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RESEARCH ARTICLE

New indicators of vulnerability and resilience of agroforestry systems to climate change in West Africa

West African agroforestry systems and climate change

Isidore Gnonlonfoun[1,2] · **Achille Ephrem Assogbadjo**[2] · **Césaire Paul Gnanglè**[1,3] · **Romain Lucas Glèlè Kakaï**[1]

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Abstract
Climate change threatens ecosystems, including traditional agroforestry parklands. Assessing the level of vulnerability and resilience of any ecosystem to climate change is important for designing sustainable adaptation strategies and measures. We assessed farmers' perceptions of the vulnerability of agroforestry systems to climate change in Benin. The objectives of the study were to (i) assess the effect of changes in climatic conditions on agroforestry systems, (ii) assess the endogenous indicators of vulnerability of agroforestry systems to climate change, and (iii) analyze agroforestry and cropping systems' resilience to climate change. We hypothesized that some agroforestry systems are more resilient to climate change than others. A total of 233 household heads were surveyed, and seven agroforestry systems were assessed. Data collected included components, indicators of vulnerability, and the level of resilience of agroforestry systems. We characterized the agroforestry systems using a proportion of each woody trees species and density of tree. We differentiated the agroforestry systems with regard to vulnerability indicators using canonical factorial discriminant analysis with heplots for pairs of discriminant variables. The resilience of agroforestry and cropping systems was evaluated on a scale of 0 to 3 (0—not resilient to 3—most resilient). The number of components damaged in the system was the main indicator of the vulnerability of *Anacardium occidentale* and *Citrus sinensis* parks to climate change effects. Local people perceived age and density of *Vitellaria paradoxa* parks and mixed parks (*Vitellaria paradoxa–Parkia biglobosa*) as factors determining the vulnerability of these agroforestry systems to the effects of climate change. All agroforestry systems were perceived to be resilient to climate change but in different degrees. *Manihot esculenta* was reported as the most resilient crop to climate damage. For the first time, we found out specific endogenous indicators of the vulnerability of agroforestry systems to climate change, which are important to identify better adaptation strategies.

Keywords Agroforestry systems · Climate change · Traditional ecological knowledge · Ecosystem services · Food security

1 Introduction

The climate change is affecting all economic sectors and ecosystems. Several reports from trends analysis of temperature and precipitation predict hotter periods with negative consequences for the next decades (Intergovernmental Panel on Climate Change (IPCC) 1990 and IPCC 2007). In Africa, climate change effects vary widely across the continent, with western Africa predicted to get drier and hotter (Collier et al. 2008). In this context, assessing the impact of climate change on how ecosystems function is needed for successful adaptations.

Several studies have documented the impacts of climate change on terrestrial life forms (Bellard et al. 2012; Luedeling et al. 2014). However, future impacts of climate change on agroforestry systems and their relative services are uncertain (Reed et al. 2013). Three main methods are often used to assess and predict climate change impacts on agroforestry systems (Luedeling et al. 2014). One of these methods is process-based modeling using detailed and quantified

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✉ Isidore Gnonlonfoun
isidore.gnonlonfoun@labef-uac.org

[1] Laboratoire de Biomathématiques et d'Estimations Forestières, Université d'Abomey-Calavi, Abomey-Calavi, Benin

[2] Laboratoire d'Ecologie Appliquée, Université d'Abomey-Calavi, Abomey-Calavi, Benin

[3] National Institute of Agricultural Research of Benin, Cotonou, Benin

information of all relevant processes in the system, estimating system performance under future climate as output (Luedeling et al. 2014). The second method is species distribution modeling based on the collection of system occurrence data over entire distribution range and then identifying the suitable habitat for agroforestry systems. The third method aims at identifying analog locations and then undertakes trials to infer climate change impacts on the system from observations (Luedeling et al. 2014). In addition to these methods, indigenous knowledge-based assessment methods to predict climate change impacts on agroforestry systems are required.

Traditional ecological knowledge may help connect the present to the past and re-establish resilience to the projected negative effects of climate change (Gunderson et al. 1997). Incorporating indigenous knowledge into climate change policies can lead to the development of effective mitigation and adaptation strategies that are cost-effective, participative, and sustainable (Hunn 1993). Thus, indigenous knowledge-based assessment of the vulnerability and resilience of agroforestry systems to climate change are needed to bridge the gap between environmental research and traditional knowledge.

Agroforestry is an efficient adaptation strategy known for its capacity to increase resilience and reduce the vulnerability of agricultural production systems to climate change effects (Palsaniya and Ghosh 2016). Nonetheless, in West Africa, agroforestry systems (Fig. 1) face many challenges such as prolonged droughts, heavy rains, floods, increased heat, and biotic stresses (Coulibaly et al. 2014). In West Africa, products from wild edible trees play significant role in the livelihood of rural communities. Agriculture is the main activity and farmers often plant and conserve tree species with important provisioning ecosystem services significance (Sinare and Gordon 2015). These ecosystems services (i) provide nutritional diversity (leaves, fruits, etc.), (ii) offer medicinal uses (leaves, fruits, barks, roots, etc.), (iii) sustain livestock (branches and fruits from trees and shrubs used as fodder for livestock), and (iv) provide energy and (v) income (Sinare and Gordon 2015). Several studies (e.g., Boffa 1999 and Assogbadjo et al. 2012) have documented the usefulness of these agroforestry systems or trees species for local communities, but the level of the vulnerability and resilience of each agroforestry system to climate change are not well understood (De Leeuw et al. 2014). Considering the specificity of each geographical region, what are the resilient agroforestry and cropping systems that farmers can promote to successfully cope with the negative effects of climate change? Answering this question requires empirical and quantitative studies.

The adaptation of traditional agroforestry parkland systems to climate change and variability needs a sufficient level of understanding of the systems, its components, and their interactions (Coulibaly et al. 2014). This raises questions on which trees and management options will be suitable in future climates and how to minimize negative impacts of climate change on farming systems and reduce their vulnerability (Nguyen et al. 2013).

IPCC (2007) defines vulnerability as “the degree, to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes.” Vulnerability depends not only on a system’s sensitivity but also on its ability to adapt to new climatic conditions. Vulnerability of life forms and ecological systems to climate change will vary according to their specificity and intrinsic characteristics (Bellard et al. 2012). Leverage points to reduce vulnerability to climate change can be identified through comparison of vulnerability across countries, regions, or systems (Frich et al. 2002). Identification of indicators used by local communities to assess agroforestry systems’ vulnerability to climate change is crucial to a better understanding of vulnerability of such systems and to identify vulnerability “hotspots.” Given the high degree of geographical variation in the nature of climate hazards and the resulting difficulty in comparing “levels of hazard” across different countries or regions (Brooks et al. 2005), it is possible that the indicators of vulnerability assessment used by local communities differ between regions or districts within a given country.

In addition to vulnerability assessment, another very important aspect is ecological resilience of agroforestry systems, which measures their capacity to maintain their function when facing disturbances and this depends here on both the trajectory and the rate of change in climate over time (Allen et al. 2005). Understanding factors that contribute to the resilience of ecological systems is critical for maintaining a sustainable global human population and ensuring human well-being (Diaz et al. 2006).

This study analyzed how farmers perceive the vulnerability and resilience of their agroforestry systems to climate change along Ouémé catchment area in southern and central Benin, West Africa. We addressed the following questions (i) how are agroforestry systems affected by changes in climatic conditions? (ii) what indicators do local communities use to assess the vulnerability of agroforestry systems? and (iii) what are the resilient agroforestry and cropping systems which can be promoted to successfully cope with climate change?

2 Materials and methods

2.1 Study area

This study was conducted from June 2014 to March 2016 in Benin, located in West Africa, between 6° and 12° 50 N and 1° and 3°40 E. To assess farmers’ knowledge on the vulnerability and resilience of their agroforestry systems to climate change, three rural districts were selected along the Ouémé catchment area: Tchaourou and Dassa-Zoumè in Central and Zagnanado in Southern Benin. All the districts are located in Sudano-Guinean transition zone but are under contrasted climatic conditions (Adomou 2005). Tchaourou, Zagnanado, and Dassa-

Fig. 1 Picture of seven agroforetsry systems types inventoried in the study area. This figure shows the seven agroforetsry systems types inventoried in the study area. **a** A *Citrus sinensis* park after harvesting of *Zea maize* crops. **b** An *Anacardium occidentale* park with *Manihot esculenta* crop. **c** An *Elaeis guineensis* park with *Manihot esculenta* and *Zea maize* crops. **d** A *Tectona grandis* park with *Manihot esculenta* crop. **e** A mixed park *Vitellaria paradoxa–Parkia biglobosa* after harvesting of *Zea maize* crops. **f** A *Vitellaria paradoxa* park with *Arachis hypogea* crop. **g** A mixed park *Anacardium occidentale–Vitellaria paradoxa* with *Arachis hypogea* crop

Zoumè are under sudanian, Guineo-Congolian, and in the transition between Guineo-Congolian and sudanian climatic conditions, respectively. The rainfall is bimodal, which annually averages 1200 mm, 1100 mm, and 985 mm in Tchaourou, Dassa-Zoumè, and Zagnanado, respectively (Adomou 2005). The mean annual temperature is 26.4 °C, 27.2 °C, and 27.4 °C in Tchaourou, Dassa-Zoumè, and Zagnanado, respectively. Farming is the main occupation in these areas with rainfed cropping systems. The typical form of agricultural land use is the parkland agroforestry system, which involves intercropping agricultural crops under scattered mature trees in cultivated fields (Boffa 1999). Some tree species commonly found in parklands are *Vitellaria paradoxa* C.F.Gaertn., *Parkia biglobosa* (Jacq.) R.Br.ex G.Don., *Adansonia digitata* L., and *Tamarindus indica* L. (Boffa 1999). In central Benin, farmers commonly grow *Zea mays* L., *Gossypium* spp., *arboretum*, and *Dioscorea* spp. L. In the south, *Zea mays* L. and *Manihot esculenta* Crantz. are the major food crops. Among the leguminous plants, we have *Vigna unguiculata* (L.) Walp and *Arachis hypogeal* L. which are cultivated and widely consumed throughout the country.

2.2 Sampling techniques and data collection

2.2.1 Inventory of agroforestry systems

In each district, villages were selected during focus group discussion with farmers. The selection criterion was the number of farmers who had agroforestry systems along the catchment area. In villages with a large number of farmers, owners of agroforestry systems were selected. The survey was conducted in 6, 11, and 6 villages in Tchaourou, Dassa-Zoumè and Zagnanado, respectively. We inventoried agroforestry systems by establishing parallel line transects (two to four) of 150 m width and two kilometers long. The line transects were perpendicular to the catchment area. Along each line transect, 1-ha plot was delimited in each type of agroforestry system encountered and the components of the systems were recorded. Total number of tree species in each system, crops species, the different type of soils, and the general feature of agroforestry tree species were recorded. When needed, farmers were contacted for further explanations about the history of a given agroforestry system.

2.2.2 Farmers' assessment of vulnerability and resilience of agroforestry systems to climate change

A random sampling technique was applied to select household heads. The sampling size n was determined following the normal approximation of the binomial distribution (Dagnelie 1998) based on the proportion of farmers practicing agroforestry system farms (Eq. 1).

$$n_i = \frac{U^2_{1-\alpha/2} \times P(1-P)}{d^2} \qquad (1)$$

where n_i is the sampling size in the village i of each district, p is the proportion of farmers practicing agroforestry systems, $U_{1-\alpha/2}$ is the value of the normal random variable (1.96 for $\alpha = 0.05$), and d is the margin error of the estimation, set at 5% due to the fact that it allowed to sample more farmers and then to cover diverse views of local people. Data were collected using semi-structured interviews. A total of 233 farmers were interviewed in the three districts, comprising 91 farmers in Tchaourou, 90 farmers in Dassa-Zoumè, and 52 farmers in Zagnanado. The main research questions were (i) are there changes in climatic conditions over last three decades in your region? (ii) what are the impacts of these changes on agroforestry systems? (iii) what are the indicators of vulnerability of agroforestry systems? and (iv) what is the level of resilience of each agroforestry system?

In each village, to comply with avoid social norms related to gender (women have no right of decision if their husband is still alive in the household), we first conducted focus group discussion with the men to explain to them the aim of the study. Then, with men's agreement, women who were household head or not and grew crops in agroforestry systems were interviewed.

In addition to data related to previous questions, farmers' socioeconomic attributes (ethnicity, gender, age, education, landowner, or not) were also collected. Semi-structured questionnaires were used during the interviews, and all comments made were recorded.

To assess the resilience of agroforestry systems, four levels of resilience were defined ranging from 0 to 3, where 0 corresponds to not resilient, 1—moderately resilient, 2—resilient, and 3—most resilient. Each farmer assigned a value to each type of agroforestry system based on its perceived ability to cope with climate change. Regarding the crops, farmers enumerated only the crops which are resilient to climate change.

2.3 Statistical analysis

2.3.1 Characterization of agroforestry systems

We characterized the agroforestry systems using the proportion of each tree species in the system and density of tree. The proportion of each tree species in the system was computed as the absolute frequency of each tree species divided by the total number of trees in each plot multiplied by 100. Density of tree was computed per tree species and for the whole system as total number of trees per unit of surface (ha). Tree species with the highest proportion was used to designate the systems.

2.3.2 Analysis of farmers' perception on trends in climate and impacts on agroforestry systems

We first analyzed the sociodemographic characteristics of the interviewees as these may affect their perception of climate change. Descriptive statistics based on the proportion of each sociodemographic characteristic were computed. Farmers reported two changes in two main climatic parameters (temperature and precipitation) and two main impacts of these changes on agroforestry systems. The proportions (P) of people reporting each change and impacts across the district were computed as followed (Eq. 2):

$$P = \frac{\mathrm{ni}}{n} \tag{2}$$

where ni is the number of farmers reporting a given change in each climatic parameters or a given impact on agroforestry systems and n is the sample size.

The proportions of farmers reporting the main drivers of these changes were calculated per age category (young age ≤ 30 years, adult 30 years < age ≤ 60 years, and old person age > 60 years) (Byg and Balslev 2001). To assess the effects of age category on farmers' perception on climatic trends and related impacts, we used multiple tests of comparison of proportion.

2.3.3 Determination of main indicators of vulnerability of agroforestry systems to climate change

The total number of indicators of vulnerability was recorded, and their relative importance was computed based on citation frequency. To discriminate the seven agroforestry systems retained based on the main vulnerability indicators, we designed a data frame composed of the absolute frequency of citation (Fr) of each indicator per category of agroforestry system (Eq. 3).

$$\mathrm{Fr} = \sum_{i=1}^{n} \mathrm{IV}_i \tag{3}$$

where Fr is an absolute frequency of citation of a given indicator of vulnerability (IV_i) to climate change and n the sample size.

We analyzed the data using canonical factorial discriminant analysis with heplots for pairs of discriminant variables in R statistical software version 3.3.2 (R Development Core Team 2016) with candisc function, packages candisc, and heplots to assess differences between categories of agroforestry systems based on the vulnerability indicators. Before the canonical discriminant analysis, a stepwise discriminant analysis was performed with function greedy.wilks and packages MASS, combinat, and klaR to find the combination of variables (vulnerability indicators), which best discriminated the categories of agroforestry systems. These analyses revealed the specific indicators of vulnerability to climate change linked with each type of agroforestry systems.

The influence of social characteristics (age and sociolinguistic groups) and geographical location of interviewees on vulnerability of agroforestry systems to climate change assessment was analyzed through an analysis of covariance on the overall vulnerability indicators listed by each farmer. Relationship between vulnerability indicators and geographical zones was revealed using a principal component analysis (PCA**)** with the functions PCA and biplot in FactoMineR package. All analyses were done in R 3. 3. 2 statistical software (R Development Core Team 2016).

2.3.4 Determination of the most resilient agroforestry systems and most resilient crops

We computed the overall citation frequency of each level of resilience and the citation frequency for all resilience level per category of agroforestry system. The proportion of each level of resilience in relation to overall citation frequency was calculated for the identification of the most resilient agroforestry systems. We did similar analyses on crops to determine the most resilient crops.

3 Results and discussion

3.1 Diversity of agroforestry systems

Seven main agroforestry systems were encountered along Ouémé Catchment area in Benin. These agroforestry systems were *Elaeis guineensis* parks, *Citrus sinensis* parks, *Tectona grandis* parks in southern and central Benin (Zagnanado and Dassa-Zoumè), *Vitellaria paradoxa* parks and mixed parks *Vitellaria paradoxa–Parkia biglobosa* encountered only in Tchaourou (Central Benin), mixed parks *Anacardium occidentale–Vitellaria paradoxa* in Central Benin (Tchaourou and Dassa-Zoumè), and *Anacardium occidentale* parks common to three areas (Table 1). The overall density of tree species ranged between 17 trees/ha (*Vitellaria paradoxa* parks) to 147 trees/ha (*Citrus sinensis* parks). The main crops in the agroforestry systems were *Zea mays*, *Vigna unguiculata*, *Manihot esculenta*, and *Arachis hypogaea.* The tree species across the agroforestry systems are trees with diverse edible products of high economic and nutritional importance for the rural communities (Sinare and Gordon 2015; Boffa 1999 and Assogbadjo et al. 2012). We simultaneously characterized different agroforestry systems in Ouémé catchment. This finding will be very important for designing climate change adaptation strategies (De Leeuw et al. 2014). Tree species alike food crops have specific climatic and soil requirements, and their performance may be negatively affected when the optimum conditions are not met (Luedeling et al. 2016). For this purpose, we provided information on the features of agroforestry systems which influence resource capture and competition (Luedeling et al. 2016) and are important for decision-making on adaptation strategies and measures. The resilient agroforestry systems can be promoted as adaptation strategies to minimize the effects of climate change.

Table 1 Description of agroforestry systems

Agroforestry systems/ location	General feature	Crops practiced	Average density of trees	Use categories
Elaeis guineensis parks (Zagnanado and Dassa-Zoumè)	*Elaeis guineensis* is the main tree species in such systems (95% of arborescent population). These trees are either grown naturally or planted.	*Zea mays*, *Vigna unguiculata*, *Arachis hypogaea*, and *Glycine max*	The overall density of trees was 98 stems/ha. The one of *Elaeis guineensis* was 97 stems/ha.	Food (palm nuts for oil palm and sauce), broom (leaves of twig), fuel, and construction (branches)
Citrus sinensis parks (at Zagnanado and Dassa-Zoumè)	*Citrus sinensis* is the main tree and represented 90% of arborescent population.	*Zea mays*, *Vigna unguiculata*, *Manihot esculenta*, and *Arachis hypogaea*	The mean density of *Citrus sinensis* was 147 stems/ha. The average density of other trees was 2 stems/ha.	Food (oranges), medicinal (use of leaves)
Tectona grandis parks (Zagnanado and Dassa-Zoumè)	*Tectona grandis* is the main tree species in such systems (60% of arborescent population). These trees are either grown naturally or planted.	*Zea mays*, *Vigna unguiculata*, *Arachis hypogaea*, *Sorghum bicolor*, and *Glycine max*	The overall density of trees was 30 stems/ha. The one of *Tectona grandis* was 26 stems/ha.	Fuel (branches), construction (wood), services (chairs, stools), wrapping (leaves)
Vitellaria paradoxa parks (Tchaourou)	*Vitellaria paradoxa* is the main tree species and represented 70% of arborescent population. These trees are grown naturally.	*Zea mays*, *Vigna unguiculata*, *Arachis hypogaea*, *Manihot esculenta*, and *Glycine max*	The overall density of trees was 17 stems/ha. The one of *Vitellaria paradoxa* was 13 stems/ha.	Food (fruits, shea butter), medicinal (shea butter), fuel (branches)
Anacardium occidentale parks (common to three districts)	*Anacardium occidentale* is the main tree species and represented 86% of arborescent population. These trees are planted.	*Vigna unguiculata*, *Arachis hypogaea*, *Sorghum bicolor*, and *Glycine max*	The overall density of trees was 36 stems/ha. The one of *Anacardium occidentale* was 32 stems/ha.	Food (cashew nuts)
Mixed parks—*Anacardium occidentale–Vitellaria paradoxa* (Tchaourou and Dassa-Zoumè)	*Anacardium occidentale* and *Vitellaria paradoxa* are the main trees species and represented 40% and 37% respectively of arborescent population.	*Zea mays*, *Vigna unguiculata*, *Arachis hypogaea*, *Sorghum bicolor*, *Cajanus cajan*, and *Glycine max*	The overall density of trees was 25 stems/ha. The ones of *Anacardium occidentale* and *Vitellaria paradoxa* were 11 and 12 stems/ha respectively.	Food (fruits, shea butter, cashew nuts), medicinal (shea butter), fuel (branches)
Mixed parks *Vitellaria paradoxa–Parkia biglobosa* (Tchaourou)	*Vitellaria paradoxa* and *Parkia biglobosa* are the main trees species and represented 57% and 37% respectively of arborescent population.	*Zea mays*, *Vigna unguiculata*, *Arachis hypogaea*, *Ipomoea batatas*, and *Glycine max*	The overall density of trees was 23 stems/ha. The ones of *Vitellaria paradoxa* and *Parkia biglobosa* were 13 and 8 stems/ha respectively.	Food (fruits, shea butter, mustard of *Parkia biglobosa*), medicinal (shea butter), fuel (branches)

This table presents the seven agroforestry system types assessed in the study areas, their general features and crops grown, the density of tree species, and uses

3.2 Perception of farmers on trends in climate and impacts on agroforestry systems

A total of 233 farmers were interviewed in the three districts. Most of them (95%) were male and 5% were female. This could be explained by the fact that, in Benin, women are not usually landowners, whereas practicing agroforestry requires land availability. Gender effect was not taken into account for the analyses. Age of interviewees ranged from 25 to 80 years, of whom 5%, 67%, and 28% were young, adult, and elderly respectively. Most of the respondents were small-scale farmers who grew crop and trees on 0.5 to 13 ha mainly for livelihood, or herders who owned land, and most were illiterate (55.36%). The sociolinguistic groups of the respondents per district were Idatcha (34%), Mahi (34%), Fon (19%), Holi (5%), Nago (4%), and Bariba (4%) in Dassa-Zoumè; Bariba (17%), Ditamari (17%), Nago (15%), Lokpa (12%), Wama (13%), Yom (10%), Peulh (8%), Haoussa (4%), and Idatcha (4%) in Tchaourou; and Fon (79%), Nago (11%), and Holi (10%) in Zagnanado.

All the respondents perceived some changes in the climate. In the surveyed districts, all of the farmers reported late onset and shortening of rainy seasons as compared to some decades ago. Increased temperatures during the dry seasons were also perceived by respondents. Significant impacts related to these changes in climate were observed in crops and trees production. Farmers reported that current dry seasons are too long and then negatively impact on agroforestry systems. Farmers reported a decrease in trees fruit yield and fruits size; increased incidence of insects pests attack was observed and were especially detected on small fruits produced by some trees species and farmers noticed a decline in crops production due to dry spells in rainy season. Seventy five percent of the interviewees think that the destruction of the forest (either itself or via God punishment) is the cause of climate change, and 25% did not identify any driving force. There was significantly higher proportion of elderly people (57%) than adult (43%) who cited God punishment as driving force of climate change. On the other hand, 86% of adult farmers were of the opinion that the destruction of forests was the driving force of climate change, as against the old (13%) and young (1%) farmers (P value < 0.001). Elderly and adult farmers pointed out the drastic decrease in forest areas and in rainfall. The harvesting of timber and the extension of agricultural land into forest areas were also reported as the main factors of deforestation, and these resulted in increased temperature and decrease in rainfall. In fact, farmers perceived trees as the crucial components for rainfall and should be planted and protected. Farmers' perceptions on trends in climate and the roles of trees substantiate scientific knowledge. Trees absorb an important part of the carbon dioxide emitted either naturally or by anthropic human activities such as industrialization which destroys ozone layer and leads to global warming (IPCC 1990). Farmers have a spiritual perception of the causes of climate change. They believed that God has the power to stop or/and to control greenhouse gas emission effects on the climate, but because humans were destroying their own environment, God abandoned them to experience the drawbacks of their actions. These findings suggest that farmers are aware of the role of trees in mitigating the effects of climate change, and they feel the promotion of tree planting should be intensified.

3.3 Main indicators of the vulnerability of agroforestry systems

To assess the vulnerability of agroforestry systems to climate change, farmers identified several indicators, which mainly included the length of dry season ("most of the dry seasons are nowadays too long, hot and limit early blossom of trees"), number of components or levels damaged ("in some agroforestry systems, only crops are affected, in others both crops and edible fruit trees are affected"), amount of damages ("climate change decrease totally yield of crops and fruits in some agroforestry systems"), intensity of dry winds ("nowadays dry winds occur with high speed and suppress the flowers and young fruits of the plants"), level of soil fertility ("in the agroforestry systems where the soil is good, the system produces well even if there is a lack of rainfall"), and density of trees ("agroforestry systems with many trees reduce crop yields under current climatic conditions") (Fig. 2a). Age of tree, flood intensity, bush fires, and threshold resistance of the system were also reported by few farmers. An analysis of these indicators showed that some of farmers' vulnerability assessment indicators are congruent with the elements of vulnerability of a system as developed by Reed et al. (2013): exposure to a hazard; sensitivity to that hazard, and the capacity of the system to cope, adapt, or recover from the effects. Schneider et al. (2007) identified seven criteria for vulnerability assessment of any terrestrial system to climate change. Three of these criteria that are consistent with farmers' indicators of vulnerability to climate change of agroforestry systems are the following: (i) heterogeneous distribution of the impacts which expresses the different component of a given system that might be impacted by climate change effects, (ii) magnitude of impacts which correspond to amount of damage a given system can tolerate from climate change effects, and (iii) importance of vulnerable systems, which expresses the property of the system, i.e., the role and benefits the system can offer to people or living organisms dependent on the system. In fact, the number of components or levels damaged in the system matches the heterogeneous distribution of the impacts. According to farmers, climate change is responsible for decline of crop production due to water deficit, causing the spread of some insects that damage trees flowers and fruits and sometimes cause trees' death. The magnitude of impacts corresponds exactly to amount of damage reported by farmers which includes both the scale of impacts (the area or number of agroforestry systems affected) and its intensity (the degree of damage caused). The importance of vulnerable systems equals to threshold resistance of the system which measures the strength of inherent characteristic of an agroforestry system to face changes in climatic parameters (Schneider et al. 2007). Threshold resistance was used by farmers to describe resistance of the two morphotypes of *A. occidentale* that farmers grow. *A. occidentale* with big apple and big nut was reported to be very vulnerable to climate change. Its flowers dry up and abort, and young fruits fall during the strong and dry winds of "harmattan." However, *A. occidentale* with small apple and small nut was less vulnerable to climate damage. It produces a lot of inflorescences and fruits which are able to mitigate the flower abortion and fruit drops. The indicators of vulnerability of agroforestry systems to climate change are of great importance for making informed decisions regarding adaptation strategies. We recommend more cultivation of the *A. occidentale* morphotype with small apple to deal with climate change in the region.

Results from analysis of covariance revealed that local people's perception of agroforestry systems vulnerability to climate change was determined by their geographic location, age, and sociolinguistic groups (P value < 0.05). PCA showed that farmers in Tchaourou district (rainfall = 1200 mm, temperature = 26.4 °C) revealed all the indicators of vulnerability to climate change identified in this study: intensity of dry winds, threshold resistance of the system, amount of damage, density of tree, age of tree, flood intensity, the level of soil fertility, bush fires, the number of components, or the level of damages and length of dry seasons to assess the vulnerability of their agroforestry systems (Fig. 2b). In Dassa-Zoumè

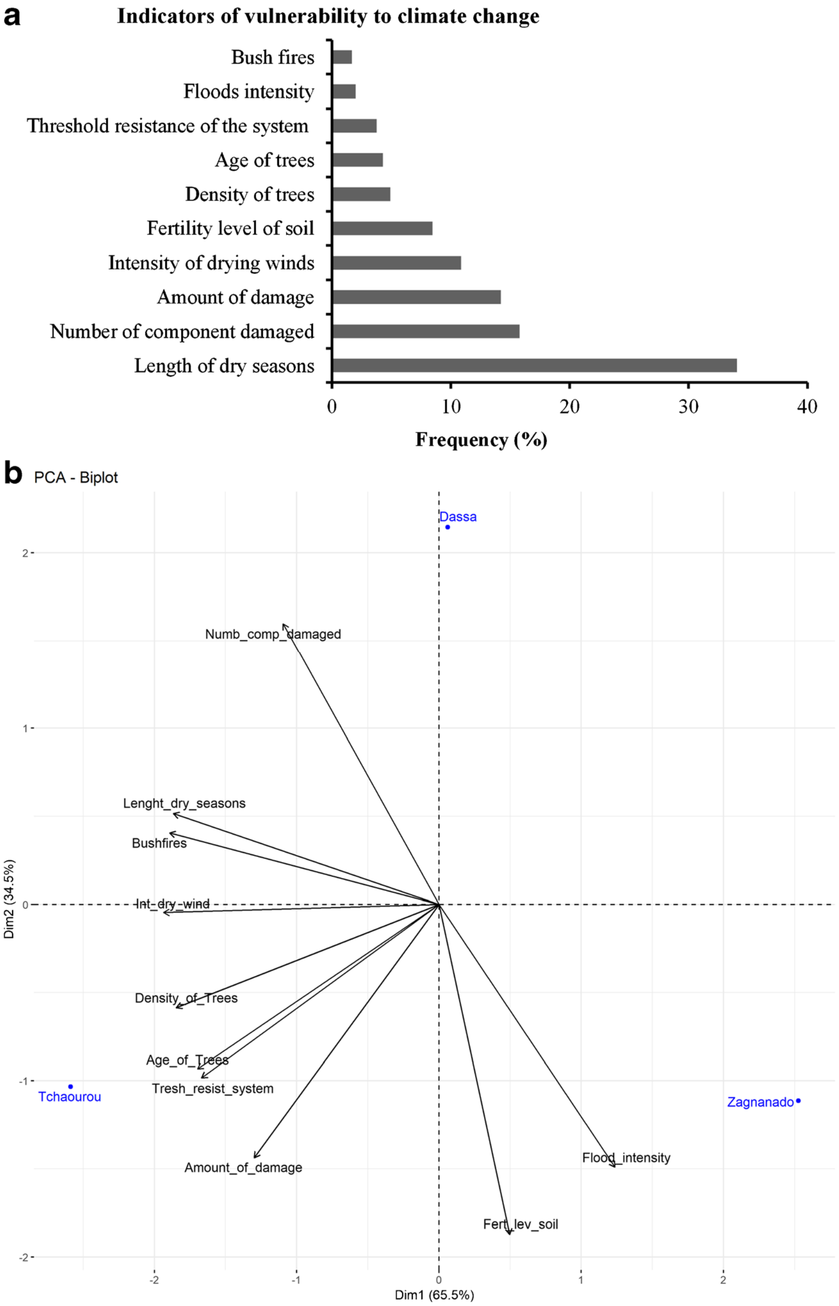

Fig. 2 Indicators of vulnerability of agroforestry systems (**a**) and PCA-biplot main indicators of vulnerability per district (**b**). **a** The importance of the indicators of vulnerability to climate change of agroforestry systems in the study areas and highlights the most important vulnerability indicators. **b** The most important indicators of vulnerability used by farmers in each district to assess the vulnerability of agroforestry systems to climate change. Lenght_dry_seasons length of dry seasons, Amount_of_damage amount of damage, Int_dry_wind intensity of dry winds, Numb_comp_damaged number of components damaged, Tresh_resist_system threshold resistance of the system, Fert_lev_soil fertility level of soil, Flood_intensity flood intensity, Age_of_Trees age of trees, Density_of_Trees density of trees, Bushfires bush fires, PCA principal component analysis

district (rainfall = 1100 mm, temperature = 27.2 °C), farmers mainly used the number of components or the level of damages, bush fires, and the length of dry seasons to evaluate the damage of climate change on their agroforestry systems (Fig. 2b). Farmers in Zagnanado district (rainfall = 985 mm, temperature = 27.4 °C) particularly relied on the amount of damage, the level of soil fertility, density of trees density, age of trees, threshold resistance of the system, and the flood intensity to characterize vulnerability of their agroforestry systems to climate change (Fig. 2b). These results from PCA confirmed our hypothesis that the indicators of vulnerability assessment used by local communities may differ between

Table 2 Results from selection procedure of stepwise discriminant analysis on vulnerability indicators

Vulnerability indicators	Fisher statistics	*P* value	Wilks' lambda
Density of trees	8.50	0.000	0.56
Number of component damaged	7.63	0.000	0.32
Age of trees	7.05	0.000	0.19
Length of dry seasons	1.31	0.265	–
Amount of damage	0.38	0.887	–
Intensity of drying winds	1.07	0.392	–
Threshold resistance of the system	1.23	0.305	–
Bush fires	0.80	0.572	–
Fertility level of soil	1.06	0.398	–
Floods intensity	0.90	0.502	–

The stepwise discriminant analysis helps to identify the most discriminant vulnerability indicators of agroforestry systems through the *P* value of Fisher statistics. The most discriminant indicators are those with *P* value < 0.05. The indicators with *P* value > 0.05 are those common to all agroforestry systems and cannot allow differentiating them

regions or districts within a given region or system. This finding suggests that designing adaptation and mitigation strategies to climate change should be driven by indigenous knowledge and practices.

3.4 Agroforestry systems' vulnerability to climate change

Results of stepwise discriminant analysis on vulnerability indicators (Table 2) showed three main indicators (density of tree, number of components, or levels damaged and age of tree) that discriminate the categories of agroforestry systems (*P* value < 0.001). These variables improved the predictive power to the discriminant function.

A canonical discriminant analysis with heplots for pairs of discriminant variables was conducted on the selected variables. Results indicated that the first axis explains 45.80% of the total variance and the second accounted for 42%.

The number of components damaged in the system was the main determinant of the vulnerability to climate change of *Anacardium occidentale* and *Citrus sinensis* parks (Fig. 3a). *Anacardium occidentale* and *Citrus sinensis* parks were

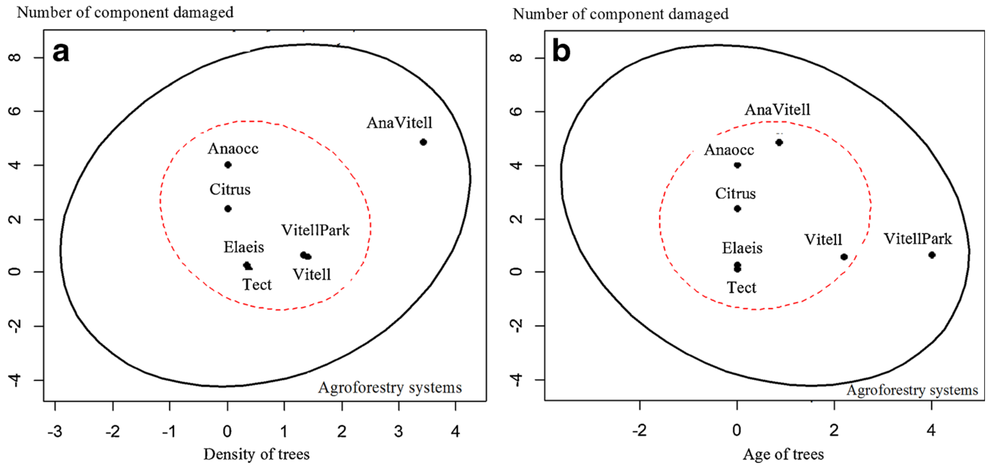

Fig. 3 Plot of canonical factorial discriminant analysis with heplots for pairs of discriminant variables based on the three selected variables by the stepwise procedure. Figure 3 highlights the specificity of each agroforestry system with respect to the indicators of vulnerability to climate change. Two canonical axes were used to map the agroforestry systems showing pair of the discriminant indicators of vulnerability to climate change. The agroforestry system suitability with a given indicator of vulnerability to climate change is determined by the length of their projection on the axis characterizing such an indicator. In other words, the longer is the agroforestry system projection, the better the agroforestry system is suitable with the indicator of vulnerability. Given that the names of agroforestry systems are too long and make the result not clear, we abbreviated agroforestry systems and the legend is below. **a** The pair of discriminant variables number of component damaged and density of trees. **b** The pair of discriminant variables number of component damaged and age of trees. Figure for the pair of discriminant variables, density of trees, and age of trees showed the same result than **a** and **b** and, in this fact, is not useful to show again. AnaVitell mixed park *Anacardium occidentale–Vitellaria paradoxa*, VitellPark mixed park *Vitellaria paradoxa–Parkia biglobosa*, Vitell *Vitellaria paradoxa* park, Anaocc *Anacardium occidentale* park, Citrus *Citrus sinensis* park, Elaeis *Elaeis guineensis* park, Tect *Tectona grandis* park

affected by drought, strong dry winds, and insects attack. The beetle *Apate terebrans* of Bostrychidae family digs holes inside *Anacardium occidentale* trees' trunk and main branches. This weakens the trees, and winds are able to easily break the branches. Also, the production performance of the remaining branches is negatively affected. The Hymenoptera *Oecophylla longinoda* of the Formicidae family attacks inflorescences and fruits of both species and thereby alters the quality of *Anacardium occidentale* nuts and oranges fruits.

Age and density of trees determined the vulnerability of *Vitellaria paradoxa* parks and mixed parks *Vitellaria paradoxa–Parkia biglobosa* to climate damage (Fig. 3a, b). Density of trees and the number of components or level expected to be damaged in the system were the main factors affecting the vulnerability of mixed parks *Anacardium occidentale–Vitellaria paradoxa* to climate change damage (Fig. 3a). Density of trees plays a significant role in parklands, and it varies based on the main objective of the agroforestry system, the local environmental conditions, and the tree species (Nair 1993). Increased density of trees in the system increases both competition among trees and between trees and crops. We recorded 17, 25, and 23 trees per ha in *Vitellaria paradoxa* parks, mixed parks *Vitellaria paradoxa–Parkia biglobosa*, and mixed parks *Anacardium occidentale–Vitellaria paradoxa*, respectively (Table 1). Farmers considered these densities of trees to be too high for efficient crops production in these systems under current climate. In the study areas, most of agroforestry systems' trees, especially *Vitellaria paradoxa* and *Parkia biglobosa* grow wild. Farmers reported that it was prohibited by forestry administration to cut down tree species in the farms because, in Benin, natural forest or agroforestry stands are protected by laws to promote sustainable use of natural resources, the conservation of biodiversity and mitigation of climate change. Farmers record a decrease in crops yields each year in these agroforestry systems due to high competition between trees and crops for nutrients, water, and light or have complementary needs (Luedeling et al. 2016). Similarly, in Burkina-Faso, Coulibaly et al. (2014) found that under current climate conditions, increasing density of tree in agroforestry systems will negatively affect sorghum growth if crown pruning is not applied. However, Lin et al. (2015) and Luedeling et al. (2016) found that the microclimate resulting from tree species in agroforestry systems (temperatures under trees' canopies) can be substantially lower than in open fields. This can potentially reduce heat stress for crops and animals, particularly during the hottest periods, showing the potential of agroforestry systems for adaptation to climate change. In order to harness the full potential of agroforestry systems, we recommend that farmers increase density of trees along with crown pruning at the onset of rainy season to limit competition and improve production of staple crops. Farmers reported that the oldest *Vitellaria paradoxa* trees have extremely low yield, and some of them die due to heat stress during dry seasons. For that reason, it may be useful to develop successive generations (ages) of trees species in agroforestry parkland systems and to remove old trees when their productions start to decline. In the short term, this practice may be a limitation for delivery of other ecosystem services (e.g., carbon sequestration and reduction of the intensity of heat stress) but it would enable farmers to keep crop yields at their optimum.

3.5 Resilience of agroforestry systems and crops to climate change

The knowledge of factors that contribute to the resilience of ecological systems to natural hazards is the first step for

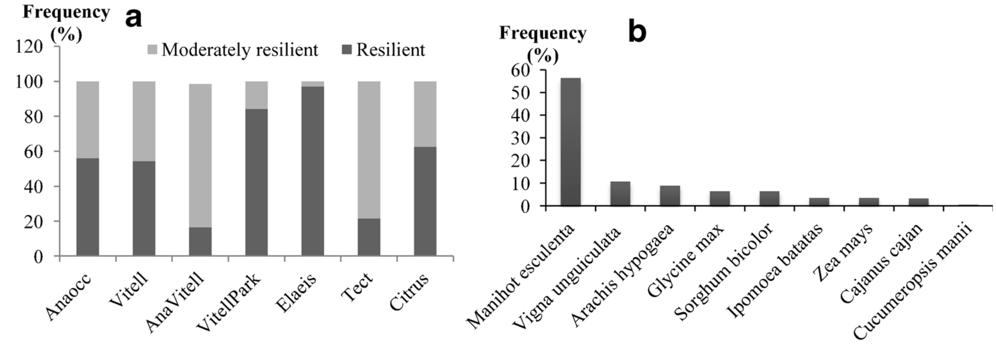

Fig. 4 Resilience's level of agroforestry systems and crops. Agroforestry systems and crops resilient to climate change according to farmers' daily experience with changing in climatic conditions. The resilience of agroforestry systems was assessed through four levels of resilience ranging from 0 to 3, where 0 corresponds to not resilient, 1 to moderately resilient, 2 to resilient, and 3 most resilient. Only two levels of resilience: moderately resilient and resilient were quoted by all of the farmers to assess the resilience of agroforestry systems (**a**). On the figure, we have both levels with two different colors: moderately resilient (ash) and resilient (black) and the resilience level with high relative frequency characterized the level of resilience of the agroforestry systems. It is clear that *Elaeis guineensis* parkland is the most resilient of all of agroforestry systems according farmer perception. For crops (**b**), only the resilient ones are cultivated by farmers and then we differentiated them through their value of quotation frequency across the study areas. *Manihot esculenta* has been more quoted (56.49%) by farmers as crop that has capacity to recover from or adapt to climate damage followed by *Vigna unguiculata* (10.81%) and *Arachis hypogea* (8.92%). AnaVitell mixed park *Anacardium occidentale–Vitellaria paradoxa*, VitellPark mixed park *Vitellaria paradoxa–Parkia biglobosa*, Vitelll *Vitellaria paradoxa* park, Anaocc *Anacardium occidentale* park, Citrus *Citrus sinensis* park, Elaeis *Elaeis guineensis* park, Tect *Tectona grandis* park

designing adaptation strategies. Farmers perceived *Elaeis guineensis* parks, *Citrus sinensis* parks, *Vitellaria paradoxa* parks, *Anacardium occidentale* parks, and mixed parks *Vitellaria paradoxa–Parkia biglobosa* as the most resilient agroforestry systems to climate change (agroforestry systems which maintain their function in face to climate change) while 50% of function of mixed parks *Anacardium occidentale–Vitellaria paradoxa* and *Tectona grandis* parks were affected by climate change (moderately resilient) (Fig. 4a). Farmers reported that in mixed parks *Anacardium occidentale–Vitellaria paradoxa*, *Vitellaria paradoxa* tree species contributes minimally to the improvement of soil fertility, and it negatively affects the growth of *Anacardium occidentale* and crops under current climatic conditions. For *Tectona grandis* parks, farmers indicated that *Tectona grandis* species rapidly impoverishes soils and, combined with erratic rainfall, they induced a decline in crops yields in such a system. Another criterion used by farmers to assess agroforestry systems' resilience was the utility provided by tree species in each system. In *Tectona grandis* parks, only crops provide periodic or annual incomes. Thus, erratic rainfall in a given year significantly decreases yields and consequently reduces benefit provided by such a system and makes it less resilient. Similar results were reported in South Mali in *Vitellaria paradoxa* and *Parkia biglobosa* agroforestry systems, which reduced millet yield by 50–80% (Kater et al. 1992). Nevertheless, the trees are highly valued by farmers because economic yields from marketable tree products compensate for the loss of crop yield. In *Elaeis guineensis* parks that are the most resilient, farmers reported that trees do not compete strongly with crops for soil's nutrients and palm trees also provide palm fruits regardless of climatic conditions. In Burkina-Faso, Coulibaly et al. (2014) found that sorghum biomass and grain yield were more negatively affected by *Parkia biglobosa* compared to *Vitellaria paradoxa* and *Adansonia digitata* trees. We concluded that local people of Ouémé catchment area in southern and central Benin recognize that agroforestry systems have diverse degree of resilience to climate change.

Considering crops resilience (Fig. 4b), farmers identified cassava (*Manihot esculenta*) as the most resilient crop to climate change effects. Cassava is a root crop which, according to farmers, requires little rainfall for its growth and thrives on soils with low fertility levels. This observation is consistent with the preview works of Jarvis et al. (2012) that indicated that cassava is potentially resilient to future climatic changes and could provide Africa with options for adaptation, while other major food staples face challenges.

Beyond farmers' perceptions, the plasticity of each tree or crop species will surely have a great influence on their resilience to climate change. Each tree or crop species has the ability to adjust its physiological characteristics to climatic and growing conditions. In this regard, some tree or crop species will evolve genetically (natural selection (Colleen 2007)) and others will disappear or become more vulnerable due to their inability to modify their physiological characteristics. That may justify the death of the oldest *Vitellaria paradoxa* tree species in Tchaourou district where they are abundant. Modeling the future distribution range of each agroforestry tree species using various climate change scenarios is needed. Also, researches using molecular markers are needed on agroforestry tree and crop wild relative species in order to determine the ability of each species to face the projected conditions of future climate.

4 Conclusion

Climate change is affecting West African agroforestry systems, mainly crop and fruit production. We encourage agroforestry systems based on *Elaeis guineensis*, *Anacardium occidentale*, and *Citrus sinensis* for Dassa-Zoumè and Zagnanado region and *Vitellaria paradoxa* parks, *Anacardium occidentale*, and mixed parks *Vitellaria paradoxa–Parkia biglobosa* for the Tchaourou districts in Benin. Growing *Manihot esculenta* crop across the agroforestry systems will be very useful for successful adaptations. We identified indicators of agroforestry systems' vulnerability to climate change which can form a basis help for future research and provided useful information for decision making. It would be useful for further research to assess the viability of the main agroforestry tree species and the crop wild relative's resilience to climatic conditions through demographic and genetic studies, respectively. Also, long-term field experiments that will examine the effect of density of agroforestry trees on the use of nutrients and light by trees and crops across contrasting ecological conditions are required to design successful adaptation strategies to climate change in West Africa.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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