Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 18(4): 1260-1271, August 2024

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Investigating relationship between different soil chemical properties and the biomass and grain yield of *Sorghum bicolor* (L.) Moench (Sorghum) in agroforestry parklands systems along an increasing rainfall gradient in Burkina Faso (West Africa)

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Received: 18-01-2024 Accepted: 03-04-2024 Published: 31-08-2024

ABSTRACT

Cereal crops biomass and grain yield generally reduced under trees canopy, are also improved depending on trees species and structure in agroforestry parklands suggesting complex interactions in these systems. This research investigated the relationship between soil chemical properties and sorghum biomass and grain yield in agroforestry parklands for recommendations to maintain or improve sorghum productivity under climate change. Studied parklands consisted of *Vitellaria paradoxa* C. F Gaertn and *Parkia biglobosa* (Jacq.) Benth in association with sorghum in three climatic zones. Soil chemical parameters were measured using the spectrophotometry infrared method and sorghum biomass and grain yield were calculated by dividing their weight with the area of production. Cation exchange capacity (CEC) and potassium (K) had a positive effect on sorghum biomass and grain yield when rainfall decreased suggesting the application of management options improving soil carbon and moisture to increase sorghum productivity with reduced rainfall due to climate change. CEC had a negative effect on sorghum biomass and in association with *P. biglobosa* when rainfall increased suggesting the optimisation of mineral fertilisers use and tree pruning to increase sorghum productivity when rainfall increased due to climate change. Further research is required to assess the effects of these recommended management options.

Keywords: Fertility, Climate, Crop, Trees, Environment, Ecophysiology.

INTRODUCTION

Agroforestry parklands systems, widely expanded in Burkina Faso (Bayala et al., 2002) are farms with crops grown under a discontinuous cover of scattered trees (Bayala et al., 2014). The products of the trees in agroforestry parklands systems are used for income generation, for consumption and use of households, as fodder, as medicinal products and for religious ceremonies (Teklehaimanot, 2004). Trees in agroforestry parklands systems also provide ecological services such as soil improvement (Ndiaye et al., 2012; Abdou et al., 2013; Aliou et al., 2013). The agroforestry parklands systems degradation in the Sahelian region was reported through trees density and diversify reduction in farms which is mainly

DOI : https://dx.doi.org/10.4314/ijbcs.v18i4.5

caused by lack of tree species regeneration (Boffa et al., 2000).

Crops can compete with trees or have complementary needs in agroforestry parklands systems. Teklehaimanot (2004) and Zomboubré et al. (2005) reported significant crops yields reductions under tree canopy in agroforestry parklands systems due to light quantity and quality reduced under tree canopy (Bazié et al. 2012) despite increased soil fertility around the trees (Bayala et al., 2014). Trees transpiration in agroforestry parklands systems was reported to reduce crop performance through increased belowground competition to access soil water (Pattanayak, 2004). However, it was reported that the parklands trees increase crop yield depending on species composition and structure of the tree cover (Bayala et al., 2012). Also, Kuyah et al. (2019) reported that the yields of the staple crops were higher in agroforestry compared to yields in treeless systems.

These controversial results show that crops productivity in agroforestry parklands systems is under the influence of complex interactions. It is then relevant to understand which soil chemical parameters explain crops performance in agroforestry parklands systems under different rainfall levels and trees species as this could contribute to adaptation and reduction of the adverse effects of parklands degradation under climate change. However, literature review does not identify such research carried out in the Sahel region. Yet, the Sahel region, and Burkina Faso in particular, is subject to climate change, with an increase in extreme events such as droughts and floods, and more frequent droughts (Traore et al., 2013). The agroforestry parklands systems productivity in Burkina Faso, largely depend to rainfall and are then vulnerable to climate change (Laudien et al., 2022).

This research investigated the relationship between different soil chemical properties and sorghum biomass and grain yield along an increasing rainfall gradient for recommendations to maintain or improve sorghum productivity in agroforestry parklands systems under climate change.

MATERIALS AND METHODS

Sites description

Field experiments were conducted in Burkina Faso at three different sites along an increasing rainfall gradient: Tougouri (13˚ 18' 59" latitude North and -3˚ 12' 1" longitude West) in the Sahelian zone, Nobere (11˚ 33' 29" latitude North and -1˚ 12' 16" longitude West) in the Sudano-Sahelian zone and Sokouraba (10˚ 51’ 00’’ latitude North and -5˚ 11’ 00’’ longitude West) in the Sudanian zone.

The soils of the three sites are generally poor and have low Nitrogen (N), Organic Matter (MO) and Phosphorus (P) contents. In addition, they are weakly acidic with low Exchange Cation Capacity (CEC) (Table 1). The average rainfall and temperature (year 1980-2013) were 557 mm and 26.6ºC in Tougouri respectively, 859 mm and 25.7ºC in Nobere, and 1061 mm and 25.1ºC in Sokouraba (DGM, 2013). The average rainfall totaled 620, 775 and 927 mm, respectively in Tougouri, Nobere and Sokouraba during the three years (2010, 2011 and 2012) of measurement. The soil at all the sites is classified tropical ferruginous (INSD, 2022). The previous management practices analysis showed that before the implementation of this research at all the sites, sorghum was the crop cultivated and the farmers did not use fertilisers and phytosanitary products.

Experimental design

The studied parklands systems consisted of an association of sorghum with two native tree species: *V. paradoxa* and *P. biglobosa*. The sorghum cultivar used in the experiments was sariasso 14. The sorghum planting density consisted of 80 cm between the lines and 40 cm between the plants on the lines with only one plant maintained after seedlings emergence. Sorghum was planted at the same dates in July 2010, 2011 and 2012 at all the sites and fertilisers were not used so as to be able to appreciate trees contribution in improving soil fertility. Two weedings at the same dates in all the sites were conducted. Phytosanitary products for weeds and plant diseases control were not used before and during the experiments.

Sorghum was cultivated in concentric zones from the trunk of each tree. The area around each of the sampled trees was split into three concentric tree influence zones and a control plot which were:

- Zone A - from tree trunk to half of the crown radius of the tree;
- Zone B - from half of the crown radius of the tree up to the edge of the crown;
- Zone C - from the edge of the tree crown up to 3 m away; and
- Zone H - a control plot for crop in monoculture which was an area of 4 x 4 m situated at least 40 m away from the edge of the crown and unshaded by any of the surrounding trees at any time during the day throughout the cropping season.

This design was replicated eight times for each tree species at each site to give a total of sixty-four (= 8 reps x (2 species x 4 zones)) tree-by-zone sorghum biomass, grain yield and soil chemical properties measurements at Sokouraba, Nobere and Tougouri. The dendrometric characteristics of sampled tree species are presented in Table 2.

Data collection

The biomass and grain yield of sorghum were measured at each zone associated to the trees during the three years of experiment (2010, 2011 and 2012). This approach allows taking into account soil properties, light and rainfall variability effects on these parameters in agroforestry parklands systems. For the biomass measurement, all the stems with leaves were harvested each year, dried at the sun during one month and weighed using a balance. The dry biomass weight obtained in tons for each zone was divided by the area of the zone to obtain the dry biomass produced per unit area in hectare. For the grain yield measurement, all the sorghum grains were harvested for each zone, dried and weighed using a balance. For each zone, the weight of the grain in tons was divided by the area of the zone to obtain the grain yield produced per unit area in hectare.

The soil chemical properties measured were cation exchange capacity (CEC), potassium (K), nitrogen (N), total carbon (C) and pH. Soil sampling was conducted randomly in 2010 during the experiments at two points in all the zones associated to each tree species at 10 cm interval depth up to 50 cm (0-10; 10-20; 20-30; 30-40 and 40-50 cm) using an auger of 5 cm diameter with a volume of 250 cm^3. This method was used to take into account soil chemical properties vertical and horizontal variability in agroforestry parklands systems when determining the average values of soil chemical properties per site. The two soil samples for the same depth and zone were mixed to have a composite sample of 500 cm^3 for soil analysis. The spectrophotometry infrared method was used for soil chemical properties measurement (Shepherd and Walsh, 2002; Du and Zhou, 2009) in 2011 at the Sotuba laboratory in Bamako (Mali). The principle of this method is based on the fact that different components of the soil absorb the near rays differently according to the level of their importance in the sample. The composites soil samples were dried at open air, sieved using a sieve of 2 mm mesh and scanned at Near Infrared (NIR) and middle infrared (MIR) using the spectrophotometer « Bruker Fourier-Transform MultiPurpose Analyzer spectrometers (MPA) » (Bruker Optik GmbH, Germany) equipped with a software which predicts the soil chemical properties measured. For the purpose of scanning, soil subsamples of about 20 g from each composite dried soil samples were taken and put into a petri dish. Moreover, 10% of the whole soil samples were selected from which the soil chemical properties were analyzed using a humid chemistry in laboratory. The results from the humid chemistry in laboratory were used to estimate the accuracy of the results predicted by the software integrated in the spectrophotometer through calibration.

Statistical analysis

The average values of sorghum biomass and grain yield for the three years and the four zones associated to each tree species at each site were calculated using the Excel software. The average values of measured soil chemical properties for the five soil layers and four zones associated to each tree species at each site were calculated using the Excel software. These mean values were used for the simple linear regression to analyse relationship between soil chemical properties and the biomass and grain yield of sorghum at each site independently to tree species and at each site according to tree species.

The linear regression is a statistical method of predicting the value of a response variable from a given value of the explanatory variable. In this research, CEC, K, P, C, N and pH were explanatory variables and the biomass and grain yield of sorghum were response variables. The following assumptions need to be verified to perform a simple linear regression: multivariate normality, no or little multicollinearity, no auto-correlation and homoscedasticity. All these assumptions were examined to know if there is any indication for nonlinear analysis but no reason was found. The linear model strength is generally evaluated using R^2 that informs about the percentage of variability in the response variable and it is always between 0 and 1. If the R^2 is greater than 0.5 then the relation between the response and the explanatory variables is quite high. The simple linear regression was implemented using the software XLSTAT 2022.

RESULTS

The simple linear regression results did not show significant relation between soil chemical properties and the biomass and grain yield of sorghum at Nobere. The simple linear regression results showed a significant relation between CEC and the biomass (P=0.039**)** and grain yield (P=0.021) of sorghum at Tougouri. Also, the simple linear regression results showed a significant relation between K and the biomass (P=0.022) and a very significant relation between K and the grain yield (P=0.003**)** of sorghum at Tougouri. There was no significant relation between other soil chemical properties and the biomass and grain yield of sorghum at Tougouri. The equations of regression showed a positive relation between CEC and the biomass (Figure 1a) and grain yield (Figure 1b) of sorghum at Tougouri, which meant that the biomass and grain yield of sorghum increased with CEC. The R^2 indicated that 27% of sorghum biomass variation was explained by CEC (Figure 1a) and 32% of sorghum grain yield variation was explained by CEC (Figure 1b) at Tougouri. The equations of regression showed a negative relation between K and the biomass (Figure 2a) and grain yield (Figure 2b) of sorghum at Tougouri, which meant that the biomass and grain yield of sorghum decreased with K. The R^2 indicated that 32% of sorghum biomass variation was explained by K (Figure 2a) and 49% of sorghum grain yield variation was explained by K (Figure 2b) at Tougouri.

The simple linear regression results showed a significant relation between CEC and sorghum biomass (P=0.032) at Sokouraba but it was not significant between CEC and sorghum grain yield at Sokouraba. There was no significant relation between other soil chemical properties and the biomass and grain yield of sorghum at Sokouraba. The equation of regression showed a negative relation between CEC and the biomass of sorghum at Sokouraba (Figure 3a), which meant that the biomass of sorghum decreased with CEC. The R^2 indicated that 29% of the sorghum biomass variation was explained by CEC (Figure 3a) at Sokouraba.

The simple linear regression results did not show a significant relation between soil chemical properties and the biomass and grain yield of sorghum in association with *P. biglobosa* and *V. paradoxa* at Tougouri and Nobere. The simple linear regression results showed a significant relation between CEC and the biomass of sorghum in association with *P. biglobosa* at Sokouraba (P= 0.041). There was no significant relation between CEC and the grain yield of sorghum in association with *P. biglobosa* at Sokouraba. Also, the relation between other soil chemical properties and the biomass and grain yield of sorghum in association with *P. biglobosa* and *V. paradoxa* at Sokouraba was not significant. The equation of regression showed a negative relation between CEC and the biomass of sorghum in association with *P. biglobosa* at Sokouraba (Figure 3b), which meant that the biomass of sorghum decreased with CEC. The R^2 indicated that 53% of sorghum biomass variation with *P. biglobosa* was explained by CEC at Sokouraba (Figure 3b).

Table 1: Soil characteristics at Tougouri (Sahelian zone), Nobere (Sudano-Sahelian zone) and Sokouraba (Sudano-Guinean zone) in Burkina Faso (West Africa).

Parameters	**Tougouri**	**Nobere**	**Sokouraba**
clay (%)	42.6	33.8	56.1
Silt (%)	25	25.6	23.3
Sand (%)	32.4	40.6	20.6
CEC (meq/100 g)	10.13	5.81	9.34
Organic matter (%)	0.43	0.39	1.05
N content (%)	0.03	0.02	0.07
P content (P-Bray) (ppm)	2.2	9.56	5.38
pH	5.92	6.43	5.71

The values are the average of top 50 cm soil layer. The soil samples for data analysis were collected during field experiments in agroforestry parkland systems.

Table 2: Dendrometric characteristics of the sampled tree species at Tougouri, Nobere and Sokouraba in Burkina Faso (West Africa). The values are the average for all the eight trees.

Sites	**Species**	**Height (m)**	**Canopy height (m)**	**Canopy diameter (m)**	**Trunk diameter (cm)**
Tougouri	*V. paradoxa*	9.10±0.20	6.10±0.20	14.05±0.86	83.00±0.04
	P. biglobosa	10.25±0.75	7.25±0.75	11.00±1.30	38.00±0.02
Nobere	*V. paradoxa*	9.54±0.37	4.04±0.37	11.84±0.43	53.00±0.02
	P. biglobosa	11.03±0.38	5.03±0.37	18.39±1.32	73.00±0.05
Sokouraba	*V. paradoxa*	7.20±0.60	4.22±0.57	10.00±0.60	30.00±0.04
	P. biglobosa	7.90±0.50	3.43±0.45	14.40±1.50	50.00±0.02

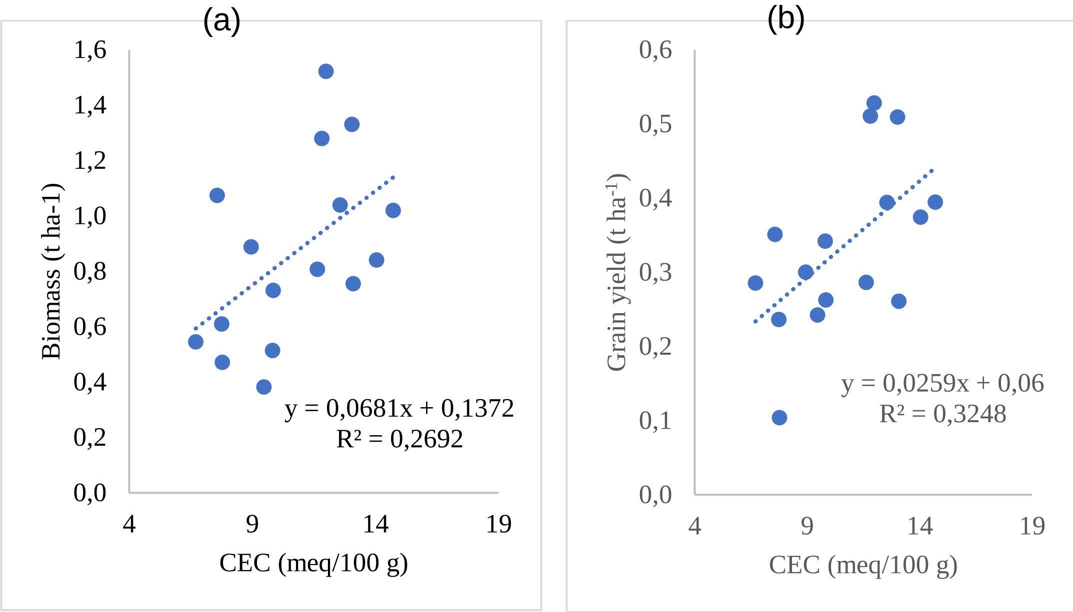

Figure 1: (a) regression between Cation Exchange Capacity (CEC) and the biomass of sorghum at Tougouri and (b) regression between Cation Exchange Capacity (CEC) and the grain yield of sorghum at Tougouri. The biomass and grain yield values used for the regression were the average values of the three years measurement and the four zones associated to the tree species. The CEC values used for the regression were the average values for the four zones and five depths associated to the tree species. The soil samples were collected during the field experiment.

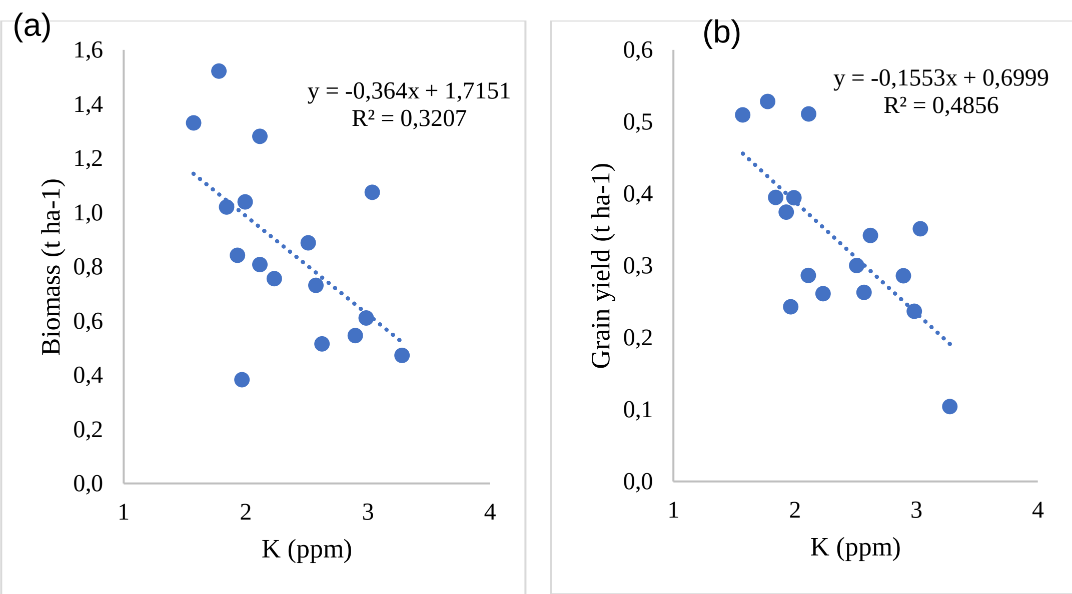

Figure 2: (a) regression between K and the biomass of sorghum at Tougouri and (b) regression between K and the grain yield of sorghum at Tougouri. The biomass and grain yield values used for the regression were the average values of the three years measurement and the four zones associated to the tree species. The K values used for the regression were the average values for the four zones and five depths associated to the tree species. The soil samples were collected during the field experiment.

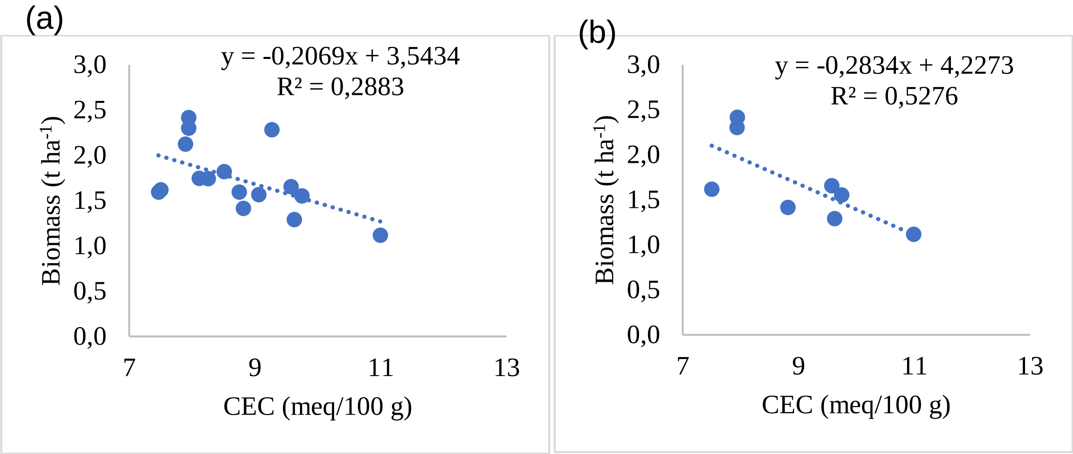

Figure 3: (a) regression between cation exchange capacity (CEC) and the biomass of sorghum at Sokouraba and (b) regression between cation exchange capacity (CEC) and the biomass of sorghum in association with *P. biglobosa* at Sokouraba. The biomass and grain yield values used for the regression were the average values of the three years measurement and the four zones associated to the tree species. The CEC values used for the regression were the average values for the four zones and five depths associated to the tree species. The soil samples were collected during the field experiment.

DISCUSSION

The simple linear regression results showed that the biomass and grain yield of sorghum are dependent to CEC at Tougouri, which means that this soil property could be used to predict sorghum performance in agroforestry parklands systems. The positive effect of CEC on sorghum performance in agroforestry parklands systems at Tougouri could suggest that nutrients are the most limiting factors in these systems when rainfall decreased. It was reported that soil organic matter is the most important contributor to the CEC in the soils in the tropics (Oorts et al., 2003). Previous research assessed the effects of *P. biglobosa* and *V. paradoxa* on soil total carbon in agroforestry parklands systems according to an increasing rainfall gradient represented by the sites of Tougouri, Nobere and Sokouraba by Coulibaly et al. (2020). The results revealed that soil total carbon was lower at Tougouri, but it was significantly higher in soil with *V. paradoxa*. The lower soil total carbon observed at Tougouri was probably due to the process of litter decomposition reduction because of low rainfall and moisture levels as shown by Yahdjian et al. (2006). The higher soil total carbon observed with *V. paradoxa* at Tougouri could probably be explained by the large size of the measured crown that would generate more litter for decomposition as this was reported by Roose and Barthes (2001). Also, *V. paradoxa* characterised by an open canopy (Bazié et al., 2012) allows more water (Zomboudré et al., 2005) and light (Bayala et al., 2002) to reach the soil at Tougouri with limited rainfall, increasing then the process of litter decomposition leading to higher soil total carbon under *V. paradoxa*.

Improving CEC through increasing soil organic carbon at Tougouri in general, and in particular with *P. biglobosa*, could contribute to increase sorghum productivity in agroforestry parklands systems. Fullen and Catt (2004) reported that the higher the CEC of a soil, the more nutrients it is likely to hold and the higher will be its fertility level. The application of crop and soil management that improve soil organic carbon could be suggested to contribute increasing sorghum productivity in agroforestry parklands systems with *V. paradoxa* and *P. biglobosa* when rainfall decreased with climate change. The recommended soil and crop management options include but are not limited to the reduction of erosion, runoff and leaching (Roose and Barthes, 2001), the reduction of continuous cultivation of crops although the effect of this on soil organic carbon depend on management practices such as the choice of the cropping system, soil tillage and the application of mineral and organic soil amendments (Ouédraogo, 2004), the application of organic material such as green manures, crop residues, compost, or animal manure (Peinemann et al., 2000), the application of crop rotation (Cuvardic et al., 2006) and the use of high cover crops (Scavo et al., 2022).

The simple linear regression results showed that the biomass and grain yield of sorghum are dependent to K at Tougouri, which means that it could be used to predict sorghum performance in agroforestry parklands systems. The negative effect of K on the biomass and grain yield of sorghum in agroforestry parklands systems at Tougouri could suggest that K is not a limiting factor in these systems when rainfall decreased. It was reported that soil content in clay determines the potential of K adsorption and accumulation in soil (Raheb and Heidari, 2012). Previous research assessed the effects of *P. biglobosa* and *V. paradoxa* on soil content in clay in agroforestry parklands systems according to an increasing rainfall gradient represented by the sites of Tougouri, Nobere and Sokouraba by Coulibaly (2014). The results revealed that higher soil content in clay was observed at Tougouri and Sokouraba while there was not a significant difference of soil content in clay between tree species at all the sites. The higher soil content in clay gives a greater potential of K adsorption and accumulation in soil at Tougouri. However, the limited rainfall at this site could reduce the sorghum performance due to the decrease of K uptake. Similar results were reported by Baque et al. (2006) who showed that the uptake of K by wheat (*Triticum aestivum*) was lowered by the water stress and as a consequence the grain yield was significantly reduced. These results could suggest that soil content in water is one of the most limiting factor that influence the K uptake by sorghum in agroforestry parklands systems when rainfall decreased.

The application of soil management that improves soil moisture (Oduor et al., 2021) including but not limited to the techniques of soil and water conservation (Da, 2008) for improving sorghum productivity in agroforestry parklands systems with *V. paradoxa* and *P. biglobosa* when rainfall decreased with climate change could be recommended.

The biomass of sorghum is dependent to CEC at Sokouraba, which means that it could be used to predict sorghum performance in agroforestry parklands systems. The negative effect of CEC on sorghum biomass in agroforestry parklands systems at Sokouraba and when it was in association with *P. biglobosa* could suggest that light is the most limiting factor instead of nutrients in these systems when rainfall increased. Previous research assessed the effects of *P. biglobosa* and *V. paradoxa* on soil total carbon in agroforestry parklands systems according to an increasing rainfall gradient represented by the sites of Tougouri, Nobere and Sokouraba by Coulibaly et al. (2020). The results showed that higher soil total carbon was observed at Sokouraba, but the difference was not significant between soil with *P. biglobosa* and *V. paradoxa*. The greater soil total carbon observed at Sokouraba was probably due to the high rainfall level which led to higher tree aboveground biomass as this was reported by Coulibaly et al. (2014) and consequently, higher litter accumulation and decomposition into organic matter was observed (Yahdjian et al., 2006). The higher soil total carbon observed at Sokouraba could also be explained by the possibility to continue fallow practice (Coulibaly, 2014). Also, previous research results showed that higher soil content in clay was observed at Sokouraba (Coulibaly, 2014). The combined effect of higher soil total carbon and clay in soil give a greater CEC and soil fertility to the soil at Sokouraba. The negative effect of CEC on sorghum at Sokouraba under *P. biglobosa* could be explained by its dense canopy which reduces soil evaporation leading to more organic matter accumulation (Coulibaly, 2014).

It could be suggested to optimise the use of mineral fertilisers and to practice tree pruning (Bayala et al., 2002) for increasing sorghum productivity in agroforestry parklands systems with *V. Paradoxa* and *P. biglobosa* when rainfall increased with climate change.

The simple linear regression results showed that the variation of the biomass and grain yield of sorghum due to CEC and K at Tougouri and Sokouraba remains modest, suggesting that soil fertility was not the only factor that explains sorghum performance in the studied agroforestry parklands systems, but that it is under the influence of several biophysical factors. In fact, the reduction of crops yields under trees crown in agroforestry parklands systems was attributed to reduced light quantity and quality under trees crown (Bazié et al., 2012). The reduction of sorghum performance in agroforestry parklands systems was attributed to tree and crop belowground competition to access water and nutrients in soil (Bayala et al., 2004). Crop performance was also under the influence of tree and crop roots distribution in soil layers in agroforestry parklands systems as this affects belowground competition (Bayala et al., 2008; Coulibaly, 2014). Different sorghum yields were observed under *V. paradoxa* according to the crown architecture which has influence on soil moisture (Zomboudré et al., 2005).

There was no significant relationship between other soil chemical properties and the biomass and grain yield of sorghum at each site as well as between other soil chemical properties and the biomass and grain yield of sorghum in association with the two studied tree species at each site, probably due to high variability of measured soil chemical properties because of the method used for soil analysis.

Conclusion

CEC and K had an effect on the biomass and grain yield of sorghum in agroforestry parklands systems when rainfall decreased suggesting that soil content in nutrients and in water were probably the most limiting factors of sorghum performance. The application of crop and soil management that improve soil organic carbon and moisture could be suggested for increasing sorghum productivity in agroforestry parklands systems with *V. paradoxa* and *P. biglobosa* when rainfall decreased due to climate change. CEC had an effect on the biomass of sorghum at Sokouraba and when it was in association with *P. biglobosa* in agroforestry parklands systems suggesting that the most limiting factor of sorghum performance was probably light instead of nutrients. The optimisation of the mineral fertilisers use and tree pruning could be recommended to increase sorghum productivity in agroforestry parklands systems with *V. Paradoxa* and *P. biglobosa* when rainfall increased due to climate change. CEC and K could be used for planning agricultural production with climate change. However, it is suggested further research to study the effects of the recommended management options on sorghum productivity in agroforestry parklands systems with *V. paradoxa* and *P. biglobosa* along an increasing rainfall gradient.

COMPETING INTERESTS

The authors declare that they have no competing interests

AUTHORS' CONTRIBUTIONS

YNC is the first author of this article. He developped the research protocol, collected and analysed the data, initiated and finalised this paper. GZ supervised the work and contributed in revising this paper**.**

ACKNOWLEDGMENTS

We are grateful to the farmers, technicians and supervisors for their valuable contributions in the implementation of this research study.

REFERENCES

Abdou MM, Alzouma ZM, Kadri A, Ambouta JMK, Dan Lamso N. 2013. Effet de l'arbre *Acacia senegal* sur la fertilité des sols de gommeraies au Niger. *International Journal of Biological and Chemical Sciences,* **7**(6): 2328-2337. DOI: 10.4314/ijbcs.v7i6.13

Aliou SB, Koné I, Gnangle B, Césaire AN. 2013. Effet d'un système agroforestier à karité (*Vitellaria paradoxa* C. F Gaertn) sur le sol et le potentiel de production du maïs (*Zea mays* L.) en zone Soudanienne du Bénin. *International Journal of Biological and Chemical Sciences,* **6**(5): 2066-2082. DOI: http://dx.doi.org/10.4314/ijbcs.v6i5.16

Baque AM, Karim MA, Hamid A, Tetsushi H. 2006. Effects of fertilizer potassium on growth, yield and nutrient uptake of wheat (*Triticum aestivum*) under water stress conditions. *South Pacific Studies,* **27**: 25-35. URL: http://hdl.handle.net/10232/9518

Bayala J, Sanou J, Teklehaimanot Z, Kalinganire A, Ouédraogo SJ. 2014. Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Current Opinion in Environmental Sustainability,* **6**: 28-34. DOI: https://doi.org/10.1016/j.cosust.2013.10.004

Bayala J, Teklehaimanot Z, Ouédraogo SJ. 2002. Millet production under pruned tree crowns in a parkland system in Burkina Faso. *Agroforestry Systems,* **54**: 203-214. DOI: https://doi.org/10.1023/A:1016058906682

Bayala J, Teklehaimanot Z, Ouédraogo SJ. 2004. Fine root distribution of pruned trees and associated crops in parkland system in Burkina Faso. *Agroforestry Systems,* **60**: 13-26. DOI: https://doi.org/10.1023/B:AGFO.0000009401.96309.12

Bayala J, van Noordwijk M, Lusiana B, Kasanah N, Teklehaimanot Z, Ouédraogo SJ. 2008. Separating the tree-soil-crop interactions in agroforestry parkland systems in Saponé (Burkina Faso) using WaNuLCAS. *Advances in Agroforestry,* **4**: 296-308. DOI: https://doi.org/10.1007/978-1-4020-6572-9_17

Bayala J, Sileshi GW, Coe R, Kalinganire A, Tchoundjeu Z, Sinclair F, Garrity D. 2012. Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis. *J. Arid Environ.,* **78**: 13–25. DOI: https://doi.org/10.1016/j.jaridenv.2011.10.011

Bazié HR, Bayala J, Zombré G, Sanou J, Ilstedt U. 2012. Separating competition-related factors limiting crop performance in an agroforestry parkland system in Burkina Faso. *Agroforestry Systems,* **84**: 377-388. DOI: https://doi.org/10.1007/s10457-012-9483-y

Boffa JM, Taonda SJ, Dickey JB, Knudson DM. 2000. Field-scale influence of karité (*Vitellaria paradoxa*) on sorghum production in the Sudan zone of Burkina Faso. *Agroforestry Systems,* **49**: 153-175. DOI: https://doi.org/10.1023/A:1006389828259

Coulibaly YN, Bayala J, Gaiser T, Zombré G. 2020. Assessing tree effect on total soil carbon in agroforestry parklands systems along a rainfall gradient in Burkina Faso (West Africa). *International Journal of Biological and Chemical Sciences,* **14** (9): 3030-3046. DOI: https://doi.org/10.4314/ijbcs.v14i9.6

Coulibaly YN, Mulia R, Sanou J, Zombré G, Bayala J, Kalinganire A, van Noordwijk M. 2014. Crop production under different rainfall and management conditions in agroforestry parkland systems in Burkina Faso: observations and simulation with WaNuLCAS model. *Agroforestry Systems,* **88**: 13–28. DOI: https://doi.org/10.1007/s10457-013-9651-8

Coulibaly YN. 2014. Production de *Sorghum bicolor* (L.) Moench (sorgho) dans les parcs agroforestiers sous trois conditions pluviométriques différentes et effets des options de gestion de ces parcs au Burkina Faso : observations et simulations avec le modèle WaNuLCAS. PhD thesis, University of Ouagadougou, p.157.

Cuvardic M, Tveitnes S, Krogstad T, Lombnæs P. 2006. Long-term effects of crop rotation and different fertilization systems on soil fertility and productivity. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science,* **54** (4): 193-201. DOI: https://doi.org/10.1080/09064700410030258

Da CED, 2008. Impact des techniques de conservation des eaux et des sols sur le rendement du sorgho au centre-nord du Burkina Faso. *Les Cahiers d'Outre-Mer*, **242** *:* 99-110. DOI : https://doi.org/10.4000/com.3512

Direction Générale de la Météorologie (DGM) du Burkina Faso. 2013. Base de données climatiques du Burkina Faso, Ouagadougou. DGM.

Du C, Zhou J. 2009. Evaluation of soil fertility using infrared spectroscopy: a review. *Environmental Chemistry Letter*, **7**: 97-113. DOI: https://doi.org/10.1007/978-90-481-2716-0_16

Fullen MA, Catt JA. 2004. *Soil Management: Problems and Solutions* (1st edn). Routledge: London.

Institut National de la Statistique et de la Démographie (INSD) du Burkina Faso. 2022. Cinquième recensement général de la population et de l'habitation. Monographie des régions des Hauts Bassins, du Centre Nord et du Centre Sud. INSD: Burkina Faso

Kuyah S, Whitney C, Jonsson M, Sileshi G, Oborn I, Muthuri C, Luedeling E. 2019. Can agroforestry enhance ecosystem services provision without reducing productivity? World Agroforestry: Montpellier.

Laudien R, Bernhard S, Jillian W, Christoph G. 2022. A forecast of staple crop production in Burkina Faso to enable early warnings of shortages in domestic food availability. *Scientific Reports,* **12**: 1638. DOI : https://doi.org/10.1038/s41598-022-05561-9

Ndiaye SSA, Elhadji F, Tala G, Hank M, Camire C. 2012. Cordyla pinnata améliore les propriétés du sol et la productivité des cultures. *International Journal of Biological and Chemical Sciences*, **6**(2): 714-725. DOI: http://dx.doi.org/10.4314/ijbcs.v6i2.15

Oduor N, Kiboi MN, Muriuki A, Adamtey N, Musafiri CM, Ngetich FK. 2021. Soil management strategies enhanced crop yield, soil moisture, and water productivity in Nitisols of the Upper Eastern Kenya. *Environmental Challenges,* **5**: 100375. DOI: https://doi.org/10.1016/j.envc.2021.100375

Oorts K, Vanlauwe B, Merckx R. 2003. Cation exchange capacities of soil organic matter fractions in a Ferric Lixisol with different organic matter inputs. *Agriculture, Ecosystems and Environment,***100** (2–3): 161-171. DOI: https://doi.org/10.1016/S0167-8809(03)00190-7

Ouédraogo E. 2004. Soil quality improvement for crop production in semi-arid West Africa. PhD Dissertation, Wageningen University, p.209.

Pattanayak SK. 2004. Valuing watershed services: concepts and empirics from southeast Asia. *Ecosystems and Environment*, **104**: 171–184. DOI: https://doi.org/10.1016/j.agee.2004.01.016

Peinemann N, Amiotti N, Zalba P, Villamil M. 2000. Effect of Clay Minerals and Organic Matter on the Cation Exchange Capacity of Silt Fractions. *Journal of Plant Nutrition and Soil Science*, **163** (1): 47-52. DOI: https://doi.org/10.1002/(SICI)1522-2624(200002)163:1<47:AID-JPLN47>3.0.CO;2-A

Raheb A, Heidari A. 2012. Effects of clay mineralogy and physico-chemical properties on potassium availability under soil aquic conditions. *Journal of Soil Science and Plant Nutrition*, **12**: 747-761. DOI: http://dx.doi.org/10.4067/S0718-95162012005000029

Roose E, Barthes B. 2001. Organic matter management for soil conservation and productivity restoration in Africa: a contribution from francophone research. *Nutrient Cycling in Agroecosystems*, **61**: 159–170. DOI: http://dx.doi.org/10.1023/A:1013349731671

Scavo A, Fontanazza S, Restuccia A et al. 2022. The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, **42**: 93. DOI: https://doi.org/10.1007/s13593-022-00825-0

Shepherd KD, Walsh MG. 2002. Development of reflectance spectral libraries for characterization of soil properties. *Soil Sciences Society of America Journal*, **66**: 988-998. DOI: https://doi.org/10.2136/sssaj2002.9880

Teklehaimanot Z. 2004. Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. *Agroforestry Systems*, **61**: 207-220. DOI: https://doi.org/10.1023/B:AGFO.0000029000.22293.d1

Traore S, Owiyo T. 2013. Dirty droughts causing loss and damage in Northern Burkina Faso. International *Journal of Global Warming*, **5**: 498–513. DOI: https://doi.org/10.1504/IJGW.2013.057288

Yahdjian L, Sala OE, Austin AT. 2006. Differential controls of water input on litter decomposition and nitrogen dynamics in the Patagonian steppe. *Ecosystems*, **9**: 128–141. DOI: 10.1007/s10021-004-0118-7

Zomboudré G, Zombré G, Ouédraogo M, Guinko S, Roy Macauley H. 2005. Réponse physiologique et productivité des cultures dans un système agroforestier traditionnel : cas du maïs (*Zea mays* L.) associé au karité (*Vitellaria paradoxa* Gaertn.) dans la zone est du Burkina Faso. *BASE*, **9**: 75-85.