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Effects of Soil Fertility Restoration Practices on Maize Growth and Yield Parameters in the Municipalities of Kouande, Kerou and Pehunco in Northwestern Benin

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Abstract

In the municipalities of Kouandé, Kérou, and Péhunco, ongoing soil degradation has become a major concern for thousands of farmers who depend heavily on the land for their livelihoods. The main objective of this research is to analyze the effects of soil fertility restoration practices on maize growth and yield parameters in these municipalities. The methodological approach employed consists of a literature review, direct observations, and surveys conducted with 364 individuals using a questionnaire. Methods for measuring maize grain yield parameters and estimating maize performance parameters were used. The processing of soil data and their analysis was carried out at the Laboratory of Soil, Water and Environment Sciences (LSSEE) of INRAB. The results obtained show that the two agricultural seasons (2017-2018 and 2018-2019) yielded the best performance in terms of plant height, stem circumference, and maize leaf width. No significant difference ($P > 0.05$) was found between the two seasons regarding maize leaf length. Yields varied, reflecting variations in soil restoration practices during the 2017-2019 agricultural seasons 2018 and 2018-2019. Rotational grazing of cattle (890.28 kg/0.25ha), mineral fertilizers (815.1 kg/0.25ha), and compost (742.45 kg/0.25ha), gave the best yield during these two campaigns in the municipalities of Kouandé, Kérou and Péhunco.

Keywords

Municipalities of Kouandé, Kérou and Péhunco, Restoration, Fertilization, Growth and Yield of Maize

1. Introduction

Ongoing soil degradation, particularly in sub-Saharan Africa, has become a major concern for millions of farmers who depend heavily on the land for their livelihoods [1]. This phenomenon affects 20 to 60% of the land in Africa, resulting in an annual loss of 6 million hectares of productive land, or an estimated US$42 billion in lost revenue due to land degradation [2]. This results in negative impacts on food security and the fight against poverty.

In Benin, agriculture is a major driver of economic development. It contributes approximately 23% to the Gross Domestic Product [3]. It provides approximately 75% of export earnings and 15% of state revenue [4]. However, these lands are subject to severe degradation due to poor farming practices. Agriculture, the foundation of the country's economy, employs 70% of the working population [5]. In Benin, faced with this situation of soil degradation, producers are developing strategies for soil and water conservation and for restoring soil fertility. Most of these practices are primarily aimed at improving crop yields. These local strategies allow producers, to some extent, to meet their basic needs for subsistence and livelihood [6].

The Atacora Department, in northwestern Benin, is subject to these constraints. The department is often cited as being characterized by widespread poverty where land issues are particularly acute [7]. The population largely practices extensive farming on depleted soils. It is therefore essential and imperative to rethink land restoration in the Atakora region in order to increase agricultural production [8]. This type of soil exploitation cannot guarantee sustainable land use. Therefore, maintaining soil fertility remains a major concern for farmers [9]. Indeed, the municipalities of Kouandé, Kérou and Péhunco are essentially agricultural and employ more than 80% of the active population and cover an area of 10,259 km^2 [10]. Agriculture in the research area is carried out using rudimentary methods and techniques (use of fire, tree felling) that accelerate soil degradation. Furthermore, rapid population growth, from 197,975 in 2002 to 289,954 inhabitants in 2013, representing a gross increase of 46.46% in eleven years with an annual growth rate of 3.04% between 2002 and 2013, puts pressure on natural resources, whose uncontrolled exploitation continues to exacerbate soil degradation problems. In the research area, farmers use practices to restore degraded soils. Thus, the aim of this research is to analyze the performance of soil fertility restoration practices on maize growth and yield parameters in the Municipalities of Kouandé, Kérou and Péhunco.

2. Materials and Methods

2.1. Study Area

Located in northwestern Benin, the municipalities ofKouandé, Kérou and PéhuncoThey extend between 10˚2'30" and 11˚24'10" North latitude and between 1˚22'5" and 2˚23'20" East longitude. They cover an area of 10,259 km^2, of which 20% is forest and 64% is arable land, and are home to 289,954 inhabitants [11].

Figure 1 shows the sgeographical and administrative situation of the municipalities of Kouandé, Kérou and Péhunco.

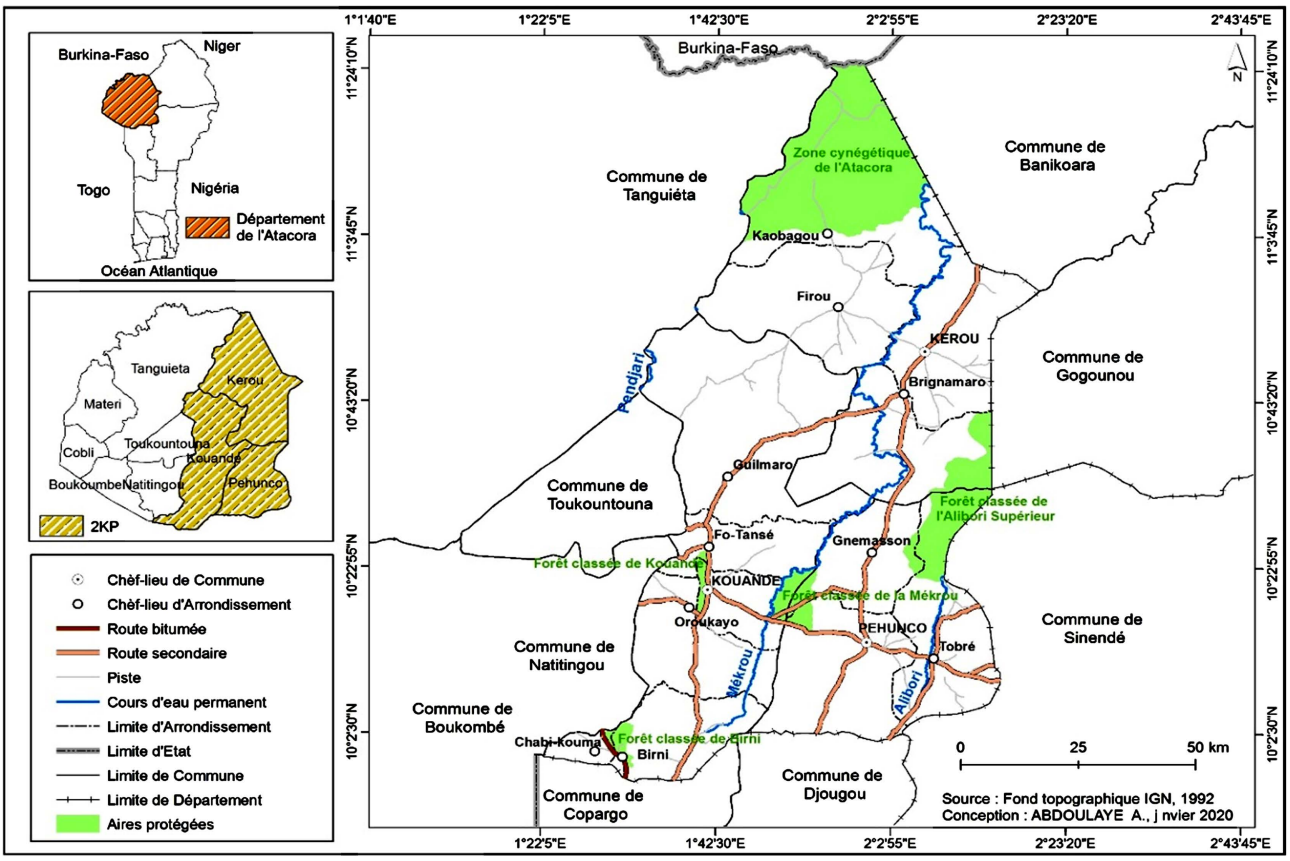


Figure 1. Geographical and administrative situation of the municipalities of Kouandé, Kérou and Péhunco.

The dominant climate type is determined by geographical factors. It is classified as a Sudanese (tropical) climate, with two main seasons: a rainy season and a dry season that structure life and human activities. The rainy season, from May to October, is characterized by predominant monsoon flows from the west to southwest, but squall lines also bring heavy downpours to the region. The wet season extends from mid-June to mid-October. The very wet season lasts from mid-July to the end of September, and the dry season begins in October and ends in June. In an average rainfall year, eleven ten-day periods are favorable for crop development, with ten being very wet. The climatic regime of the study area is unimodal, typically beginning in May-June and ending in October-November.

The area's hydrographic network is organized around two main rivers: the Pendjari (135 km) and the Mékrou (410 km), along with their tributaries, which water most of the department's municipalities. The Pendjari originates in Perpoyakou (Natitingou commune), flows north, crosses the Atacora mountain range, and then turns southwest into Pendjari National Park [12]. The Mékrou River drains the municipalities of Kouandé, Péhunco, and Kérou. In the study area, the soil is a loose structure of varying thickness, resulting from the transformation of the

parent rock under the influence of various physical, chemical, and biological factors. Several soil types have been identified, including poorly developed soils, raw mineral soils, hydromorphic soils, ferruginous soils, and ferralitic soils, and they follow a varied topography.

2.2. Data and Methods

Two types of data were used: qualitative and quantitative data. The qualitative data concerns the endogenous knowledge of farming households on restoration practicesSoil fertility and historical, social, and cultural data and information provided by elders and resource persons are used to understand the determinants of soil degradation. Quantitative data concerns the population figures in the municipalities of Kouandé, Péhunco, and Kérou, based on the 1979, 1992, 2002, and 2013 General Population and Housing Censuses (RGPH) provided by INSAE, and the number of socio-cultural groups, in order to analyze local perceptions of soil degradation factors in the research area.

2.3. Selection of Districts and Respondents

The farmers were not selected in advance. Their selection was made in the field through observation, a step-by-step approach, and with the assistance of crop production technical advisors who work with the farmers. A sample was defined for each municipality using the following method [13] Its formula is:

$$N = \frac{(Z\alpha)^2 PQ}{i^2}$$

with: N = Sample size per municipality; $Z\alpha$ = deviation fixed at 1.96, which corresponds to a 95% confidence level; P =the number of households in the surveyed villages/the total number of agricultural households in the municipality, $Q = 1 - P$; i = margin of error which is equal to 5%.

According to the present formula, the sample size N = (1.96)2 × (13915/24913) × (1 − 0.56)/(0.05)2 therefore N = 364.3404, *i.e.* 364 agricultural households distributed in Table 1.

Thus, the total number of people surveyed per village is obtained by applying a coefficient k = p/P; where p = sample size obtained using the Schwartz method and P = total number of households in the villages surveyed according to the RGPH4 of the INSAE. Indeed, k = p/P implies k = 364/13,915, therefore k = 0.03, or k = 3% assigned to each household size per surveyed locality. The size of the surveyed sample is presented in Table 1.

The choice of villages visited is essentially based on agricultural potential, the size of the agricultural population and the geographical location of each village.

2.4. Methods for Surveying and Evaluating Maize Yields

The performance evaluation of soil fertility restoration practices was conducted over two agricultural seasons (2017-2018 and 2018-2019) with thirteen (13) farm-

ers participating in trials. These farmers were selected from the list of sampled individuals. This selection was based on their soil fertility restoration practices and socio-cultural groups. Agronomic monitoring was carried out on 26 yield plots, with two replicates per practice in the farmers' fields. During the two agricultural seasons, maize was monitored using twelve (12) soil fertility restoration practices: crop residues, fallow, crop rotation, intercropping, soybeans, pigeon peas, rotational cattle grazing, stone bunds, mineral fertilizers, mucuna, compost, and stylosanthes, as well as a control plot. These practices were identified as priority practices used in the research community. The yield plots (spots) each measured 25 m^2 (5 m × 5 m). Various measurements and observations were taken within these yield plots.

Table 1. Distribution of the sample by selected localities.

Municipalities	Boroughs	Village	Total number of agricultural households	Number of Households surveyed	Percentage (%)
Kerou	Kerou	Boukou Bourou	702	**18**	4.95
		Pikiré	661	**17**	4.67
	Brignamarou	Brignamarou	1400	**37**	10.16
		Kossou	608	**16**	4.39
	Firou	Kabongourou	429	**11**	3.03
		Djolini	294	**08**	2.19
	Kaobagou	Kaobagou	229	**06**	1.65
		Yinsiga	264	**10**	2.75
Kouandé	Fô-tancé	Fô-tancé	328	**07**	1.92
		Tikou	280	**07**	1.92
	Guilmaro	Sinakpagourou	1438	**38**	10.44
		Damouti	241	**06**	1.65
	Kouandé	Mary	230	**06**	1.65
		Sékégourou	460	**12**	3.29
	Birni	Gorgoba	280	**07**	1.92
		Tassigorou	422	**11**	3.03
	Chabi couma	Chabi couma	423	**11**	3.03
		Papatia	273	**07**	1.92
	Orou-kayo	Orou-kayo	367	**10**	2.75
		Niékéné Banssou	1579	**42**	11.54

Continued

Péhunco	Gnemasson	Doh	349	**09**	2.47
		Gnemasson	521	**14**	3.84
	Tobré	Ouassa Kika	315	**08**	2.19
		Guimbérérou	678	**18**	4.95
	Péhunco	Bouerou	688	**18**	4.95
		Soaodou	356	**10**	2.75
Total	**13**	**26**	**13815**	**364**	**100**

Source: Field survey, 2022.

2.4.1. Intra-Plot Sampling and Monitoring of Maize Morpho-Physiological Parameters

To evaluate growth parameters and yield components, random intra-plot sampling was performed across the usable area of each experimental unit, systematically excluding the two border rows and two hills at each end of the row to eliminate border effects. Morphometric growth measurements (plant height, crown circumference, and length and width of the leaf beneath the ear) were taken at the flowering-fruiting stage (50% female flowering/silk emergence) on a representative sample of 10 randomly marked plants per plot. Leaf color was assessed at the same phenological stage using the Munsell Plant Tissue Color Charts under uniform natural lighting. At harvest, all ears from the 10 sampled plants per plot were collected and evaluated to determine the number of full ears, ear weight, and dimensions (length and width).

2.4.2. Method for Measuring Maize Growth Parameters

The growth parameters measured in the field during this research were: stem circumference, plant height, leaf width, leaf length, and leaf color. Photos 1(a)-(c) show the stem circumference, leaf length, and leaf width measurements of maize in Pikiré, respectively.



(a) (b) (c)

Filming location: Z. Bakiri, July 2026.

Photo 1. Measurement of maize growth parameters in the Municipalities of Kouandé, Kérou and Péhunco. (a) Measurement of the circumference at the collar of Pikiré corn; (b) Measuring the length of the Pikiré leaf; (c) Measuring the width of Pikiré corn leaves.

Using a 10-meter measuring tape, the height of the plants, the width of the leaves (Photo 1(c)), and the length of the leaves (Photo 1(b)) of the corn are measured. Additionally, the circumference at the base of the plants (Photo 1(a)) is measured using a tape measure wrapped around the base of the plants. The analysis of these photos shows that these measurements have made it possible to understand the effect of soil restoration practices on corn yield.

2.4.3. Method for Measuring Corn Grain Yield Parameters

The parameters measured during this study are: the number of ears harvested, the number of full ears, the weight of the ears, the width of the ears, the length of the ears and the grain yield.

✓ To determine the number of ears of corn harvested, the ears were counted;
✓ for the number of full ears, the weight of the ears, the width of the ears and the length of the ears, this sampling was done directly on the peasant plots of 25 m^2;
✓ the weight of the ears of corn and straw is taken per elementary plot;
✓ the weight of the ears was measured after drying the ear samples for 72 hours;
✓ grain yield.

After measuring the weight of the corn kernels, 1000 kernels were counted and weighed during data processing using the 40 kg capacity electronic balance.

2.4.4. Estimation of Corn Performance Parameters

o **Corn grain yield**

After drying the ears in an oven at 60˚C for 72 hours, they are shelled per experimental unit and the weight of the grains is recorded. Grain yields were estimated using the method developed by [14] and which can be summarized as follows:

$$Rg = \frac{1000 \times P \times MS \times n}{SI}$$

with *Rg*: Grain yield (kg DM/ha);

P: Total weight of ears weighed in the field (kg);

MS: Dry matter content of the ears (DM) = $\frac{\text{Poids Sec}}{\text{Poids frais}} \times 100$;

SI: Interpretable Surface (m^2);

n: Ratio of dry grain weight of the sample after threshing to total weight of dry ears of the sample.

2.4.5. Concise Protocol for Each Restoration Practice

Table 2 presents the concise protocol for each restoration practice, including corn variety, seeding density, input rates, crop residue management, previous crop, intercrop composition, and duration and intensity of livestock enclosure.

In terms of technical procedures, maize planting relies on the standard system promoted by the National Institute of Agricultural Research of Benin (INRAB) for sub-Saharan areas, characterized by a spacing of 80 cm x 40 cm with two seeds per hill, resulting in an optimal density of 62,500 plants/ha (31,250 hills/ha) in

monoculture. However, when intercropping, this density is adjusted to approximately 50,000 plants/ha to minimize interspecific competition for photosynthetically active radiation and soil nutrients. Furthermore, the implementation of rotational grazing for cattle relies on the use of modular, mobile enclosures with dynamic staking. A stabling period of two to three nights per location is chosen to prevent the risk of physical compaction and over-trampling of clay-sand soils, while ensuring a homogeneous return of organic matter from solid and liquid excrement (manure and urine).

Table 2. Protocol for each soil restoration practice in the research area.

Restoration practice	Recommended corn variety	Maize sowing density (spacing and planting holes)	Input rates (Fertilizers/Compost/Soil amendments)	Crop residue management	Previous culture recommended	Intercropping/Associated Culture Composition	Duration and intensity of the enclosure (Livestock penning)
Association of cultures	Short/medium cycle varieties (Faaba, EVDT 97 STR)	80 cm × 40 cm (2 plants/hole, *i.e.* 62,500 plants/ha)	NPK 15-15-15: 100 kg/ha + Urea 46%: 50 kg/ha	Maintaining partial mulching or light incorporation	Cotton or Legume	Maize + Cowpea (*Vigna unguiculata*) or Crotalaria (1 row of legume for 1 to 2 rows of maize)	Not Applicable (Out-of-Parking Management)
Compost	High-performing varieties (TZEE-Y, Faaba)	80 cm × 40 cm or 75 cm × 50 cm (53,000 to 62,500 plants/ha)	Mature compost: 5 to 10 t/ha at plowing/hill + 50% of the recommended dose of mineral fertilizer	Incorporation of compost during soil preparation; return of corn residues	Cotton, Soybeans or Cowpeas	Pure (or lightly mixed with other ingredients)	Not Applicable (Contribution in the form of a stored amendment)
Stone ridges	Any suitable type (TZEE-W, EVDT)	80 cm × 40 cm (contour lines)	NPK: 150 kg/ha + Urea: 100 kg/ha (Adjustable according to accumulated fertility)	Trapping of residues upstream of the dikes/cords (natural mulching)	Any cultural precedent	Pure maize with strips of Vetiveria or Pennisetum along the strands	Not Applicable (Physical Layout)
Mineral fertilizers	Hybrids/Improved (EVDT 97 STR, Faaba)	80 cm × 40 cm (62,500 plants/ha)	NPK (15-15-15): 150 kg/ha at thinning (Day 14-Day 21) + Urea (46%): 100 kg/ha in 2 fractions (Day 21 and stem elongation)	Partial export or post-harvest burial	Cotton or Legume	Pure (recommended to maximize fertilizer efficiency)	Not Applicable
Fallow (Regenerating/Natural)	High hardiness varieties (TZEE-Y)	80 cm × 50 cm (50,000 plants/ha) upon re-cultivation	Reduced starting dose: NPK 100 kg/ha + Urea 50 kg/ha	Mowing and complete incorporation of fallow biomass upon return to cultivation	Natural or assisted fallow (2 to 5 years)	None during the fallow period; pure maize upon reopening the field	Not Applicable (Parking available during the off-season)
Mucuna (Green fertilizer)	Short-cycle varieties (TZEE-W)	80 cm × 40 cm (during the following maize crop)	No nitrogen fertilizer required in the first year after Mucuna; Phosphate application alone recommended (e.g., TSP or natural phosphate: 50 kg/ha)	Thick mulch left on the surface (dried Mucuna mulch) without burning; direct sowing of corn through the mulch	*Mucuna pruriens* in its pure form or as an off-season relay	As a follow-on crop: Mucuna sown 45 days after maize (or in pure rotation)	Not Applicable

Continued

Rotational cattle penning	High-yielding, high-demand varieties (EVDT, Faaba)	80 cm × 40 cm (62,500 plants/ha)	50% to 70% reduction in mineral fertilizer (Supplementary application of Urea: 25 - 50 kg/ha at stem elongation)	Partial consumption on site by livestock, burial of the trampled remains mixed with excrement	Cotton, Sorghum or Maize	Pure	**Duration:** 2 to 3 nights per stake/site. **Intensity:** 50 to 100 head of cattle/ha (*i.e.* about 10 to 15 animals for a modular enclosure of 100 m^2).
Pigeon peas (*Cajanus cajan*)	Tolerant varieties (TZEE-Y, Faaba)	80 cm × 40 cm for corn	NPK: 100 kg/ha (Cajanus provides the retained nitrogen)	Cutting back the Cajanus stems; returning the leaves as organic mulch	Cotton or Cereal	Maize + *Cajanus cajan* (Alternating sowing: 1 row of Cajanus every 2 to 4 rows of maize)	Not Applicable
Crop residues (Mulching/Replenishment)	Local/improved varieties	80 cm × 40 cm	NPK: 100 - 150 kg/ha + Urea: 75 - 100 kg/ha	Strict ban on burning; mowing and spreading of stems/straw as ground cover (2 to 4 t/ha of dry matter)	Cotton, Corn or Cereals	Pure maize or maize combined with a legume	Not Applicable
Crop rotation	Varieties according to the crop rotation	80 cm × 40 cm (62,500 plants/ha)	Standard recommendation: NPK 150 kg/ha + Urea 100 kg/ha (Adjusted downwards after legume)	Differentiated management according to the crops in the rotation (burying legume haulms)	Cotton (2017) Legume/Soybean (2018) Corn (2019)	Pure during the Maize phase	Not Applicable
Soy (Crop rotation/Association)	High-potential varieties (EVDT 97 STR)	80 cm × 40 cm (62,500 plants/ha)	NPK: 100 kg/ha + Urea: 50 kg/ha (Residual effect of nitrogen fixation by soybeans)	Complete burying and burial of soybean haulms after pod harvest	Pure cultured soybean (Glycine max)	Corn after soybean rotation (or alternating strip cropping of 2 rows of corn/4 rows of soybeans)	Not Applicable
Stylosanthes (Foam & Blanket)	Varieties adapted to BCTR/Atacora	80 cm × 40 cm (at re-pouring)	Natural phosphate/Simple superphosphate (TSP): 50 - 100 kg/ha at Stylosanthes sowing	Maintaining ground cover; selective mowing for forage and mulch return to the soil	*Stylosanthes hamata* or *S. guianensis* (1 - 2 years old forage fallow)	Pure culture of Stylosanthes followed by maize in direct seeding or with minimal soil tillage	Controlled grazing during the off-season is possible before planting corn

Source: Fieldwork and data processing, 2018 and 2019.

2.4.6. Evaluation and Standardization of Grain Yields

To ensure consistency and comparability of yield performance across the manuscript, all grain yield data were standardized and expressed in kilograms per hectare (kg/ha). The initial raw values measured correspond to the net weight of grain harvested from the usable area of the elementary 0.25 ha plot. These plot weights were then converted into yield per hectare after careful drying and adjustment of the grain moisture content to the standard marketing threshold of 14%.

2.5. Processing of Socioeconomic Data

The questionnaires and field data sheets were manually and statistically analyzed. The data were presented in the form of graphs (diagrams). These graphs primarily

concern the evolution of maize yields produced from 1995 to 2018, in order to better assess the effect of agricultural practices aimed at restoring soil fertility on yield.

2.6. Processing and Analysis of Soil Data

The processing and analysis of the soil data were carried out at the Laboratory of Soil, Water and Environment Sciences (LSSEE) of the National Institute of Agricultural Research of Benin (INRAB).

2.7. Statistical Analysis Methods: Two-Way ANOVA (Fisher's Test) Performed on the Growth Parameters of Maize Plants

The rigorous analysis of the collected data required the use of advanced statistical modeling tools adapted to multi-year agronomic experiments. Thus, the effect of different soil fertility restoration practices and agricultural seasons on the morphological and growth parameters of maize plants was evaluated using a two-way analysis of variance (ANOVA) with Fisher's F-test. The chosen statistical model incorporated the twelve restoration practices implemented in the field as the first principal factor. The second principal factor considered was the two successive agricultural seasons, namely 2017-2018 and 2018-2019. The interaction between these two sources of variation (Practices x Seasons) was also modeled to analyze the temporal stability of agronomic performance. This approach made it possible to decipher the impact of these interventions on key morphometric variables such as stem circumference, plant height, and leaf length, width, and color. Prior to the analysis of variance, the normality of the residual distributions and the homogeneity of the variances (homoscedasticity) were systematically verified. When the ANOVA revealed significant sources of variation between treatments, a more detailed analysis of the groupings was essential. To this end, the comparison and hierarchical ranking of means were performed using the Student-Newman-Keuls (SNK) test at a significance level of 5% ($P < 0.05$). All numerical processing, variance matrices, and statistical tests were executed using appropriate statistical software.

To account for the structural effect of farms and experimental sites (on-farm trials), the analysis of variance (ANOVA) was formalized using a generalized linear model (GLM) or a linear mixed model. The statistical model is expressed as follows:

$$Y_{ijkl} = \mu + \text{Practice}_i + \text{Season}_j + \left(\text{Practice} \times \text{Season}\right)_{ij} + \text{Site}_k + \varepsilon_{ijkl}$$

The degrees of freedom (df) for the statistical model were partitioned as follows: df = 11 for the restoration practices factor (i = 12 levels), df = 1 for the agricultural campaigns or seasons factor (j = 2 years), and df = 11 for their interaction (Practice X Season). The farm or site factor (k sites/blocks, corresponding to s sites) accounted for df = s − 1 when incorporated as a random block or farm effect, while the residual error and total degrees of freedom were determined by the total number of observed experimental plots.

2.8. Sampling Protocol and Laboratory Analyses

To document the impact of restoration practices on soil chemical fertility and nutrients, a soil sampling campaign was conducted at the end of the experiments. On each plot, composite sampling was carried out in the topsoil at a standard depth of 0 to 20 cm, by taking soil cores along a diagonal at four points to obtain a representative 500 g sample per experimental unit. In total, stratified sampling encompassing all blocks and all 12 restoration practices was used to create the analysis batches. After air drying, grinding, and sieving through a 2 mm mesh, the samples were analyzed using standardized laboratory methods: pH (water and KCl in a 1:2.5 ratio) was measured potentiometrically to assess acidification; organic carbon and total organic matter were determined using the Walkley-Black method; and total nitrogen was determined using the Kjeldahl method. assimilable phosphorus by the Bray-1 method; and cation exchange capacity (CEC) as well as exchangeable cations by ammonium acetate extraction. These laboratory analyses thus made it possible to accurately quantify the dynamics of nutrient stocks (NPK), the evolution of the organic matter content, the behavior of the absorption complex (CEC) and the degree of acidity correction of tropical ferruginous soils [15].

3. Results and Discussion

The results of this research focus on the effects of different soil fertility restoration practices on maize growth and yield parameters.

3.1. Effects of Different Soil Fertility Restoration Practices on Maize Plant Growth Parameters

In the study area, the degradation of ferruginous soils and water erosion pose major constraints to agricultural productivity. To curb this phenomenon, the Beninese government (through the DDAEP, ATDA, and INRAB), in partnership with international organizations (UNDP, GIZ, ProSol) and civil society, is promoting new Sustainable Land Management (SLM) and Soil and Water Conservation (SWC) practices. Consequently, restoration practices have been assigned to farmers. To analyze the performance of soil fertility restoration practices on maize growth parameters, stem circumference, plant height, leaf width, leaf length, and leaf color were measured over two growing seasons (2017-2018 and 2018-2019) across twelve (12) practices identified in the research area. The effects of the different soil fertility restoration practices on maize plant growth parameters are summarized in **Table 3**.

The results of the analysis of variance (two-way ANOVA incorporating the site/farm effect) performed on the growth parameters show that there are significant to highly significant differences between restoration practices and the majority of the measured morphological variables. While the main effect of agricultural campaigns remains generally non-significant ($P > 0.05$), with the exception of stem circumference, the interaction between practices and agricultural campaigns is significant with regard to stem circumference, plant height, and leaf width. Indeed, from one restoration practice to another, very marked and significant variations are observed in stem circumference ($P < 0.001$), leaf width ($P < 0.001$), and plant color ($P < 0.001$),

as well as a highly significant effect on plant height ($P < 0.01$) during the two evaluation campaigns. On the other hand, the effect of practices and seasons on leaf length was found to be insignificant ($P > 0.05$). Table 4 presents the average values of maize plant growth parameters according to the growing season and cropping systems.

Table 3. A two-way ANOVA (Fisher's test) was performed on the growth parameters of maize plants.

Source of variation	ddl	Fischer's value				
		Neck circumference	**Plant height**	**Sheet width**	**Leaf length**	**Color of the leaves**
Soil restoration practices	11	18.31***	13.17**	67.82***	8.8^{ns}	61.43***
Campaigns agricultural	1	0.63**	0.5^{ns}	0.72^{ns}	0.77^{ns}	0.00^{ns}
Restoration practices *Countryside	11	11.62**	5.78**	0.79**	25.63^{ns}	0.48^{ns}

Source: Results of fieldwork and data processing, 2018 and 2019. ns: $P > 0.05$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.01001$.

Table 4. Effect of soil restoration practices on maize growth parameters (average) ± standard error) during the 2017-2018 campaign.

	Growth parameters (2017-2018 campaign)			
Soil restoration practices	**Circolet**	**High plants**	**Largfeuil**	**Longfeuil**
	$m \pm e$	$m \pm e$	$m \pm e$	$m \pm e$
Association	$8.21^{f} \pm 0.14$	$1.37^{b} \pm 0.03$	$8.18^{d} \pm 0.09$	$73.70^{g} \pm 0.17$
Compost	$10.14^{c} \pm 0.11$	$1.67^{ab} \pm 0.03$	$9.97^{ab} \pm 0.10$	$85.65^{b} \pm 0.97$
Stone ridges	$7.54^{g} \pm 0.13$	$1.43^{b} \pm 0.45$	$7.64^{e} \pm 0.22$	$67.20^{i} \pm 0.37$
Mineral fertilizers	$11.26^{a} \pm 0.08$	$2.15^{a} \pm 0.05$	$10.18^{a} \pm 0.15$	$88.60^{a} \pm 0.30$
Fallow	$9.46^{e} \pm 0.11$	$1.37^{b} \pm 0.04$	$8.19^{d} \pm 0.03$	$76.45^{f} \pm 0.21$
Mucuna	$10.69^{b} \pm 0.08$	$1.51^{b} \pm 0.02$	$9.57^{bc} \pm 0.10$	$83.70^{c} \pm 0.43$
Rotational cattle penning	$10.84^{b} \pm 0.13$	$2.02^{a} \pm 0.07$	$9.97^{ab} \pm 0.16$	$87.60^{a} \pm 0.67$
Pigeon peas	$10.29^{c} \pm 0.07$	$1.51^{b} \pm 0.02$	$8.41^{d} \pm 0.08$	$78.30^{e} \pm 0.45$
Harvest residues	$10.75^{b} \pm 0.03$	$1.77^{ab} \pm 0.04$	$9.43^{c} \pm 0.18$	$80.35^{d} \pm 0.73$
Crop rotation	$9.30^{e} \pm 0.10$	$1.37^{b} \pm 0.04$	$8.15^{d} \pm 0.10$	$77.40^{ef} \pm 0.33$
Soy	$9.82^{d} \pm 0.11$	$1.48^{b} \pm 0.02$	$8.03^{d} \pm 0.10$	$78.85^{e} \pm 0.47$
Stylosanthes	$9.35^{e} \pm 0.07$	$1.48^{b} \pm 0.02$	$8.10^{d} \pm 0.09$	$71.00^{h} \pm 0.38$
control field	$6.12^{f} \pm 0.11$	$1.31^{b} \pm 0.09$	$7.10^{d} \pm 0.02$	$67.80^{g} \pm 0.18$
Probability	0.000	0.000	0.000	0.000

Source: Results of fieldwork and data processing, 2026. Legendre: Neck circumference (cm): Neck circumference; Height of plants (m): Plant height; Width of leaves (cm): Sheet width; Leaf length (cm): Leaf length. Means followed by the same letter of the same character and for the same factor are not significantly different ($P > 0.05$) according to the Student Newman-Keuls test.

Analysis of Table 4 shows that the mineral fertilizers, THE rotational grazing of cattle, crop residues, mucuna and the Angola weight and the compost have recorded the best performance with regard to growth parameters during the 2017-2018 season. During the same period, crop residues have allowed for a wide Collar circumference ($0.03 > P < 0.05$) and fallow resulted in the widest leaves ($P < 0.05$) according to the Student-Newman-Keuls test during the 2017-2018 growing season. Intercropping with mucuna, pigeon pea, soybean, and stylosanthes resulted in taller maize. Width varied considerably among the practices, while length remained consistent across different practices during the same growing season. The same parameters were studied during the 2018-2019 growing season (Table 5).

Table 5. Effect of soil restoration practices on maize growth parameters (average) ± standard error) during the 2018-2019 campaign.

	Growth parameters (2018-2019 campaign)			
Soil restoration practices	**Circolet**	**High plants**	**Largfeuil**	**Longfeuil**
	$m \pm e$	$m \pm e$	$m \pm e$	$m \pm e$
Association	$8.10^{e} \pm 0.13$	$1.12^{c} \pm 0.03$	$7.68^{d} \pm 0.06$	$73.60^{f} \pm 0.18$
Compost	$9.45^{cd} \pm 0.20$	$1.51^{abc} \pm 0.02$	$9.47^{bc} \pm 0.15$	$86.60^{a} \pm 0.97$
Stone ridges	$7.54^{f} \pm 0.09$	$1.34^{abc} \pm 0.40$	$7.73^{d} \pm 0.20$	$67.15^{h} \pm 0.40$
Mineral fertilizers	$10.94^{a} \pm 0.05$	$1.77^{a} \pm 0.07$	$10.23^{a} \pm 0.16$	$88.10^{a} \pm 0.36$
Fallow	$9.03^{d} \pm 0.14$	$1.29^{abc} \pm 0.03$	$8.07^{d} \pm 0.02$	$76.35^{e} \pm 0.24$
Mucuna	$9.67^{c} \pm 0.17$	$1.40^{abc} \pm 0.03$	$9.40^{bc} \pm 0.08$	$84.70^{b} \pm 0.43$
Rotational cattle penning	$10.78^{ab} \pm 0.07$	$1.51^{abc} \pm 0.01$	$9.71^{b} \pm 0.17$	$87.10^{a} \pm 0.61$
Pigeon peas	$10.52^{b} \pm 0.05$	$1.46^{abc} \pm 0.02$	$8.07^{d} \pm 0.10$	$78.90^{d} \pm 0.45$
Harvest residues	$10.52^{b} \pm 0.03$	$1.71^{ab} \pm 0.05$	$9.25^{c} \pm 0.12$	$81.10^{c} \pm 0.77$
Crop rotation	$9.12^{d} \pm 0.15$	$1.21^{bc} \pm 0.03$	$8.07^{d} \pm 0.10$	$76.50^{e} \pm 0.28$
Soy	$9.32^{cd} \pm 0.12$	$1.37^{abc} \pm 0.02$	$7.70^{d} \pm 0.06$	$78.90^{d} \pm 0.47$
Stylosanthes	$9.02^{d} \pm 0.08$	$1.41^{abc} \pm 0.02$	$7.87^{d} \pm 0.09$	$71.10^{g} \pm 0.41$
Control field	$5.12^{f} \pm 0.11$	$1.31^{b} \pm 0.09$	$7.07^{d} \pm 0.02$	$59.49^{g} \pm 0.99$
Probability	0.000	0.000	0.000	0.000

Source: Results of fieldwork and data processing, 2026. Legendre: Circ. Collar (cm): Collar circumference; Plant height (m): Plant height; Leaf width: Leaf width; Leaf length: Leaf length.

Analysis of Table 5 shows that the mineral fertilizers, the rotational cattle penning and to a lesser extent the pigeon peas and crop residues have recorded the best performance in terms of growth parameters during the 2018-2019 season. Also, crop residues have allowed for a large circumference at the collar ($0.03 > P < 0.05$). The height of the corn was significantly impacted by the practice of composting, fallow land, mucuna, rotational grazing of cattle, pigeon peas, soy and

stylosanthes ($P < 0.05$) according to the Student-Newman-Keuls test during the 2018-2019 campaign. The width and length of the leaves did not vary significantly ($P > 0.05$) from one practice to another during the same campaign.

In general, the two (2) growing seasons (2017-2018 and 2018-2019) resulted in the best performance in terms of plant height, stem circumference, and maize leaf width. No significant difference ($P > 0.05$) was found between the two seasons with respect to maize leaf length (Table 5).

Also, the differences between the values around the mean for the maize growth parameters are not significant (Table 3 and Table 4). In the comparison of the standard deviations of the maize growth parameters, the disparities in the differences between leaf length are more considerable than those of the other growth parameters (±0.97 and ±0.67 in 2018 and ±0.97 and ±0.99 in 2019 (leaf height, leaf width and collar circumference).

3.2. Effects of the Different Soil Fertility Restoration Practices and the Impact on Maize Yield Parameters

The analysis of the performance of soil fertility restoration practices on maize yield parameters considered the number of harvested ears, the number of full ears, ear weight, ear width, ear length, and grain yield. These parameters were measured over two growing seasons (2017-2018 and 2018-2019) for the 12 practices identified in the research area. Table 6 presents a summary of the different types of cropping systems and the methods of application soils on maize yield parameters.

Table 6. A two-way ANOVA (Fisher's test) was performed on the yield parameters of maize plants.

Source of variation	Ddl	Fischer's value					
		Number of ears harvested	Number of full ears	Weight of the ears of corn	Width of the ears	Ear length	Grain yield
soil restoration practices	11	6.21*	16.99***	82.98***	68.3^{ns}	100.59***	52.68***
agricultural campaign	1	1.05*	1.05^{ns}	0.61**	0.28^{ns}	0.35^{ns}	0.83**
Catering practice *Countryside	11	12.05^{ns}	13.5^{ns}	11.49^{ns}	0.31^{ns}	18.21^{ns}	0.98*

Source: Results of fieldwork and data processing, 2018 and 2026 ns: $P > 0.05$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

Analysis of Table 7 reveals significant to highly significant differences exist between restoration practices for all corn yield parameters, with the exception of ear width. Marked variations (ranging from $P < 0.05$ to $P < 0.001$) were observed between restoration practices in the number of ears harvested, the number of full ears, ear weight, ear length, and grain yield. Conversely, the main effect of agricultural campaigns was generally not significant for most yield components (number of full ears, ear length, and ear width), although minor adjustments were observed for the number of ears harvested and overall yield. Similarly, the inter-

action between the sources of variation (Restaurant practices X Agricultural campaign) is statistically significant for grain yield ($P < 0.05$), reflecting relative stability or moderate fluctuations in productive performance from year to year, while the other morphometric parameters of the ears remain non-significant for this interaction (Table 7). Therefore, to assess the effectiveness of the different soil fertility restoration practices during the two years of experimentation, a t-test was performed. Table 7 shows the results of the t-test.

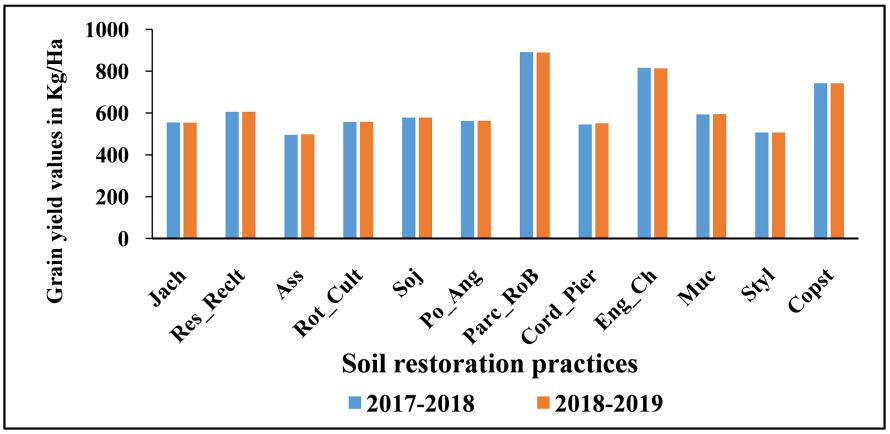
Table 7. Results of the Student's t-test assessing the effectiveness of soil fertility restoration practices.

Soil restoration practices	Yield		(INRAB standards) Average yield in kg/0.25ha	Probability (t. test)
	2017-2018	2018-2019		
	m ± e	*m* ± e		
Association	496.05^{k} ± 4.41	497.55^{k} ± 4.40	875 to 1250	0.8109
Compost	742.70^{c} ± 1.02	742.20^{c} ± 1.0	875 to 1250	0.735
Stone ridges	544.50^{i} ± 2.38	550.80^{i} ± 2.40	875 to 1250	0.0698
Mineral fertilizers	815.90^{b} ± 2.54	814.30^{b} ± 2.45	875 to 1250	0.653
Fallow	555.30^{h} ± 0.77	554.25^{h} ± 0.71	875 to 1250	0.3242
Mucuna	592.7^{e} ± 0.97	595.25^{e} ± 1.09	875 to 1250	0.09421
Rotational cattle penning	890.70^{a} ± 1.27	889.85^{a} ± 1.72	875 to 1250	0.6937
Pigeon peas	562.30^{g} ± 0.35	562.5^{g} ± 0.39	875 to 1250	0.706
Harvest residues	605.65^{d} ± 0.83	605.50^{d} ± 0.89	875 to 1250	0.903
Crop rotation	557.15^{h} ± 0.93	557.65^{h} ± 1.19	875 to 1250	0.7434
Soy	577.55^{f} ± 0.41	578.10^{f} ± 0.44	875 to 1250	0.3615
Stylosanthes	506.90^{j} ± 0.42	507.15^{days} ± 0.41	875 to 1250	0.6695
control field	474.09^{k} ± 8.41	447.55^{k} ± 1.21	875 to 1250	0.8109
INRAB standards	-	-	875 to 1250	-

Source: Results of fieldwork and data processing, 2026.

During the 2017-2018 and 2018-2019 growing seasons, rotational grazing of cattle and mineral fertilizers significantly improved corn grain yields, averaging 890.28 kg/0.25ha and 815.1 kg/0.25ha, respectively. The lowest yields were observed with intercropping, averaging 496.8 kg/0.25ha over both seasons.

Analysis of the results using the Student's t-test showed that corn grain yield was not significantly different between the various soil fertility restoration practices over the two years. Yields from the practices were similar from one year to the next. However, rotational grazing of cattle and mineral fertilizers yielded the best grain yields over the two growing seasons. Figure 2 shows the grain yield for each soil restoration practice over the two growing seasons.



Source: Results of fieldwork and data processing, 2026. Legend: As = Association; Pigeon Peas; Soybeans; Fallow; Crop Residues; Crop Rotation; Stone Cordons; Enclosure; Chemical Fertilizer; Mucus; Stylosanthes; Compost.

Figure 2. Corn grain yield obtained in the two agricultural seasons in the research area.

Analysis of Figure 2 shows that corn grain yields varied with soil restoration practices during the 2017-2018 and 2018-2019 agricultural seasons. Rotational grazing of cattle, mineral fertilizers and compost yielded the best results during these two seasons. However, no significant difference in yield was noted between the two agricultural seasons.

3.3. Impact of Agricultural Practices on Chemical Fertility and Soil Nutrients in Northwest Benin

In the agro-ecosystems of Northwest Benin, the intensification of farming and ongoing human pressure are leading to a progressive degradation of soil chemical fertility. The adoption of sustainable management practices, such as crop residue incorporation and organic matter addition, is therefore essential to restore major nutrient stocks and ensure the sustainability of production. Table 8 presents the positive impact of various farming and agroecological practices on soil chemistry and chemical fertility (NPK nutrient and organic matter dynamics) in the agricultural systems of Northwest Benin.

Analysis of Table 8 shows that the application of organic manure and composting triggers a slow mineralization process that significantly increases nitrogen and carbon stocks while releasing available phosphorus. The integration of crop rotation and improved fallow periods allows for biological fixation of atmospheric nitrogen and deep biogenic recycling of major nutrients. Rigorous management of crop residues and intercropping of maize and cowpea reinforce this dynamic by maintaining protective plant cover and enriching the humus fraction. This synergy of biochemical actions sustainably improves the soil's cation exchange capacity and limits acidification of the plots. The positive impact of these practices on maize growth results in optimized nitrogen and phosphorus nutrition, promoting tillering, vegetative elongation, and ear filling. Thanks to improved soil structure and increased nutrient availability, the cereal's root system develops vigorously

and deeply. These agronomic innovations ensure greater resilience of maize to water and nutrient stresses, thus guaranteeing high and stable yields for producers. In the northwestern regions of Benin, subject to intense human pressure and soil depletion resulting from intensive cotton and maize cultivation, the combined adoption of these practices (particularly the use of manure/crop residues and crop rotation with legumes) constitutes the main chemical lever for counteracting the decline in CEC (Cation Exchange Capacity) and restoring the absorption complex of ferruginous tropical soils.

Table 8. Impact of agricultural practices on soil chemical fertility and nutrients in Northwest Benin.

Agricultural practices adopted	Mechanisms of biochemical action	Effects on key nutrients (N, P, K)	Impact on Organic Matter (OM)
Application of organic manure and composting	Direct return of animal and plant biomass; slow mineralization by microbial activity.	Significant increase in Carbon and total nitrogen (N) stocks, improvement in the availability of assimilable phosphorus (P) by complexation of blocking ions.	Marked increase in organic matter content, improvement in cation exchange capacity (CEC).
Crop rotation (Cereals/Legumes)	Association or alternation between maize, sorghum or cotton and cowpea (or soybean).	Biological fixation of atmospheric nitrogen by the nodules of legumes, sustainably enriching the soil with N without excessive depletion of potassium (K).	Moderate improvement thanks to crop residues left on the surface and root diversity.
Management and burial of crop residues	Return of maize stalks, crushed cotton stems or cowpea stalks after harvest.	Return to the soil of the nutrients taken up, in particular large quantities of potassium (K) and residues of nitrogen (N) and phosphorus (P).	Progressive increase in the humic fraction and structural stability of the surface horizon.
Improved fallow (woody/herbaceous legumes)	Introduction of pioneer or fast-growing cover species (e.g., Mucuna pruriens).	Restoration of mineral balances deep down through root pumping and biogenic recycling of nutrients (N, P, K).	Strong replenishment of soil organic matter, reducing acidification and increasing humus levels.
Intercropping (Maize/Cowpea)	Simultaneous cultivation combining a creeping root system (cereal) and a taproot system (legume).	Synergistic use of edaphic space; sharing and partial transfer of fixed nitrogen (N) to the benefit of the companion cereal.	Maintenance or stabilization of organic matter by continuous plant cover which protects the soil from erosion.

Source: Results of fieldwork and data processing, 2026.

3.4. Discussion

The results of analysis of corn growth parameters shows that mineral fertilizers, the rotational grazing of cattle, crop residues, mucuna and to a lesser extent the

pigeon peas and compost recorded the best performance with regard to growth parameters during the 2017-2018 and 2018-2019 campaigns. Similar results were obtained us by [15] and [16] These authors demonstrated that, in light of soil degradation phenomena, an artificial regeneration trial of woody species using land management technologies was conducted in the Sudanian-Sahelian zone of Burkina Faso and Benin. Their objective was to understand the impact of soil restoration techniques (half-moons, subsoiling, and soil amendment) on the performance of *Combretum micranthum*, *Jatropha curcas*, and *Faidherbia albida* in Gampéla. A randomized block design combining planting of the three species with the land management techniques was used on bare and crusted soil. The results after the first rainy season indicate that the land management techniques significantly influenced ($P < 0.0001$) plant growth, with the exception of *F. albida* ($P = 0.627$). After two years, growth and survival rates were significantly improved in the half-moon layouts and, to a lesser extent, in the subsoiled layouts, with high survival rates (>70% in the half-moons for all species) and growth rates sometimes reaching double those of the control plots. This positive impact is attributable to the improved soil conditions (compaction, fertility, and moisture) induced by the different techniques, which led to increased yields. Similarly, the results of the analysis of corn growth parameters show that the mineral fertilizers, the rotational cattle penning and to a lesser extent compost have given the best yields and a large number of ears harvested during the 2017-2018 season and 2018-2019 with $P > 0.05$ according to Student's t-test. During these two agricultural campaigns, rotational grazing of cattle and mineral fertilizers significantly improved corn grain yield with respectively 890.28 kg/0.25ha and 815.1 kg/0.25ha on average. The lowest performance was obtained with the association of cultures with 496.8kg/0.25ha on average over the two campaigns. Similar results were obtained by [17] In a study of cropping system performance, he showed that the cattle grazing system resulted in the best plant growth parameters for the 2014-2015 growing season, with a dry grain yield of 2633 kg/ha. In contrast, during the 2015-2016 growing season, the cassava-maize system and the fallow system (4 - 10 years) resulted in the best growth parameters and dry grain yield, respectively (2106 kg/ha) [18] this has shown that better management of organic amendments through the grazing of small ruminants, modulated over different durations, allows for higher average grain and straw yields than those recorded under maize cultivation. These productivity gains are mainly attributed to the optimization of soil properties, and more specifically to the enrichment of plots with nitrogen and available phosphorus. Similar results have been reported by several authors in Benin [19].

Butin a study on the performance evaluation of soil fertility management practices in the Okpara River basin in Benin [20] emphasized that, 87.3% of Surveyed producers claim that natural fallow improves the yield level of maize and 30% that of yam, especially when it is long-term (over 10 years). On short-term fallow land (1 to 3 years), farmers are forced to cultivate food legumes particularly soybeans or peanuts in the hope of a better yield for the subsequent corn cultivation, which

is more demanding in terms of nutrients. Indeed, 75.6% of the producers surveyed stated that in this rotation system culturally, the level of the subsequent maize crop can be improved by 15% compared to the initial yield before the fallow period plot.

The integration of crop rotation and improved fallow periods allows for biological fixation of atmospheric nitrogen and deep biogenic recycling of major nutrients. Rigorous management of crop residues and intercropping of maize and cowpea reinforce this dynamic by maintaining protective plant cover and enriching the humus fraction. This synergy of biochemical actions sustainably improves the soil's cation exchange capacity and limits the acidification of plots. The study conducted by [21] evaluates the chemical characteristics of various local substrates used for soil organic amendment in cotton-growing systems in western Burkina Faso. Laboratory analyses reveal significant variability in biochemical properties and major nutrient content depending on the type of local organic matter tested. Characterization highlights promising levels of organic carbon and total nitrogen stocks, although deficiencies in total and available phosphorus frequently necessitate external supplementation. Furthermore, pH measurements confirm reactions ranging from slightly acidic to neutral, directly influencing nutrient solubility and correcting soil acidity. The authors thus emphasize that the judicious use of these local substrates constitutes a fundamental biological lever for restoring soil chemical fertility. The study recommends combining these locally sourced organic amendments with phosphate sources to optimize the nutritional efficiency of cotton-based cropping systems.

The study in [22] highlights the value of using crop residues (maize and sorghum stalks, and cotton stems) through direct incorporation as a key strategy for the sustainable management of organic matter in the agroecosystems of northern Benin. Incorporating this plant biomass during soil preparation allows for the return of significant quantities of absorbed mineral elements, particularly potassium (K) and nitrogen (N), to the soil's absorption complex. This practice promotes the replenishment of the topsoil's organic carbon stock (20 cm), thereby stimulating microbial dynamics and soil biological activity. The progressive improvement in cation exchange capacity (CEC) and edaphic structural stability limits runoff and protects tropical ferruginous soils from erosion. Ultimately, this organic matter return improves the efficiency of mineral fertilizer use and ensures a sustainable increase in cereal and cotton crop yields in the region.

4. Conclusion

The performance analyses of soil fertility restoration practices on maize growth and yield parameters during two agricultural seasons (2017-2018 and 2018-2019) of the twelve (12) practices identified in the research area showed the best performance with regard to plant height, plant collar circumference, and maize leaf width. Regarding yield parameters, the analyses have shown that corn grain yields vary depending on soil restoration practices. Thus, during the two agricultural

seasons (2017-2018 and 2018-2019), out of the twelve (12) practices identified in the research area, rotational cattle grazing, mineral fertilizers and compost gave the best yield during these two seasons.

Conflicts of Interest

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

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