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Dual-purpose crops productivity and small-scale dairy farmers' food security efforts toward climate variability and change in Benin

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ABSTRACT

Dual-purpose cropping (sowing crops with the intention of both grazing them during vegetative growth and harvesting grain thereafter for household consumption) is certainly a promising way to address challenges face by small-scale dairy farmers in Benin due to climate variability and change. This study evaluated the impact of climate variability and change on dual-purpose crops productivity performances and nutritional values in Benin's climatic regions. Four dual-purpose crops were studied. They are maize fodder, sorghum fodder, peanut fodder and cowpea fodder. The grain yield across various climate regions and years were assessed. Also fodders samples were analysed according to official methods of AOAC. The results showed that dual purposes crops yield were significantly affected particularly in some years in many regions of Benin by climate parameters variation. The variation of humidity had a negative effect on cereals dual-purpose crops production in Guinean region while the impacts of temperature and rainfall on dual purpose crops were higher in Sudanian region. The model for predicting the resistance of dual-purpose crops to climate variability and change revealed that The Annual Yield of Sorghum Grain was significantly influenced by humidity (P=0.0111), Rainfall (P=0.0374) and Weather station/Region (P=0.0493), as well as by the interaction between temperature and Grain Yield per Hectare (P=0.0423). The annual quantity of maize produced varied significantly with temperature (P=0.00154), humidity, Rainfall (P=0. 00792), Weather station/ Region (P=0.00362). The Annual Yield of Cowpea Grain production varied significantly with Temperature and Humidity (0.0205). Furthermore, temperature, humidity, year and Grain Yield per Hectare significantly affected the Annual Yield of Peanut Grain Produced. Nutritional values of the four studies dual-purpose crops were assessed. The energy values were 0.60 and 0.50 UFL/kg of Dry Matter respectively for sorghum-fodder and maize-fodder, the contents of digestible nitrogenous materials (MAD) were 1 and 0 g/kg of DM respectively for sorghum-fodder and maize-fodder. If the energy values were quite good for cereals fodder, the nitrogen values were very low. This study highlighted the nutritional advantage of leguminous fodders over cereal fodders.

Keywords: climate change, dairy farms, feeding practices, dual-purpose crops, resilience, Benin.

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INTRODUCTION

Smallholders in most developing countries including Benin produce milk, and this contributes to household livelihoods, food security and nutrition. In addition, milk provides relatively quick returns for smallholders and is an important source of income (Ahozonlin et al., 2022; Achaglinkame et al., 2023). However, dairy farmers in Sub-Saharan Africa experience more dryness and warmer temperatures (Thornton et al., 2009). This leads to the drying up of natural pastures and difficulties to supply the animals with food (Gauly et al., 2013; Egeru, 2016). It's well known that recurrent droughts have put dairy farming systems in arid and semi-arid regions of Sub-Saharan Africa under pressure. Therefore, feeding livestock adequately throughout the year remains a challenge for many smallholders in sub-Saharan Africa (Rufino et al., 2013; Erenstein et al., 2013). Djenontin et al (2009) reported that in Benin the fodder supply of natural pasturage is increasingly reduced with the degradation of land cover combined with climate change and the production performance of cattle herds is affected by this and has remained low because of the poor fodder value of natural pastures.

In response to livestock feed constraints, farmers are increasingly exploring new options to improve the productivity and efficiency of their crop-livestock enterprises (Kimaro et al., 2018; Snapp et al., 2018). One of such option is dual-purpose crops, which has a high potential to simultaneously improve grain yields and livestock feed availability and quality (Erenstein, et al., 2013; Hassan et al., 2015). A promising method of enhancing crop and livestock productivity is increasing the availability and quality of cereal residues as livestock feed (Roseland et al., 2020; Alkemade et al., 2012). Dual-purpose crops provide food and income to households, while crop residues are an essential fodder source for livestock (Tarawali et al., 2011 ; Melesse et al., 2018). Compared to grain-only crops, dual-purpose crops help to significantly improve the profitability, environmental sustainability, and resilience of the whole farm system (Tarawali et al., 2011). Dual-purpose crops can also offer great opportunities for intensifying farming systems. In Benin, dual-purpose crops like groundnuts have a great interest because it does not require fertilizers and can give an interesting biomass for ruminants' nutrition. Survey of the typology of groundnut farmers in the Sudanian zone of Benin showed that the numbers of groundnut farmers have continuously increase and several varieties are grown from one year to the next and producers do not cultivate the same varieties (Adjahossou et al., 2009 ; Atta et al.,2011). Groundnut is mainly produced for edible oil (40- 50%) and for direct consumption (Thirumala Rao, 2016). In addition, groundnut crops produce protein-rich haulms that are used in animal feed (Reddy et al., 2014). About Cowpea, several, authors highlighted that Cowpea (*Vigna unguiculata*) is one of the important fodder legume crops grown round the globe for multiple uses such as green fodder and hay for livestock, green pods and grain rich in protein as vegetable and protein source for human consumption (Reddy et al., 2014; Thirumala Rao, 2016). In addition, fodder cowpea is a legume genetically tolerant to drought than other fodder legumes (Augustine et al., 2019) and provides nutritionally rich seasonal fodder to sustain livestock productivity. In rain deficit regions and relatively infertile soils, cowpea is wisely cultivated as fodder crop. Most of livestock owners grow fodder cowpea as an intercrop with other crops and fodder cowpea forms an integral component of crop livestock farming system (Tarawali, 2011). Samireddypalle et al. (2017) have stressed for multidimensional improvement of cowpea for mixed crop livestock systems in Africa. Cowpea is a fast growing leguminous fodder of Kharif season yielding 90–120qt fodder/acre. It can be grown as sole crop as well as mixed crop with sorghum, maize, pearl millet or other grasses and usually ready for feeding after 2 months of growth. Furthermore, the importance of any forage crop depends on the green fodder yield, chemical composition and nutritive value. The chemical composition and nutritive value are influenced by variety of crop and climatic factors (Atta et al., 2011; Melesse et al., 2021)

In order to overcome livestock feeding and food security challenges among small-scale dairy farmers, it is essential to contribute to strengthening the integration of dual-purpose crops in dairy farms through research. This study aimed to assess the impact of climate variability and change on the productivity of principal dual-purpose crops (Sorghum, Maize, Cowpea, Groundnut) used in dairy farming in Benin.

MATERIALS AND METHODS

Study areas

The study was carried out in Benin. Benin is located between the latitudes 6◦20'N and 12◦30'N and the longitudes 0◦45'E and 03◦70'E (figure 1). Data were collected in the three climatic zones of the country (Guinean zone, Sudano-Guinean and Sudanian zones). The Guinean zone is characterized by a bimodal rainfall regime (April-June and September-November). Its mean annual rainfall is 1,200 mm. Temperature ranges from 25◦C to 29°C and the relative humidity from 69% to 97%. Soils are mainly ferrallitic with hydromorphic soils and black cotton soils in some localities. The Sudano-Guinean zone is characterized by unimodal rainfall varying annually from 900 mm to 1,110 mm. The rainy season is from May to October. The annual temperature of this zone ranges from 25°C to 29°C and the relative humidity from 31% to 98%. Soils are mainly ferruginous. The Sudanian zone has one rainy season ranging from May to October and one dry season from November to April. Its mean rainfall is 900 mm .The temperature varying from 24°C to 31°C and the relative humidity from 18% to 99%. The study focused on the productivity of the main dual-purpose crops (maize, sorghum, cowpea and groundnuts) across the different climatic regions and agroecological zones of Benin over the years (Figure1).

Data collection

Grain yield of dual-purpose crops per hectare across climate regions

In order to compare the real trends of climate parameters and the productivity of dual-use crops over the years, climate data (temperature, rainfall, humidity) covering 1995-2020 from weather stations and dual purpose crops productivity data (Farmed land size, Grain yield per Hectare, Annual yield of production) taken from the National Agency for Agricultural Statistics were used. Thus, data from Kandi, Natitingou, Parakou, Savè and Bohicon weather stations were used. The effect of climate factors on the crop production parameters were highlighted per year through region was assessed using principal component analysis with packages devtools (Wickham et al., 2021), "Factoextra" (Kassambara and Mundt, 2020). "FactoMineR" (Le et al., 2008) and "corrplot" (Wei and Simko, 2021). Their significance was evaluated through a Generalized linear model per crop. Annual yield grain production (PG) was the response factor, while Farm Land Size (FL), Grain yield per Hectare (GY), Humidity, Temperature, and Rainfall were the explainatories factors of the model. The interaction among these explainatories factors were taken in count.

Chemical analyses

Fodder samples were analyzed according to the standard methods of AOAC (2005) for dry matter (DM), crude protein (CP), ether extract (EE) and ash. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined by the procedure of Van Soest et al. (1991) using Fiber Tech. Heat-stable alpha amylase and sodium sulfite were not used in NDF determination. Lignin was determined by solublization of cellulose with sulphuric acid in the ADF residue. Hemicellulose was calculated as NDF minus ADF, and cellulose was estimated as the difference between ADF and lignin in the sequential analysis.

Ingestibilities, digestibility coefficients and energy and nitrogen values of forages

The experiment was carried out at the Sheep and Goat Unit, Teaching and Research Farm, School of Animal Husbandry and Livestock Production Systems, National University of Agriculture, Benin. The experimental animals consisted of five groups of four (04) growing West African Dwarf bucks of 4 - 6 months of age, weighed between 6.50-9.00kg. The animals were acclimatized for two (2) weeks and treated against ectoparasites of the commencement of the experiment. The animals were allocated at random into five treatments of four goats per treatment and each animal serves as a replicate, in a completely randomized design (CRD). The experimental diets were the four dual-purpose crops (sorghum-fodder, maize-fodder, cowpea-fodder and groundnut-fodder) and the control diet (bush straw). Each group of animals was assigned to experimental diets, and was fed ad libitum while fresh water was made available.

Daily feed intake was estimated by the differences in the feed provided and the left over which was weighed the following morning, before another fresh feed was supplied. The initial and final weight obtained for each replicate were arranged in a completely randomized design (CRD) . After acclimatized for two weeks, urine and feaces were collected separately from each animal daily throughout the last seven days of the experiment in metabolic cages.

Data analysis

All data obtained (ingestibilities, digestibility coefficients) were subjected to one-way Analysis of Variance (ANOVA). Differences among the means were separated using Duncan's Multiple Range Tests (Ducan, 1995). The statistical model was:

$\mathbf{Y_{ij} = u + T_i + e_{ij}}$

where:

$\mathbf{Y_{ij}}$ = Variable of measurement ij

$\mathbf{u}$ = overall mean

$\mathbf{T_i}$ = effect of ith treatment diet i

$\mathbf{e_{ij}}$ = random residual error

All analyses were performed with R software, version 4.1.2 (R Core Team, 2021).

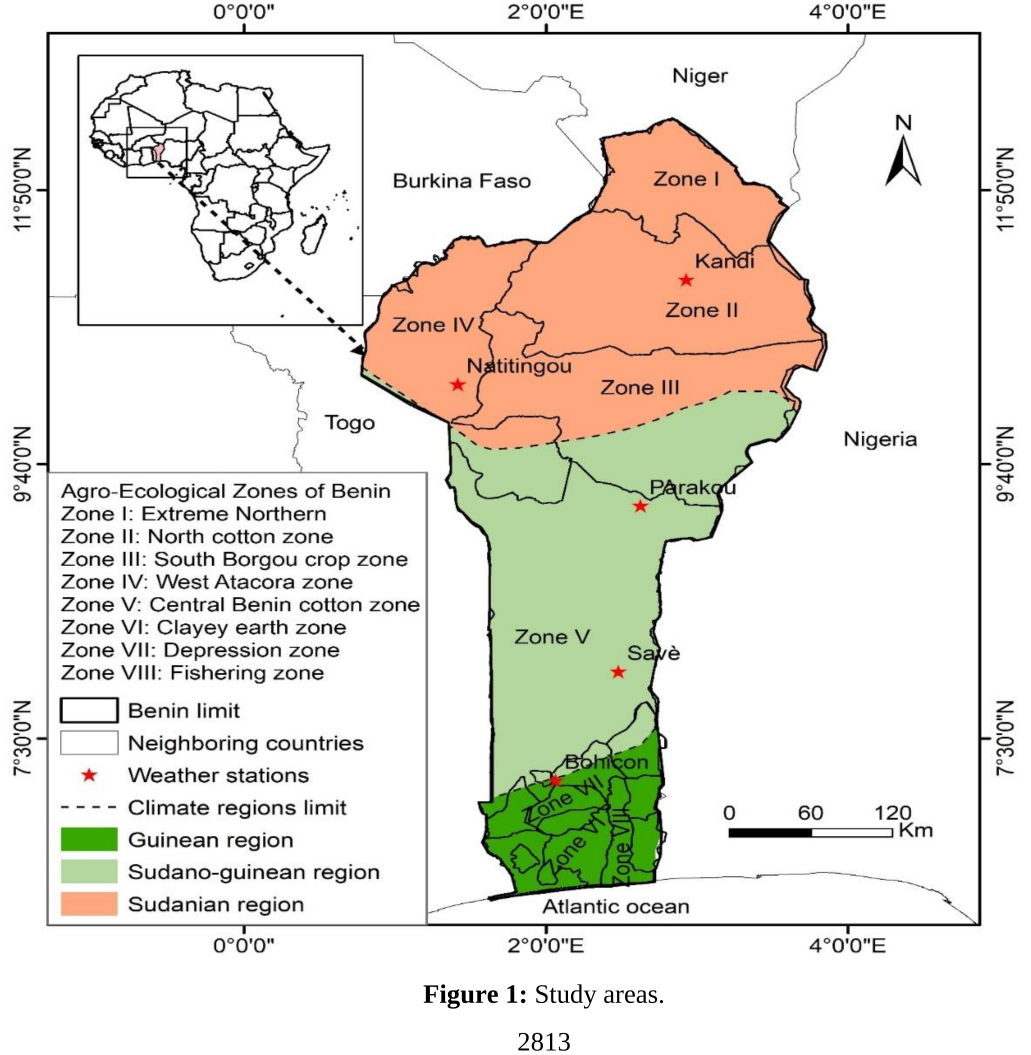

Figure 1: Study areas.

RESULTS

Variation in yield of dual-purpose crops per hectare across climate regions

Table 1 and Figure 2 presents the grain yield per hectare of studied dual-purpose crops during the period 1990 and 2022. Between 1990 and 2022, maize yields per hectare varied significantly according to climate region (P= 3.5e-05). The yield of groundnuts has also varied significantly (P=0.00436) and cowpea (P= 0.0101). Maize yield per hectare varied from one climate region to another, with average yields ranging from 842.11 kg per hectare to 1.344 tons per hectare. High maize yields were recorded in the Sudano-Guinean region (Parakou) and the Sudanian region (Natitingou). Sorghum yields per hectare did not vary significantly between climate regions. Between 1990 and 2022, low sorghum yields per hectare in Benin were recorded in Bohicon (Guinean zone) and Savè (Sudan-Guinean zone) while high yields were recorded in Kandi (Sudanian zone). About maize, high yields per hectare were recorded in the Sudanian regions while low yields were recorded in the Sudano-Guinean regions.

Impact of climate variability and change on the productivity of dual-purpose crops

The first two axes of the principal component analysis explained 82.59% of the total variation of the four studied crops yields following the climate parameters. The first principal component was strongly correlated with Humidity and Sorghum Farmed land size, Total sorghum production grain yield, Cowpea Farmed Land size whereas Rainfall, Temperature, Maize farmed land size, Total maize production grain yield, Peanut farmed land size, Total Peanut Production grain yield were associated with the second axis (Table 2). The projection of climate parameters and crops production data on the two axes showed that the variation of humidity has a negative effect on Sorghum farmed land size, Sorghum Total production, Maize grain yield per hectare, Cowpea farmed land size. The variation of Rainfall has a positive effect on Peanut farmed land size, Peanut production grain yield, Maize Farrmed Land size and Maize total production while Temperature has a negative effect on these same crops production data. Cowpea seems to be more resilient to climate variations (Figure 3).

Crop yields were significantly affected particularly in some years and especially in many regions (Table 2).

Nutritional value of dual-purpose crops forages

Table 3 shows the chemical composition of the studied dual-purpose crops. The Organic Matter (OM) contents of bush and cereal straws are little different, with the exception of sorghum-fodder which has a high ash content. The Total Nitrogenous Matter (MAT) contents of these straws are low, not exceeding 40 g/kg Dry Matter (DM). The chemical compositions of peanuts-fodder and cowpea-fodder show higher MAT contents than those of fodder cereals. These chemical analysis results highlight the nutritional advantage of legume haulms over cereal straws.

The ingestibilities, digestibility coefficients and energy and nitrogen values of studied dual-purpose crops are presented in Table 4. The digestibilities of dry matter (dMS) and organic matter and of the different constituents of bush straw (control) and sorghum straw are not significantly different (p > 0.05).

Table 1. Variation in yield of dual-purpose crops per hectare across climate regions

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Sorghum					
Climate Regions	4	668714	167178	2.084	0.113
Residuals	25	2005504	80220		
Maize					
Climate Regions	4	1320956	330239	10.66	3.5e-05 ***

Residuals	25	774371	30975		
Cowpea					
Climate Regions	4	263385	65846	4.165	0.0101 *
Residuals	25	395199	15808		
Peanuts					
Climate Regions	4	1359297	339824	4.969	0.00436 **
Residuals	25	1709812	68392		

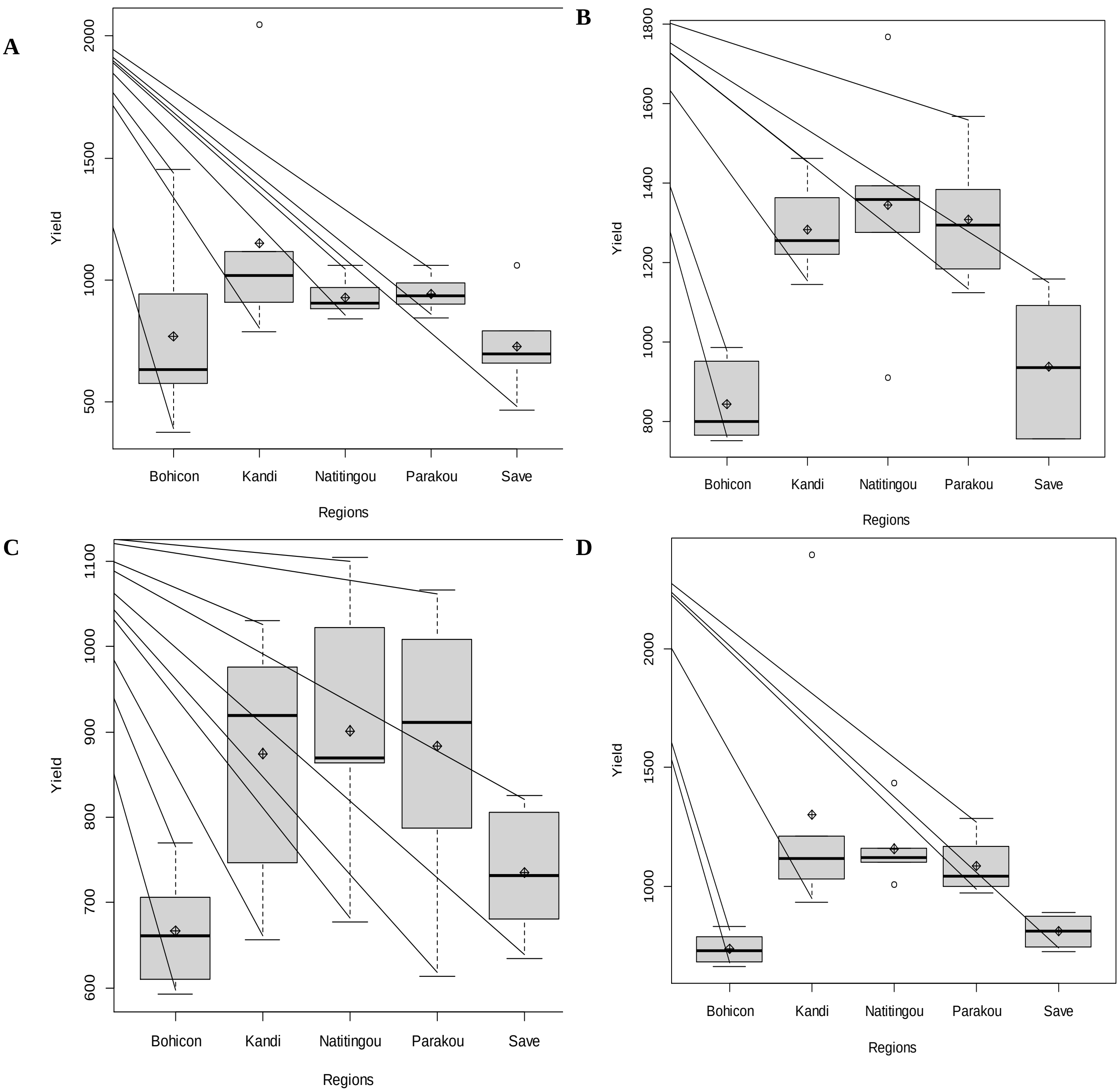

Figure 2. Variation in yield of dual-purpose crops per hectare across climate regions.
A= Sorghum ; **B**= Maize ; **C**= Cowpea ; **D** = Peanuts.

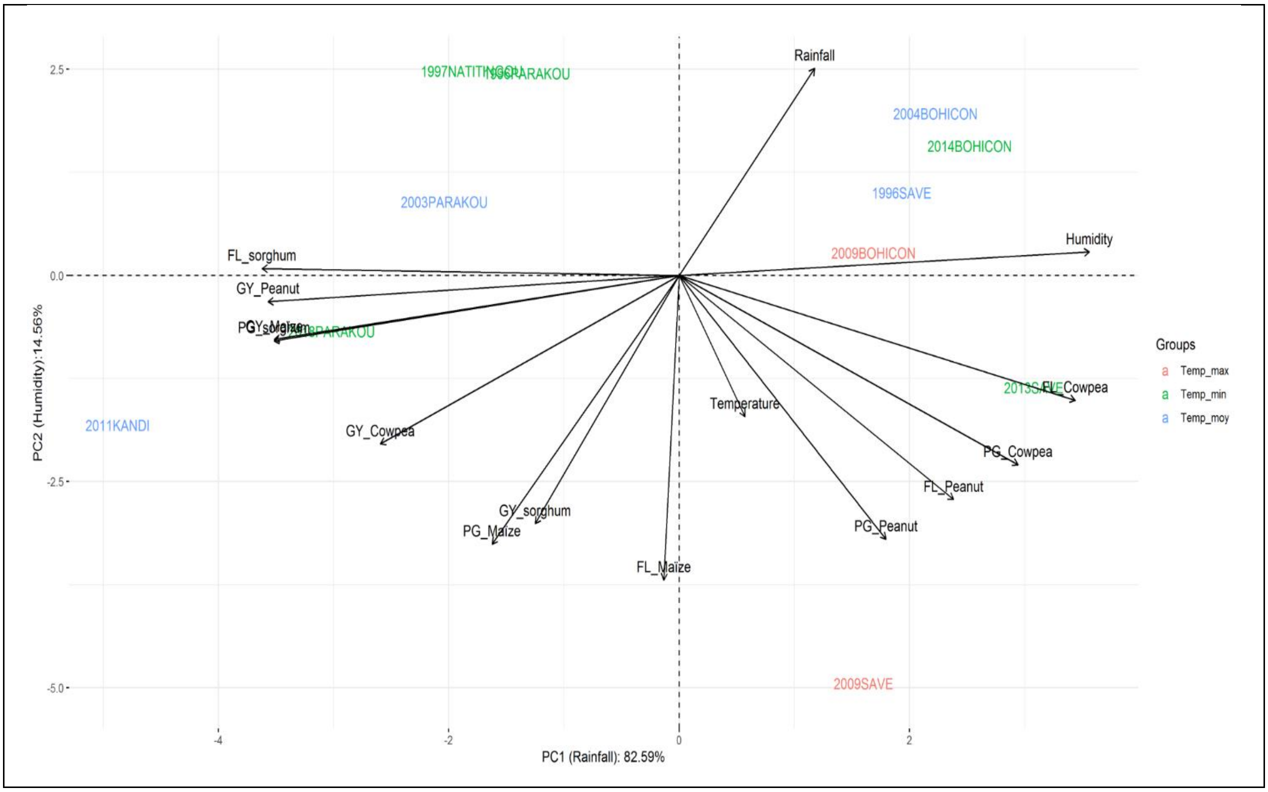

Figure 3: Impact of climate variability and change on the productivity of dual-purpose crops.

Table 2: Impact of climate variability and change on the productivity of dual-purpose crops.

Factors	Axe 1 (humidity)	Axe 2 (rainfall)
Climate parameters		
Temperature	0.020	**0.050**
Humidity	**0.67**	0.023
Rainfall	0.0004	0.100
Crops production data		
Sorghum Farmed Land size	**0.547**	0.073
Sorghum grain yield per hectare	0.109	0.017
Total Sorghum production grain yield	**0.618**	0.155
Maize Farmed Land size	0.042	**0.662**
Maize grain yield per hectare	**0.651**	0.0029
Total Maize production grain yield	0.219	**0.504**
Cowpea Farmed Land size	**0.605**	0.235
Cowpea grain yield per hectare	0.412	0.106
Total Cowpea production grain yield	0.288	0.357
Peanut Farmed Land size	0.365	0.554
Peanut grain yield per hectare	**0.576**	0.011
Total Peanut production grain yield	0.163	**0.713**

Table 3: Dry matter content and chemical composition of dual-purpose crop forages.

Components	Bush straw (Control)	Cereals fodder		Leguminous fodder	
		Sorghum	Maize	Peanuts	Cowpea
Dry Matter (g/kg brut)	936^{a}	919^{a}	899^{b}	862^{c}	863^{c}
Ashes (g/kg MS)	90^{c}	103^{b}	80^{c}	103^{b}	127^{a}
Organic Matter (g/kg MS)	910^{a}	897^{b}	920^{a}	897^{b}	873^{b}
Total Nitrogenous Matter (g/kg MS)	31^{b}	33^{b}	22^{c}	111^{a}	119^{a}
Crude cellulose (g/kg MS)	394^{b}	455^{a}	418^{b}	375^{c}	367^{c}
Neutral detergent fiber (g/kg MS)	812^{a}	722^{a}	-	-	-
Acid detergent fiber (g/kg MS)	464^{b}	593^{a}	-	-	-
Calcium (g/kg MS)			2.9^{c}	7.4^{b}	8.5^{a}
Phosphore (g/kg MS)			0.7^{c}	1.2^{b}	1.9^{a}

Table 4: Ingestibilities, digestibility coefficients and energy and nitrogen values of forages

Components	Bush straw (Control)	Cereals fodder		Leguminous fodder	
		Sorghum	Maize	Peanuts	Cowpea
Ingestion :					
g MS/kg P0,75	62^{b}	51^{b}	40^{c}	97^{a}	99^{a}
kg MS/100 kg PV*	2,54^{b}	2,17^{b}	1,75^{c}	4,25^{a}	4,37^{a}
Digestibility Coefficients (%) :					
Dry Matter	57,0^{c}	51,5^{c}	49,3^{d}	65,6^{a}	57,2^{b}
Organic Matter	63,0^{b}	57,8^{b}	49,5^{c}	66,3^{a}	59,2^{b}
Crude cellulose	9,1^{c}	2,4^{c}	62,7^{a}	58,2^{a}	45,7^{b}
Total Nitrogenous Matter	9,1^{c}	2,4^{c}	0 (-73,5)^{d}	60,3^{a}	48,3^{b}
Energy value:					
UFL/kg MS	0,71^{b}	0,60^{c}	0,50^{d}	0,76^{a}	0,63^{c}
Valeur azotée :					
MAD**/kg MS	3^{c}	1^{d}	0 (-14,3)^{d}	57,6^{a}	49,7^{b}

DISCUSSION

Dual-purpose crops can be used to overcome feed quality gaps observed in the dry season with recurrent drought and dryness of grazing areas. These dual-purpose crops include cereal straws and leguminous haulms (Digrado et al., 2022). Although cereal residues are poor in nitrogen because they are mainly composed cellulose, they are increasingly used directly by animals on pasture or collected and stocked to supplement animals in the dry season. On the other hand, legume haulms are used to supplement the animals in the dry season. Legume haulms have higher protein content (Blümmel et al., 2013) and have also a higher energy concentration than cereal residues. They are an important source of animal supplementation in the dry season (Delma et al., 2016 ; Abroulaye et al., 2020). These two types of dual-purpose crops residues can often constitute the daily ration for animals during the dry season (Zampaligre et al., 2022). Also, this dual-purposes cropping system improves soil fertility and helps control weeds and climatic hazards (Konlan et al., 2018). The groundnut-corn cropping association constitute a key to strengthening the resilience of small-scale dairy farmers to climate variability and the adverse impacts of environmental conditions (Sanfo et al., 2023). In West Africa, several studies have allowed the selection of improved dual-purpose varieties of graminaceous and leguminous plants with good fodder and grain performance (Sanginga et al., 2003; Hassan et al., 2015 ; Ouattara et al., 2015). Dual-purpose maize varieties for food and feed provides a promising technological option to intensify both crop and livestock production by simultaneously increasing the availability and quality of grain production and livestock feed (Lalsaga et al, 2017 ; Zampaligre et al., 2022). The potential of these dual-purpose technologies would depend on the environment, i.e. agro-ecological, climate parameters and socio-economic context of agricultural production (Notenbaert et al., 2017), farm management, i.e. crop-livestock farming systems (Ojiem et al., 2006; Hassan et al., 2015). Furthermore, sorghum is an important food and feed source in mixed crop-livestock production systems where its dual usage is a preferred option, especially among the resource poor small-scale farmers (Kagwiria et al., 2019). Cowpea (Vigna unguiculata (L.) Walp) is one of the most important food legumes and a valuable component of the traditional cropping systems in the semi-arid tropics (Zampaligre et al, 2022). In Benin, the third largest producer of cowpeas in the world, cowpea is traditionally the main fodder crop. In this country, FAO (2008) estimates cultivation of cowpea on 5,294,700 ha and a production of 1,569,300 tons in 2008. Cowpea offers a valuable contribution towards human food as well as livestock fodder and due to this dual-purpose character, it is a very attractive crop (Zampaligre et al., 2022). The grains are consumed as a major source of cheap protein by humans, and the haulms are fed to livestock as a nutritious fodder.

Conclusion

The model for predicting the resistance of dual-purpose crops to climate variability and change revealed that The Annual Yield of Sorghum Grain is significantly influenced by humidity, Rainfall and Weather station/Region, as well as by the interaction between temperature and Grain Yield per Hectare. The annual quantity of maize produced varied significantly with Temperature, Rainfall, Weather station/ Region, the interaction between Temperature and Year, the interaction between Temperature and Farmed Land size and the interaction between temperature and Grain Yield per Hectare. Temperature, Humidity, year and Grain Yield per Hectare significantly affect the Annual Yield of Peanut Grain Produced. Cowpea seems to be more resilient to climate variations. Furthermore, our study clearly showed that low total nitrogen content, high content of lignocellulosic compounds and low digestibility are found in cereals-fodder. In addition, the latter have a low energy value and zero nitrogen value. Legume haulms (peanut and cowpea) are rich in nitrogenous materials and have average contents of cell wall constituents. Their digestibility and ingestibility are higher and therefore their energy and nitrogen values are satisfactory.As a result, supplementing cereal straw with legume tops is necessary.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

MM designed the study. CCA reviewed literature. MM and CCA implemented the study and collected data. CCA analyzed the data. ABA and FMH supervised the study. MM, CCA, ABA and FMH wrote the manuscript.

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