate change is crucial to avoid food insecurity in sub-Saharan Africa. Farmers’ perception of climate change is a crucial element in adaptation process. The aim of this study was (i) to compare farmers’ perception of climate change with actual weather data recorded in central Mali, (ii) to identify changes in agricultural practices implemented by farmers to adapt to climate change, and (iii) to investigate the link between farmers’ perception of climate change and implementation of adaptation practices. Focus group discussions and individual surveys were conducted to identify climate-related changes perceived by farmers and agricultural adaptation strategies they consider relevant to cope with these changes. A majority (>50%) of farmers perceived an increase in temperature, decrease in rainfall, shortening of growing season, early cessation of rainfall, and increase in the frequency of dry spells at the beginning of the growing season. In line with farmers’ perception, analysis of climate data indicated (i) an increase in mean annual temperature and minimum growing season temperature and (ii) a decrease in total rainfall. Farmers’ perception of early cessation of rainfall and more-frequent drought periods were not detected by climate data analysis. To cope with the decrease in rainfall and late start of the growing season, farmers used drought-tolerant cultivars and implemented water-saving technologies. Despite a perceived warming, no specific adaptation to heat stress was mentioned by farmers. We found evidence of a link between farmers’ perception of climate change and the implementation of some adaptation options. Our study highlights the need for a dialogue between farmers and researchers to develop new strategies to compensate for the expected negative impacts of heat stress on agricultural productivity.

KEYWORDS: Social Science; Climate change; Adaptation; Agriculture; Land use; Societal impacts

1. Introduction

Sub-Saharan Africa staple production must increase to feed a rapidly growing population (FAO 2006a). Agricultural production in this region is strongly affected by the variability in seasonal rainfall regimes (Sultan et al. 2005). With high dependence on rain-fed agriculture and limited adaptive capacity (i.e., individual and collective skills to respond to environmental and socioeconomic changes) resulting from lack of resources and technologies, sub-Saharan Africa will be one the most vulnerable regions of the world to climate change (Sultan and Gaetani 2016). Food security “exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO 2006b). Changes in temperature, rainfall, and frequency of extreme events may negatively impact crop yield and food availability (Ouedraogo et al. 2010; Sultan et al. 2013) and also other aspects of food security such as accessibility and utilization (Hamani 2007).

Supplemental information related to this paper is available at the Journals Online website: https://doi.org/10.1175/WCAS-D-21-0003.s1.

Corresponding author: Traoré Amadou, traoreamadou2000@gmail.com; amadou.traore@ier.ml

DOI: 10.1175/WCAS-D-21-0003.1

© 2021 American Meteorological Society. For information regarding reuse of this content and general copyright information, consult the AMS Copyright Policy (www.ametsoc.org/PUBSReuseLicenses).
(Thomas et al. 2007). However, the current literature on this topic does not give a clear-cut picture. In affluent countries, farmers who perceived the potential consequences of climate change on their immediate environment showed a firmer intention to take action and get involved in adaptation programs (Arbuckle et al. 2013; Niles et al. 2013). These intentions, however, seldom translated into effective implementation (Niles et al. 2016). In developing countries, where farmers are often more hard hit, several studies have shown the direct connection between perception of climate change and effective implementation of adaptation practices. For instance, Lalou et al. (2019) and Muller et al. (2015) showed that farmers in Senegal perceived accurately the recent recovery in rainfall and reused an old variety of millet that was adapted to wetter climate. In the Gambia, farmers who perceived a decrease in growing season length were more likely to implement water-conservation techniques (Bagagnan et al. 2019). But this link between perception and adaptation is not always systematic. For example, only half the smallholders in Central America who perceived a climate change impact implemented an adaptation option (Harvey et al. 2018), pointing to constraints prevailing in smallholder systems related to farm resource endowment, for example, land tenure and lack of financial support or working capacities. More immediate concerns (e.g., food security, financial concerns) were found to be other important predictors of adoption of adaptation practices (Waldman et al. 2019). These complex interactions call for “place based” insights on whether perception of climate change leads to more adaptation.

Another key dimension of the adaptation process is the analysis of the consistency between farmers’ perception and measured climate trends. This investigation is crucial, as farmers’ misinterpretation of climate variations can lead to maladaptation (e.g., denial of the problem) (Grothmann and Patt 2005). Studying perception can also help building a dialogue between researchers and farmers to support colearning of how climate is changing and how such changes are detected on the ground (Flood et al. 2018). Assessing the factors driving perception can help targeting specific groups to raise their awareness of climate change issues. For example, U.S. ranchers’ and farmers’ perception of the occurrence and causes of climate change was influenced by political ideology (Liu et al. 2014). In the smallholder context of south Ethiopia, farm resource endowment mattered as farmers with larger herds and better access to extension services perceived more acutely climate change (Debela et al. 2015). Other studies suggest that age or farming experience can be an important driver of perception, as prolonged stay in a given place may facilitate recognition of environmental change, older people having in-depth knowledge of local conditions (e.g., Akerlof et al. 2013; Deressa et al. 2011). Assessing the factors driving perception can also help explain discrepancies between farmers perception and climate records. For example, in the developed context of New Zealand, growth in irrigation facilities shaped a perceived increase in annual rainfall that was not supported by the analysis of historical weather records (Niles and Mueller 2016).

Linking into a comprehensive assessment (i) farmers’ perception of climate change and observed trends in weather records and (ii) farmers’ perception and implementation of adaptation can bring crucial insights for the codesign of sound adaptation strategies that fit the needs of smallholder farmers.

Central Mali, where annual rainfall fluctuates between 700 and 900 mm (Traore et al. 2013), is representative of land-constrained sub-Saharan Africa, with high population density and limited land availability for agriculture expansion, and degradation of animal grazing areas exerting pressure on livestock systems. The majority of rural people in the region are vulnerable to climate variability and change (Sivakumar et al. 2005). In this study, we focused on this constrained region and aimed at (i) analyzing farmers’ perception of ongoing climate change, their drivers, and their consistency with past climate observations, (ii) identifying the adaptation strategies implemented by farmers to adapt to climate change, and (iii) testing whether perception of climate change by farmers impacted the implementation of adaptation strategies. By doing so, we explored the hypotheses that (i) farmers in the study area perceive climate change through local modification of their immediate environment, (ii) farmers perception of climate change and the analysis of historical weather data align, (iii) farmers who perceived climate change are more likely to implement adaptation strategies, and (iv) covariates like farmer age and farm resource endowment are drivers of perception of climate change and implementation of adaptation strategies. Farmers’ perception of climate change and adaptation options were identified during focus groups discussions followed by individual farm-level surveys to analyze the connection between perception and adaptation strategies implemented by farmers. A long-term series of meteorological data recorded at two stations in central Mali was analyzed to compare climate change with farmers’ perception.

2. Material and methods

a. Study area

The study was conducted in the Béguéné village in central Mali (12°91’N, −5°91’ W), in the northern part of the cotton growing area (Fig. 1). Advice on agricultural techniques is provided by extension workers of the Malian Textile Development Company (CMDT). The climate of the study area is typical of the Sudanian domain, where annual rainfall ranges between 600 and 1000 mm yr$^{-1}$. The rainy season generally starts in June and ends in October with rain peaks in July and August. Sandy and gravelly soils prevail in the region. Farming systems integrate agriculture and livestock: cattle are used for draft power and manure production, and cereal and legume residues are used as animal feed. The region shares several similar characteristics with smallholder farming systems in semiarid regions of sub-Saharan Africa. Farmers are smallholders, that is, they manage areas in the range 1–10 ha (http://www.fao.org/family-farming/detail/fr/273864/; last accessed 10 September 2021). Agriculture in the region is the main livelihood strategy. Agricultural and livestock productivity is low: cereal yield is around 30% of their potential (https://www.yieldgap.org/gygaviewer/index.html?roi_id=6), due to high cost and low use of external agricultural inputs. About one-half the population of sub-Saharan Africa is below...
the $1.90 day$^{-1}$ poverty line (Dzanku et al. 2015), and this holds for this region of central Mali (Falconnier et al. 2018). On top of that, farmers face diverse risks and have to cope with an uncertain production context. Interannual rainfall variability and seasonal rainfall distribution result in great crop yield variability: short rainfall seasons and/or a high number of dry spells lead to strong crop yield decrease (Traore et al. 2013). Socioeconomic and institutional factors, such as the institutional support for cotton production, are also heavily fluctuating (Falconnier et al. 2015), as it is also the case in other countries of sub-Saharan Africa [see, e.g., the collapse of cotton marketing institutions (Ebanyat et al. 2010) and dysfunctional coffee cooperatives (Sassen et al. 2013)]. Africa’s population is growing faster than that of any other continent (Alexandratos 2005). Mali is no exception and ranks among the 10 countries with the fastest population growth rate in the world (Alexandratos 2005). Population pressure causes cropland expansion, at the expense of grazing land (Hiernaux et al. 2009), disturbing the transfers of manure and nutrient from rangelands to cropland, hence threatening the sustainability of farming systems (Powell et al. 1996).

In central Mali, majority of farmers own at least one pair of oxen, a cultivator and a seed drill and use animal traction for soil preparation, weeding and seeding (Falconnier et al. 2015). Most of the cultivated land (70%) is used for cereal production (PASE2 2015). Millet [Pennisetum glaucum (L.) R. Br.] and maize (Zea mays) are the main cereals accounting for 38% and 20% of the cultivated area, respectively, but sorghum cultivation [Sorghum bicolor (L.) Moench] is also significant with 12% (PASE2 2015). Cereals are grown in biennial or triennial rotation with cotton [Gossypium hirsutum (L.)]. Organic and mineral fertilizers, and pesticides, are mainly applied to cotton and maize. Millet and sorghum benefit from nutrient carryovers due to fertilizer applications on cotton or maize.

b. Data collection on farmers’ perception

A combination of focus group discussions to gather qualitative information and individual questionnaires to collect quantitative data are often used to assess farmers’ perception of climate change and adaptation (Dhanya and Ramachandran 2016; Zampaligré et al. 2014). In the present study, we used focus group discussion and individual interviews.

1) FOCUS GROUPS

Three focus group discussions were conducted in April 2017 to gain insights on farmers’ perception of ongoing climate change, following the methods described in Zampaligré et al. (2014). The groups of 15–20 male farmers consisting in a mix of young (aged ~20–40) and old (over 50) people. These groups were formed randomly based on farmers’ willingness to participate with the support of the village chief in organizing the meetings in the village. Farm managers are exclusively men in the region, so our decision to assess the representation of climate was gender-biased. Discussions at each focus group level were facilitated by a researcher or agricultural advisor in the local language, Bamanan. Farmers were asked to elaborate on past and current climate change, focusing sequentially on rainfall, temperature, and wind. When referring to past climate, no specific time horizon was indicated by the facilitator. At the level of each focus group discussion, the questions were a mix of open and close ended-questions: Have you experienced any changes in climate in your community? What do you think of the length of the growing season? What do you think about the
start and end of the growing season in the past and currently? What do you think of temperature in the past and currently? What do you think about wind speed now and in the past? Farmers were also asked about the foreseen impacts of these changes on agricultural production, and the specific adaptation strategies they were implementing to cope with each of the changes in climate variables, that is, rainfall, temperature, and wind.

For questions with regard to changes in rainfall, temperature, and wind, farmers’ answers were noted by the researchers and development workers during the focus group discussion. The most frequent answer to these questions in each of the group was computed based on the transcript of the research assistant in each group, and an aggregated answer (i.e., the most frequent answer among the group) was considered as the final output of the discussion. For answers related to the adaptation strategies, the research team listed all adaptations mentioned in the different groups and this list was the final output.

The synthesis of the focus group discussion work on farmers’ perception and endogenous coping strategies to climate variability and change was presented to the farmers two weeks

<table>
<thead>
<tr>
<th>Table 1. Climate-related changes mentioned by farmers during three focus groups in the Béguéné village in central Mali.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Changes mentioned by farmers</strong></td>
</tr>
<tr>
<td>Decreasing rainfall</td>
</tr>
<tr>
<td>Shorter growing season</td>
</tr>
<tr>
<td>Delayed rainfall</td>
</tr>
<tr>
<td>Early cessation of rainfall</td>
</tr>
<tr>
<td>Increasingly intense rainfall</td>
</tr>
<tr>
<td>More-frequent dry spells at the start of the growing season</td>
</tr>
<tr>
<td>More-frequent dry spells at the end of the growing season</td>
</tr>
<tr>
<td>More-frequent dry spells in the middle of the growing season</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Meteorological indicators, calculation method, and data source.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meteorological indicator</strong></td>
</tr>
<tr>
<td>Total rainfall over the season</td>
</tr>
<tr>
<td>Length of the growing season</td>
</tr>
<tr>
<td>Start date of the growing season</td>
</tr>
<tr>
<td>End date of the growing season</td>
</tr>
<tr>
<td>No. of daily rainfalls above 30, 50, 70 mm</td>
</tr>
<tr>
<td>No. of dry spells at start, end, and middle of the growing season</td>
</tr>
<tr>
<td>Avg max and min temperature per year</td>
</tr>
<tr>
<td>Avg max and min temperature in the growing season</td>
</tr>
<tr>
<td>Avg temperature per year and during the growing season</td>
</tr>
</tbody>
</table>
were assumed to be similar to the ones experienced at B
topography. Therefore, temperatures measured at Koutiala
was significant, pairwise comparisons of periods were performed
from normality or heteroscedasticity. When period effect
0.05. Visual inspections of residuals plots did not reveal devia-
ables was tested with ANOVA using a probability threshold of
Tables 1 and 2. The effect of the factor "period" on these vari-
cent 7-yr period (2011–17) for which no record was available.
analyzed by considering four 15-yr historical periods

2) INDIVIDUAL SURVEYS

Individual surveys with farm managers (63 farms of 75 in
the village) were then conducted in January 2018. The first
objective was to compare the perception obtained during
focus groups discussions with individual perception. A second
objective was to explore whether the mentioned agricultural
adaptation strategies were effectively implemented by the
surveyed farmer. Last, we also wanted to investigate the potential
connection between perception and implementation of adaptation
options. The farm managers surveyed had participated (them-
selves or a member of their farm, e.g., the field manager) in
the previous focus group discussion. Data on farm characteristics,
farmers' perception of climate change (based on the list of changes
mentioned during the focus group discussion), and farmers' ad-
aptation strategies (based on the list of adaptation strategies
mentioned during the focus group discussion) were collected
from a structured questionnaire containing closed-ended questions
(see Table S3 in the online supplemental material). The questions
were administered in local languages by interviewers.

c. Analysis of meteorological data

The changes mentioned by farmers could not directly be
translated into quantifiable indicators, therefore, these per-
ceived changes were converted by the research team into me-
teorological indicators that could be computed with available
weather record (Table 1). Daily rainfall (1951–2017) was ob-
tained from the station closest to the studied village (distance =
13 km), namely N’tarla (12°35’N, 5°42’W; 302 m), and the daily
temperatures (1951–2010) from the Koutiala weather station
(12°23’N, −5°27’W; 350 m) located 40 km away from the study
site. Land cover is similar at Koutiala and Béguené, with flat
topography. Therefore, temperatures measured at Koutiala
were assumed to be similar to the ones experienced at Béguené.
To take into account decadal variability of climate, rainfall data
were analyzed by considering four 15-yr historical periods
(2011–17) representing the current period. Temperatures were
analyzed using the same periods, but we excluded the most re-
cent 7-yr period (2011–17) for which no record was available.
The variables included in the analysis are listed and defined in
Tables 1 and 2. The effect of the factor “period” on these vari-
able was tested with ANOVA using a probability threshold of
0.05. Visual inspections of residuals plots did not reveal deviations
from normality or heteroscedasticity. When period effect
was significant, pairwise comparisons of periods were performed
with a Tukey test. The statistical analysis was performed with
the R software (R Development Core Team 2021).

d. Comparison of meteorological data with farmers’
perception

Farmers’ perception was compared with the trends in me-
teorological indicators computed from the climate data from the two
stations mentioned above. For this analysis, farmer’s perception
was analyzed without considering farmer age or farm type, that is,
all farmers were pooled together for the analysis. When majority
of farmers (i.e., at least 50% of the surveyed farmers) perceived a
given change and the analysis of meteorological data indicated a
significant change in the corresponding meteorological indicator,

<table>
<thead>
<tr>
<th>Change mentioned by farmers</th>
<th>No. of farmers</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainfall</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreasing rainfall</td>
<td>Yes</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>17</td>
</tr>
<tr>
<td>Shorter growing season</td>
<td>Yes</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>6</td>
</tr>
<tr>
<td>Delayed rainfall</td>
<td>Yes</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>11</td>
</tr>
<tr>
<td>Early cessation of rainfall</td>
<td>Yes</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>20</td>
</tr>
<tr>
<td>Increasingly intense rainfall</td>
<td>Yes</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>34</td>
</tr>
<tr>
<td>More-frequent long dry spells at the start of the growing season</td>
<td>Yes</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>24</td>
</tr>
<tr>
<td>More-frequent long dry spells at the end of the growing season</td>
<td>Yes</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>31</td>
</tr>
<tr>
<td>More-frequent long dry spells in the middle of the growing season</td>
<td>Yes</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>39</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasingly hot temperature</td>
<td>Yes</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Increased temperature during the growing season</td>
<td>Yes</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>6</td>
</tr>
<tr>
<td>Nighttime temperature increase</td>
<td>Yes</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>4</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasingly violent winds</td>
<td>Yes</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>12</td>
</tr>
</tbody>
</table>
we considered that farmers’ perception and weather records matched. When the change in the corresponding meteorological indicator was not significant, we considered that there was a discrepancy between farmers’ perception and weather records. When only minority of farmers (i.e., less than 50% of the surveyed farmers) perceived a given change, and the analysis of meteorological data indicated a significant change in the corresponding meteorological indicator, we also considered that there was a discrepancy between farmers’ perception and weather records.

e. Statistical analysis of the drivers of farmers’ perception and the links between perception and implementation of adaptation

To better understand the drivers of farmers’ perception and to investigate the potential link between perception of climate change and implementation of adaptation options, we used logit models (following Niles and Salerno 2018) to estimate (i) perception of climate change and (ii) effective implementation of an adaptation, as binomial responses.

To estimate perception of climate change, the categorical covariates “farmer age” and “farm type” were included in the model. For the “farmer age” covariate, we defined four age groups: 20–39, 40–49, 50–69, and >70. It was assumed that farmers start recalling climate at 15 years of age (Kabore et al. 2019). The 15-yr-period division for climatic data matches the different length of farmers experience of climate change according to their age group (Fig. 2). For the “farm type” covariate, farms were classified into four resource endowment groups according to the typology established by the Agricultural Research Institute of Mali (IER) and the CMDT: type A is a well-equipped farm with a herd of more than 10 cattle and at least four oxen and two ploughs, type B is an equipped farm with two oxen and one plough, type C is a farm with only one ox and/or plough; and type D is a farm without oxen and plough.

To estimate the implementation of an adaptation option, the 11 binomial (yes/no) covariates related to the perception of the 11 changes listed by farmers in Table 3 were included in
the model, that is, “PC” variables, in addition to the “farmer age” and “farm type” covariates.

The log odds of response were estimated as follows:

(Model 1) \( \text{logit}(p_{\text{perception}}) = a + b \text{FT}_j + c \text{FA}_k + R \) and

(Model 2) \( \text{logit}(p_{\text{adaptation}}) = a + b \text{PC1}_j + c \text{PC2}_k + \ldots + l \text{FT}_t + m \text{FA}_u + R \).

In model 1, \( p_{\text{perception}} \) is the probability for a farmer to perceive a given change \( i \) (the 12 changes mentioned in Table 3 were successively investigated), \( \text{FT}_j \) is the \( j \)th level for the “farm type” covariate, \( \text{FA}_k \) is the \( k \)th level of the “farmer age” covariate, \( R \) is the residual, \( a \) is the intercept, and \( b \) and \( c \) are slope coefficients.

In model 2, \( p_{\text{adaptation}} \) is the probability for a farmer to implement and adaptation option \( i \) (the eight adaptation options mentioned in Table 6 were successively investigated), \( \text{PC1}_j \) is the \( j \)th level of the PC1 variable (i.e., the perception of the first change listed in Table 3), \( \text{FT}_t \) is the \( t \)th level for the “farm type” covariate, \( \text{FA}_u \) is the \( u \)th level of the “farmer age” covariate, \( R \) is the residual, \( a \) is the intercept, and \( b, c, \ldots, l, \) and \( m \) are slope coefficients.

The logistic regression models were implemented with the generalized linear model (glm) function in the R software package.

3. Results

a. Climate-related changes mentioned by farmers during focus group discussion

For changes related to rainfall, farmers mentioned a decrease in rainfall, shorter growing season, delayed and early cessation of rainfall, increase in the frequency of dry spells, and an increase in the intensity of rainfall events (Table 1). With regard to temperature, increasingly hot temperature in general, during the night, and during the growing season were reported. Increasingly violent winds were also mentioned (Table 1).

b. Climate-related changes perceived by individual farmers and drivers of perception

Most of the changes related to rainfall mentioned by farmers during the focus group discussions (Table 1) were consistent with those mentioned by the majority of individually interviewed farmers (Table 3). Majority (>50%) of individually interviewed farmers confirmed the listed changes related to rainfall, except the change “increasingly intense rainfall” and “more frequent long dry spells in the middle of the growing season” that were only mentioned by minority of farmers. Changes in temperature and wind as reported during focus group discussions were also consistent with those reported by the majority of farmers during individual interviews (Table 3).
None of the covariates included in the logit model to determine the drivers of perception (see section 2d) were significant: we did not find evidence of a significant impact of farmer age or farm type on the perception of the different climate change indicators.

c. Analysis of measured historical climate indicators

The measured climatic indicators chosen to correspond to the changes mentioned by farmers are given in Table 1. Data sources and computation methods are displayed in Table 2. Because of lack of data, we could not analyze climate indicators related to wind, despite the fact that changes in the frequency of strong winds were mentioned by farmers. Total rainfall over the season significantly differed between periods ($p < 0.001$) (Fig. 3a, and Table S1 in the online supplemental material). Total rainfall over the season decreased during the first three periods (1951–65, 1966–80, and 1981–95), rose again during the fourth period (1996–2010), and decreased during the fifth period (2011–17). The length, start, and end of growing season did not differ significantly between periods (Figs. 3b–d; Table S1). The frequency of intense rainfall (i.e., daily rainfall above 30 mm) differed significantly between periods ($p = 0.002$) (Fig. 4a). The frequency of intense rainfall decreased from 1951 to 1995 and increased onward: it was significantly greater in 1951–65 than in 1981–95. The frequency of daily rainfall above 50 and 70 mm was small and not significantly affected by the period (Figs. 4b,c; Table S1).

The number of 5-, 7-, 10-, 15-, and 20-day dry spells during the start, middle, and end of the growing season did not differ significantly between periods (Figs. 5, 6; Table S1). The average maximum temperature per year differed significantly between periods, with a clear upward trend between the periods of 1981–95 and 1996–2010 (Fig. 7a, and Table S2 in the online supplemental material). Average maximum temperatures during growing season did not differ significantly between periods (Fig. 7b; Table S2). Average minimum temperatures per year and during growing season significantly increased (Figs. 7c,d; Table S2). Average temperatures per year and during growing season significantly increased (Figs. 7c,d; Table S2). Minimum temperatures increased significantly per year and during the growing season (Figs. 7e,f). The greatest annual minimum temperature for 1951–65 was 20.1°C, and that of the period 1996–2010 was 22.8°C, that is, an increase of 2.7°C. The average minimum temperature during growing season increased by 1°C between 1951 and 2010.

d. Comparison of meteorological data with farmers’ perception

Farmers’ perception of changes in climate indicators was sometimes in agreement with the trends highlighted by the
analysis of measured historical climate indicators (Table 4). Measured changes in total rainfall was in line with farmers’ perception. Contrastingly, the analysis of past weather data did not match farmers’ views with regard to length of growing season, delayed rainfall season, earlier cessation of rainfall, and more-frequent dry spells (Table 4): although majority of farmers perceived these changes, they were not supported by the analysis of meteorological data. Also, though the analysis of meteorological data indicated an increase in the frequency of intense rainfall, only minority of farmers perceived such a change. Average temperature per year and the average minimum temperature per year significantly increased in line with farmers perception (Table 4).

e. Adaptation strategies of Béguéné farmers in response to climate change

Farmers indicated during the focus group discussions and individual surveys that they were using adaptation measures to address the perceived climate changes (Table 5, Fig. 8). The use of drought-tolerant sorghum (i.e., early-maturing Djakoumbé and Grinka cultivars) was mentioned as a strategy for coping with decreasing rainfall and growing season length. To cope with the perceived increase in dry spell frequency, farmers also mentioned the use of rock bunds and contour bunds in fields to maintain water in plots. For farmers, rising temperature favored drought stress, so that adaptation to changes in rainfall patterns also addressed the rising temperature issue. Specific adaptation to decrease in crop duration and heat stress at key plant development stages were not mentioned by farmers. Agroforestry and living and dead hedges were mentioned as means to cope with the increase in intense rainfall and violent winds. Surprisingly, rock or contour bunds were not mentioned as a response to increased erosion risk resulting from more intense rainfall events (Table 5).

The analysis of the individual survey showed that maize–cowpea intercropping and drought-tolerant cultivar were adaptation options widely implemented by farmers, whereas dead hedges and living hedges were only seldom implemented.

f. Link between perception and implementation of adaptation strategies

The analysis of the connection between perception of climate change and implementation of adaptation options revealed contrasting relations, perception either increased or decreased the odds of having implemented an adaptation strategy (Table 6).

The perception of an increase in the frequency of long dry spells at the beginning of the growing season significantly
increased the odds of having implemented rock bunds by a factor of 2.6 (1.7–187.7). Similarly, the perception of an early cessation of rainfall significantly increased the odds of having implemented sorghum–cowpea intercropping by a factor of 3.1 (2–1477). On the other hand, the perception of a decrease in rainfall significantly decreased the odds of having implemented contour bunds [0.0 (0.0–0.7)] and sorghum–cowpea intercropping [0.0 (0.0–0.2)]. Similarly, the perception of an increase in the frequency of dry spells at the end of the growing season had a significant effect to reduce the odds of implementing rock bunds [0.2 (0.0–0.9)] and the perception of an increase of the frequency of dry spells at the beginning of the growing season significantly decreased the odds of having implemented agroforestry [0.1 (0.0–0.8)]. The perception of
increasingly violent winds also significantly decreased the odds of having implemented agroforestry [0.1 (0.0–0.9)].

The farm type covariate also mattered. Lower farm endowment (i.e., types B, C, and D as compared with type A) significantly decreased the odds of having implemented water-conservation techniques (i.e., rock bunds and contour bunds). Conversely, age groups did not significantly alter the odds of implementing any of the adaptation options. For the widely implemented adaptation options “drought-tolerant cultivar” and “maize–cowpea intercropping,” no significant effect of perception, farmer age and farm type could be found. Similarly, for the very seldom implemented adaptation options “living hedge” and “dead hedge,” no significant effect of perception, farmer age and farm type could be found.

4. Discussion

Our comprehensive assessment of the two-step process of adaptation provides crucial insights for farmers and researchers to develop a common understanding of the impact of climate change on crops and to design site-specific strategies to offset the expected negative impacts of climate change. In what follows, we successively discuss (i) farmers perception of climate change and their drivers, (ii) the comparison between farmers’ perception and meteorological data, (iii) the relevance of farmer-identified adaptation strategies, and (iv) the connection between farmers’ perception and implementation of adaptation strategies.

a. Farmers’ perception of climate change and their drivers

Farmers’ perceptions of a delay, decrease and early cessation of rainfall revealed in our study was also found in another study in Sudanian West Africa (Zampaligré et al. 2014). Studies on individuals’ perceptions of climate change in high-income countries found an influence of age on perception (Li et al. 2011; Weber and Stern 2011). This also held true for populations similar to the one of our study site, that is, smallholder farmers in subhumid and semiarid Ethiopia (Deressa et al. 2011; Habtemariam et al. 2016), possibly because elderly farmers have experienced the relations between agriculture and their environment for a longer time and detect climate change more easily than young farmers. However, we did not find a significant link between farmers’ age and farmers’ perceptions (see section 3b). In our study, a majority of farmers, whatever their age, perceived the changes in the other indicators mentioned during the focus group discussions, for example the increase in the frequency of violent winds. This is in line with the study of Rodriguez-Cruz et al. (2021) in Puerto Rico that found no relationship between age and farmers’ perception of climate change, possibly because in places with constant climate shocks age matters less than...
direct experience of extreme event. However, this also contrasts with the finding that extreme climatic events usually have a stronger impact on the minds of younger people than of older people (Marx et al. 2007; Weber and Stern 2011). Possibly, our sample of study farmers was not large enough to detect such an effect of farmer age, and future research should aim at unraveling the context-dependent contribution of age and direct experience of extreme event in explaining farmers’ perceptions.

Farm managers being exclusively male in the region, we did not account for possible differences between men and women in the way climate change is perceived and adaptation are conceived or practiced. We assumed that adaptation of farming to climate change will impact the whole production system, with a predominant role of the farm manager in designing and implementing these adaptations. However, we acknowledge that female farm workers have a significant and sometimes specific role in decisions relative to crop and farm management in West Africa (Lado 1992; Ogunlela and Mukhtar 2009), and that gender can influence the perception of climate change (Habtemariam et al. 2016). Some specific fields, crops or management practices are under women sole responsibility; women may have their own, specific perception of climate change as well as their own views on relevant adaptation. These would have to be accounted for in studies focusing on the way innovative practices emerge from the experience of farmers.

Education is also a crucial covariate than can help explain farmers’ perception, better-educated farmers often more acutely perceiving climate change (e.g., Roco et al. 2015). We did not investigate this factor, and this would deserve more specific attention in future studies aiming at identifying the drivers of farmers’ perception to assist the design of projects and programs to enhance the understanding of climate change by farmers.

**b. Comparison of farmers’ perception of climate change with meteorological data**

Human perception of climate is influenced by farmers expectations, and its correlation with the nature of climate as provided by data recorded with scientific instruments may be limited or nonexistent (Rebetez 1996). The most salient changes perceived by farmers in this study were related to temperature and rainfall. This is not surprising because these two variables have a direct influence on agricultural production.

Farmers’ perception of an increase in temperature during growing season and at night was consistent with the significant increase in average and minimum annual and seasonal
temperatures provided by the analysis of measured climate data. Kosmowski et al. (2015) also found consistency between temperature records and farmers’ perceptions in Benin and Senegal. Farmers’ perception of change in rainfall was in line with climate data analysis (see section 3d) that showed a decrease in total rainfall.

However, some discrepancies were depicted. The increase of the intensity of intense rainfall events was only perceived by a minority of farmers, though such a change was supported by our analysis of meteorological data, and also by studies covering the broader West African region (Taylor et al. 2017). Farmers perceived an early cessation of rainfall and an increase in the frequency of dry spells during the growing season that could not be detected with the analysis of climate data (see section 3d). Meze-Hausken (2004) and Zampaligr et al. (2014) also found that farmers often perceived long-term rainfall trends in a more negative way than indicated by weather records. An explanation of such discrepancies could possibly lie in farmers’ dependence on seasonal rainfall to meet household food demand. Years when production decreases and impact household food availability will likely be considered as bad by farmers. The cause of poor performance is not necessarily related to rainfall and may include other factors, including household economic situation (Osbaugh et al. 2011).

The neat perception of farmers of an increase in the frequency of violent winds, which can damage crops, is also reported by several authors in West Africa (Ouedraogo et al. 2010; Vissoh et al. 2012). Precise wind data, which were not available in our case, would be required for assessing the consistency between farmers’ perception and meteorological facts with regard to this variable. A fine time resolution of wind speed recording would probably be necessary to capture very short and very intense wind blasts that may severely damage crops. Unfortunately, the network of weather stations in sub-Saharan Africa is notably precarious, and, when measured, wind speed is at best a daily average, in which such blasts may be completely indiscernible.

c. Relevance of the agricultural adaptation strategies mentioned by farmers

Adaptation refers to the strategies adopted by farmers to cope with climate variability and change and its adverse effects on their agricultural activities. The diversity of adaptation measures mentioned and implemented by farmers (Table 5 and Fig. 8) indicated their awareness of and willingness to mitigate the impacts of climate change.

In the study area, rain-fed crops are highly dependent on rainfall duration, distribution, abundance, or deficit. Insufficient water supply to crops during seed filling can decrease yield by 40% (Barron et al. 2003). Farmers mentioned implementation of water-conservation techniques (contour bunds and rock bunds) to cope with the decrease in rainfall and the increase in the frequency of dry spells. Water-conservation techniques can improve water availability for crops thus reducing the impact of water stress (Birhanu et al. 2019; Dumanski et al. 2006; Gigou et al. 2006). Intercropping of cereals and legumes, another adaptation strategy mentioned and implemented by farmers, improves productivity per unit area through more efficient water use, which could mitigate the impact of an increase in water stress (Balde et al. 2011; Rezig et al. 2010; Tsubo et al. 2003; Yang et al. 2011). Drought-tolerant (i.e., short duration) varieties were also mentioned by farmers as an option for adapting to changes in rainfall patterns in contrast to their local long duration varieties. The modern cultivars Grinkan and Jakumbe mentioned by farmers have shorter duration, are less sensitive to photoperiods and have a greater harvest index than the traditional cultivar. They were found to be more adapted to future climate than the traditional cultivar, in addition to providing higher yields with current climate (Sultan et al. 2014). Rise in temperatures leads to greater evapotranspiration and can favor the occurrence of water stress on crops. Therefore, for farmers, adaptation to changes in rainfall patterns also addressed the rising temperature issue.

Agroforestry was mentioned by farmers as a strategy for adapting to climate variability and change. For farmers, agroforestry techniques (i.e., the maintenance of existing parklands, the plantation of hedges) improves soil fertility and reduce wind and water erosion of agricultural land. In line with farmers expectations, Reij et al. (2009) found that the agroforestry techniques had enabled farmers in southern Niger to regenerate and reduce soil erosion due to wind.

d. Link between farmers’ perception of climate change and implementation of adaptation options

The analysis of the connection between perception of climate change and implementation of adaptation options did not fully support our initial hypothesis that perception drives the implementation of adaptation options. On the one hand, the connection held true for sorghum–cowpea and rock bunds that were implemented more often by farmer who perceived more-frequent dry spells at the beginning of rainy season, or early cessation of rainfall. Such finding is in line with other studies showing that farmers perceiving a change were more likely to implement water-conservation practices (Deressa et al. 2009). Interestingly, the two perceived changes that triggered the implementation of water-conservation techniques were not supported by the analysis of meteorological data. We could conclude here that misinterpretation has been driving the implementation of adaptation option, with a risk of maladaptation that could increase the negative impacts of climate change (Grothmann and Patt 2005). However, these water-conservation techniques help address the issue of a decreasing rainfall (that was in agreement with meteorological data), and therefore the risks of “wrong” adaptation are limited.

There was also substantial evidence for the opposite connection, that is, farmer who did perceive a change were less likely to have implemented an adaptation option. This could be understood in the light of a relation between the impact of the option on cropping systems sensitivity to climate change, for example, farmers who did not implement agroforestry (i.e., who did not keep a dense and diverse tree network in their fields) were more likely to actually experience an increase in violent winds. Similarly, farmers who did not implement water-conservation techniques (i.e., rock and contour bund) were more likely to perceive a decrease in total rainfall and an
TABLE 6. Logit model estimates of the effect of variables related to perception of climate change, farm type, and farmer age on the implementation of adaptation strategies by farmers in one village of central Mali. Positive log odds indicate greater probability of implementation. Results that are statistically significant within a 95% confidence interval are in boldface type. The effect of variables for the adaptation options “drought-tolerant cultivar,” “living hedge,” “dead hedge,” and “maize–cowpea intercropping” was not displayed because none of the variables add a significant effect. Here, CI = confidence interval, LB = lower bound, and UB = upper bound.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rock bunds</th>
<th>Contour bunds</th>
<th>Sorghum-cowpea intercropping</th>
<th>Agroforestry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Log odds</td>
<td>Odds</td>
<td>95% CI LB</td>
<td>95% CI UB</td>
</tr>
<tr>
<td>Perception of climate change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreasing rainfall</td>
<td>−1.1</td>
<td>0.3</td>
<td>0</td>
<td>3.7</td>
</tr>
<tr>
<td>Shorter growing season</td>
<td>0.6</td>
<td>1.8</td>
<td>0</td>
<td>91.2</td>
</tr>
<tr>
<td>Delayed rainfall</td>
<td>0.3</td>
<td>1.3</td>
<td>0.1</td>
<td>14</td>
</tr>
<tr>
<td>Early cessation of rainfall</td>
<td>−0.4</td>
<td>0.7</td>
<td>0.1</td>
<td>7.4</td>
</tr>
<tr>
<td>More-frequent long dry spells at the beginning of growing season</td>
<td>2.6</td>
<td>14.1</td>
<td>1.7</td>
<td>187.7</td>
</tr>
<tr>
<td>More-frequent long dry spells at the end of growing season</td>
<td>−1.7</td>
<td>0.2</td>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>More-frequent long dry spells in the middle of growing season</td>
<td>1.5</td>
<td>4.4</td>
<td>0.7</td>
<td>38.1</td>
</tr>
<tr>
<td>Increasingly intense rainfall</td>
<td>−1.7</td>
<td>0.2</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>Increasingly hot temperature during the growing season</td>
<td>−15.6</td>
<td>0</td>
<td>−&gt;10^6</td>
<td>15</td>
</tr>
<tr>
<td>Increasingly violent winds</td>
<td>−1.7</td>
<td>0.2</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>Farm type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type CDMT B</td>
<td>−1.7</td>
<td>0.2</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>Type CDMT C</td>
<td>−4.2</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>Type CDMT D</td>
<td>−2.5</td>
<td>0.1</td>
<td>0</td>
<td>1.1</td>
</tr>
<tr>
<td>Farmer age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39–49 years old</td>
<td>2.2</td>
<td>8.9</td>
<td>0.4</td>
<td>629.7</td>
</tr>
<tr>
<td>49–69 years old</td>
<td>2.6</td>
<td>13.1</td>
<td>0.9</td>
<td>664.4</td>
</tr>
<tr>
<td>Above 70 years old</td>
<td>−0.3</td>
<td>0.8</td>
<td>0</td>
<td>47.8</td>
</tr>
</tbody>
</table>
increase in the frequency of dry spells at the end of growing season, probably because their soil could store less water. This connection between perception and infrastructure that modify water availability in farmers’ fields was also evidenced for farmers in New Zealand (Niles et al. 2016). This interaction between farm management, cropping system sensitivity, and farmers’ perception (Simelton et al. 2013) could also possibly explain why some changes perceived by farmers (e.g., more-frequent dry spells) could not be supported by the analysis of climate data.

Farm type was an important variable driving the adoption of water-conservation techniques. Less wealthy farms of type B, C, and D were less likely to have implemented water-conservation techniques, thus confirming that, though perception matters, other constraints related to farm resource endowment need to be alleviated for adoption to happen (Harvey et al. 2018). Rodríguez-Cruz and Niles (2021) also found that implementation of adaptation practices is explained more by structural factors (e.g., social networks, governance systems and infrastructure) than by individual farmers’ perception. Possibly, constant exposure to climate-related hazards acts to lower the importance of individual perception in the adaptation process (Rodríguez-Cruz and Niles 2021). Overall, these findings highlight the need for future research on how context influences the link between perception and implementation of adaptation (e.g., climate change hot spots where climate-related hazards are frequent as compared with less-exposed regions). Broader institutional barriers (e.g., lack of resources to implement a given adaptation option) should also be investigated.

Some of the perceived changes, and notably the “increasingly intense rainfall,” were not connected to the implementation of any adaptation option. This is worrying, given the fact that the issue is real (Taylor et al. 2017). Although not mentioned directly by farmers, cereal-legume intercropping and the associated improved soil cover and denser root system could help reduce drainage and loss of nutrients when intense rainfall events occur (Walker and Ogindo 2003; Zougmore et al. 2000). Also, farmers did not mention rock and stone bunds to prevent soil erosion associated with the increase in intense rainfall events. Rock and stone bunds can prevent soil loss on farmers’ plots and thus preserve essential nutrients (Birhanu et al. 2019; Dumanski et al. 2006; Gigou et al. 2006). Similarly, the perceived changes in temperature, also supported by the analysis of meteorological data, was also not connected to the implementation of any adaptation options. Rising temperatures impact crop growth and yield through several processes. Above-threshold temperatures reduce radiation-use efficiency (Idso 1991; Stockle et al. 1992). Rising temperature accelerates crop development and shortens crop cycle, which reduces the amount of solar radiation intercepted, crop biomass and grain yield (Sultan et al. 2014, 2013). Thermal stress during crop’s reproductive stage can cause a drop in grain number, with negative impact on grain yield (Gérarddeaux et al. 2015). For example, with night temperature increase from 22°C to 28°C, Prasad and Djanguiriman (2011) showed an increase in the sterility of sorghum spikelet. Hatfield et al. (2011) and Hatfield and Prueger (2015) showed that increases in minimum air temperature can have negative effect on maize and sorghum growth and phenology. Excessive temperature increase would significantly reduce average yields and variations in precipitation would only modulate the magnitude of this negative impact (Sultan et al. 2013). Surprisingly for the research team, specific adaptation to the decrease in crop duration and heat stress at key plant development stages were not mentioned by farmers. According to Guan et al. (2017), switching from traditional cultivar to a modern cultivar with increased tolerance to high temperatures could offset the decrease in yield associated with an increase in temperature during grain set.

These two examples of a change in climate indicator that was both supported by the analysis of meteorological data and perceived by farmers, but for which no adaptation was implemented by farmers, highlights the need for development efforts that strengthen the dialogue between farmers and researchers to develop a common understanding of the impact of climate change on crops and to design site-specific strategies to offset the expected negative impacts of climate change. Current top-down extension approaches, based on the technology transfer model, may not support the development of this shared vision. Methods related to social learning (Coudel et al. 2011), including collective diagnosis and serious games (Flood et al. 2018), will be essential to build trust and knowledge sharing between researchers and farmers. The identification and involvement of wider stakeholders (e.g., district governors and national policy makers) is necessary for such codesign to be supported by effective policy change (Totin et al. 2018). Therefore, the implementation of medium- and long-term adaptation measures must be supported by national and regional policies that provide effective technical and financial assistance to vulnerable groups.

5. Conclusions

We analyzed farmers’ perception of climate change in a village of central Mali and compared their perception with an analysis of historical meteorological data. Farmers’ perception of climate change was consistent with climatic data with regard to increasing temperatures and decreasing rainfall amount. Farmers’ perception disagreed with climatic data with regard to the increased frequency of dry spells and the early end of growing season. Farmers mentioned a range of adaptation strategies to cope with the adverse effects of climate change on crops. Households that perceived some changes in rainfall regimes were associated with an increased likelihood of adopting adaptation practices such as stone bunds and contour bunds, relative to households that did not perceive such changes. But the inverse also held true, that is, households that did not implement an adaptation option (e.g., water saving technologies, agroforestry) were sometimes more likely to perceive a change, possibly because their cropping systems were more sensitive to weather variations. Better-off households were also more likely to implement some adaptation measures (stone bunds, contour bunds), stressing the need to alleviate resource constraints if adaptation is to occur. Our analysis provides a rich basis for development efforts that should strengthen the dialogue between farmers and researchers so as to develop a common
understanding of the impact of climate change on crops and to design site-specific strategies to compensate for the expected negative impacts of climate change.

Acknowledgments. The lead author thanks the Agriculture and Climate Risk Management program: Tools and Research in Africa “Agricora” through the “Eco-Fert-Clim” project that funded the field work of this study. The lead author also thanks the French Ministry of Foreign Affairs through its Service of Cooperation and Cultural Action (SCAC) in Mali for providing a three-year Ph.D. scholarship. The lead author thanks the government of the Republic of Mali for making this study possible by allowing a training leave. We are grateful to two anonymous reviewers who commented on an earlier version of this paper and greatly helped us to improve it. The authors declare that they have no relevant competing financial or nonfinancial interests to report.

REFERENCES
Alexandratos, N., 2005: Countries with rapid population growth
[50x431]


