Submitted on: 28/05/2022
Revised form accepted on: 16/01/2023
Corresponding author : wouyoatakpama@outlook.com

Revue
Nature et Technologie
http://www.univ-chlef.dz/revuenatec
ISSN: 1112-9778 – EISSN: 2437-0312

Priority area for sustainable Cashew (*Anacardium occidentale* L.) growing in Togo: Economic implications and conservation areas

Mèwèmenreré Denise ASSANG[a,b], Wouyo ATAKPAMA[a],* , Enagnon Benoit Olivier AHOUANDJINOU[c,d], Kangbeni DIMOBE[a,e,f], Gérard Nounagnon GOUWAKINNOU[c] & Koffi AKPAGANA[a]

[a] *Laboratoire de Botanique et Écologie Végétale, Département botanique, Faculté des sciences, Université de Lomé, 01 BP 16515, Togo.*
[b] *Département d'Agriculture, Institut Nationale de Formation Agricole (INFA) de Tové, BP 401 Kpalimé Togo.*
[c] *Laboratoire d'Écologie, de Botanique et de Biologie végétale (LEB), Faculté d'Agronomie, Université de Parakou, 03 B.P. 125, Parakou, Bénin.*
[d] *West African Service, Science Centre on Climate Change and Adapted Land use (WASCAL), Department of Climate Change &Human Habitat, Federal University of Technology, Minna, Niger State, Nigeria.*
[e] *Laboratoire de Biologie et Écologie Végétales, UFR/SVT, Université Joseph Ki-Zerbo, 03 B.P. 7021 Ouagadougou 03, Burkina Faso.*
[f] *Institut des Sciences de l'Environnement et du Développement Rural, Université de Dedougou, B.P. 176 Dedougou, Burkina Faso.*

Abstract

Understanding a species' current and future potential habitat is crucial to design its policy for management and cultivation practices that are more resilient in the face of climate change. This study assessed the present-day distribution and predicted the potential effect of climate change on the distribution of *Anacardium occidentale*'s habitat in Togo under two Representative Concentration Pathways (RCP4.5 and RCP8.5) by 2055. Maximum Entropy algorithm, 2538 species occurrence records, and a combination of 23 climate- and soil-related variables were used. Soil, isothermality, temperature seasonality, and annual precipitation are the most significant environmental factors affecting the distribution of the species in Togo. Based on the current model, 54.45% of the Togolese landscape is favourable for cashew development, mainly in the plains of Guinean and Sudanese savannahs. Unfavourable areas (15.20%) are in the southern mountainous areas of Togo and coastal areas. An increase in favourable areas and a slight decrease in unfavourable and moderately favourable areas are predicted by 2055, considering the two scenarios.

Keywords: Fruit crops; Climate change; Habitats; MaxEnt; Togo.

1. Introduction

Climate change is now broadly recognized and accepted as evident and one of the world's most pressing environmental challenges. Global climate change, mostly driven by increases in atmospheric concentrations of anthropogenic greenhouse gases, has significant impacts on human health, socio-economic activities, and ecosystems [1]. Under climate change, species may shift their ranges to cope with changes in climate [2].

In Africa, forestry and agriculture are likely to be the economic sectors affected mainly by climate change and variability [3, 4]. To cope with these changes, rural populations have embarked on a process of diversifying their income through the use of new resilience strategies, mainly cashew cultivation.

The cashew tree (*Anacardium occidentale* L.) belongs to the Anacardiaceae family [5, 6]. The genus *Anacardium* contains eight native species from tropical America, among which *A. occidentale* is the most economically important [7]. This introduced tree species has become an essential source of income for rural populations [8, 9]. It is mainly cultivated for its nut which is an important industrial and export raw material [10]. Within Africa, the crop is booming and a raw nut production has increased from 1 million tons to 1.8 million tons with an annual growth of 5.8% between 2011 and 2018 [11].

Reducing atmospheric carbon levels promotes a healthy environment conducive to human development. The cashew plantations contribute to the efforts to address climate change through carbon sequestration

[12]. Reducing atmospheric carbon levels promotes a healthy environment conducive to human development. The increase in the cultivated area of the cashew is due to its high hardness and low soil and climate requirements. It is especially suitable for areas with a warm tropical climate with alternating wet and dry seasons. The species adapts to various soils. In response to the projected negative impacts of climate change on biodiversity [1], there is a need for data regarding the future geographical range of high socio-economic value species like cashew. This understanding will help develop effective adaptation strategies to maintain ecosystem services and functions [13].

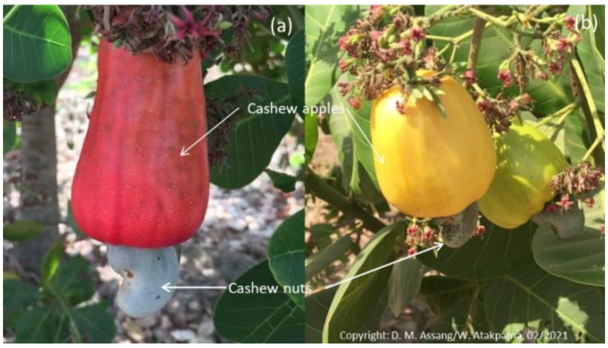
In Togo as in the Sub-Saharan African region, cashew cropping is gaining importance due to the recent trade development in the two main products: cashew kernels and cashew balms. The species' cost-effectiveness pushes producers to establish new plantations even in areas that are sometimes not favourable enough for its growth. This study aims to provide tools that allow quick detection of favourable habitats for cashew cultivation in Togo by answering the following three questions. Can cashew cultivation succeed anywhere in Togo? What role do the local environmental conditions play in determining the success of cashew plantations, and how will climate change impact these areas in the future?

2. Methodology

2.1. Description of the plant material the *Anacardium occidentale* L.:

Anacardium occidentale L. is a woody species with a flared canopy of up to 15 m in height, sometimes more than 15 m. It has a highly branched trunk with dense, evergreen, dark-green foliage (red or pale green in the juvenile state) with a regular, hemispherical canopy measuring 12 to 14 m in diameter. The branches have a globular and drooping habit. The stem bark is rough grey with a pinkish edge. The leaves of alternate phyllotaxis are simple, whole, oval or oblong, rounded at the top, and leathery of dark-green colour.

The flowers, supported by a very short pedicel, are small, pentamerous, zygomorphic, white or pale yellow streaked of pink at the time of the bloom, becoming pink a little afterwards. They are covered with broad bracts that are slightly pubescent. The calyx is made up of free, green, oblong, erect sepals, with quincunx pre-flowering and forming a kind of tube of a length equal to that of the pedicel. The petals are white or yellow, sometimes streaked of pink, free, linear to lance-shaped, alternated, and with imbricate pre-flowering. The stamens, generally to the number of 10, are welded by the base of the nets in a tube of 2 mm length. Generally, the terminal flower of each cyma is hermaphroditic and the laterals are unisexual [14]. The cashew fruit is an achene (Figure 1), notably a grey or greyish-brown kidney-shaped nutlet at maturity.



Copyright © D.M. Assang/W. Atakpama, 02/2021

Figure 1: Cashew tree fruits: red apple variety (a) and yellow apple variety (b).

2.2. Description of the study area

With an extent of 56,600 km^2, Togo is a West African country. The climate is intertropical with significant variations from the south to the north. The rainy season is shorter from south to north. From 8°30 north in the West and 9° north in the East to the border of Burkina Faso, there is a subtropical Sudanian dual-season pattern and its variants with three to six ecologically dry months. The southern part of the country experiences a sub-Equatorial Guinean climate with four seasons and two variants: the Guinean lowland type, which is less rainy with 1,000 to 1,300 mm/year, and the Guinean mountain type, which is rainier with about 1,600 mm/year. Most of the country is covered by savannahs and is divided into five ecological zones [15]: ecological zone I or northern plains, ecological zone II or northern mountains, ecological zone III or central plains, ecological zone IV or southern mountains, and ecological zone V or the coastal plain of southern Togo (Figure 2).

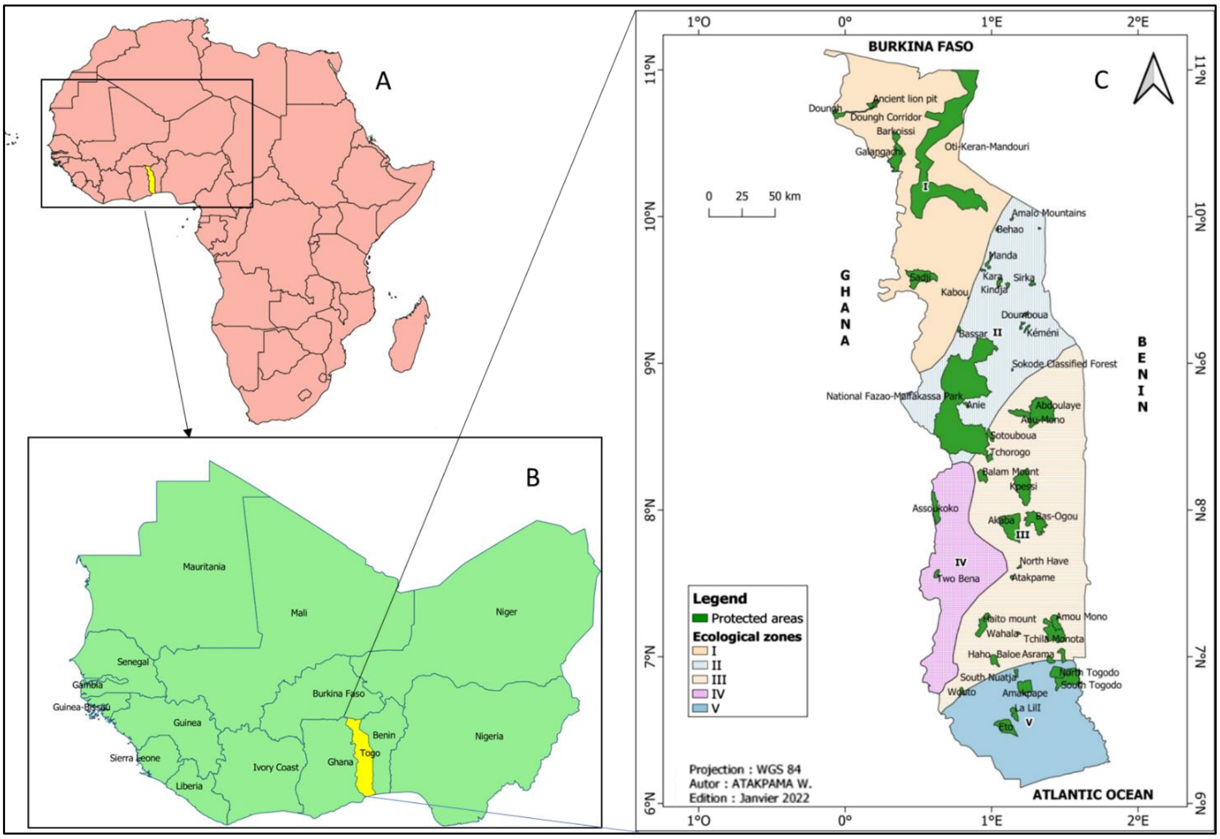


Figure 2: Location of the study area: Togo in Africa (A), Togo in West Africa (B) and Ecological subdivision and protected areas of Togo (C).

The northern plains (ecological zone I), located in the country's northern part, are dominated mainly by Sudanian tree and shrub savannahs. In the northern parts of this zone, a thorny shrub savannahs similar to that found in Burkina Faso between Ouagadougou and Kaya develops on eroded, more or less rocky soils [16]. There are vast agroforestry parks, notably those with: roasted trees (*Borassus aethiopum* Mart. and *Borassus akeassii* Bayton, Ouédraogo & Guinko), African locust beans trees (*Parkia biglobosa* (Jacq.) R.Br. ex Benth.), shea butter trees (*Vitellaria paradoxa* C.F. Gaertn.), baobabs (*Adansonia digitata* L.), etc. [17-20], which are important sources of income for local populations. Along the rivers, gallery forests are characterized by a high level of anthropogenic influence [21, 22].

The northern mountains (Zone II) are characterized by the Kabyè massif and the Defalé Mountains that border the Niamtougou plateaus and the Binah plain. It is an area of dense dry woodlands, open woodlands, and grassy savannahs [23]. It is also home to agroforestry parks dominated by the African locust beans trees, the shea butter trees, and the baobab trees [17, 18, 24].

The Central Plains or Ecological Zone III refers to the large areas of plains in the country's centre with elevations between 200 and 400 m. The dominant vegetation is wooded Guinean savannahs. Open forests and discontinuous gallery forests are also [25].

Ecological zone IV corresponds to the southern part of the Togolese mountains, still called the Atakora unit [26]. It consists of the Litimé and Ahlon plains, the Akébou, Akposso, Dayes, and Kloto plateaus. It constitutes the area of moist and semi-deciduous forests of Togo [27]. There are also extensive areas of Guinean savannahs, also known as mountain savannahs [6]**.** Native plants' communities in this zone are subject to strong human pressures. Most of them are transformed into agroforestry and agrarian areas for cocoa or coffee [28, 29].

The coastal plain of southern Togo (zone V) is dominated by the coastal sedimentary basin located country's extreme south. Due to the high population density, the coastal plain vegetation is characterized by a mosaic of farmland and fallows [30]. There are also scrublands, bushes, and derived savannahs [6]. Within the grassy savannahs of the littoral, there are savannahs with bushy termite mounds and patches of sacred forests [31]. Mangroves, floodplain grasslands, and savannahs also occur in the extreme southeast of the zone [32]. These grasslands and savannahs are highly solicited for cow pastures [33].

2.3. Occurrence Data Collection

Occurrence data of the cashew trees across Togo, Benin, and Ghana were collected using a GPS (Global Positioning System) Garmin receiver and android application MAPS.ME between November 2020 and February 2021. To improve the accuracy of the model, it was recommended to use occurrence data that cover as much as possible the area where the species is driven by the same climatic factors. Therefore, additional occurrence data of the cashew in West Africa provided by the Global Biodiversity Information Facility platform (https://www.gbif.org/) were collected using the "gbif" extension in the QGIS 2.18 software[1] (Figure 3). These data are the updated data from 1950 to 2020. A total of 2,538 points of occurrence were used for the modelling after crosschecking and suppression of wrong and duplicated occurrences. These considered occurrences included 833 across Togo and 1,705 of GBIF.

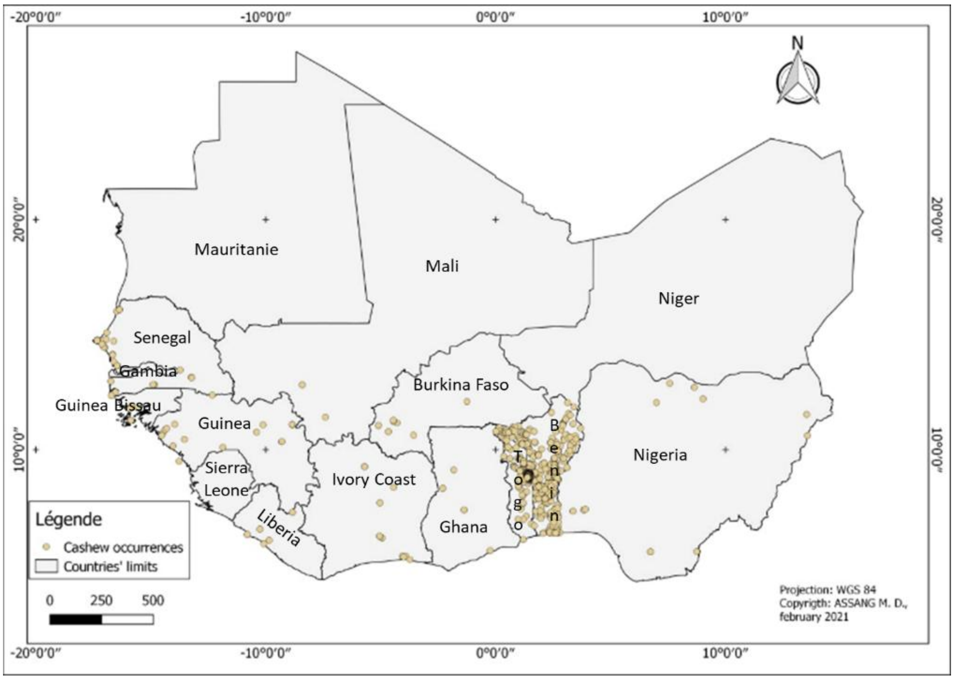


Figure 3: Spatial distribution of cashew tree presence in West Africa.

2.4. Environmental Data

A total of 23 environmental variables were used to model the cashew-growing areas. These included 21 bioclimatic variables combined with altitude and soil data (Table 1). The bioclimatic variables and altitude data were extracted from the AFRICLIM[1] database [34] and the soil data from the Harmonized Soil[2] base [35]. The resolution is 30 seconds, equivalent to 1 km^2 at the equator. These variable layers were cropped along the West African boundaries and then converted to ASCII files compatible with the MaxEnt algorithm[3].

The models were performed using all environmental variables [36, 37] instead of correlative analysis and choice of variables as done in several several previous studies [38, 39]. Two scenarios of emission called RCPs

[1] https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_30s/
[2] http://www.fao.org/land-water/databases-and-software/hwsd/en/

[3] Detailed description of the program is given by C. Merow *and al.*: https://doi.org/10.1111/j.1600-0587.2013.07872.x

(Representative Concentration Pathways)[4] were used for the future climate projections based on the four scenarios of greenhouse gas emission. The two selected scenarios are the most realistic ones. These include the optimistic scenario (RCP 4.5) and the pessimistic scenario (RCP 8.5) [40]. The RCPs were designed to test the global climate response to greenhouse gas emissions.

Table 1
Environmental variables used for modelling.

Environmental variables	**Description of the variable**
Soil	Soil
Elevation	Altitude
Temperature Variables	
bio1	Annual Mean Temperature
bio2	Mean Diurnal Range
bio3	Isothermality (BIO2/BIO7) (* 100)
bio4	Temperature Seasonality (standard deviation *100)
bio5	Max. Temperature of Warmest Month
bio6	Min. Temperature of Coldest Month
bio7	Temperature Annual Range (BIO5-BIO6)
bio10	Mean Temperature of Warmest Quarter
bio11	Mean Temperature of Coldest Quarter
Pet	Potential Evapotranspiration
Pluviometry variables	
bio12	Annual Precipitation
bio13	Precipitation of Wettest Month
bio14	Precipitation of Driest Month
bio15	Precipitation Seasonality (Coefficient of Variation)
bio16	Precipitation of Wettest Quarter
bio17	Precipitation of Driest Quarter
dm	Number of dry months
llds	Duration of the longest dry season
miaq	Moisture index of the wettest quarter
mimq	Dry quarter moisture index
mi	Annual moisture index

2.5. Modelling and validation of the model

The modelling was performed with the MaxEnt algorithm, which has its basis in information theory, via a stand-alone Java program in the field of artificial intelligence [41]. This algorithm is one of the most powerful modelling methods capable of generating strong biogeographic information while providing good discrimination of habitats suitable for a species based on bioclimatic variables [41].

The occurrence data were entered into an Excel file and then converted to a “CSV” format, compatible with the MaxEnt algorithm. The model was repeated ten times to increase accuracy. To evaluate the model, 25% of the occurrence data were used to test the model and 75% of the points to calibrate the model.

The model accuracy was assessed using the Receiver Operating Characteristics Curve (ROC) index[5], obtained by calculating the area under the curve (AUC). The AUC values are interpreted as proposed by Swets [42]: AUC<0.75 (the model is bad), 0.75<AUC<0.90 (the model is fair), AUC > 0.90 (the model is good). The evaluation of the model was completed by assessing the contribution of each variable used in the model run from the Jackknife test and the projection of the occurrences onto the model mapped. A new field investigation for the collection of 123 new occurrences allowed completion of the validation of the model.

The QGIS software was used to map the cashew potential current and future growing areas. Two habitats were first defined based on the 10 percentile threshold: unfavourable habitat (habitats with a probability below the threshold) and favourable habitat. Then the favourable habitat was subdivided into: less favourable, moderately favourable, and highly favourable. The area of each habitat and its dynamics under each scenario were calculated.

3. Results

3.1. Contribution of variables and model performance

The average AUC value is 0.952 showing a good prediction of habitat. The variable that contributed the mostly to the models was the soil variable (solresam), followed respectively by the isothermality (bio3), the temperature seasonality (bio4), the annual precipitation (bio12), and the annual moisture index (mi). The least contributing variable was the altitude (Figure 4).

[4] An overview: https://doi.org/10.1007/s10584-011-0148-z

[5] https://online.stat.psu.edu/stat504/lesson/7/7.4

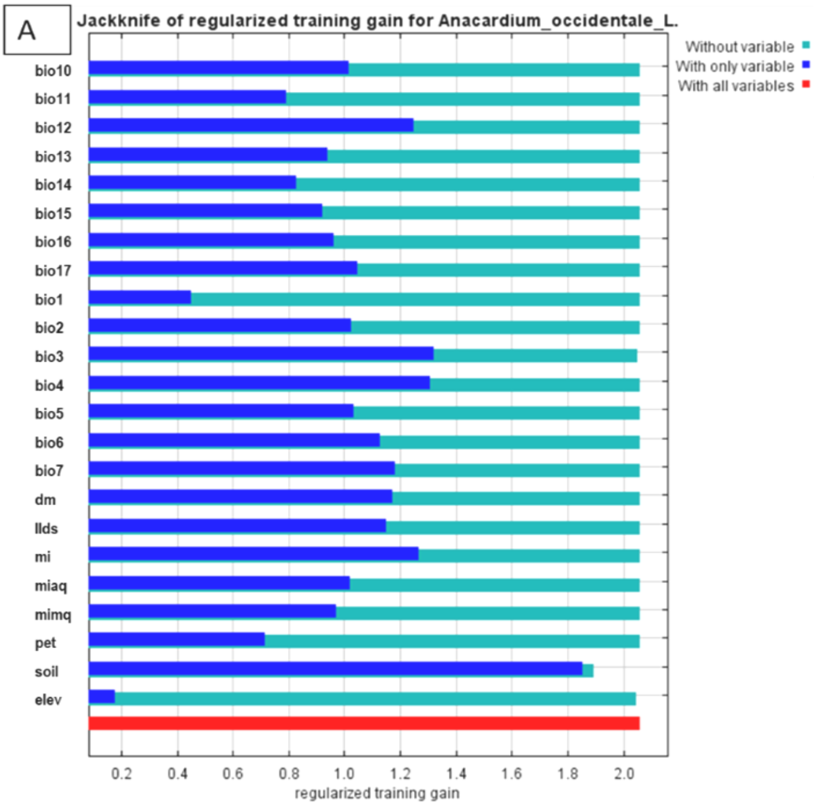


Figure 4A: Contribution of variables in the modelling according to the Jackknife test

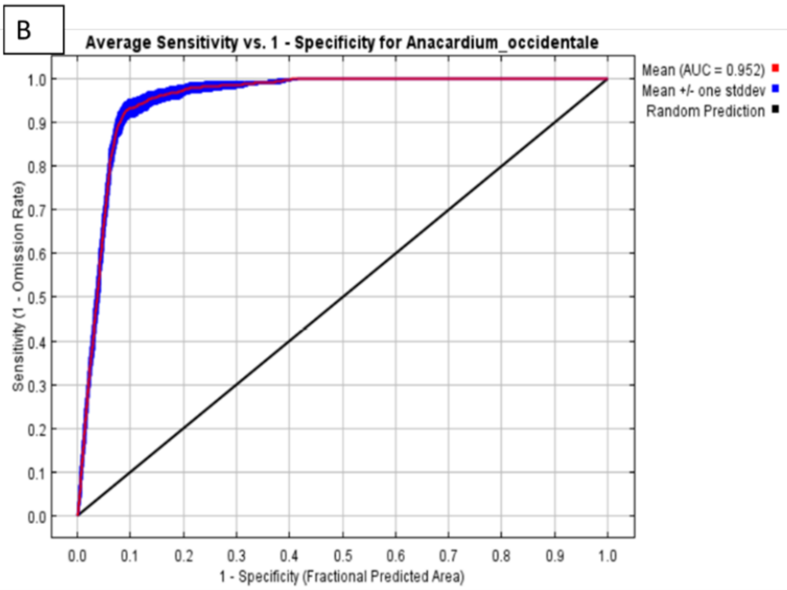


Figure 4B: The Cross-validated areas under the receiver operating characteristic curve (AUC)

3.2. Current and future potential cropping area of *A. occidentale* in 2055

More than half (54.45%) of Togo's territory is potentially highly favourable for cashew cultivation (Figure 5). These highly favourable habitats are located more in ecological zones II and III corresponding to the

Sudanian and Guinean savannahs. The species' medium and less favourable habitats are located in the northwest of the ecological zone I and in the southeast of ecological zones III and V. The unfavourable habitats are estimated to be 15.2%. They are located more towards the country's southwest, specifically in ecological zone IV and south of ecological zone V.

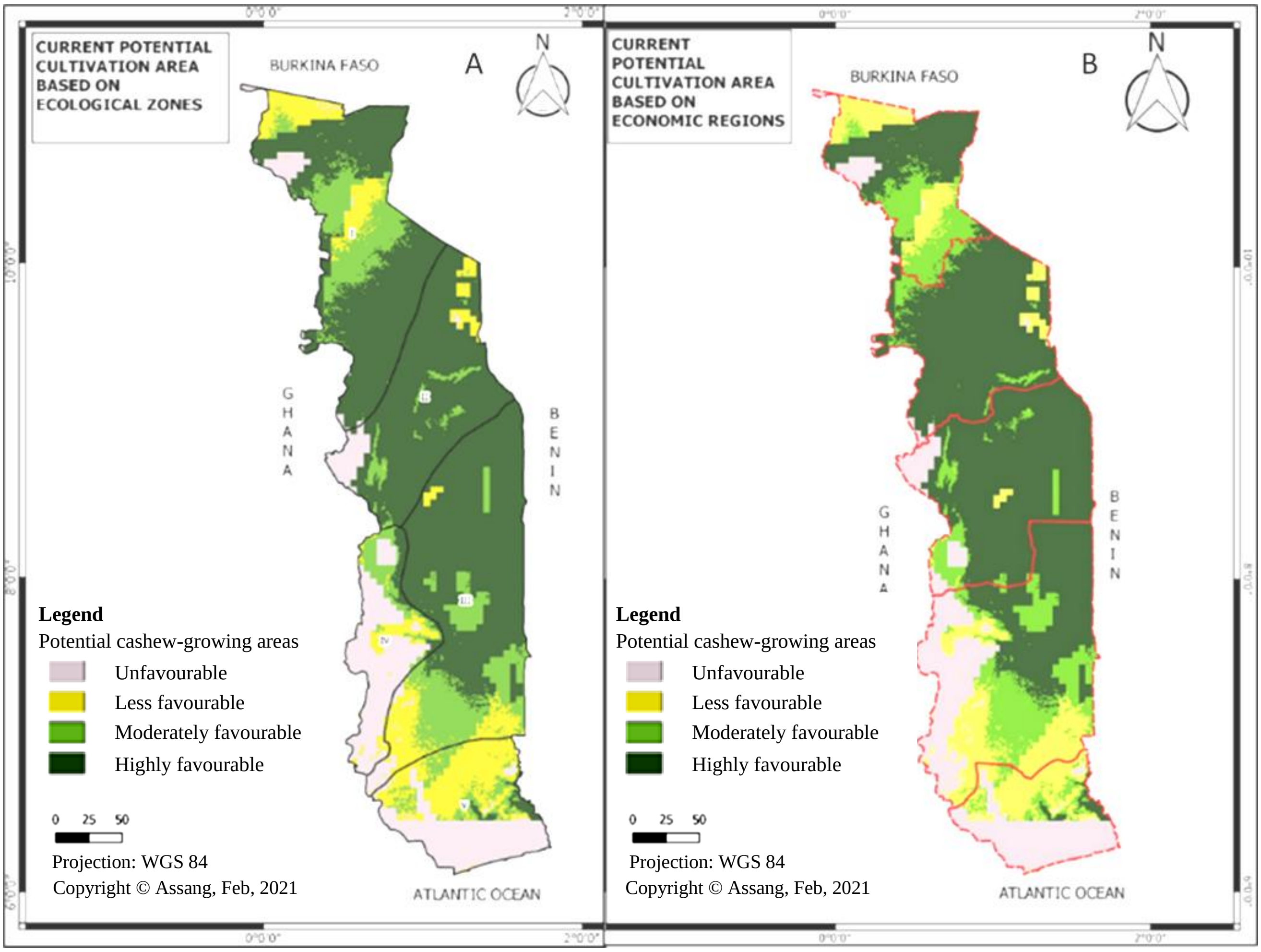


Figure 5: Current potential cultivation area of the cashew tree according to ecological zones (A) and economic regions (B) of Togo.

The RCP 4.5 predicts a large (64.90%) and small (15.30%) favourable and unfavourable habitats, respectively, by 2055. RCP 8.5 shows the same trends (62.20% and 18.50% for the highly favourable and unfavourable habitats, respectively) (Figure 6). The projections show a 10% expansion in the area of highly favourable habitat by 2055 under the RCP 4.5 scenario. The medium and low favourable habitats will decrease by 3% and 7%, respectively. Scenario 8.5 indicates an increase of 8% in current highly favourable habitats. The medium and low favourable habitats decreased by 6% and 5%, respectively. Meanwhile, a 3% increase in unfavourable habitats is predicted.

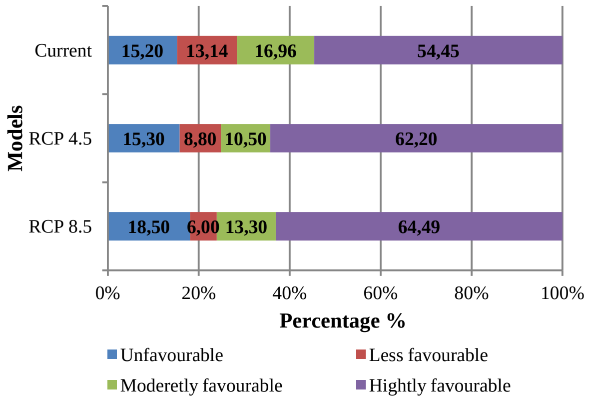


Figure 6: Proportion of current and potential future habitats according to the RCP 4.5 and RCP 8.5 scenarios of the cashew tree in Togo.

4. Discussion

4.1. Model reliability and 'variables' contribution

The strength and validity of species distribution models depend on the input data. This study used the maximum entropy (MaxEnt) approach used by several authors in species distribution [43, 44] for mapping potential growing areas of the cashew in Togo. This 'approach's strength is its ability to combine occurrence data and environmental variables across the study area [45]. It also has the facility to run with quantitative and qualitative data simultaneously. The value of the Area Under the Curve showed a good prediction of the cashew trees' favourable habitat in Togo.

The least favourable habitat for cashew cropping is found in areas of high rainfall, particularly in the mountainous areas of the south and the coastal zone of Togo. The Kara and Central regions are predicted to be highly favourable. This prediction is partly in line with the current cultivation areas of the species and is also consistent with the rainfall requirements of the cashew tree. [46]. Results showed that the fundamental habitat differs very little from the realized habitat. This contradicts several previous studies that showed that realized habitat is more frequently the most important than fundamental habitat [39, 47]. This finding is justified by the fact that this crop is adopted by farmers who implement plantings across the country without considering the climatic and soil requirements.

Edaphic factors are one of the environmental factors that can predict and affect species distribution, specifically plant species [48, 49]. The distribution pattern of distribution showed that soil is a major factor in the spatial distribution of the cashew, followed by the bioclimatic variables, the isothermality, the temperature, and the annual precipitation. Soil affects plants physiological state, so its effect on the model is considerable. The implication of edaphic requirements of the cashew were stated by Gnahoua & Louppe [50]. The species does not thrive in clayey and flooded soils of lowlands such as those in the Maritime region of Togo. This situation could be linked to soil pH which was shown to affect considerable plant species distribution [51]. The pH can affect soil resource availability and nutrients up taking by plants [52]. The use of soil ecological characterization has become necessary in predicting multiple-use endogenous species. Thus, to improve plant SDM, appropriate indices of soil nutrients are needed. Seasonal temperature and precipitation define the soil moisture content [49]. The contribution of the seasonality, the temperature, and the annual precipitation supports the findings of Lyam *et al.* [44]. These authors showed that temperature and precipitation are major factors in plant species and vegetation distribution. Both of these variables added to soil act directly in the spatial distribution of the cashew and could be the primary environmental parameters in the ecology of the species. Variability in climatic factors across species populations highlights the ability of specific population models to lead experiences to disentangle local adaptive or functional differentiation.

4.2. Implications of future climate conditions

Predicting how the species might respond to climate change is a fundamental component in designing biodiversity conservation and management policies. Climate projections indicate that the area of habitat currently favourable for the cashew cropping in Togo is not expected to be stable under both scenarios (RCP 4.5 and RCP 8.5). This could be due to the ability of the species to develop tolerance to climate change.

The predictive models used for the 2055 horizon showed that habitats highly favourable to cashew development will expand. Considering the evolution of habitats with the different scenarios RCP 4.5 and RCP 8.5, it may be stated that climate change will not be a major threat to cashew cultivation in Togo. It is therefore a crop that is resilient to climate change. However biotic factors and anthropogenic disturbances can affect the species niche distribution [49]. Including natural disturbances such as herbivory, human settlements and density in the SDMs should be an excellent predictor of understanding the impact of climate change on the species niche. This can lead to understanding how temperature and rainfall change patterns could affect vegetation distribution. Ecological zones II and III are not only favourable for the species valorization, but also adequate for the conservation/sustainable cultivation of cashew trees, in contrast to ecological zone I showed as less favourable for its conservation. The habitats favourable to the species in the ecological zone I will consequently be more affected than those in ecological zones II and III.

5. Conclusion

The study assessed the effects of climate change in predicting the spatial distribution of potential cultivation for cashew trees in Togo by 2055. The results show that soil is the most important predictor of the spatial distribution of the cashew in Togo. The climate conditions indicate that 54.45% of the country's land area is highly favourable for cashew cultivation in the next few years. This proportion of highly favourable habitats will increase significantly by 2055 under the two climate scenarios (RCP 4.5 and RCP 8.5). Taking these findings into account for cashew plantations by the farmers and the Ministry of Agriculture, Livestock and Rural Development will increase the resilience of the populations to future climate conditions.

Acknowledgements

Islamic Development Bank (IsDB) under The World Academy of Sciences (TWAS)-UNESCO Postdoctoral Programme[6], help the second author for gaining knowledge on Ecological Niche Modelling. We thank the field assistants who helped in data collection. Finally, we thank the anonymous reviewers for their valuable comments on the earlier version of this article

References

[1] Bogner J., Pipatti R., Hashimoto S., Diaz C., Mareckova K., Diaz L., Kjeldsen P., Monni S., Faaij A. & Gao Q., Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). Waste Management & Research, 26 (1) (2008): 11-32. https://doi.org/10.1177/0734242x07088433

[2] Walther G.-R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J., Fromentin J.-M., Hoegh-Guldberg O. & Bairlein F., Ecological responses to recent climate change, Nature, 416 (6879) (2002): 389-395. https://doi.org/10.1038/416389a

[3] Koungbanane D., Zahiri P.E., Totin Vodounon H.S., Amoussou E., Lare L.Y. & Koubodana D.N., Analyse fréquentielle et détermination des seuils pluvio-hydrologiques de risques d'inondation dans le bassin-versant de l'Oti au Togo, Afrique SCIENCE, 17 (1) (2020): 73-88. Available online: http://www.afriquescience.net/PDF/17/1/7.pdf (accessed on: 03/03/2022)

[4] Folega F., Diwediga B., Guuroh R.T., Wala K. & Akpagana K., Riparian and stream forests carbon sequestration in the context of high anthropogenic disturbance in Togo, Moroccan Journal of Agricultural Sciences, 1 (1) (2020). [HTLM version]: https://techagro.org/index.php/MJAS/article/view/820 (accessed on: 05/03/2022)

[5] APG III, An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III, Bot. J. Linn. Soc., 161 (2) (2009): 105-121. https://doi.org/10.1111/j.1095-8339.2009.00996.x

[6] Brunel J.F., Hiepko P. & Scholz H., Flore analytique du Togo : Phanerogames (1984) Berlin & Eschborn: GTZ, 751p. https://doi.org/10.2307/3776742

[7] Somé L.F.M.C., "*Analyse socio-économique des systèmes de production d'anacarde au Burkina Faso : cas des régions des Cascades et des Hauts-Bassins*", Université polytechnique de Bobo-Dioulasso, (2014), 66p. Available online: https://beep.ird.fr/collect/upb/index/assoc/IDR-2014-SOM-ANA/IDR-2014-SOM-ANA.pdf (accessed on: 19/02/2022)

[8] Ndiaye S., Charahabil M.M. & Diatta M., Caractéristiques des plantations d'anacardiers (*Anacardium occidentale* L.) et déterminants économiques des exploitations en Casamance, VertigO-la revue électronique en sciences de l'environnement, (2021). https://doi.org/10.4000/vertigo.28723

[9] Bezerra M.A., Lacerda C.F.d., Gomes Filho E., de Abreu C.E. & Prisco J.T., Physiology of cashew plants grown under adverse conditions, Brazilian Journal of Plant Physiology, 19 (4) (2007): 449-461. https://doi.org/10.1590/S1677-04202007000400012

[10] Akinhanmi T., Atasie V. & Akintokun P., Chemical composition and physicochemical properties of cashew nut (*Anacardium occidentale*) oil and cashew nut shell liquid, Journal of Agricultural, Food and Environmental Sciences, 2 (1) (2008): 1-10. Available online: https://unaab.edu.ng/wp-content/uploads/2010/11/1538_1315.pdf(accessed on: 31/03/2022)

[11] Hien S., "*Aperçu de l'évolution de la production d'anacarde et évolution du marché de noix brutes de cajou dans la sous-région et perspectives pour 2019/2020*". In Forum sur la CAjou Sahélien. FOCAS, 2019, 5-7 August, Bamako, Mali, 16p. Available online: https://www.africancashewalliance.com/sites/default/files/2_focas_2019_sansan_nkalo_marche_et_production_fr.pdf (accessed on: 22/05/2022)

[12] Ndiaye I.S., "*Analyse de la performance d'une filière d'exportation et impact dans l'atténuation des effets des changements climatiques : Cas de l'anacarde au Sénégal*". In Conference on Climate Change and Food Security in West Africa. 7-18 November, 2018, Dakar, Sénégal, 13p. Available online: https://research4agrinnovation.org/publication/proceedings-wascal-conference/ (accessed on: 24/05/2022)

[13] Rosenzweig C., Karoly D., Vicarelli M., Neofotis P., Wu Q., Casassa G., Menzel A., Root T.L., Estrella N. & Seguin B., Attributing physical and biological impacts to anthropogenic climate change, Nature, 453 (7193) (2008): 353-357. https://doi.org/10.1038/nature06937

[14] Lefèbvre A., L'anacardier, une richesse de Madagascar, Fruits, 24 (1) (1969): 43-61. Available online: https://revues.cirad.fr/index.php/fruits/article/view/33606 (accessed on: 11/03/2022)

[15] Ern H., Die Vegetation Togos, Gliederung, Gefährdung, Erhaltung, Willdenowia, 9 (2) (1979): 295-315. ISSN : 0511-9618. https://www.jstor.org/stable/3995654

[16] Akpagana K. & Bouchet P., Etat actuel des connaissances sur la flore et la végétation du Togo, Acta botanica gallica, 141 (3) (1994): 367-372. https://doi.org/10.1080/12538078.1994.10515170

[6] https://twas.org

[17] Padakale E., Atakpama W., Dourma M., Dimobe K., Wala K. & Akpagana K., Woody species diversity and structure of *Parkia biglobosa* Jacq. Dong parklands in the sudanian zone of Togo (west africa), Annual Review & Research in Biology, 6 (2) (2015): 103-114. https://doi.org/10.9734/ARRB/2015/14105

[18] Kebenzikato A.B., Wala K., Dourma M., Atakpama W., Dimobe K., Pereki H., Batawila K. & Akpagana K., Distribution et structure des parcs à *Adansonia digitata* L. (baobab) au Togo, Afrique Sci., 10 (2) (2014): 434-449. Available on: https://www.ajol.info/index.php/afsci/issue/view/11603 (accessed on: 14/03/2022)

[19] Atakpama W., Atoemne K., Egbelou H., Padakale E., Batawila K. & Akpagana K., Distribution et démographie des parcs à rôniers dans la Région des Savanes du Togo, African Journal on Land Policy and Geospatial Sciences, 5 (2) (2022): 290-302. Available on: https://revues.imist.ma/index.php/AJLP-GS/article/view/28341 (accessed on: 29/03/2022)

[20] Folega F., Atakpama W., Kanda M., Wala K., Batawila K. & Akpagana K., Agroforestry parklands and carbon sequestration in tropical Sudanese region of Togo, Revue Marocaine des Sciences Agronomiques et Vétérinaires, 7 (4) (2019): 563-570. [version HTML]: https://www.agrimaroc.org/index.php/Actes_IAVH2/article/view/745 (accessed on: 30/08/2022)

[21] Diwediga B., Batawila K., Wala K., Hounkpè K., Gbogbo A.K., Akpavi S., Tatoni T. & Akpagana K., Exploitation agricole des berges : une strategie d'adaptation aux changements climatiques destructrice des forets galleries dans la plaine de l'Oti, African Socio. Rev., 16 (1) (2012): 77-99. Available on: https://www.ajol.info/index.php/asr/article/view/87627 (accessed on: 07/05/2022)

[22] Folega F., Diwediga B., Guuroh R., Wala K. & Akpagana K., Riparian and stream forests carbon sequestration in the context of high anthropogenic disturbance in Togo, Mor. J. Agri. Sci., 1 (2020): 39-49. [HTML version]: https://www.techagro.org/index.php/MJAS/article/view/820 (accessed on: 29/11/2022)

[23] Atsri H.K., Abotsi K.E. & Kokou K., Enjeux écologiques de la conservation des mosaïques forêt-savane semi-montagnardes au centre du Togo (Afrique de l'Ouest), Journal of Animal & Plant Sciences, 38 (1) (2018): 6112-6128. Available online: http://m.elewa.org/Journals/wp-content/uploads/2018/10/6.Atsri_.pdf (accessed on: 11/05/2022)

[24] Wala K., Sinsin B., Guelly K.A., Kokou K. & Akpagana K., Typologie et structure des parcs agroforestiers dans la préfecture de Doufelgou (Togo), Sécheresse, 16 (3) (2005): 209-216. Available on: http://www.secheresse.info/spip.php?article7087 (accessed on: 14/03/2022)

[25] Kokou K., Atato A., Bellefontaine R., Kokuste A.D. & Caballé G., Diversité des forêts denses sèches du Togo (Afrique de l'Ouest), Rev. Ecol. Terre Vie, 61 (2006): 225-246. Available online: https://hal.archives-ouvertes.fr/hal-03533267 (accessed on: 16/03/2022)

[26] Sylvain J.P., Collart J., Aregba A. & Godonou S., 1986. Notice explicative de la carte géologique 1/500.0000è du Togo, Mém. n°6, D.G.M.G./B.N.R.M., Lomé – Togo. Direction Generale des Mines de la Géologie et du Bureau National de Recherches Minières [Printed text].

[27] Akpagana K., "*Recherches sur les forêts denses humides du Togo*", Univ. Bordeaux III, France, Phd Thesis. (1989), 181 p.

[28] Kombate B., Dourma M., Folega F., Woegan A.Y. & Akpagana K., Structure et potentiel de séquestration de carbone des formations boisées du Plateau Akposso en zone sub-humide au Togo, Afrique Sci., 15 (2) (2019): 70-79. Available online: http://www.afriquescience.net/AS/15/7.pdf (accessed on: 21/03/2022)

[29] Djiwa O., Pereki H. & Guelly A.K., Typology of cocoa-based agroforestry systems of the semi-deciduous forest zone in Togo (West Africa), International Journal of Biodiversity and Conservation, 12 (4) (2020): 270-282. https://doi.org/10.5897/IJBC2020.1426

[30] Batawila K., "*Recherches sur les formations dégradées et jachères de la plaine côtière du sud Togo*". Univ. Lomé, Lomé, Togo, Mém. DEA, (1997), 65 p.

[31] Kokou K. & Caballé G., Les îlots forestiers de la plaine côtière togolaise, BFT, 263 (1) (2000): 39-51. https://doi.org/10.19182/bft2000.263.a20059

[32] Guelly A.K., Pereki H. & Djiwa O., 2020. "*Cartographie des acteurs et des écosystèmes de mangrove du littoral togolais*". In. FAO, Lomé, Togo, 43. https://doi.org/10.4060/ca8640fr

[33] Amegnaglo K.B., Dourma M., Akpavi S., Akodewou A., Wala K., Diwediga B., Atakpama W., Agbodan K.M.L., Batawila K. & Akpagana K., Caractérisation des formations végétales pâturées de la zone guinéenne du Togo : typologie, évaluation de la biomasse, diversité, valeur fourragère et régénération, International Journal of Biological and Chemical Sciences, 12 (5) (2018): 2065-2084. https://doi.org/10.4314/ijbcs.v12i5.9

[34] Platts P.J., Omeny P. & Marchant R., AFRICLIM: high-resolution climate projections for ecological applications in Africa, African Journal of Ecology, 53 (1) (2015): 103-108. https://doi.org/10.1111/aje.12180

[35] FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. *Harmonized World Soil Database (version 1.2)*. Laxenburg, Austria: FAO, Rome, Italy and IIASA, 38 p. https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ (accessed on: 05/03/2022)

[36] Moukrim S., Lahssini S., Rifai N., Menzou K., Mharzi-Alaoui H., Labbaci A., Rhazi M., Wahby I., El Madihi M. & Rhazi L., Modélisation de la distribution potentielle de *Cedrus atlantica* Manetti au Maroc et impacts du changement climatique, Bois & Forets des Tropiques, 344 (2020): 3-16. https://doi.org/10.19182/bft2020.344.a31888

[37] Feng X., Park D.S., Liang Y., Pandey R. & Papeş M., Collinearity in ecological niche modeling: Confusions and challenges, Ecology and evolution, 9 (18) (2019): 10365-10376. https://doi.org/10.1002/ece3.5555

[38] Dimobe K., Ouédraogo A., Ouédraogo K., Goetze D., Stein K., Schmidt M., Nacoulma B.M.I., Gnoumou A., Traoré L. & Porembski S., Climate change reduces the distribution area of the shea tree (*Vitellaria paradoxa* CF Gaertn.) in Burkina Faso, Journal of Arid Environments, 181 (2020): 104237. https://doi.org/10.1016/j.jaridenv.2020.104237

[39] Atakpama W., Wala K., Gouwakinnou G.N., Pereki H., Akodewou A., Batawila K. & Akpagana K., Abundance, distribution pattern and potential suitable habitat of *Sterculia setigera* Del. in Togo (West Africa), International Journal of Innovation and Scientific Research, 26 (1) (2016): 23-38. http://www.ijisr.issr-journals.org/abstract.php?article=IJISR-16-131-02 (accessed on: 17/04/2022)

[40] Meinshausen M., Smith S.J., Calvin K., Daniel J.S., Kainuma M.L., Lamarque J.-F., Matsumoto K., Montzka S.A., Raper S.C. & Riahi K., The RCP greenhouse gas concentrations and their extensions from 1765 to 2300, Climatic change, 109 (1) (2011): 213-241. https://doi.org/10.1007/s10584-011-0156-z

[41] Phillips S.J., Anderson R.P. & Schapire R.E., Maximum entropy modeling of species geographic distributions, Ecol. Model., 190 (3-4) (2006): 231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

[42] Swets J.A., Measuring the accuracy of diagnostic systems. Science, 240 (4857) (1988): 1285-1293. https://www.science.org/doi/10.1126/science.3287615 (accessed on: 21/04/2022)

[43] Abdou L., Diouf A., Inoussa M., Mamoudou B., Illiassou S. & Mahamane A., Modeling the geographic distribution of *Prosopis africana* (G. and Perr.) Taub. in Niger., Environment and Natural Resources Research, 6 (2) (2016): 136-144. https://doi.org/10.5539/enrr.v6n2p136

[44] Lyam P.T., Adeyemi T.O. & Ogundipe O.T., Distribution modelling of *Chrysophyllum albidum* G. Don. in South-West

Nigeria, Journal of Natural & Environmental Sciences, 3 (2) (2012): 7-14. Available on: https://www.researchgate.net/publication/259569958_Distribution_Modeling_of_Chrysophyllum_albidum_GDon_in_South-West_Nigeria (accessed on: 15/10/2022)

[45] Lahoz-Monfort J.J., Guillera-Arroita G. & Wintle B.A., Imperfect detection impacts the performance of species distribution models, Global ecology and biogeography, 23 (4) (2014): 504-515. https://doi.org/10.1111/geb.12138

[46] Ricau P., 2013. *Connaître et comprendre le marché international de l'anacarde*. 48 p. Available online: https://www.inter-reseaux.org/wp-content/uploads/Guide_RONGEAD___Le_Marche_International_de_l_Anacarde_v-light.pdf (accessed on: 11/11/2022)

[47] Gouwakinnou N.G., Using niche modeling to plan conservation of an indigenous tree species under changing climate: example of Sclerocarya birrea in Benin, West Africa, Res. Dev. sub-Saharan Africa, 5 (5) (2013): 1-8. Availableon: https://www.researchgate.net/profile/Gerard-Gouwakinnou/publication/281296116_Using_niche_modeling_to_plan_conservation_of_an_indigenous_tree_species_under_changing_climate_example_of_Sclerocarya_birrea_in_Benin_West_Africa/links/55e0cb4b08aecb1a7cc5711e/U (accessed on: 20/12/2022)

[48] Austin M.P. & Van Niel K.P., Improving species distribution models for climate change studies: variable selection and scale, Journal of Biogeography 38(1) (2010), 1-8. https://doi.org/10.1111/j.1365-2699.2010.02416.x

[49] Mod H.K., Scherrer D., Luoto M. & Guisan A., What we use is not what we know: environmental predictors in plant distribution models, Journal of Vegetation Science, 27 (6) (2016): 1308-1322. [HTML version]: https://onlinelibrary.wiley.com/doi/epdf/10.1111/jvs.12444 (accessed on: 19/12/2022)

[50] Gnahoua G.M. & Louppe D., 2003. Anacardier, HAL-Archives ouvertes. http://hal.cirad.fr/cirad-00429280 (accessed on: 19/12/2022)

[51] Chytrý M., Tichý L. & Roleček J., Local and regional patterns of species richness in Central European vegetation types along the pH/calcium gradient, Folia Geobotanica, 38 (4) (2003): 429-442. https://doi.org/10.1007/BF02803250

[52] Hossner L., 2008. Field pH. *Encyclopedia of Soil Science*. 271-272. https://doi.org/10.1007/978-1-4020-3995-9 (accessed on: 07/11/2022)