Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2023, 11, 171-191
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Agriculture and Soil Management in the Context of Sustainable Development in the Sudano-Sahelian Zone of Cameroon

Sidsi Bienvenu[1*], Vounba Claudine[1], Bahouro Arka[2], Kolaouna Bruno Labara[1]

[1]Institut of Agricultural Research for Development (IRAD), Agricultural Research Center (CRA) in Maroua, Maroua, Cameroon
[2]Chadian Institute of Agronomic Research for Development (ITRAD), N'Djamena, Chad
Email: *sidsibienvenu@gmail.com

How to cite this paper: Bienvenu, S., Claudine, V., Arka, B., & Labara, K. B. (2023). Agriculture and Soil Management in the Context of Sustainable Development in the Sudano-Sahelian Zone of Cameroon. *Journal of Geoscience and Environment Protection, 11,* 171-191.
https://doi.org/10.4236/gep.2023.1111013

Received: October 16, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Abstract

The Sudanian-Sahelian zone of the Far-North Cameroon faces an extreme climate challenge resulting in increased vulnerability to erosion, soil degradation, and the effects of climate change, impacting soil fertility and agricultural yields. The objective of this study was to analyze agricultural practices, challenges related to climate change and soil degradation, as well as the solutions adopted by farmers to address these issues. To achieve this, 600 farmers from the six departments of the region were interviewed. The results highlight the significant impact of climatic conditions on soil health, agricultural activities, and food security. Farmers identified various indicators of soil degradation, including agricultural yields, bioindicator plants, plant growth, soil fauna, and root density. The main causes of soil degradation are associated with practices such as deforestation, intensive agriculture, the use of chemical fertilizers and pesticides, overgrazing, and the effects of climate change. The impacts of this degradation are multiple, including soil fertility loss, reduced agricultural yields, deforestation, reduced biodiversity, income loss, water resource pollution, and food insecurity. In response to these challenges, farmers have adopted sustainable soil management practices, including crop rotation, intercropping, fallowing, the use of organic fertilizers, and the adoption of conservation agriculture. To effectively address these challenges, concerted collaboration between farmers, civil society organizations, and government authorities is imperative to develop sustainable and effective solutions against soil degradation in the region.

Keywords

Agriculture, Soil Degradation, Climate Change, Food Security, Sudanian-Sahelian Zone, Cameroon

1. Introduction

Food security and poverty alleviation are global concerns (FAO et al., 2020). In sub-Saharan African countries, agriculture is a pivotal sector in the economy, and its intensification and diversification remain a top priority (Asirvatham et al., 2022). Sub-Saharan Africa is home to over 950 million people, approximately 13% of the global population. This population is projected to increase to nearly 22%, comprising 2.1 billion people by 2050 (Delaunay & Guengant, 2019). Malnutrition and undernourishment have persisted as challenges for several decades (Mbogori et al., 2020). Although they have decreased, from 33% in 1990-1992 to 23% in 2014-2016, the percentage of undernourished individuals remains highest in developing countries (FAO et al., 2020).

Agriculture plays a significant role in the Cameroonian economy (Nyamnding & Mireille, 2011; Bayila et al., 2019). It contributes to 30% of the GDP and represents over 40% of the country's total exports (Ndjidda et al., 2022). According to the Minister of Agriculture and Rural Development, the agricultural sector is the leading employer, with 62% of the active population engaged. However, the varying pedoclimatic conditions found from the north to the south within the country's five agro-ecological zones (Sudano-Sahelian zone, high Guinean Savannas, high plateaus of the West, monomodal rainfall tropical rainforest, and bimodal rainfall tropical rainforest) result in a rich and diverse agricultural potential (Bayiha et al., 2019). Cultivated products encompass horticultural crops (tomato, lettuce, cabbage, onion, garlic) to staple crops (millet, sorghum, cassava, yams) while also including the major export crops (cotton, cocoa, coffee, oil palm, banana, plantain, sugarcane, rubber) (Bikié et al., 2000; Kaffo, 2005).

From a perspective of sustainable development, different agricultural practices are a significant concern as some current fertilization techniques can cause substantial and potentially irreversible harm to the soil (soil pollution, soil degradation, soil erosion) (Folega et al., 2022). Agricultural activities, such as the Green Revolution, have an evident impact on soil natural conditions, climate change, and the agronomy-environment balance (Zhou et al., 2021). The development of agriculture through acquiring knowledge about a crop's mineral requirements, mastering fertilization, post-World War II development of herbicides and insecticides, and the early synthesis of fungicides have profoundly transformed farming systems and environmental equilibrium (Bayiha et al., 2019; Loyem et al., 2020).

Due to its geographical location, the Sudanian-Sahelian zone of the Far-North Cameroon is particularly exposed to the adverse effects of climate change. These effects, combined with inappropriate agricultural practices, result in advanced erosion and soil degradation, significantly impacting agricultural productivity and, consequently, food security (Montoroi, 2012). According to a study conducted by the International Center for Agricultural Research and Development Cooperation (CIRAD), the Extreme-North region exhibits a high soil degradation rate, estimated at 45% in 2010. Therefore, it is crucial to adopt less soil-intensive agricultural techniques to promote sustainable agriculture (Benoit et al., 2020). The objective of this study is to analyze current agricultural practices, challenges related to climate change and soil degradation, and understand the solutions employed by farmers to promote sustainable agriculture in the Extreme-North region of Cameroon.

2. Materials and Methods

2.1. Study Site Location

The Far-North region of Cameroon, which is part of the Sudanian-Sahelian zone, is situated between 10˚ and 13˚ North latitude and between 13˚ and 16˚ East longitude. It has a triangular shape, bordered to the north by Lake Chad, to the south by the North region, to the east by the Republic of Chad, and to the west by the Republic of Nigeria (**Figure 1**). Maroua serves as the capital of the Far-North region, which is further divided into six departments: Diamaré, Logone and Chari, Mayo Danay, Mayo Kani, Mayo Sava, and Mayo Tsanaga. Our study was conducted in the localities of Maroua, Kousseri, Yagoua, Kaélé, Mokolo, and Mora.

The Sudanian-Sahelian zone of the Far-North is characterized by a Sudanian-Sahelian tropical climate, which, according to Suchel (1987), is divided into

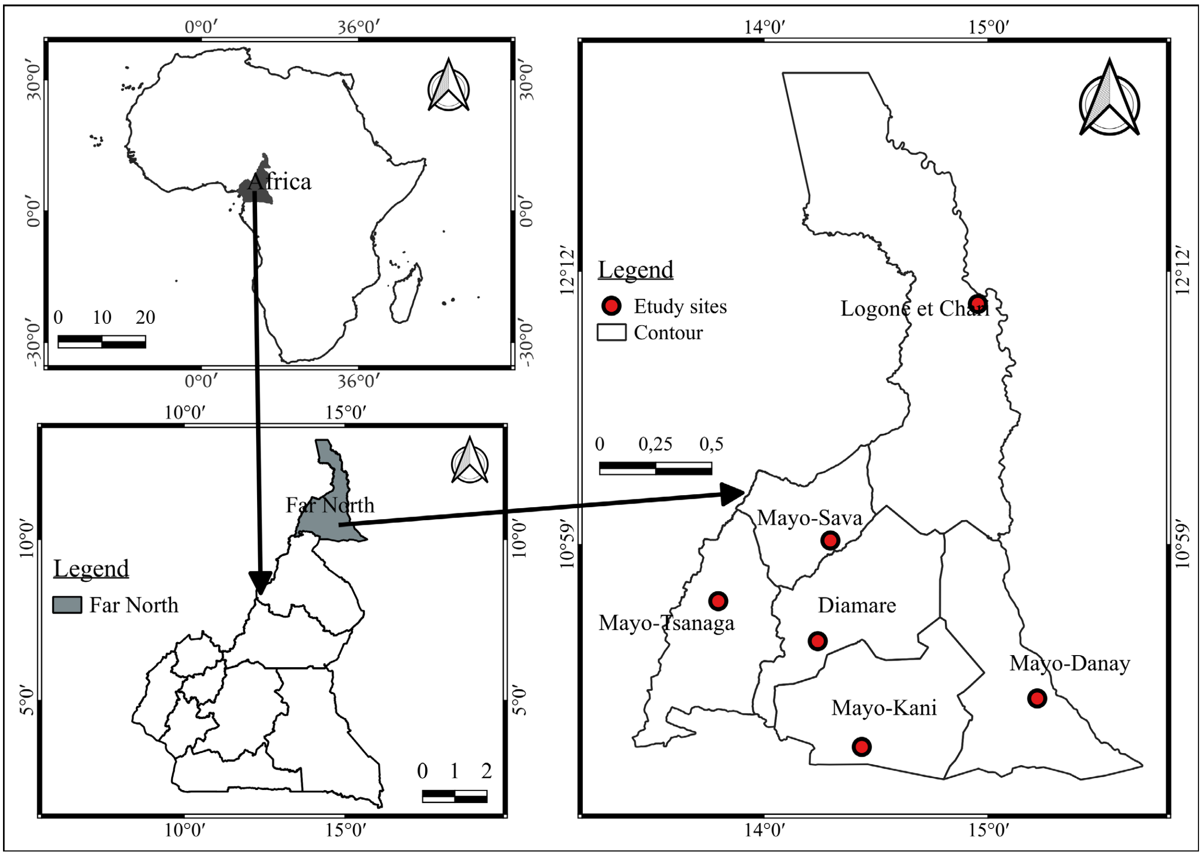

Figure 1. Location of the study site.

two distinct seasons. The first season is a prolonged dry season lasting approximately seven months, starting in October and extending through April, followed by a shorter rainy season that begins in late April and ends in early October. Rainfall varies from 400 to 1050 mm annually, with an average of 244.7 mm per year according to L'hote (2000). Regarding temperatures, they decrease from north to south and vary with the seasons and localities, with an average temperature of 27.6˚C in Maroua-Salak. The hottest months are March (39˚C) and April (37˚C), while the coldest months are January (33˚C) and December (33.5˚C).

2.2. Site Selection and Sampling

The selection of localities and households surveyed is based on several criteria. Consequently, all six (6) departments of the Far-North region were chosen for field surveys. The selection of localities was not only based on the size of agricultural households but also took into account the intensity of agricultural activities in these areas. Accessibility and the level of community involvement in agricultural activities were also crucial factors for this selection. Only heads of households were investigated. The selection of individuals surveyed was based on at least one of the non-cumulative criteria, namely age (being at least 30 years old), residency duration in the locality (having resided in the locality for at least ten (10) years before the survey), and involvement in agriculture (being an agricultural producer). In total, 600 individuals were surveyed, with 100 in each of the following departments: Mayo Danay, Mayo Kani, Diamaré, Mayo Tsanaga, Mayo Sava, and Logone et Chari.

2.3. Methodology

In order to conduct this research effectively, we have chosen to adopt a hypothetico-deductive approach. This methodology involves formulating hypotheses based on a theoretical framework, which is then subjected to empirical verification using a questionnaire. Two (2) methodological axes were used: a documentary analysis to identify and define the various aspects of the agriculture-environment-sustainable development concept, and a primary analysis based on a questionnaire where we collected the necessary information for empirical analysis from farmers. The samples for our study consist of individuals whose primary activity is agriculture. The sampling method used is random, using a convenience sample. Our target includes farmers with more than 5 years of farming experience. We have decided to limit the number of respondents to 100 per department, considering that these farmers tend to periodically move in search of fertile land. Therefore, we have opted for a snowball sampling approach since not all farmers are easily identifiable. The operators identified with the help of traditional leaders will help us connect with others. To carry out our study, we developed and administered a questionnaire. This questionnaire is a quantitative data collection instrument composed of four distinct parts: respondent identification, their knowledge of local producers' farming practices, their knowledge of yield variations and soil types, as well as their level of soil degradation and potential sustainable soil restoration techniques.

2.4. Data Analysis

The collected data were entered and organized using Microsoft Excel 2016. Descriptive statistics (frequencies and means) were used to establish the environmental and agricultural characteristics of the soil, soil degradation indicators, the main causes of soil degradation, and sustainable soil management practices in the Sudanian-Sahelian zone of Cameroon using the S.P.S.S. (Statistical Package for the Social Sciences) software. Spearman correlation coefficients calculated at a 5% threshold were used to understand the relationships between various variables.

3. Results

3.1. Environmental and Agricultural Characteristics of Soils in the Far-North Region: Fragility and Vulnerability to Degradation

Table 1 below highlights the environmental and agricultural characteristics as well as vulnerability to degradation in the Sudanian-Sahelian zone of Cameroon. The table reveals that the Far-North region of Cameroon experiences a dry climate characterized by relatively low annual precipitation levels. This persistent arid condition can have significant repercussions on the availability of water required for plants and soil regeneration processes. Due to the prevalence of climatic aridity, the region is vulnerable to both wind and water erosion. These erosion types can lead to soil structure deterioration and the loss of the top fertile soil layer. This vulnerability is exacerbated by extreme weather conditions, including extended periods of drought that weaken ecosystem resilience, and sudden flooding episodes that can erode and carry away exposed soil. The capacity of ecosystems to maintain soil fertility and resist degradation is compromised. Plants that manage to survive in these conditions are often specialized to

Table 1. Environmental and agricultural characteristics and vulnerability to degradation in the Sudanian-Sahelian Zone of Cameroon.

Characteristic	Description	Fragility	Vulnerability to Degradation
Climatic Conditions	Semi-arid zone with average annual rainfall of 500 to 1000 mm, short rainy season, and long dry season	Climatic conditions favor wind and water erosion	Wind and water erosion are the main causes of soil degradation in the region
Soil Types	Generally shallow, leached, sandy soils rich in clay and iron, sensitive to acidification	Shallow soils make them vulnerable to erosion	Shallow soils. acidification. and erosion sensitivity are factors making soils vulnerable to degradation
Agricultural Practices	Traditional, often unsustainable farming practices, including shifting cultivation, overgrazing, and deforestation	Unsustainable farming practices contribute to soil degradation	Unsustainable farming practices contribute to soil degradation by reducing soil organic matter content. increasing soil compaction. and promoting erosion

tolerate periods of drought and less fertile soils. This situation can have a ripple effect on the entire food chain and ecological interactions, with potential consequences for the sustainability and resilience of the local environment.

The soils typically have shallow depths, resulting from pronounced leaching and displaying a combination of sandy and clay textures. These soils are particularly sensitive to acidification and are characterized by low nutrient and organic matter content. Drought, flooding, and the significant pressure exerted by farmers contribute to the rapid erosion of soils, making them more vulnerable to degradation. The direct consequences of soil degradation include a noticeable reduction in biodiversity, increased soil erosion, and a significant decrease in agricultural productivity. These negative environmental impacts lead to biodiversity loss and contribute to land desertification. Additionally, they affect the livelihoods of local populations, who heavily depend on agriculture for their economic well-being. Furthermore, the region's food security is compromised as soil degradation reduces the region's capacity to produce enough food to meet the growing needs of its population.

Agriculture is particularly influenced by the inherent fragility and vulnerability of soils to degradation. The agricultural situation is strongly marked by significant environmental pressures resulting from a convergence of complex factors such as climate, topography, agricultural practices, and population growth. The increased pressure exerted by farmers on these already vulnerable lands further exacerbates the issue, leading to rapid soil erosion. Nevertheless, the adoption of traditional farming practices, based on the use of rudimentary techniques, can help mitigate soil degradation. These techniques only allow farmers to produce sufficient food to meet the needs of their families and communities. However, the introduction of modern agricultural practices, based on the use of more sophisticated tools and techniques to maximize agricultural production, has increased pressure on the soil. Farmers use chemical fertilizers and pesticides to boost agricultural production. These techniques enable farmers to produce larger quantities of food, but they also have a negative impact on the environment.

3.2. Soil Degradation Indicators in the Far-North Region of Cameroon

Soil degradation is a phenomenon that affects soil fertility, biodiversity, and land productivity, especially in arid and semi-arid regions. It is a process that results in a loss of soil fertility, structure, and productivity, requiring a multi-sectoral approach to its management. Several criteria are used by farmers to determine soil degradation indicators in the Far-North region of Cameroon (**Table 2**).

In total, farmers use 11 criteria (**Figure 2**) to determine soil degradation indicators in the Sudanian-Sahelian zone of Cameroon. These criteria encompass physical characteristics related to topography, texture, permeability, color, and depth of the arable layer, biological aspects centered on root abundance, soil fauna, presence of bioindicator plants, and agricultural factors related to plant

Table 2. Evaluation criteria for soil degradation indicators by farmers in the Sudano-Sahelian Zone of Cameroon.

Indicators	Descriptions	Associated Evaluation Criteria
Soil Erosion	Loss of soil due to strong winds (wind erosion) and rainfall (water erosion)	Topography, soil texture, permeability, depth of the arable layer, root abundance, bioindicator plants
Decreased Fertility	Reduction in soil quality in terms of nutrients, affecting agricultural yields	Agricultural yield, plant growth, soil texture, bioindicator plants, permeability, root abundance, soil fauna, duration of use
Biodiversity Decline	Loss of variety in plant and animal species due to soil degradation	Soil fauna, root abundance, duration of use, bioindicator plants
Loss of Vegetative Cover	Decrease in vegetation that protects soils from erosion and conserves moisture	Bioindicator plants, root abundance, plant growth, soil texture, bioindicator plants, soil fauna
Desertification	Process of land degradation in arid and semi-arid areas. often related to a combination of factors	Bioindicator plants, root abundance, depth of the arable layer, soil fauna

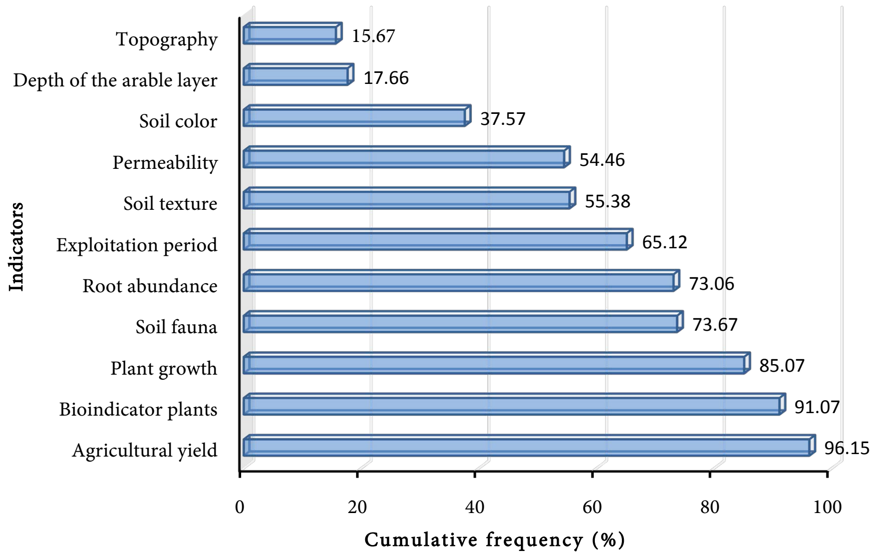

Figure 2. Frequencies of use of evaluation criteria for soil degradation indicators by farmers in the Sudano-Sahelian Zone of Cameroon.

growth and crop yields. The combination of these criteria has led farmers to distinguish five soil degradation indicators: soil erosion, decreased soil fertility, reduced biodiversity, loss of vegetation cover, and desertification.

The criteria most frequently used by farmers to assess soil degradation in the Sudanian-Sahelian zone of Cameroon are agricultural yield, bioindicator plants, and plant growth, with percentages of 96%, 91%, and 81% respectively. These criteria play a crucial role in how farmers measure and evaluate changes in soil quality and fertility. Similarly, other factors are also considered important by farmers in determining soil degradation indicators in this region. Soil fauna at 76.66%, root abundance (73.00%), and the duration for which the lands are exploited (64.66%) are also crucial elements for assessing soil conditions. Among the physical soil criteria, texture at 55.33% and permeability at 54.66% influence the soil's ability to retain water and nutrients, which is crucial for crop health and productivity. However, it is worth noting that some criteria have relatively less weight in determining these indicators for farmers. Soil color is considered with a percentage of 37.33%, suggesting that it is less systematically used to judge soil degradation. Furthermore, the depth of the arable layer, i.e., the depth at which plants can root, and the terrain's topography have respective percentages of 17.66% and 15.66% and are therefore less predominant in farmers' considerations for evaluating soil degradation.

An analysis of the correlation matrix (**Table 3**) of soil degradation indicators has shown that agricultural yield is positively correlated with plant growth, root abundance, exploitation duration, soil texture, and the depth of the arable layer. Bioindicator plants are strongly correlated with plant growth, soil fauna, root abundance, exploitation duration, soil texture, and the depth of the arable layer. Soil permeability is weakly correlated with the other variables, showing moderate positive correlations with soil texture and soil color. Topography is weakly correlated with most other variables, except for the depth of the arable layer, with which it has a moderate negative correlation.

3.3. Main Causes of Soil Degradation in the Sudanian-Sahelian Zone of Cameroon

Soil degradation in the Sudanian-Sahelian zone results from several interdependent factors that have significant implications for ecological balance and ecosystem sustainability. **Figure 3** illustrates the primary causes of soil degradation in the Far-North region of Cameroon. Farmers assert that deforestation, which is the leading cause, is responsible for the degradation of nearly all soils (91.83%)

Table 3. Correlation matrix among soil degradation indicators.

	Agricultural yield	*Bioindicator plants*	*Plant growth*	*Soil fauna*	*Root abundance*	*Exploitation period*	*Soil texture*	*Permeability*	*Soil color*	*Depth of the arable layer*	*Topography*
Agricultural yield	1										
Bioindicator plants	0.78	1									
Plant growth	0.89	0.83	1								
Soil fauna	0.77	0.57	0.88	1							
Root abundance	0.89	0.92	0.78	0.63	1						
Exploitation period	0.96	0.81	0.79	0.66	0.96	1					
Soil texture	0.89	0.85	0.86	0.56	0.82	0.86	1				
Permeability	0.56	0.29	0.55	0.60	0.38	0.41	0.27	1			
Soil color	0.15	−0.02	0.16	−0.13	−0.15	−0.05	0.29	0.34	1		
Depth of the arable layer	0.43	0.86	0.60	0.46	0.71	0.52	0.53	0.00	−0.41	1	
Topography	−0.36	−0.04	−0.17	−0.52	−0.37	−0.46	−0.01	−0.17	0.68	−0.08	1

Significant at $p < 0.05$.

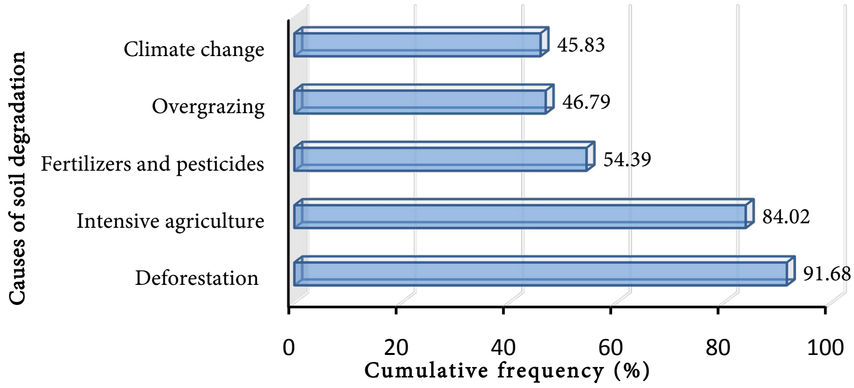

Figure 3. Main causes of soil degradation identified by farmers in the Sudano-Sahelian Zone of Cameroon.

with devastating consequences on fertility, biodiversity, and flooding of riparian areas. Intensive agriculture, accounting for 84.66% of degraded soils, emerges as the second cause, driven by the growing demand for food.

The use of fertilizers, herbicides, and pesticides, identified in 53.5% of cases, significantly impacts groundwater and aquifers, as well as beneficial soil organisms, such as earthworms and bacteria. Overgrazing, excessive pressure from livestock on pastures, represents 45.50% of cases. It reduces soil regeneration capacity and increases vulnerability to erosion. Finally, the increasingly noticeable climate changes in the region account for 40.66% of cases of this phenomenon. It leads to an increase in the frequency and intensity of extreme weather events, such as droughts, floods, and storms.

The correlation matrix between various factors that could impact deforestation (**Table 4**) shows that deforestation is strongly correlated with intensive agriculture (0.22) and fertilizer and pesticides (0.26). Intensive agriculture and the use of fertilizers and pesticides are highly correlated with each other (0.74), overgrazing has a strong correlation with intensive agriculture (0.79) and fertilizer and pesticides (0.82), and climate change exhibits a negative correlation with intensive agriculture (−0.58) and a weak correlation with fertilizers and pesticides (−0.16).

3.4. Consequences of Soil Degradation in the Sudano-Sahelian Zone of Cameroon

Soil degradation in the Sudano-Sahelian region of Far-North Cameroon has significant consequences, both at the physical and socio-economic levels, directly affecting the local population. Our analysis results (**Figure 4**) reveal that the most frequently mentioned physical consequence by farmers is the loss of soil fertility, with an alarming percentage of 92.09%. This loss of fertility leads to a decline in agricultural yields, directly impacting the food security of the population. The second most commonly observed consequence is the decrease in agricultural yields, which results directly from the loss of soil fertility, cited in over 91.43% of cases by the farmers. Other important physical consequences include

Table 4. Correlation matrix among different factors causing soil degradation in the Sudano-Sahelian Zone of Cameroon.

	Deforestation	*Intensive agriculture*	*Fertilizers and pesticides*	*Overgrazing*	*Climate change*
Deforestation	1				
Intensive agriculture	−0.22	1			
Fertilizers and pesticides	0.26	0.74	1		
Overgrazing	0.41	0.79	0.82	1	
Climate change	0.40	−0.58	−0.16	−0.21	1

Significant at $p < 0.05$.

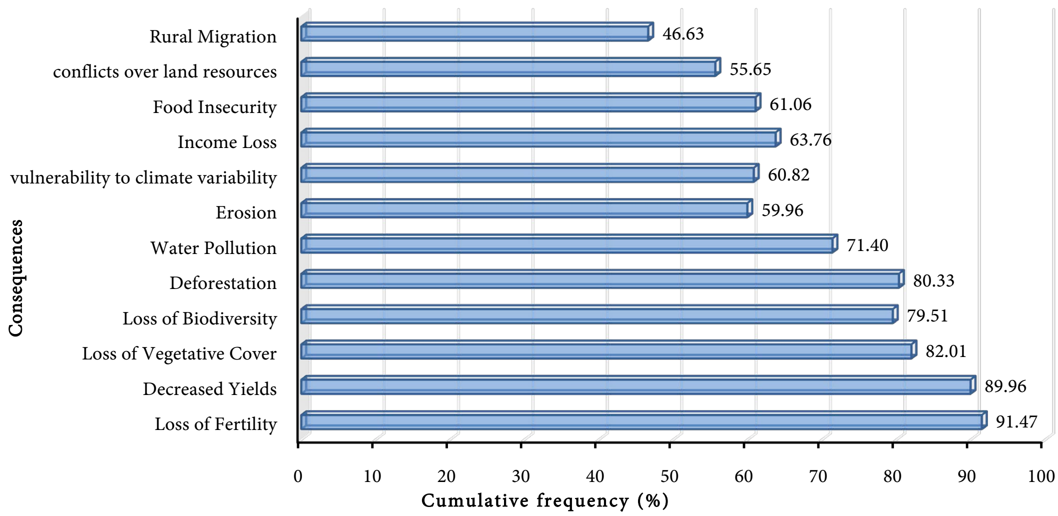

Figure 4. Consequences of soil degradation identified by farmers in the Sudano-Sahelian Zone of Cameroon.

the loss of vegetation cover (78.44%), a decrease in biodiversity (76.25%), and deforestation (74.12%). Water pollution (65.57%), erosion (58.77%), and vulnerability to climate variations (57.83%) are also significant challenges in the region. In addition to these physical consequences, farmers have identified socio-economic consequences that have a substantial impact on the lives of local populations. These consequences include income loss (67.14%), food insecurity (64.07%), conflicts related to land resources (54.09%), and rural migration (44.92%).

The correlation matrix between different consequences of soil degradation (**Table 5**) indicates that crop rotation is strongly correlated with organic fertilization and agroforestry. Conservation agriculture, on the other hand, has a weak correlation with the other practices. Intercropping is moderately correlated with contour farming and water management. Fallow lands are moderately negatively correlated with reforestation. Finally, water management is strongly correlated with intercropping, agroforestry, contour farming, and reforestation.

Table 5. Correlation matrix among the various consequences of soil degradation.

	Crop Rotation	*Crop intercropping*	*Fallow Land*	*Organic Fertilization*	*Conservation agriculture*	*Agroforestry*	*Contour Farming*	*Reforestation*	*Water Management*
Crop rotation	1								
Crop intercropping	0.43	1							
Fallow land	0.32	0.24	1						
Organic fertilization	0.82	0.26	0.50	1					
Conservation agriculture	−0.08	0.44	−0.21	0.20	1				
Agroforestry	0.68	0.64	0.22	0.80	0.59	1			
Contour farming	0.65	0.50	0.61	0.88	0.33	0.88	1		
Reforestation	0.14	−0.08	0.94	0.45	−0.26	0.05	0.49	1	
Water management	0.48	0.80	0.68	0.59	0.36	0.75	0.85	0.46	1

Significant at $p < 0.05$.

3.5. Sustainable Soil Management Practices in the Far-Nord Region of Cameroon

The analysis of the survey results reveals that in the Far-North Region of Cameroon, farmers employ sustainable soil management strategies (**Figure 5**). These strategies are designed to preserve, maintain, and enhance the valuable soil and water resources while ensuring sustainable development and food security for the region. Crop rotation emerges as a predominant management method, adopted on a large scale (90.66%). This technique, rooted in tradition, involves the implementation of various crop combinations to orchestrate successive cycles (such as millet-sorghum-cowpea, maize-cowpea-peanut, cotton-maize-cowpea…). Crop association, practiced in about 77% of cases, proves to be a proven strategy to maximize the judicious use of natural resources and increase agricultural productivity.

In parallel, fallow land plays a crucial role in the sustainable preservation of soils, given the environmental and agricultural characteristics specific to the region. It stands out as an ancient practice, having been adopted in 67.66% of cases by farmers. Additionally, organic fertilization, mainly through the use of organic manure and cow dung, is a significant method implemented in 49.33% of situations to preserve soil quality. Furthermore, conservation agriculture (39%), agroforestry (35.33%), contour farming (31.33%), and reforestation (28.66%) are also among the methods frequently adopted by growers to optimize the use of agricultural lands. Alongside these commonly used practices, other approaches such as water management, mulching, and vegetative cover, as well as the use of soil-improving plants, are implemented at respective rates of 24.33%, 8.33%, and 5.66%. It is important to note that the use of soil-improving plants represents an innovative technique currently being popularized through institutions such as

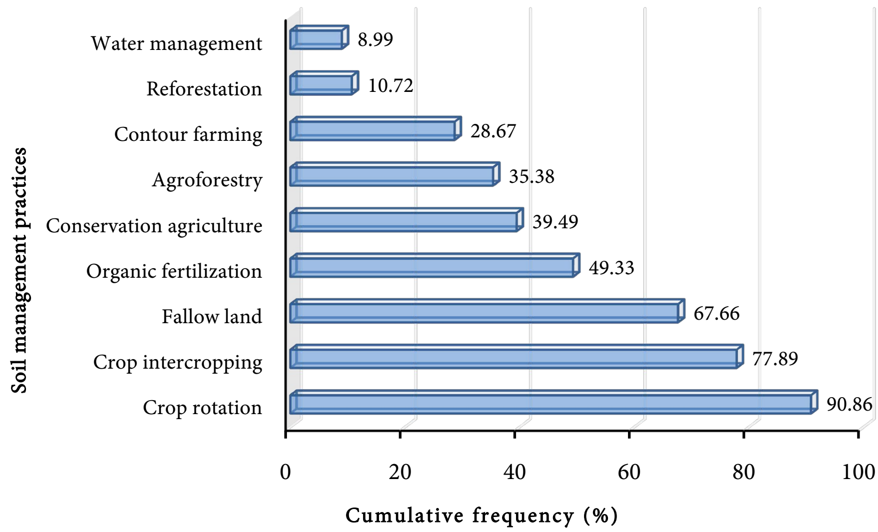

Figure 5. Sustainable soil management practices used by farmers in the Sudano-Sahelian Zone of Cameroon.

the Institute of Agricultural Research for Development (IRAD), the Ministry of Agriculture and Rural Development, as well as various interest groups and non-governmental organizations.

The correlation matrix among the different variables related to soil degradation (Table 6) shows that most of the variables are positively correlated, meaning they increase or decrease together. For example, fertility loss is strongly correlated with loss of vegetation cover, loss of biodiversity, and erosion. This means that these factors all contribute to soil degradation. However, some variables are also negatively correlated, indicating that they increase or decrease in opposite directions. For instance, vulnerability to climate change is negatively correlated with fertility loss. This means that more fertile soils are less vulnerable to the effects of climate change.

4. Discussion

4.1. Environmental and Agricultural Characteristics of Soil in the Far-North Region: Fragility and Vulnerability to Degradation

The Far-North Region of Cameroon is part of arid and semi-arid zones. This area is facing land degradation due to various factors. Among these factors are climate variations, including persistent drought and sudden flooding episodes, as well as human activities that have a significant impact on the availability of water required for plants and soil regeneration processes. As a result, the ecosystems' ability to maintain soil fertility and resist degradation would become increasingly challenging. These phenomena have also been observed by Tchindjang et al. (2015) and Mariel et al. (2022) in the Sudan-Sahelian zone of Cameroon and in Madagascar, respectively. It appears that plant species that manage to survive in these conditions are generally those that tolerate periods of drought and less fertile soils. This situation could have significant impacts on the entire

Table 6. Correlation matrix among various variables related to soil degradation.

	Loss of Fertility	*Decreased Yields*	*Loss of Vegetative Cover*	*Loss of Biodiversity*	*Deforestation*	*Water Pollution*	*Erosion*	*vulnerability to climate variability*	*Income Loss*	*Food Insecurity*	*conflicts over land resources*	*Rural Migration*
Loss of Fertility	1											
Decreased Yields	0.42	1										
Loss of Vegetative Cover	−0.14	−0.58	1									
Loss of Biodiversity	0.05	0.22	0.31	1								
Deforestation	−0.42	−0.53	0.90	0.49	1							
Water Pollution	−0.05	0.16	0.63	0.82	0.74	1						
Erosion	−0.28	−0.11	0.68	0.21	0.58	0.59	1					
Vulnerability to Climate Variability	0.03	0.12	−0.18	0.55	−0.11	0.07	−0.03	1				
Income Loss	0.40	0.41	−0.70	−0.50	−0.70	−0.56	−0.77	−0.46	1			
Food Insecurity	0.34	0.25	−0.78	−0.20	−0.68	−0.60	−0.99	0.09	0.79	1		
Conflicts over Land Resources	0.30	0.51	−0.16	0.71	−0.13	0.36	0.10	0.87	−0.35	0.00	1	
Rural Migration	−0.62	−0.16	−0.20	0.06	0.20	−0.01	−0.43	−0.19	0.24	0.35	−0.36	1

Significant at $p < 0.05$.

food chain and ecological interactions, with potential repercussions on the sustainability and resilience of the local environment (Jiagho & Banoho, 2021; Njoya et al., 2022).

Agriculture, as a human activity, is inherently linked to soil characteristics. These characteristics, in turn, are influenced by various factors such as climate, topography, biodiversity, and human actions (Njouenwet et al., 2021). Agricultural practices can encompass both traditional and modern methods, each with their own advantages and disadvantages in terms of their impact on the environment and agriculture (Coulibaly et al., 2019). It is essential to adopt sustainable land management practices to preserve soil functions and ecosystem services (Koguia et al., 2021; Chimi et al., 2022). These practices may include actions such as improving vegetative cover, combating erosion, conserving water and nutrients, rehabilitating degraded soils, diversifying crops, and adopting agroforestry. These findings are consistent with the conclusions of Njoya et al. (2022) in the Far-North Region of Cameroon.

Furthermore, our study highlights the potential of these approaches to enhance the adaptive capacity of local populations to climate change. This could result in increased agricultural productivity, reduced water scarcity risks, soil degradation mitigation, and improved food security. These observations are also supported by the research of Tendonkeng et al. (2021) in the North-West region of Cameroon and by the work of Zakari et al. (2022) in the Sahelian region of Nigeria.

4.2. Soil Degradation Indicators in the Far-North Region of Cameroon

Farmers have developed local knowledge and endogenous indicators to assess and manage soil health in their region. These indicators are based on physical, biological, and agricultural criteria that reflect soil properties and functions (M'Biandoun & Bassalan, 2007; Seibou et al., 2021). The empirical and pragmatic knowledge of farmers for evaluating signs of soil degradation is founded on their observations and experiences. They are capable of recognizing natural variations and adapting their agricultural practices accordingly (M'Biandoun & Bassala, 2007; Manssour et al., 2021).

In the Extreme-North region of Cameroon, farmers primarily rely on agricultural yield, the presence of bioindicator plants, plant growth, soil fauna, root abundance, and land use duration to determine soil degradation indicators. These indicators would be considered as direct signs of soil quality and performance (M'Biandoun & Bassala 2007; Kome et al., 2018). Similarly, the findings of Manssour et al. (2021) in Eastern Niger highlight that, in addition to these indicators, soil color, depth of the arable layer, and terrain topography are crucial indicators for identifying soil degradation. These empirical and pragmatic farmer knowledge, based on their observations and experiences, enable them to recognize natural variations and adapt their agricultural practices accordingly (M'Biandoun & Olina, 2006; Manssour et al., 2021).

In addition to the above, farmers' endogenous indicators can be complemented by exogenous indicators derived from scientific research, such as physico-chemical or biological soil analyses, erosion or salinization measurements, or simulation and mapping models, to enhance sustainable land management, as suggested by Sawadogo et al. (2020). A participative and integrated approach that combines local and scientific knowledge could contribute to a better understanding and management of soils in the Sudanian-Sahelian region of Cameroon while fostering dialogue and learning among various stakeholders involved in the fight against soil degradation, including farmers, researchers, development agents, and policymakers (Mariel et al., 2022).

4.3. Causes of Soil Degradation in the Sudanian-Sahelian Zone of Cameroon

Soil degradation represents a major environmental issue with significant implications for ecosystem sustainability and food security, particularly in the Sudano-Sahelian region (Moksia et al., 2019; Njoya et al., 2022). It is evident in this study, as well as in those by Victor et al. (2019) and Zeng et al. (2023), that the primary cause of soil degradation is deforestation. This deforestation would expose the soils to erosion, resulting in fertility loss, biodiversity destruction, and increased flood risks. Another significant cause of soil degradation is intensive agriculture. Cultivating the same piece of land over an extended period is considered a substantial contributor to soil degradation by farmers, leading to fertility loss and soil compaction, making them more susceptible to erosion. These findings align with the work of Taïda (2016) and Njoya et al. (2022). Additionally, the use of chemical fertilizers and pesticides serves as another source of soil degradation. Chemical fertilizers can acidify soils, pollute groundwater and aquifers, while pesticides can harm beneficial soil organisms such as earthworms, as demonstrated in the results of Sidsi et al. (2022). On the other hand, overgrazing and climate change are causes of soil degradation beyond the control of producers in our study area. Overgrazing involves maintaining an excessive number of livestock on the same piece of land, contributing to soil degradation by causing vegetation loss, which plays a protective role against erosion, and leading to soil compaction, as confirmed in the studies of Mbaiyetom et al. (2020) and Njoya et al. (2022). Climate change, characterized by an increase in the frequency and intensity of extreme weather events such as droughts, floods, and storms, could also exacerbate soil degradation. These meteorological events could erode the soil and result in fertility loss. Noumbissié (2019) and Ayanlade et al. (2022) argue that extreme weather events are primarily caused by climate change.

4.4. Consequences of Soil Degradation in the Sud Anian-Sahelian Zone of Cameroon

Soil degradation in the Sudano-Sahelian region of the Far North of Cameroon has significant socio-environmental repercussions (Hinimbio et al., 2018; Wangbé et al., 2022). Indeed, the loss of soil fertility can primarily be attributed to the reduction of organic matter, nutrients, and water in these soils. Organic matter plays a crucial role in soil development, preservation of soil properties, and its functions in agriculture, forestry, and the environment. When the organic matter content in the soil becomes insufficient, the soil becomes impoverished, resulting in, among other consequences, reduced fertility and increased vulnerability to erosion, a finding also corroborated by Somda et al. (2022). Similarly, the decrease in agricultural yields is a direct result of soil fertility loss (Schlecht et al., 2006). In the same vein, Kenfack Essougong et al. (2020) state that the reduction in vegetation cover and loss of biodiversity are attributable to excessive soil exploitation, the use of fertilizers and pesticides, deforestation, and other factors contributing to degradation and increased erosion. Furthermore, our sampled producers claim that deforestation, driven by human actions to expand agricultural lands and pastures, is responsible for the reduction in vegetation cover and soil biodiversity (Bado & Bationo, 2018; Azare et al., 2020). Moreover, water pollution could be attributed to the intensive use of chemical fertilizers and pesticides (Kate et al., 2016; Bado & Bationo, 2018; Onyekuru et al., 2023). These products contain elements that can persist in the soil or be carried by rainfall to groundwater or water bodies or transferred to plants, animals, and humans (Diop et al., 2022; Akanmu et al., 2023). Loss of income, food insecurity, conflicts related to land access, and rural migration are attributed to several factors, including recurrent drought, demographic pressure leading to increased competition for land and resources (Kodji et al., 2021; Caillault & Marie, 2023).

4.5. Sustainable Soil Management Practices in the Sudanian-Sahelian Zone of Cameroon

The sustainable management of agricultural land is of critical importance for ensuring food security and preserving the environment, especially in the Sudano-Sahelian region. This region faces various challenges such as soil degradation, climate change, and population pressure (Taïda, 2016; Njoya et al., 2022; Balgah et al., 2023). To address these issues, local farmers have developed and adopted four main agricultural practices focused on sustainable land management, aiming to optimize the use of natural resources. Among these practices, crop rotation is widely used, allowing for a planned alternation of different plant species on the same plot. The findings of Wangbé et al. (2022) confirm that this approach disrupts the cycle of pests, diversifies crops, reduces dependence on chemicals, and improves soil fertility through nutrient recycling. Another strategy adopted by producers is crop association, which appears to enhance soil health, increase yields, preserve biodiversity, and enhance resilience to changing conditions. Our results align with those of Roose et al. (2017) and Wangbé et al. (2022), who emphasize the numerous benefits of crop association, including higher productivity per unit area, reduced risks of crop loss, positive interactions between plants, and enrichment of biodiversity.

Furthermore, fallowing is a strategy commonly employed by a large number of farmers in the region. This practice is known for its advantages, as highlighted by the research of (Boukeng et al., 2023). According to their findings, fallowing restores soil fertility through the accumulation of organic matter and the regeneration of native flora. Additionally, it limits erosion, nutrient leaching, pest pressure, and promotes biodiversity. Farmers also use organic fertilization to improve soil structure, enrich nutrients, and stimulate microbial life, while reducing greenhouse gas emissions, as evidenced by the studies of Roose et al. (2017) and Wangbé et al. (2022).

Moreover, practices such as agroforestry, conservation agriculture, contour farming, cover cropping, and the introduction of beneficial plants are less commonly used among producers in our study area. However, research by scholars such as (Roose et al., 2017; Sissoko et al., 2020; Wangbé et al, 2022; Oku et al., 2021; Njoya et al, 2022) support the importance of these practices in soil management and highlight their numerous benefits for both producers and biodiversity.

5. Conclusion

The Far-North Region of Cameroon faces significant challenges related to soil degradation, resulting from factors such as climate variations, unsustainable agricultural practices, and deforestation. However, local farmers have developed valuable empirical knowledge to assess and manage soil health while adopting sustainable agricultural practices focused on crop diversification, soil regeneration, and biodiversity preservation. To effectively address these challenges, it is crucial to promote close collaboration between local and scientific knowledge to improve land management in the region. The adoption of sustainable land management practices, such as crop rotation, crop association, fallowing, organic fertilization, and agroforestry, offers promising solutions to enhance food security, preserve the environment, and adapt to climate change. However, for these practices to be fully effective, a multisectoral approach involving researchers, governments, farmers, and other stakeholders is necessary. By working together in a coordinated manner, it is possible to implement sustainable solutions that contribute to soil preservation, food security, and resilience in the face of environmental challenges in the Sudanian-Sahelian region of Cameroon.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Akanmu, A. O., Akol, A. M., Ndolo, D. O., Kutu, F. R., & Babalola, O. O. (2023). Agroecological Techniques: Adoption of Safe and Sustainable Agricultural Practices among the Smallholder Farmers in Africa. *Frontiers in Sustainable Food Systems, 7,* Article ID: 1143061. https://doi.org/10.3389/fsufs.2023.1143061

Asirvatham, R., Demi, S. M., & Ezezika, O. (2022). Are Sub-Saharan African National Food and Agriculture Policies Nutrition-Sensitive? A Case Study of Ethiopia, Ghana, Malawi, Nigeria, and South Africa. *Agriculture & Food Security, 11,* Article No. 60. https://doi.org/10.1186/s40066-022-00398-x

Ayanlade, A., Oluwaranti, A., Ayanlade, O. S., Borderon, M., Sterly, H., Sakdapolrak, P., & Ayinde, A. F. (2022). Extreme Climate Events in Sub-Saharan Africa: A Call for Improving Agricultural Technology Transfer to Enhance Adaptive Capacity. *Climate Services, 27,* Article ID: 100311. https://doi.org/10.1016/j.cliser.2022.100311

Azare, I. M., Abdullahi, M. S., Adebayo, A. A., Dantata, I. J., & Duala, T. (2020). Deforestation, Desert Encroachment, Climate Change and Agricultural Production in the Sudano-Sahelian Region of Nigeria. *Journal of Applied Sciences and Environmental Management, 24,* 127-132. https://doi.org/10.4314/jasem.v24i1.18

Bado, V. B., & Bationo, A. (2018). Integrated Management of Soil Fertility and Land Resources in Sub-Saharan Africa: Involving Local Communities. *Advances in Agronomy, 150,* 1-33. https://doi.org/10.1016/bs.agron.2018.02.001

Balgah, R. A., Ngwa, K. A., Buchenrieder, G. R., & Kimengsi, J. N. (2023). Impacts of Floods on Agriculture-Dependent Livelihoods in Sub-Saharan Africa: An Assessment from Multiple Geo-Ecological Zones. *Land, 12,* Article No. 334. https://doi.org/10.3390/land12020334

Bayiha, G. D. L. P., Makowski, D., Mathe, S., Kobou, G., & Temple, L. (2019). *Evaluation de la contribution de l'agriculture naturelle à la sécurité alimentaire au Cameroun par l'elicitation probabiliste du jugement d'experts.* https://hal.science/hal-02869385

Benoit, M., Dumont, B., Barbieri, P., & Nesme, T. (2020). Une agriculture durable pour nourrir la planète: L'élevage au cœur du débat. *Innovations Agronomiques, 80,* 23-32. https://www.researchgate.net/publication/339876190_Une_agriculture_durable_pour_nourrir_la_planete_l%27elevage_au_coeur_du_debat

Bikié, H., Ndoye, O., & Sunderlin, W. D. (2000). *L'impact de la crise économique sur les systèmes agricoles et le changement du couvert forestier dans la zone forestière humide du Cameroun (No. 27)*. Center for International Forestry Research.

Boukeng, E. J. D., Avana, M. L. T., Zapfack, L., Desrochers, A., Dzo, I. G. M., & Khasa, D. (2023). Stocks de carbone des systèmes agroforestiers de la zone soudano-sahélienne du Cameroun, Afrique centrale. *BASE*. https://doi.org/10.25518/1780-4507.20143

Caillault, S., & Marie, M. (2023). Is a Village Level Always Relevant to Describe Land Cover Changes? Analyzing the Landscape to Understand Socio-Environmental Changes in Western Burkina Faso. *Land Use Policy, 127,* Article ID: 106569. https://doi.org/10.1016/j.landusepol.2023.106569

Chimi, P. M., Mala, W. A., Fobane, J. L., Essouma, F. M., Mbom II, J. A., Funwi, F. P., & Bell, J. M. (2022). Climate Change Perception and Local Adaptation of Natural Resource Management in a Farming Community of Cameroon: A Case Study. *Environmental Challenges, 8,* Article ID: 100539. https://doi.org/10.1016/j.envc.2022.100539

Coulibaly, A., Motelica-Heino, M., & Hien, E. (2019). Determinants of Agroecological Practices Adoption in the Sudano-Sahelian Zone. *Journal of Environmental Protection, 10,* 900-918. https://doi.org/10.4236/jep.2019.107053

Delaunay, D., & Guengant, J. P. (2019). *Le dividende démographique en Afrique subsaharienne*. No. hal-02084425. https://hal.science/hal-02084425

Diop, M., Chirinda, N., Beniaich, A., El Gharous, M., & El Mejahed, K. (2022). Soil and Water Conservation in Africa: State of Play and Potential Role in Tackling Soil Degradation and Building Soil Health in Agricultural Lands. *Sustainability, 14,* Article No. 13425. https://doi.org/10.3390/su142013425

FAO, IFAD, UNICEF, WFP and WHO (2020). *The State of Food Security and Nutrition in the World 2020. Transforming Food Systems for Affordable Healthy Diets*. FAO. https://doi.org/10.1111/padr.12418

Folega, F., Datche-Danha, K. E., Folega, A. A., Woegan, A. Y., Wala, K., & Akpagana, K. (2022). Diversité des services écosystémiques et utilisation des terres dans le paysage du socle Eburnéen au Togo. *Revue Nature et Technologie, 14,* 61-75. https://journals.univ-chlef.dz/index.php/natec/article/view/43

Hinimbio, T. P., Madi, A., & Awono, J. P. M. (2018). Réponse du maïs aux effets de réhabilitation de la fertilité des sols liés à la légumineuse *Crotalaria juncea* L. au Nord-Cameroun. *Afrique Science, 14,* 423-438.

Jiagho, E. R., & Banoho, L. (2021). Facteurs de déforestation et de la dégradation du couvert ligneux dans le Parc National de Waza et sa périphérie, Cameroun. *Afrique SCIENCE, 18,* 14-37. http://www.afriquescience.net

Kaffo, C. (2005). Cultures maraîchères dans les montagnes du Cameroun occidental. *Cahiers Agricultures, 14,* 517-524. https://revues.cirad.fr/index.php/cahiers-agricultures/article/view/30546

Kate, R. J. (2016). Using Dynamic Time Warping Distances as Features for Improved Time Series Classification. *Data Mining and Knowledge Discovery, 30,* 283-312. https://doi.org/10.1007/s10618-015-0418-x

Kenfack Essougong, U. P., Slingerland, M., Mathé, S., Vanhove, W., Tata Ngome, P. I., Boudes, P., & Leeuwis, C. (2020). Farmers' Perceptions as a Driver of Agricultural Practices: Understanding Soil Fertility Management Practices in Cocoa Agroforestry Systems in Cameroon. *Human Ecology, 48,* 709-720. https://doi.org/10.1007/s10745-020-00190-0

Kodji, P., Bsala, T., & Adamou, I. (2021). Use of Plant Resources by Refugees from Minawao and Their Impact on the b3Sahelian Savannah of Cameroon. *Environnement Challlange, 5,* Article ID: 100270. https://doi.org/10.1016/j.envc.2021.100270

Koguia, W. N., Nonga, F. N., Madi, A., Leblois, A., & Laure, M. T. G. (2021). Perception of Climatic Change and Farmers' Decision to Adapt in the Sudano-Sahelian Zone in Cameroon. *Journal of Humanities and Social Sciences Studies, 3,* 22-33.

Kome, G. K., Enang, R. K., & Yerima, B. P. K. (2018). Knowledge and Management of Soil Fertility by Farmers in Western Cameroon. *Geoderma Regional, 13,* 43-51. https://doi.org/10.1016/j.geodrs.2018.02.001

L'hote, Y. (2000). *Climatologie* (12 p.). Atlas de la province Extrême-Nord Cameroun, IRD, Minrest, Inc. https://doi.org/10.4000/books.irdeditions.11540

Loyem, N. L., Lengha, N. T., & Mubeteneh, C. T. (2020). Agriculture biologique: Nécessité d'appropriation par les producteurs et attitudes des consommateurs au Moungo-Cameroun. *Journal of the Cameroon Academy of Sciences, 16,* 31-41. https://doi.org/10.4314/jcas.v16i1.3

M'Biandoun, M., & Bassala, J. P. O. (2007). Savoir paysan et fertilité des terres au Nord-Cameroun. *Cahiers Agricultures, 16,* 185-197. https://doi.org/10.1684/agr.2007.0100

M'biandoun, M., & Olina, J. P. (2006). Pluviosité en région soudano-sahélienne au Nord du Cameroun: Conséquences sur l'agriculture. *Agronomie Africaine, 18,* 95-104. https://doi.org/10.4314/aga.v18i2.1683

Manssour, A. M. et al. (2021). Farmer's Perception and Bio-Indicators of Soil Fertility in Eastern Niger. *Scholars Academic Journal of Biosciences, 11,* 373-378. https://doi.org/10.36347/sajb.2021.v09i11.007

Mariel, J., Freycon, V., Randriamalala, J., Rafidison, V., & Labeyrie, V. (2022). Local Knowledge of the Interactions between Agrobiodiversity and Soil: A Fertile Substrate for Adapting to Changes in the Soil in Madagascar? *Journal of Ethnobiology, 42,* 180-197. https://doi.org/10.2993/0278-0771-42.2.180

Mbaiyetom, H., Tientcheu, M. L. A., Ngankam, M. T., Taffo, J. B. W., & Tanougong, A. D. (2020). Dynamique spatio-temporelle de l'occupation du sol et du couvert végétal des parcs arborés du Département de la Nya, Sud du Tchad. *International Journal of Innovation and Applied Studies, 31,* 370-379. http://www.ijias.issr-journals.org/

Mbogori, T., Kimmel, K., Zhang, M., Kandiah, J., & Wang, Y. (2020). Nutrition Transition and Double Burden of Malnutrition in Africa: A Case Study of Four Selected Countries with Different Social Economic Development. *AIMS Public Health, 7,* 425-439. https://doi.org/10.3934%2Fpublichealth.2020035

Moksia, F., Azaria, D., Konsala, S., Yougouda, H., & Gilbert, T. T. (2019). Structure, Dynamics and Impact of the Exploitation of the Woody Plants of Woodlands in the Sudano-Sahelian Zones, North Cameroon. *International Journal of Advanced Research in Biological Sciences, 6,* 201-220.

Montoroi, J. P., Nizinski, J. J., Lointier, M., & Silvera, N. (2012). *French-Egyptian Project "Sustainable Management of Adverse Impacts on Farming and Soil Ecosystem Associated with Long Term Use of Low Quality Irrigation Water"* (pp. 1-38). AIRD-STDF. https://core.ac.uk/download/pdf/39832994.pdf

Ndjidda, N., Amoa, N. B. A., & Nourou, M. (2022). *Agricultural Growth in Cameroon: What Effects of Official Development Assistance Financing*? No. hal-03858915. https://dx.doi.org/10.5281/zenodo.7324075

Njouenwet, I., Vondou, D. A., Fita Dassou, E., Ayugi, B. O., & Nouayou, R. (2021). Assessment of Agricultural Drought during Crop-Growing Season in the Sudano-Sahelian Region of Cameroon. *Natural Hazards, 106,* 561-577. https://doi.org/10.1007/s11069-020-04475-x

Njoya, H. M., Matavel, C. E., Msangi, H. A., Wouapi, H. A. N., Löhr, K., & Sieber, S. (2022). Climate Change Vulnerability and Smallholder Farmers' Adaptive Responses in the Semi-Arid Far-North Region of Cameroon. *Discover Sustainability, 3,* Article No. 41. https://doi.org/10.1007/s43621-022-00106-6

Noumbissié, C. D. (2019). *Changement climatique: Vulnérabilité, dynamisme et représentation sociale des populations des regionns du Nord et de l'Extrême-Nord du Cameroun.* (pp. 1-188). Editions L'Harmattan.

Nyamnding, E., & Mireille, E. (2011). *Politiques agricoles et crise de l'économie camerounaise (1960-1998).* Doctoral Dissertation, Bordeaux 3.

Oku, E., dos Passos, A. M. A., Quintino, S. S., Odoh, N. C., & Olowookere, T. B. (2021). Soil Fertility Status of Soils of Sudano-Sahelian and Humid Forest Zones of West Africa and Some Soil Management Strategies for Smallholder Farms. *EQA—International Journal of Environmental Quality, 46,* 25-36.

Onyekuru, N. A., Marchant, R., Touza, J. M., Ume, C., Chiemela, C., Onyia, C., & Eze, C. C. (2023). A-Z of Cost-Effective Adaptation Strategies to the Impact of Climate Change among Crop Farmers in West Africa. *Environment, Development and Sustainability.* https://doi.org/10.1007/s10668-023-03474-9

Roose, E., Zougmoré, R. B., Stroosnijder, L., Dugué, P., & Bouzou Moussa, I. (2017). *Techniques traditionnelles de restauration de la productivité des sols dégradés en régions semi-aride d'Afrique occidentale.* https://doi.org/10.4000/books.irdeditions.24435

Sawadogo, J., Coulibaly, P. J. D. A., Bambara, F. J., Savadogo, A. C., Compaore, E., & Legma, J. B. (2020). Effets des fertilisants biologiques sur les paramètres physico-chimiques du sol et sur la productivité de l'oignon (*Allium cepa* L.) dans la région du Centre Ouest du Burkina Faso. *Afrique Science, 17,* 44-57.

Schlecht, E., Buerkert, A., Tielkes, E., & Bationo, A. (2006). A Critical Analysis of Challenges and Opportunities for Soil Fertility Restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems, 76,* 109-136. https://doi.org/10.1007/s10705-005-1670-z

Seibou, A., Gilbert, H., & Clement, S. (2021). Plant Structural Population and Dynamics of Degraded Ecosystems in Southern Benoue of North Cameroon. *International Journal of Ecosystems & Ecology Sciences, 11,* 777-790. https://doi.org/10.31407/ijees11.415

Sidsi, B., Vounba, C., Nyeck, B., Mvondo, V. Y. E., Kolaona, B. L., & Azi, H. A. (2022). Produits biologiques au Cameroun: Une solution aux préoccupations environnementales et écologiques. *Afrique SCIENCE, 20,* 28-41.

Sissoko, F., Traore, A., Diarra, S., & Traore, M. (2020). Effet de l'insertion des plantes de couverture sur la productivité du système de culture à base de maïs dans le cadre de l'intégration agriculture-élevage. *International Journal of Biological and Chemical Sciences, 14,* 2599-2610. https://doi.org/10.4314/ijbcs.v14i7.18

Somda, B. B., Ouattara, B., Zomboudre, G., Traore, M., Vanek, S., Kabore, R., & Sedogo, P. M. (2022). Effets de pratiques agroécologiques sur la macrofaune dans les lixisols ferriques en zone Soudano-Sahélienne du Burkina Faso. *International Journal of Innovation and Applied Studies, 36,* 734-744. https://www.researchgate.net/publication/361844919

Suchel, J. B. (1987). *Les climats du Cameroun.* Doctoral Dissertation, Bordeaux 3.

Taïda, P. H. (2016). *Agroécologie et gestion durable des sols en Afrique soudano-sahélienne* (pp. 1-215).

Tchindjang, M., Njombissie, P. I., Kamga, A., Nyemeck, M. M. L., & Chiewouo, K. I. F. (2015). La contribution de l'évaluation du Paysage à la sécurité alimentaire en zone sahélienne: Le cas de Bogo dans l'Extrême Nord du Cameroun. *Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo, 5,* 35-53. https://www.researchgate.net/publication/283572102

Tendonkeng, F., Arnaud, H. T. B., Noumbissi, M. N. B., Miegoue, E., Sawa, C., Essie, F. M. N., & Vargas-Bello-Pérez, E. (2021). Perceptions and Adaptation Strategies for Climate Change from Small Ruminant Farmers in North-West Cameroon. *Tropical and Subtropical Agroecosystems*, *25,* Article No. 10. http://dx.doi.org/10.56369/tsaes.3475

Victor, A. D., Valery, N. N., & Louis, Z. (2019). Vegetation Structure, Root Biomass Distribution and Soil Carbon Stock of Savannah Agrosystems in Sudano-Sahelian Zone of Cameroon. *Journal of Botany Research, 2,* 71-80. https://doi.org/10.36959/771/563

Wangbé, P. D., Azinaha, D., Djiangoué, B., & Auguste Ombolo, A. (2022). Perceptions des agriculteurs de la dégradation des sols et stratégies d'adaptation dans le Bassin versant du lac de Lagdo (Nord-Cameroun). *Revue Africaine d'Environnement et d'Agriculture, 5,* 11-20. http://www.rafea-congo.com/

Zakari, S., Ibro, G., Moussa, B., & Abdoulaye, T. (2022). Adaptation Strategies to Climate Change and Impacts on Household Income and Food Security: Evidence from Sahelian Region of Niger. *Sustainability, 14,* Article No. 2847. https://doi.org/10.3390/su14052847

Zeng, Y., Jia, L., Menenti, M., Jiang, M., Barnieh, B. A., Bennour, A., & Lv, Y. (2023). Changes in Vegetation Greenness Related to Climatic and Non-Climatic Factors in the Sudano-Sahelian Region. *Regional Environmental Change, 23,* Article No. 92. https://doi.org/10.1007/s10113-023-02084-5

Zhou, K., Zhang, Y., Wu, J., Dou, C., Ye, Z., Ye, Z., & Fu, W. (2021). Integrated Fertilization Regimes Boost Heavy Metals Accumulation and Biomass of Hance. *Phyton, 90,* 1217-1232. http://dx.doi.org/10.32604/phyton.2021.014951