Towards indigenous community-based adaptation to climate change: a typological analysis of tree-livestock integration in smallholding systems in dryland areas of Benin (West-Africa)

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Research Article

Keywords: agroforestry, climate change, land ownership, livestock systems, Benin

Posted Date: August 9th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-472829/v1

Abstract

Integration of livestock farming practices with trees is neglected and poorly explored in the context of climate change (CC) in drylands. However, such knowledge is urgently needed to propose effective strategies in the livestock sector to cope with CC. This study is initiated to characterize the diversity of indigenous integrated livestock systems with trees in drylands of Benin through a survey including 140 smallholder farmers. Data were submitted to a multiple correspondence analysis with hierarchical ascending classification and four types of integrated livestock smallholder farmers have been highlighted. The first type is referred to “Traditional silvopastoral systems”, consisting of farmers owning high tropical livestock unit (26 ± 0.59 TLU). They did not have land ownership and they exploited trees and shrubs in rangelands and protected areas. They used indigenous trees for treating sick animals and feeding. The second type is “Improved silvopastoral systems” with an average of 11 ± 0.21 TLU. They had a land ownership and combined livestock, forage plants and fodder trees in pasturelands. The third type, referred as “Small Integrated agrosilvopastoral systems” consisted of smallholder farmers who integrated agriculture, livestock and tree plantations. They owned a low livestock tropical unit (6 ± 0.24 TLU). The last type qualified as “Large Integrated agrosilvopastoral systems” owned an average of 18 ± 0.34 TLU and cultivated large areas of land. Leguminous trees are used to improve soil fertility and as animal feed. Based on these identified different agroforestry practices of livestock smallholder farmers in the drylands, indigenous community-based adaptation can be designed to face CC.

Introduction

Climate change (CC) is an obstacle to the socio-economic development for rural populations (Niang 2009). This phenomenon is increasingly causing a rise in temperature and a new distribution of precipitation (Bergonzini 2004). Sub-Saharan Africa where agriculture is the main source of employment and income for the majority of the population (Enete and Onyekuru 2011), appears to be the most exposed region to CC in the world (FAO 2008). Climate change is mainly caused by greenhouse gas (GHG) emissions that lead the atmosphere to global warming (IPCC 2013). The livestock sector is responsible for 14.5% of global GHG emissions (Gerber et al. 2013) and therefore contributes to climate change.

Since 1997, Benin became an evident source of GHG emissions estimated at 7,792.37 Gg CO_2 eq in 2015 that is 11 times higher than in 1997 (Ministry of Environment and Sustainable Development 2019). This change in status from sink to source is due to the increase of GHG emissions, particularly in the sectors of energy and agriculture. In the agriculture sector, these emissions come mainly from cultivated soils (36.5%) and from enteric fermentation (56.5%) (Ministry of Environment and Sustainable Development 2019). In fact, pastoral and agro-pastoral ecosystems in Sub-Saharan Africa are responsible for high levels of GHG emissions per unit of animal products due to low livestock productivity and high methanogenic rations (Assouma 2016). The challenge today, therefore, is to maintain a balance between livestock production and CC (Wright et al. 2012).

In Benin, the intensity and frequency of extreme weather events is expected to increase as well as the risks and impacts associated with them. According to MEHU (2011), rainfall in Benin will remain more or less stable in the south of the country (+ 0.2%) by 2100, but will decline by 13 to 15% in the North, which is the preferred area for ruminant farming in the country (Assani 2017). With this scenario, livestock farms located in drylands of Benin will be strongly affected by climatic variations, with decreases in livestock productivity.

To cope with these impacts, smallholder farmers are developing several adaptation strategies in Benin (Djenontin et al. 2009; Zakari et al. 2015; Lesse et al. 2017 ; Idrissou et al. 2020). These strategies vary according to the level of prosperity and the means available to them (Yegbemey et al. 2014). However, among these practices, there are several that are climate-smart and that increase productivity, develop resilience while limiting GHG emissions. This is the case with indigenous integrated livestock systems with the trees and shrubs species, which is a common adaptation and mitigation strategy used by smallholder farmers in drylands of Benin (Assani 2017). In fact, the livestock production in drylands of Benin has historically been impacted by recurrent drought and rangeland degradation. Through frequent exposure to drought and subsequent livestock feed shortage, farmers in drylands of Benin have developed various indigenous silvopastoral (SP) and agrosilvopastoral (ASP) practices using trees and shrubs species. As an agroforestry system, SP and ASP can increase carbon sequestration, thus offset GHG emissions and diminish carbon footprint produced by livestock production (Torres et al. 2017). In addition, SP has gained much more attention in recent years and is now considered as an economically viable and a sustainable alternative land use system (Jose et al. 2019).

In fact, the tree plays several roles in animal production systems in sub-Saharan Africa in general and in the drylands of Benin in particular (Akpo and Grouzis 2000 ; Houinato 2001 ; Brisso et al. 2007 ; Sèwadé et al. 2016): it participates in restoring soil fertility, ensuring plant cover, protecting the soil and raising the trophic level, supplementing livestock feed. Fodder trees and shrubs, used as supplement to ruminant rations, constitute means of survival for livestock, especially during the dry season. They participate in the maintenance of both domestic animals and transhumant herds in arid and semi-arid environments, the dry period of which can extend over seven months (Sarr et al. 2013). The use of woody fodder to feed animals, especially in the dry season, has been reported by several authors in sub-Saharan Africa (Sarr et al. 2013 ; Franzel et al. 2014 ; Balehegn et al. 2015; Paul et al. 2020 ; Simbaya et al. 2020; Koura et al. 2021 ; Habte et al. 2021). This widespread use of woody fodder is favored not only by the palatability of their leaves but also by the evergreen or semi-evergreen character of these species (Hiernaux 2000; Sèwadé et al. 2016). Apart from these benefits, in the dry season, fodder trees also provide shade for animals and protect them from severe climatic conditions during this time of year (Balehegn et al. 2015 ; Jose et al. 2019). They also participate in improving the livelihoods of smallholders in Africa through the provision of firewood, timber, hedges around fields and food for humans (edible fruits, leaves, etc.). Also, other trees have pharmacological properties and are used to treat certain human and animal diseases (Franzel et al. 2014 ; Hassen et al. 2022). Despite its importance, the characterization of these practices has never been the subject of a scientific investigation in Benin. Yet, such knowledge is urgently needed to propose effective strategies in the livestock sector to cope with CC in Benin. The study objective was therefore to characterize farms integrating trees in livestock farming in terms of diversity and feeding strategies to cope with the changing climate in drylands of Benin.

Materials And Methods

Study area

This study was conducted in drylands of Benin (7°30-12° N and 1°-3°40' E). The choice of the study region is based on the fact that drylands of Benin are the most vulnerable region to the consequences of CC (MEHU 2011), while at the same time more than 85% of the smallholder livestock farmers are concentrated in this region (Alkoiret et al. 2011). Drylands region was chosen because of (a) the vulnerability of populations in this region to climate change and their dependence on natural resources; (b) the presence of traditional livestock practices on agricultural land or natural rangelands; and (c) the increased incidence of land degradation and deforestation due to a growing population and other forces. Two ecological regions were identified in this study area: While the arid Sudanian region (7°30-9°30 N) is characterized by 800–1100 mm of rainfall annually with a growing season of 145 days, the semi-arid Sudano-Guinean region (9°30-12° N) receives 1100–1300 mm of annual precipitation resulting in a growing season of 200 days. The municipalities of Gogounou and Banikoara were selected in the arid Sudanian region and Sinendé and N'Dali municipalities in semi-arid Sudano-Guinean region for field investigations. Smallholder livestock farmers in both regions traditionally used silvopastoral practices to cope with shortages of animal feed during the dry season. Some agro-pastoralists in this study area have also used forage plants for livestock feed since their introduction by livestock development projects and programs in Benin (Livestock Development Project (PDE) Phase I, II and III; Support project for the milk and meat value chain (PAFILAV), Rural Economic Development Sector Support Project (PASDER), etc.). The total population of the four municipalities is estimated at 572,000 inhabitants, including 50.3% women against 49.7% men (INSAE 2015) with an estimated number of more than 600,000 head of cattle, 150,000 head of sheep and 120,000 head of goats in 2016 (FAOSTAT BENIN 2016). The study area is agricultural land, and agroforestry has been practiced traditionally on most of this land. As the rural households represented the main economic and income-pooling unit in the study area, it was chosen as the unit of analysis for this study.

Sampling design

Due to the fact that a list of smallholder farmers integrating trees into their production system is not available in the study area, random sampling could not be performed. Thus, interviews were carried out with technicians from the Territorial Agencies for Agricultural Development (ATDA) and key resource persons in order to obtain lists of farmers including trees in their farms in each village. Subsequently, two villages were selected per municipality. Depending on the number of farmers integrating trees in the farms identified per village, a sample of 15 or 20 smallholder farmers was carried out. In total, 35 livestock farmers were taken into account in each municipality, i.e. 140 livestock farmers for the four studied municipalities (Banikoara and Gogounou in arid Sudanian region, and Sinendé and N'Dali in semi-arid Sudano-Guinean region). Meetings were held with the farmers to explain the objectives of the study, obtain their consent to participate in the survey and agree with them on the ideal time to conduct the interviews.

Data collection

The individual interviews were conducted using a semi-structured questionnaire from December 2020 to February 2021. The criteria for selecting farmers were based on whether they integrated trees and/or shrubs in livestock farming practices. Farmers were also selected based on the accessibility of their farm, their willingness to participate in the survey and to provide information. The questions concerned the socio-economic characteristics of livestock farmers (ecological region, age, ethnic group, land ownership, level of education, main occupation, crop cultivation, farm size, household size, tree plantation size), the size and structure of livestock (sheep, goats and cattle), and the management livestock integrated practices (feeding mode, integration of trees, Integration of crop , reasons of integration of trees, contribution of trees integration to climate change resilience, health monitoring, and valorization of manure).

Data analysis

The data analysis was performed with R.4.0.4 software (R Core Team Development, 2021). To realize the typology of integrated trees-livestock farming, a Multiple Correspondence Analysis (MCA), followed by a Hierarchical Ascending Classification (HAC) were used. The variables that were retained for the interpretation of each component are those that are correlated with a coefficient greater than or equal to 0.5. Then, the farms adopting the different types of integration of trees to the livestock farming practices identified were compared. Chi-square ($\chi2$) or Fisher's exact test followed by the two-tailed Z test were used for qualitative variables. For quantitative variables, the nonparametric Kruskal-Wallis test followed by the Mann-Whitney U test (McDonald, 2009) were used. Statistical differences were considered significant at $p<0.05$. Total tropical livestock unit (TLU) was determined for each livestock. 1 TLU corresponds to 1 adult cow weighing 250 kg (Chilonda and Otto 2006). TLU for each livestock was estimated according to (Jahnke 1982), a cattle, goat and sheep, has a TLU of 0.7, 0.1 and 0.1, respectively. Then, the TLU was totaled for each household.

Results

Socio-economic characteristics of the interviewees and reasons of integration of trees in livestock farming practices

Table S1 summarizes general characteristics of the smallholder farmers. The farm managers are mainly divided into three ethnic groups, namely Fulani (53.1%), Gando (27.9%), and Bariba (19.0 %). Fulani and Gando ethnic groups practice Integration of Trees in Livestock Farming (ITLF) for feeding their animals during the dry season while Bariba ethnic group practice this for feeding animals, improving soil fertility and selling non-timber forest products. The average age of the farm managers was 45.0 ± 1.2 years. The majority of the farmers (88.5 %) did not receive any formal education, while 9.0 % reached a secondary level of education. The household size ranged from 2 to 22 people (mean 12.1 ± 0.6 people).

The main motivations for ITLF were resilience to climate change (feeding animals and people during the dry season and restoring degraded land) in 76.5 % of cases and food security and profit (income, additional income) in 34.5 % of cases. Animal production is combined with agricultural activities such as food crops (56.6 %) and cash crops (21.3%). Most of them practice subsistence agriculture with an average of 3.2 ± 0.3 ha cultivated land; while the area of tree plantations ranges from 0.25 to 3.2 ha (mean 1.6 ± 0.2 ha). Most smallholder farmers are used the family labor while hired non-family labor is used only by farm managers who practice farming as a secondary activity.

Livestock practices and feeding management

The average Tropical Livestock Unit (TLU) of the surveyed farms was 15.3 ± 0.4 TLU with a minimum of 2 TLU and a maximum of 30 TLU. The majority of farmers (98%) combine cattle, small ruminants and poultry. The farmers surveyed reared ruminants (cattle, sheep, and goats) and poultry such as chickens and guinea fowl. The average number of cattle, sheep, goats and poultry was 16 ± 1.1; 8 ± 0.4; 5 ± 0.6 and 21 ± 0.2 respectively. The dominant breeds are the Djallonke sheep, the Guinean dwarf goat, the yellow-legged Fulani chicken and the guinea fowl. The survey showed that the modes of obtaining animals were diversified. Most of the herds were acquired through inheritance, purchase, and fostering. Most often, it is the progenitors of the animals that are purchased. Cattle are often confided by Gando farmers and traders.

Livestock feeding is based on the natural pasture, supplemented by fodder trees, crop residues and cooking salt. Livestock farmers who purchase cottonseed cakes and mineral lick to supplement their animals during the dry season are well represented in the study area. The animals are watered in rivers and dams. Less than 15% of farmers had a borehole or well.

Sheep and cattle graze together while goats and poultry are allowed to roam around the huts. Smallholder farmers (68.6%) practice several types of integration (Fig. S1 and S2) which combine animals, forage plants (*Panicum maximun*, *Brachiaria ruziziensis*, *Stylosanthes guianensis, Mucuna pruriens*) and various kinds of trees, either fodder trees (*Khaya senegalensis*, *Pterocarpus erinaceus, Ficus umbellata, Ficus thonningii, etc.*), fodder shrubs (*Cajanus cajan*, *Gliricidia sepium*, *Leucaena leucocephala, Acacia auriculiformis*), fruit trees (*Citrus limon, Mangifera indica, Vitellaria paradoxa*), or timber trees (*Gmelina arborea*, *Tectona grandis*).

In addition, 31.4% of herders use trees in the natural pastures and protected areas bordering their village during the dry season. The protected areas (the forests such as Upper Alibori, Trois Rivières, Sota, Ouénou Benou, and Mekrou) are reception areas for these herders during the dry season and a refuge area during the rainy season (Fig. S3). In fact, it is coveted for its richness in numerous herbaceous plants well eaten by ruminants such as *Loxodera ledermani, Ditheteropogon amplectens, Andropogon gagnanus* and highly palatable woody plants such as *Pterocarpus erinceus, Khaya senegalensis* and *Afzelia africana*.

Also, it has the rivers which are coveted for its inexhaustible character and for the fresh herbs that surround it all year long.

Health management

Health monitoring of animals is generally limited to three vaccinations (contagious bovine pleuropneumonia, bovine pasteurellosis and small ruminant pest), carried out by agents of the Communal Unit of the Territorial Agency for Agricultural Development (CC-ATDA). The majority of farmers surveyed (73.5%) used endogenous treatments through the use of trees to treat the diseases of their animals. Thus, the leaves of *Acacia albida* and the seeds of *Acacia nilotica* are used to treat foot-and-mouth disease while the barks of *Pericopsis laxiflora* and *Parinari curatellifolia* are used in case of bovine pasteurellosis.

To treat trypanosomiasis, farmers use the leaves of *Pseudocedrela kotschyi* and *Khaya senegalensis*. The leaves of *Annona senegalensis* and the bark of *Mitragyna inermis* are used against helminthiasis of the digestive tract. Nevertheless, some farmers who have received training in animal health administer care in their own herds and in the homes of their neighbors. The prophylaxis plans proposed by the CC-ATDA services are those usually recommended in tropical environments. Internal and external deworming is practiced by nearly 82% of the farmers surveyed.

Typology of farms integrating trees in livestock farming

The multiple correspondence analysis (MCA) was performed on 140 livestock smallholder farmers in the drylands of Benin. The cumulative contribution to the total inertia of the first three factorial axes selected was 73.11% (Table 1) and the analysis of the coordinates of the main projection axes of the MCA is summarized in Table 2. The study of the correlations between the various variables considered enabled to retain a set of 14 active variables totaling 38 modalities (Table 3).

Table 1. Cumulative contribution to the total inertia of the factorial axes

Factorial axis	Inertia (%)	Cumulated percentage (%)
1	44.50	44.50
2	20.21	64.61
3	8.50	73.11

Table 2. Definition of factorial axes

Factorial axis	Negative	Positive
1	Low tropical livestock unit	High tropical livestock unit
	Low household size	High household size
	Combination maize + sorghum	Integrated maize + cotton
	Low crop cultivated land	High crop cultivated land
	Feed and Animal health reason for ITLF adoption	Improved soil fertility reason for ITLF adoption
2	Fulani and Gando ethnic group	Bariba ethnic group
	Family labour	Family and hired labour
	Trees plantation available	No trees plantation
	Fodder and fruits trees integrated	Natural shrubs uses
3	Possession of ownership	No ownership
	Valorization of manure	No valorization of manure
	No transhumance	Transhumance

In order to define the types of integrated trees-livestock farming from the MCA examination, a hierarchical ascending classification (HAC) was performed with the data set (Fig. 1). It allowed to differentiate 4 groups of livestock smallholder farmers in drylands of Benin. The best graphic representation is provided by a projection in a plane defined by the factorial axes 1 and 2 (Fig. 2).

As shown in Fig. 2, the four livestock smallholder farmers types distinguished were: “Traditional silvopastoral systems” (TSS, n=44; 31.4 %); “Improved silvopastoral systems” (ISS, n=26; 18.6 %); “Small integrated agrosilvopastoral systems” (SIAS, n=37; 26.4%) and “Large integrated agrosilvopastoral systems” (LIAS, n=33; 23.6%). The farms' characteristics are shown in Table 3 and 4.

Type 1: Traditional silvopastoral systems (TSS)

This group was found in the two ecological regions (Arid Sudanian and Semi-arid Sudano-Guinean regions). Most livestock smallholder farmers in this group were from various socio-cultural or ethnic groups (Fulani and Gando by order of importance). All farmers in this group reported livestock production as their main activity. Compared to livestock smallholder farmers in other groups, they did not cultivate land and did not use manure as fertilizer ($P<0.001$). They did not have land ownership. Their herd size was larger and averaged 26 ± 0.59 TLU. Compared with livestock smallholder farmers from other groups, all of them did not receive any formal education ($P<0.001$). Livestock smallholder farmers managing the TSS did not have tree plantations. They used the different rangelands and protected areas (livestock and protected area). Indigenous fodder tree species such as *Khaya senegalensis, Afzelia africana,* *Pterocarpus erinaceus, Daniela oliveri*, etc. are exploited during all periods of the year in protected areas or rangelands. They made small transhumance movements during the dry season. The majority of the farmers in this group treat their animals endogenously by using trees. The objective of the use of trees and shrubs by these farmers was feed and health of the animals.

Type 2: Improved silvopastoral systems (ISS)

This group was found in all ecological regions but mostly in tropical Semi-arid Sudano-Guinean region (70%). Farmers of this type were found in the peri-urban centers of the municipalities. They are relatively young (42.0 ± 1.2 years old) and attend school until the second cycle. Their household size is low (8.0 ± 0.5 people). All the farmers in this group were sedentary. They use family and hired labour. Compared to TSS, number of animals in the ISS group was low ($P<0.001$) and averaged 11 ± 0.21 TLU. They had land ownership. Silvopasture practices of this group combine livestock, forage plants and fodder trees. They had put in place forage plants (*Panicum maximun*, *Brachiaria ruziziensis*, *Stylosanthes guianensis, Mucuna pruriens*) and make fodder reserves for the dry season. Compared to other groups, they did not cultivate crops. In addition, they planted fodder tree (*Khaya senegalensis*, *Pterocarpus erinaceus*, *Cajanus cajan*, *Gliricidia sepium*, *Leucaena leucocephala, Acacia auriculiformis*) and used it during all period of the year. The total farm size was in average 2.6 ha with more than half (1.8 ha) under tree plantation. The reason of planting trees by the farmers of this group is for animal feeding.

Type 3: Small Integrated agrosilvopastoral systems (SIAS)

This group is found in all ecological regions. The group is composed of illiterate Gando (76.47%) and Bariba (23.53%) relatively young (38.0 ±1.3 years). Their average household size is low (5.6 ± 0.7 people). Smallholder farmers of this group considered agriculture as their main activity. They shared similarities with ISS group in terms of proportions of farms with land titles, labour use, and tree planting practices. Compared to LIAS groups, smallholder farmers of this group had significantly ($p<0.001$) lower total farm size (2.1 ha). The area under tree plantation represented one half of the total farm size. The second half was used for crop cultivation for self-consumption. They integrated maize and sorghum with trees plantation and livestock in the same landscape. They had also significantly lower size of tropical livestock unit (6 ± 0.24 TLU) compared to other groups. They used veterinary treatments and indigenous trees to treat sick animals. Legumes are used to improve soil fertility and feed animals.

Type 4: Large Integrated agrosilvopastoral systems (LIAS)

This group is mainly found in Arid Sudanian region. Smallholder farmers in this group were mainly native and from the Bariba socio-cultural group. They are significantly older (52.6 ±2.2 years) than farmers of the other groups ($P<0.001$). They shared similarities with ISS and SIAS in terms of proportion of farms with a land ownership and tree planting practices. But, compared to ISS and SIAS, they owned the largest tropical livestock unit (18 ± 0.34 TLU) composed mainly of cattle herd. Farmers of this group reported crop cultivation as their main activity. Compared to other group, they cultivated large areas of land (6.1 ha) under tree plantation (3.2 ha). They mainly used the crop residues for feeding their animals and manure for soil fertilization. Most of the farmers in this group integrated maize, cotton with trees and livestock. The trees are planted for timber, fruit and fodder. Legumes are used to improve soil fertility while fodder trees are used as feed for animals during the dry season.

Table 3. Distribution (frequency, %) of four integrated trees within livestock systems in drylands of Benin

Variables	Modalities	TSS	ISS	SIAS	LIAS	χ^2
Ecological region (ER)	Arid Sudanian region	73.5^a	28.3^b	22.7^b	73.6^a	60.64
	Semi-arid Sudano-Guinean	26.5^b	72.7^a	78.3^a	26.4^b	
Ethnic group (EG)	Fulani	75.8^a	70.4^a	32.2^b	0.0^c	72.17
	Gando	24.2^b	19.5^b	47.6^a	0.0^c	
	Bariba	0.0^c	10.1^b	20.2^b	100.0^a	
Main occupation (MO)	Livestock keeping	100.0^a	100.0^a	0.0^b	0.0^b	40.42
	Crop farming	0.0^b	0.0^b	100.0^a	98.2^a	
	Trade	0.0^b	0.0^b	0.0^b	1.80^a	
Level of education (LE)	None	100.0^a	19.4^c	79.9^a	50.2^b	68.2
	Secondary school	0.0^c	60.6^a	20.1^b	30.6^b	
	University	0.0^b	20.0^a	0.0^b	19.2^a	
Source of labour (SOL)	Family	89.6^a	80.2^a	100.0^a	60.1^a	134.3
	Hired	0.0^b	19.8^a	0.0^b	10.6^a	
	Both	10.4^a	0.0^b	0.0^b	29.3^a	
Crop cultivation (CCU)	Yes	0.0^c	10.6^b	100.0^a	100.0^a	38.6
	No	100.0^a	89.4^a	0.0^b	0.0^b	
Integration of Crop (IC)	Maize	0.0^b	100.0^a	0.0^b	0.0^b	111.2
	Maize + Cotton	0.0^b	0.0^b	0.0^b	80.3^a	
	Maize + Sorghum	0.0^c	0.0^c	100.0^a	19.7^b	
Tree plantation (TP)	Yes	0.0^b	100.0^a	100.0^a	80.2^a	82.3
	No	100.0^a	0.0^c	0.0^c	19.8^b	
Integration of Trees (IP)	Fruit trees	0.0^b	0.0^b	34.3^a	0.0^b	112.0
	Fodder trees	69.7^a	80.0^a	65.7^a	0.0^b	
	Fruit + Fodder trees	10.0^a	20.0^a	0.0^b	25.7^b	

	Shrubs	20.3^{a}	0.00^{b}	0.0^{b}	0.0^{b}	
	Timber + Fruit + Fodder trees	0.0^{b}	0.0^{b}	0.0^{b}	74.3^{a}	
Reasons of integration of trees (RTI)	Feed and Animal heath	100.0^{a}	100.0^{a}	31.6^{b}	39.4^{b}	146.0
	Improved soil fertility	0.0^{b}	0.0^{b}	65.2^{a}	55.3^{a}	
	Wood and fruits	0.0^{b}	0.0^{b}	3.2^{a}	5.3^{a}	
Contribution of trees integration (CTI)	Resilience to climate change	100.0^{a}	100.0^{a}	65.4^{a}	61.6^{a}	125.4
	Food security	0.0^{b}	0.0^{b}	12.4^{a}	20.3^{a}	
	Household income	0.0^{b}	0.0^{b}	22.2^{a}	18.2^{a}	
Land ownership (LO)	Yes	0.00^{b}	100.0^{a}	100.0^{a}	100.0^{a}	168.5
	No	100.0^{a}	0.0^{b}	0.0^{b}	0.0^{b}	
Feeding mode (FM)	Grazing (G)	100.0^{a}	0.0^{c}	0.0^{c}	30.8^{b}	188.1
	G+ supplementation	0.0^{b}	100.0^{a}	100.0^{a}	69.7^{a}	
Valorization of manure (VM)	Yes	0.0^{b}	80.4^{a}	100.0^{a}	100.0^{a}	88.3
	No	100.0^{a}	19.6^{b}	0.0^{c}	0.0^{c}	

abc Within a row, values with different superscript letters are significantly different at P≤ 0.001 level; TSS = Traditional silvopastoral systems; ISS= Improved silvopastoral systems; SIAS= Small Integrated agrosilvopastoral systems; LIAS= Large Integrated agrosilvopastoral systems.

Table 4. Quantitative characteristics of the four identified group of farmers in drylands of Benin

Variables	**TSS**	**ISS**	**SIAS**	**LIAS**	**p value**
Age of the farmer (year)	49.8 ± 2.2^{a}	42.0 ± 1.2^{b}	38.0 ± 1.3^{b}	52.6 ± 2.2^{a}	0.0041
Household size (people)	15.8 ± 0.4^{a}	8.0 ± 0.5^{b}	5.6 ± 0.7^{b}	13.2 ± 0.6^{a}	0.0056
Farm size (ha)	3.2 ± 0.8^{b}	2.6 ± 0.2^{c}	2.10 ± 0.4^{c}	6.1 ± 0.3^{a}	0.00001
Tree plantation size (ha)	0.0 ± 0.1^{c}	1.8 ± 0.1^{b}	0.89 ± 0.2^{b}	3.2 ± 0.3^{a}	0.00001
Tropical Livestock Unit (TLU)	26 ± 0.59^{a}	11 ± 0.21^{c}	6 ± 0.24^{d}	18 ± 0.34^{b}	0.0015

abcd Within a row, values with different superscript letters are significantly different at $p \leq 0.001$ level; TSS = Traditional silvopastoral systems; ISS= Improved silvopastoral systems; SIAS= Small Integrated agrosilvopastoral systems; LIAS= Large Integrated agrosilvopastoral systems.

Discussion

Typology of farms with integration of trees in livestock farming in drylands

Four different types of farms integrating trees in livestock farming were identified in this study. The main factors distinguishing these types were herd size, livestock practice, level of integration of livestock with agriculture and/or tree/shrub planting, size of tree plantation, crop cultivated fields and land ownership. Unlike the last variable, the other variables are often used to categorize livestock systems (Alkoiret et al. 2009; Assani et al. 2016; Houessou et al. 2019; Worogo et al. 2019). The evidence presented here supports the hypothesis that land ownership influences the herd management strategies of smallholder farmers in the context of climate change and natural resource degradation. In fact, trees and/or shrubs plantations and the installation of forage plants plots require the possession of secure land by the farmers. According to Kokoye et al. (2013), secure land ownership rights could be used as an incentive to adopt herd management strategies. When these property rights are not secured, there is a likelihood of expropriation (Ghei 2009).

The practice of Improved silvopastoral systems (ISS), Small Integrated agrosilvopastoral systems (SIAS) and Large Integrated agrosilvopastoral systems (LIAS) requires a relatively secure land tenure system to ensure that farmers who invest effort in these practices retain their property rights (Amole and Ayantunde 2016). Similarly, according to Yegbemey et al. (2013), farmers are unwilling to implement adaptation strategies that may require more investment in inputs, when their land is not secured or they do not have full rights on the land. The observed integration of trees/shrubs, livestock and/or crops on smallholder farms could be justified by the need for farmers to feed animals at lower cost, protect the soil, diversify income and better manage manure in the context of climate change. Similar observation was reported by Koura et al. (2015) in southern Benin. Agrosilvopastoral practice ensures the protection and return of nutrients to the land by planting trees and livestock practices. In addition, to improve the milk and meat production of their animals (cattle and small ruminants) in the context of degradation of fodder resources due to climate change, these farmers have decided to use fodder trees and forage plants. Likewise, in an integrated livestock production system, farmers have access to abundant manure, which provides them with very high yields and also crop residues to feed the animals. This is congruent with observation reported in other countries (Burkina-Faso) (Amamou et al. 2018; Zampaligré and Fuchs, 2019).

The farmers who practice ISS and SIAS have a much more market-oriented production objective through the production of meat (sale of live animals) and milk. These farmers are involved in small ruminant fattening and dairy cattle farming. Cattle and small ruminants farming allowed a better use of crop residues and a controlled production of manure that was used in the farms or gardens. In addition, the use of animal traction forces observed in the SIAS and LIAS systems facilitated better production of cereals, legumes, fodder and manure, while reducing expenses for livestock feed and achieving better gross margins. Similar trends was reported in Cuba where dairy cows fed on shrub fodder produced an impressive amount of milk per day without the use of additional concentrates (Ibrahim et al. 2005).

The traditional silvopastoralism combining livestock with forestry or the exploitation of trees in natural rangelands has been observed. In fact, global changes in land use, climate change impact and increased livestock corridors occupation by farmers have reduced the livestock area in Benin, and traditional silvopastoral systems have emerged (Assani 2017). This same observation has been made by several authors in protected areas (Kagone et al. 2006; Kiéma 2007; Lesse 2011 ; Manceron 2011; Assani 2017). This type of integrated animal production system is called “caívas” in southern Brazil. In addition, in Latin America, large areas of tropical forest cover have been deforested and converted to extensive livestock farming over the past decade (Graesser et al. 2015). This conversion of forests to cropland and the expansion of pastures are associated with global demand for food and feed (Gibbs et al. 2010). However, it should be noted that apart from the integration of livestock into protected areas, there are also traditional silvopastoral systems where trees are spared in pastures by natural regeneration. These types of traditional silvopastoral systems are characterized by multiple strata of trees and shrubs grown singly and / or in groups (Cajas-Giron and Sinclair 2001; Ibrahim et al. 2005).

This study found that the majority of silvopastoral farmers were of the Fulani ethnic group while the agrosilvopastoral farmers were Gando and Bariba. This could be explained by the fact that the Fulani herders attach more importance to animal production, while the Gando and Bariba have diversified their productions by giving much importance to livestock farming than agriculture. These observations are consistent with those made by Alkoiret et al. (2009) in the commune of Gogounou and by Worogo et al. (2019) in the Borgou department in Benin.

Total TLU has influenced the categorization of types of smallholder farmers. TLU was higher in TSS compared to other groups. This could be explained by the farming practice adopted in this group. In fact, TSS farmers have more heads of cattle and practice extensive farming. Extensive cattle farming systems require a lot of space and proximity to farmers and often generates conflicts (Alkoiret et al. 2011; Assani et al. 2016; Worogo et al. 2019).

In this study, for most farmers, the integration of trees to their livestock activity allows them to resiliate to the adverse impacts of climate change (drought, flooding, high temperature, etc.) and to ensure household livelihoods through animal feed in critical seasons, animal and human health care, biomass energy, sale of fruits, improvement of soil fertility, animal and crop productivity. According to Nahed-Toral et al. (2013), silvopastoral systems are a prototype of agroforestry for sustainable production because they provide a variety of goods and services to society and allow for adaptation and mitigation of climate change.

Policy implications for sustainable animal production

The State of Benin being aware of the great threat that climate change poses to the country's sustainable development, has drawn up National Action Programs for Adaptation to Climate Change (NAPA) and Low Carbon and Climate Change Resilient Development Strategy 2016-2025. The mitigation plans outlined in Benin's long-term strategy will result in reduction of emission at a minimum equivalent to the country's INDC commitments of at least 12 $MtCO_2e$ avoidance and 163 $MtCO_2e$ sequestration by 2030. Agrosilvopastoral and silvopastoral practices is one of the priority actions in this context, equally contributing to the adaptation and mitigation of climate change, as well as to food security. It is then necessary to:

- take into account agrosilvopastoral and silvopastoral systems and their potential in any development of national, sectoral and local policies on climate change;
- facilitate access to rural land for livestock smallholder farmers,
- promote tree plantations on small-scale pastoral farms in drylands;
- promote traditional and technical innovations adapted to each integrated animal production system identified;
- delineate animal corridors, including restoration of degraded rangeland with fodder trees;
- install pastoral infrastructure (water dam, livestock markets, feed storage, veterinary pharmacies and clinics) for strategies aimed at improving the animal production value chain;
- rehabilitate good management practices for silvopastoral resources, including capacity building for stakeholders (farmers, technicians, agricultural institutions, NGOs, etc.) and
- valorize indigenous knowledge of adaptation of livestock smallholder farmers to climate change;

Conclusion

Livestock production in drylands Benin has historically been affected by harsh climate as well as rangeland degradation. Induced by their frequent exposure to drought and subsequent livestock feed shortage, farmers in drylands of Benin have developed indigenous integrated livestock smallholder practices to reduce their vulnerability using tree species. This study identified four distinct types of integration of livestock farming with trees in drylands of Benin. The main factors distinguishing these types were herd size, livestock practice, level of integration of livestock with agriculture and/or tree/shrub planting, size of tree plantation, crop cultivated fields and land ownership. On the whole, integrated livestock farming is encountered in silvopastoral and agrosilvopastoral systems in drylands of Benin.

Given the diverse socio-economic characteristics and reasons that contribute to the adoption of types of integration of trees into livestock production around the world, there would be interest to promote indigenous community-based adaptation to climate change in order to contribute to the development of sustainable climate adaptation strategies and mitigation in the livestock sector.

Declarations

Acknowledgements

We deeply thank the German Academic Exchange Service (DAAD) for funding this study trough “Climate Research for Alumni and Postdocs in Africa-(ClimapAfrica)” programme and the University of Parakou for giving facilities for achieving this work. We are also grateful to all the respondents of the municipalities surveyed for their sincere collaboration during the investigation.

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Figures

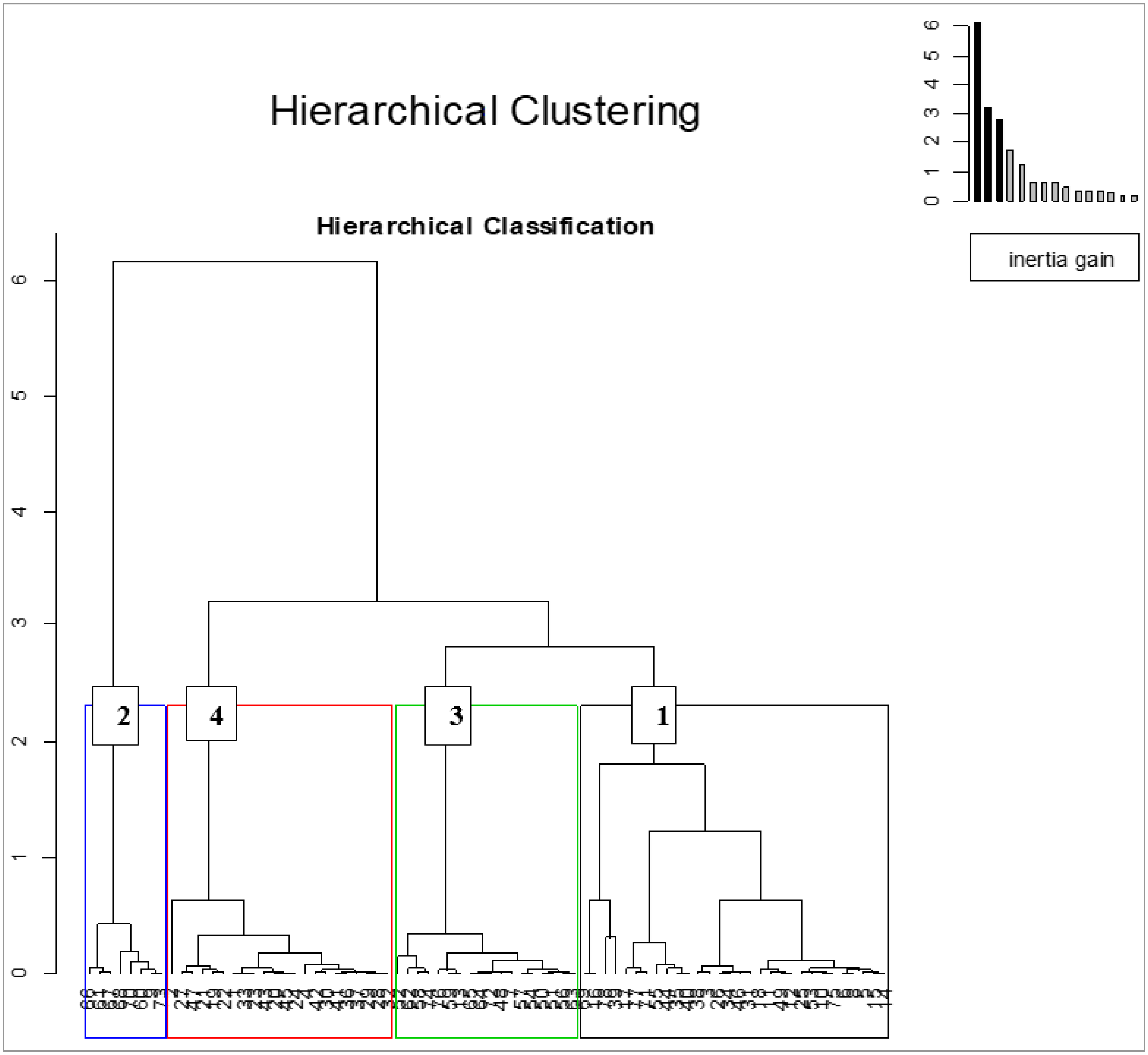

Figure 1

Dendrogram (hierarchical cluster) describing the integrated trees-livestock farming in drylands of Benin

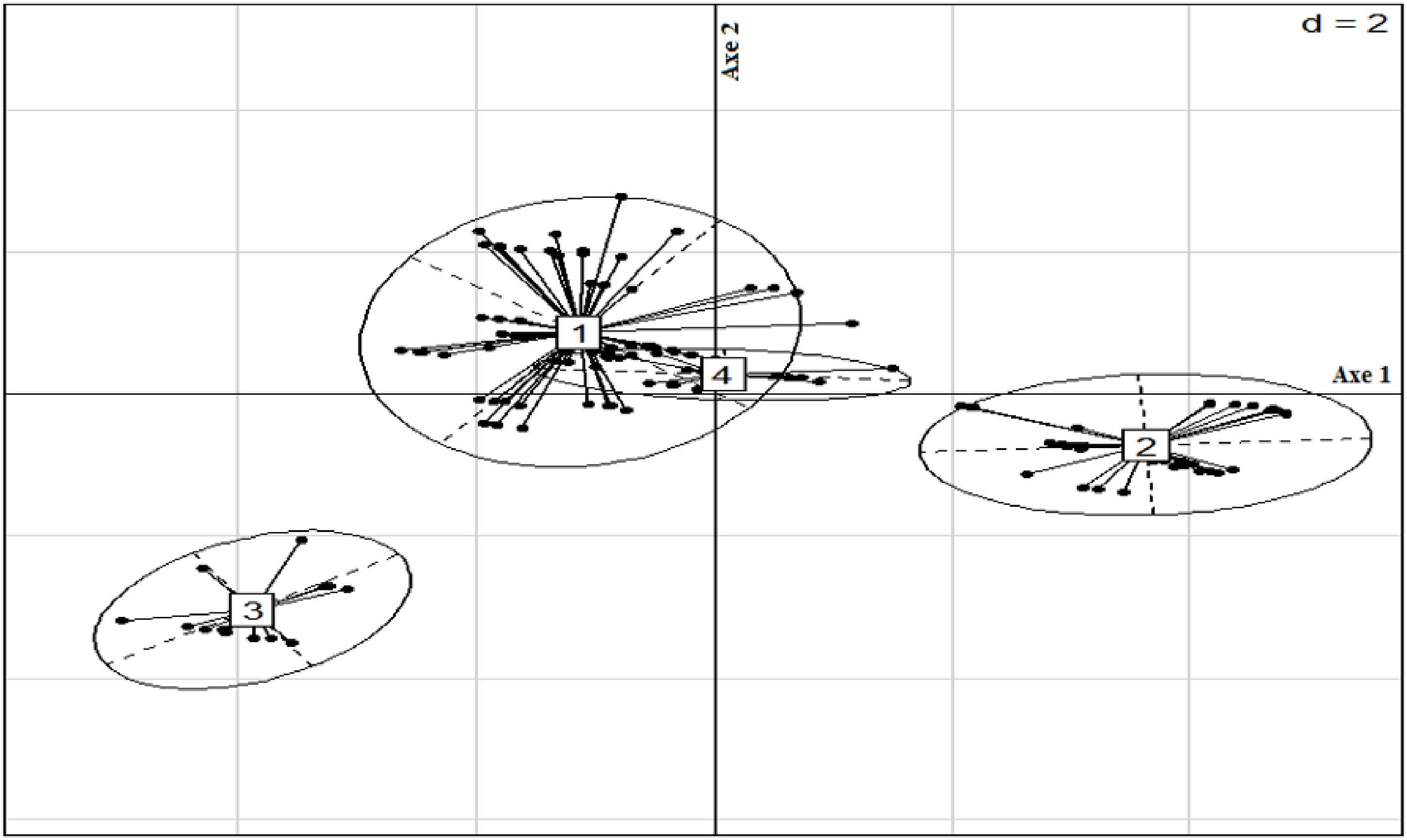

Figure 2

Graphic representation of the integrated trees-livestock farming on axes 1 and 2

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