Characterizing Cattle Corralling Practices for Sustainable Soil Fertility Management in Northern Benin

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Abstract

Climate change is a global concern posing a multitude of challenges, including significant threats to agriculture, particularly in sub-Saharan Africa. The region's reliance on rainfed agriculture and limited access to resources, such as mineral fertilizers, exacerbates soil fertility decline and reduces crop productivity. In this context, cattle corralling has emerged as a promising soil fertility management practice. This study assesses the benefits, challenges, and factors influencing the adoption of cattle corralling practices in maize-based farming systems in northern Benin. Data were collected through surveys from 392 smallholder farmers across three agroecological zones. Descriptive statistics, factorial analysis of correspondence, and ascending hierarchical classification were used to analyze cattle corralling typologies, while a binary logistic regression model examined adoption drivers. The results showed that 89% of farmers are familiar with the practice, and 71% have adopted it. Constraints include herd security (44%), water availability (33%), forage availability (27%), and cattle herd ownership (50%). Continuous overnight-rotational corralling, discontinuous overnight-rotational corralling, and corralling contracts were identified. Key adoption factors include agroecological zone, education, ethnicity, access to credit and extension services, field-house distance, breeding strategy, and production objectives. These findings enhance understanding of corralling typologies and socioeconomic drivers, crucial for scaling up sustainable cattle corralling practices.

Keywords

Sustainable Land Management (SLM) · Manure management · Crop-Livestock Integration (CLI) · Typology · West Africa

Introduction

Climate change is a critical challenge for agriculture, especially in sub-Saharan Africa, where small-scale crop-livestock farming dominates (Din et al. 2022; Pörtner et al. 2022). These systems are highly vulnerable due to their reliance on rainfed agriculture and limited resources (Lewis et al. 2018). Impacts such as rising temperatures, altered growing seasons, soil degradation, and increased climate variability threaten agricultural productivity and rural livelihoods (Lunyolo et al. 2021).

Soil and land management play a crucial role in mitigating climate change. Climate influences soil degradation, leaching, and fertility (Vanlauwe et al. 2023). Temperature and rainfall changes exacerbate soil erosion, nutrient loss, and compaction, reducing fertility (Mondal 2021). Adopting climate-smart practices is essential for food security and combating climate change. Innovations like conservation agriculture, rainwater harvesting, and drought-tolerant seed varieties are gaining traction (Patgiri et al. 2023).

In northern Benin, cattle corralling is a practice of confining livestock on cropland fields overnight to enrich the soil with manure and urine has gained attention as a soil fertility management strategy (Tovihoudji et al. 2024). This method improves soil chemical properties and crop yields but also poses environmental risks, such as nutrient imbalances and water pollution if not properly managed (Abdul Rahman et al. 2019; Sakadevan and Nguyen 2017). Sustainable adoption requires studies addressing both economic and environmental dimensions (Ichinose et al. 2020).

Research highlights cattle corralling's benefits, including enhanced soil fertility, increased crop productivity, and improved livestock management (Galindo et al. 2020). For example, combining corralling with plant density adjustments and nitrogen fertilizer boosts soil properties, weed diversity, and grain yield (Abdul Rahman et al. 2019). Multi-crop rotation further enhances soil productivity and economic returns (Şentürklü et al. 2016). However, challenges such as soil compaction and uneven nutrient distribution remain (Botta et al. 2020). While progress has been made, gaps persist in understanding the sociocultural determinants of adoption and broader environmental implications.

Given climate change's impact on agriculture (Alotaibi et al. 2023), climate-smart practices like cattle corralling are increasingly vital (Patgiri et al. 2023). Farm management characterization is essential for effective policy and extension services in complex agroecosystems (Mohammadi et al. 2020). Tools like Principal Component Analysis and Cluster Analysis simplify farm diversity, enabling targeted interventions (Goswami et al. 2014). A dual-scale approach, field- and farm-level analysis, offers insights into farmers' practices and decision-making, reducing costs in research and extension (Michels et al. 2009).

This study aims to characterize cattle corralling practices and identify factors influencing their adoption in northern Benin. It is essential at this moment due to the increasing vulnerability of agriculture to climate change and the urgent need for scalable, sustainable land management strategies. By characterizing the typologies of cattle corralling practices and identifying factors influencing their adoption, this research provides timely insights for policymakers and stakeholders. These findings are crucial for developing targeted interventions that align with the global push for climate-resilient and sustainable agricultural systems. The study also lays the groundwork for addressing existing constraints and maximizing the benefits of cattle corralling in smallholder farming contexts, contributing to broader efforts to enhance agricultural resilience and food security in sub-Saharan Africa.

Materials and Methods

Description of the Study Zone

This study was carried out in three municipalities belonging to three different agro-ecological zones in northern Benin. These municipalities are Malanville (zone 1), Gogounou (zone 2), and Bembereke (zone 3, Table 1). The choice of these zones is based on their involvement in agriculture and livestock farming as the main activities of the inhabitants (Alkoiret et al. 2011), and climate studies indicate that they are the most vulnerable to rainfall deficits and high insolation (Gnanglè et al. 2011).

Table 1 Characteristics of the study zones

	Municipalities		
Features	Malanville	Gogounou	Bembereke
Geographical coordinates	11° 52′ 00″ north, 3° 23′ 00″ east	10° 50′ 35″ north, 2° 49′ 42″ east	10°13′ 30″ north, 2° 40′ 05″ east
Altitude (m)	160	305	449
Climate based on Köppen-Geiger classification (Beck et al. 2023)	Aw (Tropical Savannah)	Aw (Tropical Savannah)	Aw (Tropical Savannah)
Rainfall	750 mm per year	1100 mm per year	1100 mm per year
Types of soil and their characteristics	Gneissic type for the most part on the territory, but in the Niger valley and its affluent, sandy-clay, ferruginous soils are encountered.	Soils are tropical ferruginous, moderately fertile, and highly leachable	The main soil types are ferruginous tropical.
Types of vegetation	Wooded savannas where herbaceous formations predominate	Wooded savannah dominated by shrubs by Butyrospermum parkii (Shea)	The well-diversified vegetation is made up of wooded, tree, and shrub savannahs with open forests in places

Source: INSAE (2023)

Data Collection

The collection of primary data was carried out from April to May 2023 in two phases: the exploratory phase and the in-depth phase. The exploratory phase was carried out in two stages: interviews with local technicians and identification of households. Semi-structured interviews were conducted with local technicians to identify the villages to be surveyed. The criteria for selecting villages were accessibility and the practice of cattle corralling. The in-depth survey phase consisted of data collection through semi-structured questionnaires and interviews with the farmers identified during the exploratory survey. The data collection consisted of three (3) main sets of questions; (a) socio-demographic characteristics of the herders (gender, age, ethnicity, household size, number of farm workers, level of education, contact with agricultural extension services), (b) farming characteristics and objectives of production, and (c) cattle corralling management practices.

At the household level, adopters and non-adopters of cattle corralling have been sampled in the same or adjacent district whenever possible, as described by Gil et al. (2015). A household in this study context consists of all members who work together in a field, pool resources, share meals, and recognize the authority of a single head. In total, the survey included 392 respondents. This number is determined by using the Dagnelie (1998) approach (Eq. 1). The repartition of the respondent across the study area has been shown in Table 2. The snowballing method has been used to select randomly the respondents (Kubiciel-Lodzińska 2021). The data were collected from the households using a structured questionnaire built under KoboCollect software (version 2023.1.3), digitized on a smartphone tablet, and administered through direct interview.

Dagnelie's formula:

$$n = \frac{z^2 p(1-p)N}{z^2 p(1-p) + (N-1)ET^2} \tag{1}$$

Table 2 Respondents repartition across the three selected municipalities

Municipalities	Agroecological zone	Administrative unit	Number of respondents
Malanville	Zone 1 (South Borgou food zone)	Guéné	46
		Tomboutou	49
		Garou	44
Gogounou	Zone 2 (Cotton zone of North Benin)	Gounarou	36
		Sori	36
		Bagou	37
Bembereke	Zone 3 (South Borgou food zone)	Bouanri	48
		Ina	51
		Beroubouay	45
Total			392

where $\boldsymbol{n}$ is the sample size, $\boldsymbol{N}$ is the actual population size ($N = 117{,}523$), $\boldsymbol{ET}$ is the tolerable standard error (margin of error) for the survey ($ET = 0.05$), $\boldsymbol{Z}$ is the standard normal value of the confidence interval ($Z \approx 1.96$), $\boldsymbol{p}$ is the proportion of farm households in the study areas ($p = 0.72$) (INSAE 2023).

Theoretical Framework

Our study is supported by key theories that provide frameworks for understanding the adoption and impact of cattle corralling practices in northern Benin. The Diffusion of Innovations Theory (Rogers et al. 2008) explains how and why agricultural innovations spread within communities, highlighting characteristics of innovators and early adopters (Agarwal et al. 1998; Diederen et al. 2003). By analyzing social networks, communication channels, and cultural values, it sheds light on how cattle corralling knowledge is disseminated (Valente and Fosados 2006). Agroecological theory emphasizes ecological principles in agriculture to enhance sustainability and resilience (Altieri 1989). This perspective evaluates how cattle corralling mimics natural processes, like nutrient cycling through manure, to improve soil fertility and biodiversity. Systems theory further enriches the analysis by focusing on interdependence within farming systems, considering interactions with crop production, labor, and market dynamics (van der Werf et al. 2014). It identifies feedback loops, such as how increased soil fertility from cattle corralling boosts crop yields, which in turn promotes broader adoption. Together, these theories provide a comprehensive understanding of the factors influencing cattle corralling practices and their outcomes.

Statistical Analysis

Descriptive statistics summarized farm households' demographic, socio-economic, and institutional characteristics using R software (version 4.2.1). A Factorial Analysis of Correspondence FactoExtra (Kassambara 2016) characterized corralling types through projections on the first factorial axes. An Ascending Hierarchical Classification (AHC) grouped corralling types based on proximity, forming a dendrogram with typology groups as branches (Pavlopoulos et al. 2010). A Kruskal-Wallis test with Dunn-Bonferroni post hoc compared group means (Ahmed and Jena 2023). Finally, a binary logistic regression was used to assess determinants of cattle corralling adoption (Kennedy 2022). The binary model equation is presented as follows:

$$\boldsymbol{Yi} = \boldsymbol{Xi}\,\boldsymbol{\beta} + \boldsymbol{\varepsilon i}.$$

where - $\boldsymbol{Yi}$ is the variable that takes the value 1 if the farmer adopts cattle corralling and 0 if they do not adopt it; - $\boldsymbol{Xi}$ is the set of explanatory variables indicating the factors that influence the adoption of cattle corralling as a soil fertility management

Table 3 Description of explanatory variables used for binary logistic regression

Variable	Modality (ies)	Expected sign
Cattle corralling adoption	Yes/No	Na
Agroecological zone	Zone 1/Zone 2/Zone 3	+/–
Educational level	Primary/Secondary/University/None	+/–
Ethnicity	Bariba/Dendi/Fulani/Other	+/–
Experience	Numeric	+
Membership in the rural organization	Yes/No	+/–
Access to credit	Yes/No	+/–
Awareness of corralling	Yes/No	+
Age	Numeric	+/–
Access to extension services	Yes/No	+/–
Distance fields-house	Far/Medium/Near	+/–
Number of agricultural workers	Numeric	+/–
Breeding mode	Sedentary/Semi-Sedentary	+/–
Production objective	Both/For sale	+/–

strategy (Table 3); - $\boldsymbol{\beta}$ represents the vector of coefficients associated with the explanatory variables Xi. These coefficients quantify the influence of each explanatory variable on the probability of the outcome Yi. In other words, β indicates how changes in the explanatory variables affect the likelihood of the farmer adopting cattle corralling as a soil fertility management strategy. - $\boldsymbol{\varepsilon i}$ is the standard error.

Results

Socio-demographic Characteristics of Respondents

Table 4 summarizes the socio-demographic characteristics of the surveyed agricultural households. Most of the heads of household were men (93.4% of the total respondents). Among these, the most prevalent socio-cultural groups were Bariba (32.7%), Dendi (31.9%), and Fulani (28.8%). On average, the surveyed heads of household were 43.3 ± 0.7 years old and 73.5% of them did not attend school. The average household size was 16.3 ± 0.6 individuals and their average experience in agriculture and/or livestock was 26.0 ± 0.7 years. Half of the respondents were members of an agricultural organization (50.5%), and 45.2% were in contact with agricultural extension services. The rate of farmers having access to credit was low (38%) within the study area.

Characterization of Cattle Corralling Practices

The results showed that 89% of the respondents are aware of the corralling practice as a tool for soil fertility management, while 71% practice it (Table 5). More than half (51%) of the surveyed population reported manually spreading the excreta after

Table 4 Socio-demographic characteristics of farmers surveyed from three municipalities in northern Benin

Variables	Modalities	Zones 1 ($n = 139$, %)	Zones 2 ($n = 109$, %)	Zones 3 ($n = 144$, %)	Study area ($N = 392$, %)	P-values
(A) Qualitative variables						$\chi 2$
Gender	Male	34.7	24.7	33.9	93.4	0.062
	Female	0.8	3.1	2.8	6.6	
Marital status	Divorced	–	1	0.3	1.3	0.036
	Married	34.7	24.5	34.7	93.9	
	Single	0.8	2.3	1.3	4.3	
	Widow	–	–	0.5	0.5	
Ethnicity	Bariba	–	19.9	12.8	32.7	0.098
	Dendi	31.4	0.3	0.3	31.9	
	Fulani	1.8	7.7	19.4	28.8	
	Other	2.3	0	4.3	6.6	
Religion	Traditional	–	0.3	–	0.3	0.341
	Christian	0.5	2.8	3.6	6.9	
	Muslim	34.9	24.7	33.2	92.9	
Educational level	None	23.5	22.4	27.6	73.5	0.058
	Primary	6.4	1.5	4.3	12.2	
	Secondary	4.6	3.3	3.1	11	
	University	1	0.5	1.8	3.3	
Membership of rural organization	No	21.4	7.9	20.2	49.5	0.052
	Yes	14	19.9	16.6	50.5	
Access to credits	No	18.4	16.6	27	62	0.041
	Yes	17.1	11.2	9.7	38	
Contact with extension services	No	21.7	5.6	27.6	54.8	0.074
	Yes	13.8	87	9.2	45.2	
(B) Quantitative variables						*T-test*
Age (years)	Mean	44.7	41.8	43.0	43.3	
	SD	12.3	10.2	11.8	13.7	0.051
	Min	20	22	20	20	
	Max	75	78	91	91	
Agricultural experience (years)	Mean	31.9	21.2	23.8	26.0	
	SD	13.4	9.7	11.2	14.1	0.118
	Min	5	2	2	2	
	Max	71	50	65	71	
Agricultural workers (#)	Mean	17.6	17.0	18.7	17.7	0.041
	SD	4.2	3.9	5.1	8.6	
	Min	0	0	0	0	
	Max	8	11	13	21	

SD Standard deviation

Table 5 Characteristics and benefits of cattle corralling practices from three municipalities in northern Benin

Variables	Modalities	Zones 1 ($n = 139$, %)	Zones 2 ($n = 109$, %)	Zones 3 ($n = 144$, %)	Study area ($N = 392$, %)	P-value
(A) Qualitative variables						χ2 test
Corralling awareness	No	6.9	1.5	3.1	11.5	0.023
	Yes	28.6	26.3	33.7	88.5	
Adoption level	No	17.1	5.1	6.9	29.1	0.033
	Yes	18.4	22.7	29.8	70.9	
Comparison with mineral fertilizer	No	1.5	0.5	0.5	2.6	0.003
	Yes	33.9	27.3	36.2	97.4	
Corralling contracts	No	23.2	25.0	31.4	79.6	0.021
	Yes	12.2	2.8	5.4	20.4	
Corralling charge	No	8.9	13.8	16.8	39.5	0.106
	Yes	26.5	14.0	19.9	60.5	
Goods for corralling contract	No	3.8	12.5	30.1	46.4	0.051
	Yes	31.6	15.3	6.6	53.6	
Manure spread after corralling	No	14.5	19.4	14.8	48.7	0.062
	Yes	20.9	8.4	21.9	51.3	
Corralling method	Overnight	7.4	8.9	10.5	26.8	0.024
	Rotative	18.6	12.0	13.0	43.6	
	Rotative and overnight	5.6	4.8	5.1	15.6	
	Corralling contract	4.6	3.6	5.9	14.0	
Corralling location	Field away from home (>1 km)	5.9	9.2	6.9	21.9	0.034
	Fields near the house (<1 km)	17.1	18.4	15.1	50.5	
	No preference	10.5	8.4	8.7	27.6	
Frequency of corralling	Other	3.3	5.9	4.6	14.3	0.004
	Every year	22.4	23.5	28.6	74.5	
	Every two years	2.3	3.6	2.8	8.7	
	Every three years	1.5	0.8	0.3	2.6	
Soil fertility status after corralling	Fertile	8.2	6.6	7.7	22.4	0.016
	Moderately fertile	0.5	1.3	0.8	2.6	
	Very fertile	23.5	22.2	29.3	75.0	

(continued)

Table 5 (continued)

Variables	Modalities	Zones 1 (n = 139, %)	Zones 2 (n = 109, %)	Zones 3 (n = 144, %)	Study area (N = 392, %)	P-value
(B) Quantitative variables						*T-test*
Amount paid for corralling (USD)	Mean	32.1	26.2	36.7	31.7	0.101
	SD	11.3	6.3	12.4	10.0	
	Min	0	0	0	0	
	Max	54.6	76.7	82.6	82.6	
Corralling duration (week)	Mean	2.5	4.3	3.1	3.3	0.055
	SD	0.3	0.7	0.4	0.5	
	Min	1	1	1	1	
	Max	5	7	5	7	
Number of cattle corralled per hectare	Mean	47.7	62.4	56.2	55.43	0.081
	SD	3.1	2.3	2.1	2.5	
	Min	0	0	0	0	
	Max	59	70	67	70	

SD Standard deviation

corralling to homogenize the corralled plots. Cattle corralling was predominantly done on generally poor plots (27%), close to the house (<1 km, 23%). Only 12% of the surveyed population claimed to practice corralling on plots far from the house (>1 km). The majority estimated using the cattle corralling every year (74%), every 2 years (9%), and every 3 years (3%). The average number of cattle corralled on one hectare was estimated at 55.54 ± 1.93, and the corralling period averaged 3.44 ± 0.1 weeks. The fertility level of the soil after corralling is perceived as very high by 75% of the respondents, fertile by 22%, and moderately fertile by 3%.

Benefits and Constraints of Cattle Corralling Practices in Northern Benin

The availability of water is considered as a highly constraining factor by 33%, moderately by 27%, and weakly by 17% of the studied populations (Fig. 1). The forage availability was a major constraint with 27% perceiving it as highly constraining, 34% as moderately constraining, and 15% as weakly constraining (Fig. 1). The ownership of cattle (50%) and the security of the livestock (44%) were perceived as highly constraining factors to the practice of cattle corralling.

Typology of Cattle Corralling Practices in Northern Benin

The first two factorial axes obtained from the factorial analysis of correspondence allowed for a cumulative percentage of explained variance greater than 50% and were therefore considered for result interpretation (Fig. 2). Hierarchical clustering

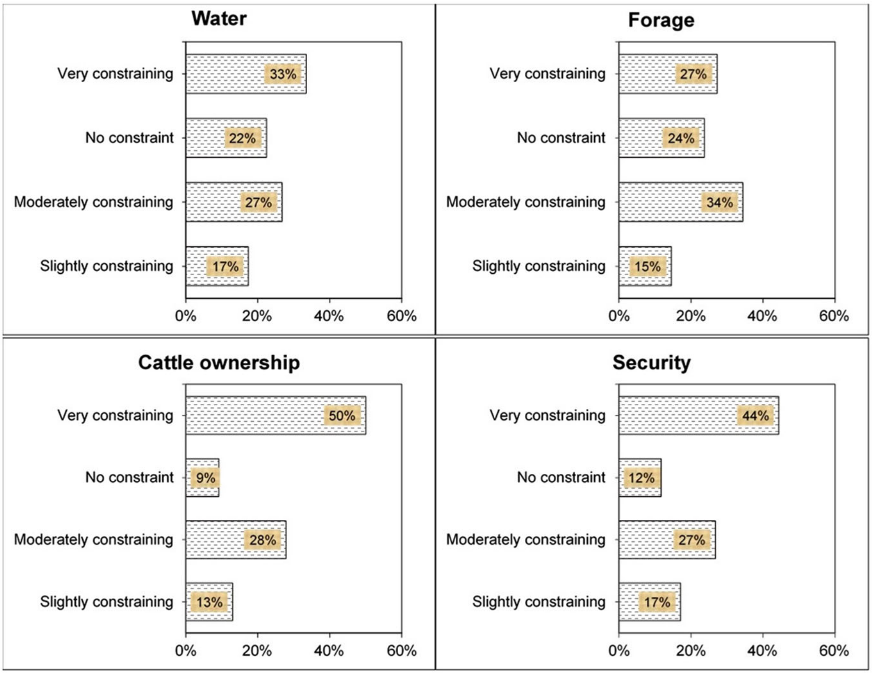

Fig. 1 Constraints of cattle corralling practices in northern Benin

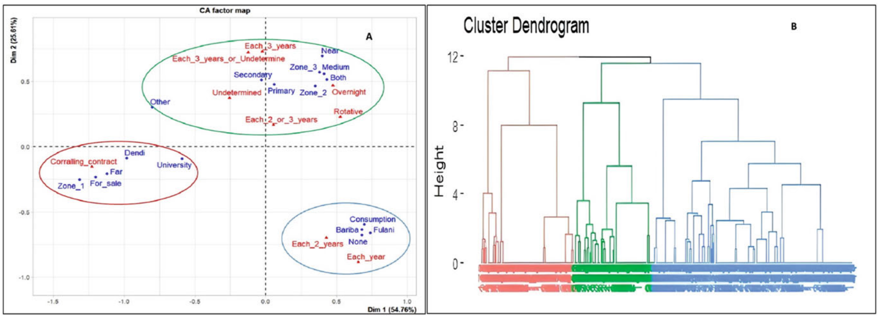

Fig. 2 Factorial correspondence analysis map (**a**), and dendrogram of different groups of cattle corralling practices by farmers from northern Benin (**b**). The various colors observed on the dendrogram represent the three groups obtained and correspond to the color of the circles obtained on Fig. 2a. Circle red shows cluster 1 (practitioners of continuous overnight-rotational corralling, CORC), the circle blue shows cluster 2 (practitioners of discontinuous overnight-rotational corralling, DORC), and the circle green shows the cluster 3 (practitioners of corralling contract, CC). "Height" on the y-axis (Fig. 2b) means the proportion weight of each variable group

indicated 3 cluster cuts of points grouped by structural and functional characteristics of the cattle corralling practices:

Cluster 1 (practitioners of continuous overnight-rotational corralling, CORC): It was mainly practiced continuously (year after year, 51.2%) by Fulani (31.7%) and

Table 6 Characteristics of different groups of cattle corralling from northern Benin

Characteristics		Group of cattle corralling				
		CORC	DORC	CC	χ2	P-value
Agro-ecological zone (%)	Zone 1	15.2^b	14.4^b	66.9^a	21.6	0.001
	Zone 2	44.7^a	46.5^a	14.7^b		
	Zone 3	40.1^a	39.1^a	18.4^b		
Educational level (%)	None	67.3^a	19.7^b	13.8^c	17.2	0.04
	Primary	18.2^b	34.1^a	21.4^b		
	Secondary	9.1^c	39.3^a	21.2^b		
	University	5.4^c	7.9^c	44.6^a		
Ethnicity (%)	Bariba	52.3^a	49.1^a	11.5^c	9.2	0.01
	Dendi	13.1^c	10.2^c	37.4^a		
	Fulani	31.7^b	28.1^b	17.4^b		
	Other	2.9^d	12.6^c	34.7^a		
Corralling frequency (%)	Each 3 years	14.1^b	30.1^a	21.6^b	31.7	0.001
	Undetermined	8.3^c	22.4^a	41.3^a		
	Each 2 years	26.4^b	37.6^a	22.7^b		
	Each year	51.2^a	9.9^b	14.4^c		
Corralling method (%)	Rotative	37.1^b	46.4^a	11.3^b	23.5	0.02
	Overnight	53.6^a	39.2^a	16.2^b		
	Corralling contract	9.3^c	13.4^b	73.5^a		
Distance fields-house (%)	Near	43.3^a	38.8^a	16.4^c	18.2	0.001
	Medium	41.1^a	47.6^a	26.2^b		
	Far	15.6^b	3.6^b	57.4^a		
Production objective (%)	For sale	16.2^b	29.1^b	48.6^a	16.3	0.05
	Both	16.7^b	48.3^a	27.6^b		
	Consumption	67.1^a	22.6^b	23.8^b		

χ2: represents the chi-square values; chi-square was used to compare categorical variables. The values of the same line indicated by different letters are significantly different at the 5% level ($p < 0{,}05$); *CORC* continuous overnight-rotational corralling, *DORC* Discontinuous overnight-rotational Corralling, *CC* Corralling contract. The letters stand for Dunn-Bonferroni post hoc group (same letter indicate same group)

Bariba (52.3%) ethnic groups with no educational (67.3%) background (Table 6). The methods employed include overnight (53.6%) corralling and rotational (37.1%) corralling. Night corralling was described by respondents as the tethering of animals on a specific plot only during the night, while rotational corralling occurs both day and night, but in a succession from one plot to another. This cluster was characteristic of agroecological zones 2 (44.7%) and 3 (40.1%), and their main production objective was for household consumption (67.1%).

Cluster 2 (practitioners of discontinuous overnight-rotational corralling, DORC): this type of corralling was practiced intermittently, either every two (37.6%) or 3 years (30.1%) or according to an indefinite (22.4%) periodicity (Table 6). It was mainly characteristic of agroecological zones 2 (46.5%) and 3 (39.1%), with an education level ranging from primary (34.1%) to secondary (39.3%) school. The characteristic method of this type was overnight (39.2%)-rotational (46.4%) corralling. The production objective was for both household consumption and sale (48.3%) and the farmer's land was near (<1 km, 39%) from their house.

Cluster 3 (practitioners of Corralling contract, CC): This type was characteristic of Dendi (37.4%) and other minorities (34.7%) ethnic in the study area, occurring without a predefined period (undetermined, 41%). It was observed among farmers with a high level of education, potentially reaching a university (44.3%) education, with a preference for land far (57.4%) from the house. This was based on a corralling contract (73.5%) which is an agreement between farmers and herders, where the latter provide corralling services in the fields in exchange for corralling and/or goods in kind (milk, corn, …). In this group, the production objective was mainly for sale (48.6%).

Drivers of Cattle Corralling Adoption as Soil Fertility Management Option in Northern Benin

The results of the binary logistic regression analysis conducted to determine the factors influencing the adoption of cattle corralling as a means for soil fertility management are summarized in Table 7. The variables agroecological zone, educational level, ethnicity, access to credit, awareness of corralling, access to extension services ($p < 0.001$), distance fields-house, breeding mode, and production objective significantly ($p < 0.001$) influence the adoption. Factors such as experience ($p > 0.05$), membership in rural organizations ($p > 0.05$), age ($p > 0.05$), and number of agricultural workers ($p > 0.05$) do not significantly impact the adoption of cattle corralling.

Discussion

Characterization, Benefits, and Constraints of Cattle Corralling Adoption in Northern Benin

Understanding socio-cultural practices in soil fertility management is crucial for sustainable agriculture. This study highlights cattle corralling as a deeply rooted agricultural tradition in northern Benin, widely recognized among Fulani, Bariba, and Dendi ethnic groups. While not universally practiced, its traditional importance aligns with findings from Shinjo et al. (2008), who emphasized its potential for efficient livestock excreta utilization.

Rotational and overnight corralling are prevalent methods, with farmers often spreading manure manually for uniform nutrient distribution. This aligns with Suzuki et al. (2014), who stressed the role of manure transport and corralling in soil fertility improvement. However, nutrient homogenization remains a challenge,

Table 7 Determinants of the adoption of the practice of cattle corralling as a soil fertility management strategy tool in northern Benin

Variable	Modality	B	Sig.	−2 Log likelihood	Model evaluation
Agroecological zone	Zone 1	0.46	0.000***	435.41	70.9
	Zone 2	−1.39	0.000***		
Educational level	None	2.24	0.000***	427.11	74.2
Ethnicity	Bariba	3.41	0.000***	396.88	72.2
	Other	2.60	0.000***		
Experience	Experience	0.01	0.505*	472.21	70.9
Membership in the rural organization	Yes/No	0.12	0.591*	472.37	70.9
Access to credit	Yes/No	0.65	0.004**	464.36	70.9
Awareness of corralling	Yes/No	3.65	0.000***	384.03	80.4
Age	Age	0.01	0.121	470.19	70.9
Access to extension services	Yes/No	−1.75	0.000***	416.62	73.2
Distance fields-house	Far	0.74	0.000***	371.65	75.8
	Medium	−2.68	0.000***		
	Near	2.15	0.000***		
Number of agricultural workers	Number of agricultural workers	0.01	0.900	472.64	70.9
Breeding mode	Sedentary	1.56	0.000***	437.81	70.9
	Semi-sedentary	−3.23	0.001***		
Production objective	Both	0.56	0.000***	119.59	95.9
	For sale	5.58	0.000***		

***: significative at 1% level ($p < 0.01$); **: significative at 5% level ($0.01 < p < 0.05$); *: significative at 10% level ($0.05 < p < 0.10$), B: Regression Coefficient

particularly on poor plots near homesteads, chosen for security, water, and forage availability (Huruba et al. 2018). Despite perceived soil fertility improvements (75% of respondents), constraints such as herd security, water access, forage availability, and cattle ownership limit broader adoption.

Corralling, practiced annually by 74% of respondents, faces nutrient loss challenges due to volatilization and leaching from urine and feces during heavy rainfall (Bisson et al. 2019). Enhancing sustainability may involve integrating biochar and mulching to improve nutrient retention. Biochar, while showing mixed effects, can improve water retention, pH, microbial activity, and reduce leaching of nitrogen, potassium, and phosphorus (Hossain et al. 2020; Kuo et al. 2020).

Cattle corralling supports food security and livelihoods by boosting crop yields (Ayantunde et al. 2018). Addressing barriers such as water and forage scarcity, labor availability, and cattle ownership could expand its adoption. Solutions include providing secure corralling areas, improving water and forage resources, and facilitating livestock ownership through credit and extension services. Also, by establishing community-based surveillance systems, local cooperatives or neighborhood watch groups can improve herd security, knowing that community involvement fosters collective responsibility and reduces the risk of theft and predation.

Typology of Cattle Corralling in Northern Benin

The typology identifies three main cattle corralling practices in northern Benin: ORCC, DORC, and CC. These practices reflect varying socio-economic and cultural contexts, showcasing their adaptability within farming systems. This diversity indicates that the effectiveness of cattle corralling as a soil fertility management tool depends on the specific method employed. For instance, ORCC provides consistent soil fertility benefits through continuous manure deposition, while DORC and CC offer flexibility but may result in less regular nutrient enrichment. Understanding these typologies enables tailored interventions to optimize their effectiveness, enhancing agricultural productivity and sustainability.

The ORCC is widely practiced by ethnic groups like the Fulani and Bariba, who often lack formal education. It involves continuous overnight corralling on specific plots, with rotational shifts between plots, ensuring regular manure deposition and sustained soil fertility enhancement (Augustine 2004). This continuity is supported by permanent cattle ownership among these groups. Conversely, DORC is intermittent, occurring every 2–3 years or irregularly, and is typical of farmers with varying education levels, from primary to secondary school. Its sporadic nature suggests a supplementary approach to soil fertility management, likely due to the lack of permanent herds (Duiker and Zampaligre 2022; Gandah et al. 2003).

The CC type, practiced by ethnic minorities, involves formal agreements between herders and farmers. Common among highly educated farmers, potentially with university degrees, it integrates livestock into crop production through services exchanged for goods or payment. This formalized approach broadens access to cattle corralling benefits for farmers without cattle, promoting wider adoption (Shinjo et al. 2008).

These typologies reflect the practice's adaptability to diverse socio-economic settings (Kuivanen et al. 2016). Targeted interventions, such as developing corralling contracts, could enhance accessibility for cattle-less farmers, while addressing broader challenges like security and water availability would benefit all practices. Understanding and promoting culturally and economically appropriate strategies can further the sustainable integration of cattle corralling into farming systems.

Determinants of Cattle Corralling Adoption as a Soil Fertility Management

Understanding the factors influencing the adoption of cattle corralling for soil fertility management in the context of climate change is crucial (Mwaura et al. 2021). This study identifies agroecological zone, education, ethnicity, access to credit, awareness, extension services, field-house distance, breeding mode, and production objective as key determinants. Similar findings on adoption drivers are noted in prior studies (Diro et al. 2022; Kwadzo and Quayson 2021).

Educational level plays a critical role: highly educated farmers lean toward intensive agriculture, while less educated ones adopt nature-based solutions like corralling (Kansanga et al. 2021). Ethnic affiliation influences livestock ownership, with groups like the Fulani and Bariba more inclined to adopt corralling (Ado et al. 2020). Access to credit has a dual impact, facilitating chemical fertilizer use but also enabling livestock purchase, which supports corralling adoption (Kwadzo and Quayson 2021). Extension services significantly increase awareness and adoption of corralling (Muhammed et al. 2020), promoting sustainable practices and innovative designs (Eeswaran et al. 2022). Distance from fields to homes is another critical factor; shorter distances provide security and water access, enhancing adoption (Belachew et al. 2020). Strategies to create accessible corralling areas near homes can mitigate logistical challenges.

Breeding mode and production objectives also influence adoption. Sedentary systems facilitate manure deposition, while mobile systems face challenges. Market-oriented farmers may prioritize short-term yields, whereas subsistence systems align with the sustainability benefits of corralling. Cattle corralling enhances resilience and sustainability by recycling nutrients, improving soil fertility, and reducing reliance on chemical fertilizers (Hidosa and Meskel 2022). It supports diversified, climate-resilient farming systems, optimizes resource use, and mitigates land degradation, making it a vital nature-based solution for sustainable agriculture (Schiere et al. 2006).

Conclusion and Policy Implications

The study's findings on cattle corralling practices in northern Benin highlight its potential for sustainable land use and soil fertility management. With widespread adoption (71% of surveyed farmers) and perceived soil fertility benefits, policies should support and scale up sustainable corralling practices tailored to agroecological and socio-cultural contexts. The identified typologies (CORC, DORC, and CC) require differentiated approaches. Policies promoting access to credit, extension services, herd security, water, and forage resources can enhance adoption and alleviate constraints.

Cattle corralling reduces reliance on costly mineral fertilizers, aligning with climate-smart agriculture goals. Contract-based corralling could expand benefits to farmers without cattle, necessitating policies to promote such agreements. To mitigate risks like nutrient imbalances and water pollution, extension services should guide optimal manure management and field rotation. A multi-faceted policy approach integrating social, economic, and environmental dimensions can enhance productivity, resilience, and sustainability. These results underscore the need for continued research and extension to support cattle corralling as a nature-based solution to soil fertility management amid climate change.

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Authors' Contributions **A. Marcellin Atakoun**: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing—original draft. **Pierre G. Tovihoudji**: Conceptualization, Methodology, Writing—review & editing, Supervision. **William Amponsah**: Writing—review & editing, Supervision. **Rodrigue V. Cao DIOGO**: Methodology, Writing—review & editing, Supervision. **Murilo dos Santos Vianna**: Methodology, Writing—review & editing. **Thomas Gaiser**: Methodology, Writing—review & editing. **Nicolas Kyei-Bafour**: Methodology, Writing—review & editing, Supervision. **Boateng Kyereh**: Methodology, Writing—review & editing, Supervision.

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