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Effects of Stone Barriers on Soil Physicochemical Characteristics under Cotton (*Gossypium hirsutum* L.) Cropping Fields Northern of Côte d'Ivoire

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Abstract

In the north of Cote d'Ivoire, the rural economy is heavily dependent on cotton cultivation which is characterized by low yield. One of the main causes of low productivity is low level of soil fertility caused by erosion. The stone barriers technique is used to fight against erosion and to improve soil fertility. This work was carried out to assess the effects during 1-year-old stone barriers on selected soil physicochemical properties on two geographical locations where soil samples from 0 to 30 cm depth were selected. A total of 60 composite soil samples (30 × 2) were collected. One year after installing the stone bunds in cotton cultivation, the soil was sampled under the same conditions. The soil samples were analyzed for pH (H_2O), organic carbon (SOC), total nitrogen (TN), available phosphorus (Av.P), cation exchange capacity (CEC), exchange bases (Ca, K, Mg, Na) and particle size (clay, coarse silt and sand) contents. The results show that the stone bunds significantly increased the water pH, the soil levels of calcium, magnesium, silt and coarse sand. On the other hand, they significantly lowered the levels of assimilable phosphorus, clay and fine sand in soils. CEC and soil carbon, nitrogen, potassium, sodium and fine silt content did not vary significantly. This study must be repeated in the years to come in order to determine the impact of stone barriers in the medium and long term on soil fertility in the north of Côte d'Ivoire.

Keywords

Cotton, Productivity, Stone Barriers, Physicochemical, Grain Yield, Côte d'Ivoire

1. Introduction

In Côte d'Ivoire, agriculture remains one of the largest sectors in the economy both in terms of its contributions to the Gross domestic product (GDP) and generating employment [1]. In the Korhogo' region, central pivot cotton production savannah area, north of Cote d'Ivoire, soil erosion and its consequences is one of the more serious problems in cotton tree crop, despite cotton fields have come to dominate the agricultural economy. Therefore it is substantial to exercise environmental rehabilitation, such as reducing soil erosion. For sustainability of livelihood and to maintain farm incomes and reduce externalities associated with erosive agricultural techniques, considerable efforts have been promoted profitable soil restoration strategies in Low productivity of cotton cropping zones. Cotton counts for less than 10% of the export incomes. It is the third most important cash crop of the country after cocoa and coffee. The fiber production average 100,000 tons per annum, of which 90% are exported and generated annual sales of around 120 billion FCFA [2]. Cotton contributes 1.7% of the GDP and its share in exports has reached 7% [3].

In Côte d'Ivoire, during the 2015-2018 season, cotton covered approximately 357,061 ha, producing 350,280,513 tons' grain, representing 7% of the total annual crop surface with a mean yield of 981 $kg{\cdot}ha^{-1}$ [4]. During the 2020-2021 season, Ivorian Scientists developed a large, high-throughput genetics centre of cotton seedling. In despite of the varieties of high-yielding, such Gouassou (4000 kg/ha), Sicama (4000 kg/ha) and BLT (3000 kg/ha), new germoplants had produced 1700 $kg{\cdot}ha^{-1}$, 1400 $kg{\cdot}ha^{-1}$ and 1200 $kg{\cdot}ha^{-1}$, respectively. Considering the large amounts of fertilizers and pesticides used, this performance is relatively low compared with major African countries [5]. Several reasons have been reported to account for the low cotton productivity on smallholder farms in Côte d'Ivoire. In past 10 years, although large fertilization rates have been increasing in cotton production savannah area of north Côte d'Ivoire, in many cases, this has not resulted in a proportional increase in crop yields [6]. This is what motivated the present work where the improved production and productivity is the major target. Productivity and conservation objectives are highly complementary. It was carried out to understand soil erosion and its consequences in assessment of yield levels.

On the one hand, [7] [8] [9] reported that in the savannah zone of Côte d'Ivoire there are mainly acidic soils, where on low pH soils may occur nutrient deficiencies, in particular, among the microelements, copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) deficiency is the most widespread problem in cashew tree fields, mostly related to acidic soils and soils. On the other hand, savannah's smallholder farmers who depend on cotton for their livelihoods, implementated better applying mineral fertilizer practices such as N-P-K-S-B and urea [10] for more than half a century to restore soil fertility status. Therefore, it is important to provide to the farmer appropriate in savannah's zone, good recommendations in soil conditions. During the 2019/2020, the response of seed cotton yield of new strains of cotton at different levels of N-P-K-S-B and urea were evaluated. Cotton at different levels of N-P-K-S-B and urea [11] were applied (81,687,400 kg and 20,421,850 kg, respectively). Despite these large inputs of fertilizer, the response of all fertilizer treatments was found no significant [12].

Indeed, land of cotton production savannah area is also becoming vulnerable to soil fertility declination and associated changes in physical and chemical properties. Due to these and other significant factors, soil need to be protected in a sustainable manner [13] [14]. On the other hand, the almost exclusive use of mineral fertilizers can lead to an accentuated acidification of the soils [15]. Soil restoration is a need to reduce soil fertility depletion and achieve sustainable land management, where agriculture is the main source of labor and supplies the food for a growing population.

Soil restoration should increase the production. This research mainly promoted and implemented physical technics such as level stone barriers and undertakes planting cotton trees of seedlings during 1-year-old at the central pivot cotton production savannah area, north of Cote d'Ivoire. These techniques were applied in Burkina Faso where contributed to significantly reduce runoff and resulted and studies in this country confirmed the positive impacts of level stone practices on soil physicochemical properties and crop yields as sorghum grain [15]. To heal the causes of such soil erosion and alleviate the problem, non-governmental organizations such as "Animation Rurale de Korhogo (ARK)" have extensively implemented stone structures. The main objective of this work assesses the quantitative results whose has been reported on the impacts of stone barriers on soil fertility improvement cotton crop productivity during 1-year-old in Nielle and Dassoungbo locations.

2. Materials and Methods

2.1. Description of the Study Area

Studies were conducted at two sites on rural roads with similar characteristics. The first site was Nielle (10˚12'Nord and 5˚38'W). The second site was Dassoungbo (9˚23'N and 5˚46'W).

2.1.1. Nielle

Nielle is characterized by a sudanese tropical strict climate. Annual average rainfall rarely exceeds 1000 mm. Due to a large intra and inter annual rainfall variability, the region is exposed to severe moisture deficiency during the growing season which is varied from 140 to 150 mm. The rainfall is erratic with more than the rains falling at intensities larger inducing severe soil erosion [16]. Monthly rainfall in this region is below monthly potential evapotranspiration except in August. The average monthly temperature ranges from 29˚C to 30˚C. The lithology of the Nielle catchment is composed of volcano-sedimentary rocks comprising heterogeneous and granites with biotite [17]. Soil variability is rather complex due to landsliding and intense erosion and deposition processes. Typical soils of the locations include ferralsols et gleysols [18] along a catena and on relatively flat topography.

2.1.2. Dassoungbo

Dassoungbo is characterized by diverse topographic features such as weak undulating and an average annual rainfall, around 1400 mm. In terms of agro-climatic zone, the Dassoungbo falls within sub-sudanese climate. It has two rainy seasons: the main rainy season occurs from May to October and the dry season is extend from November to March. Generally the annual rainfall ranges from 1100 - 1400 mm. The lowest and highest mean annual temperature ranges between 25˚C and 29˚C. There are different exotic and indigenous types of tree species found in the study area; for instance, Anogesius Leiocarpus, Andansonia digitata, Vitellaria paradoxa, Daniella oliveri, Parkia biglobosa and Terminalia glaucescens. As for the herbaceous flora, it contains Hyptis suaveolens, Andropogon gayanus, Euclasta condylotrica, Hyparrhenia diplandra, Pennisetum polystachion, Aframomum latifolium and Sorghastrum bipennatum [19] are the common tree species in an area. The total area of the study area is about 357,061 hectares of which the major crops grown in the study area includes maize, sorghum and haricot bean and most of the farm land are covered with perennial crops mainly cotton, which is the main cash crop. Granites and shales are the two types of rocks that share this zone. Alongside these two rock formations, there are formations of sedimentary and volcanic origin [20]. The relief is made up of a succession of plateaus with an altitude varying from 300 to 400 m and isolated inselbergs. In this zone, the most represented morpho-pedological landscapes are the plateaus with the armored summits and the plateaus with the partially dismantled armored summits. The dominant soil type of the study area is Ferralsols, Cambisols and Gleysols [21].

2.2. Experimental Conditions

The work was conducted on both site area (Niellé and Dassoungbo), where the experimental design consisted of 30 plots in which stone lines were installed at random in 2019 (start of the experiment). On each plot, seven (7) three-stone cords were installed along the curves level before soil preparation. Contours were determined using the water level. The spacing between the lines was 30 m when the slope ranged from 1% to 3% and 50 m where it was less than 1% [22].

2.3. Soil Sampling

Soil samples were collected from each experimental field. From each experimental field, 10 soil samples (**Figure 1**) were collected from 0 to 30 cm from 0 to 30 cm and mixed thoroughly, and a single composite sample was taken for analysis. A total of 60 (30 × 2) composite soil samples were collected for soil physicochemical analysis.

2.4. Laboratory Analysis

The disturbed composite soil samples collected from the experimental fields were air-dried, mixed well, and passed through a 2-mm sieve prior soil physicochemical analysis. Soil texture was analyzed following the Bouyoucos hydrometer method [23]. Soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 soil-to-water ratio mixture using a digital pH meter.

The total nitrogen (N) content of the soil was determined using wet digestion, by the Kjeldahl method. The available phosphorus content of the soil was determined using the Olsen extraction method. Available potassium was determined by extracting the soil sample with Morgan's solution, and K in the extract was measured by flame photometer. The cation exchange capacity (CEC) was determined using an ammonium acetate saturation method at pH 7.0. Exchangeable Ca^{2+}, K^+ et Mg^{2+} and Na^+ were quantified by saturating cation exchange sites with ammonium acetate buffered at pH 7.0 followed by measuring the cation concentrations in the filtrated extracts with inductively coupled plasma optical emission spectroscopy.

2.5. Statistical Analysis

The soil physical and chemical properties used for the conduct of the experiment are shown in **Table 1** and **Table 2**. The nutrient critical level recommended for optimum production of crop production are pH, organic matter, total N, available P, CEC, exchangeable K, Ca and Mg [24] [25]. The Paired Samples t Test compares the means of two measurements taken from 1st et 2nd year data using Statistica statistics 7.1 software [26].

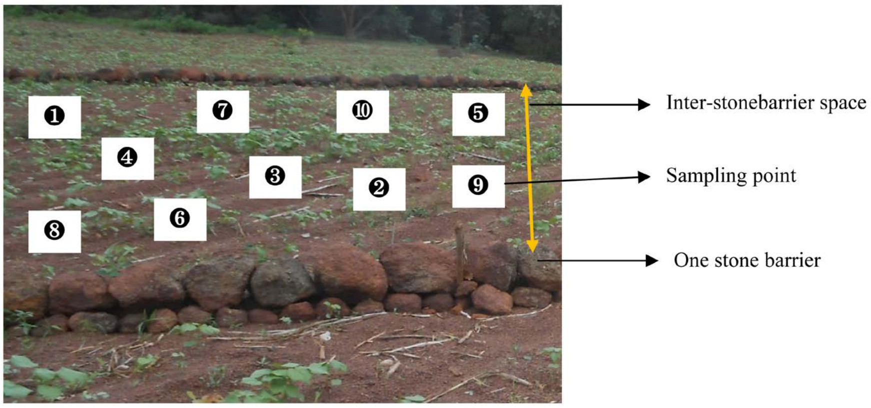

Figure 1. One Inter-stone barrier space in experiment field.

Table 1. Guideline values for various pH (H_2O).

Index	pH < 4.5	4.5 < pH < 5	5 < pH < 6.5	6.5 < pH < 7.5	7.5 < pH < 8.5	>8.5
Status of soil pH (H_2O)	Strongly acidic	Medium acidic	Slightly acidic	neutral	Slightly alkaline	Strongly alkaline

Source: [24].

Table 2. Guideline values for various nutrients.

Nutrient	Nutrient critical level recommended				
	Very poor	Poor	Satisfactory	Adequate	Very high
TN ($g \cdot kg^{-1}$)	<0.5	0.5 à 1	1 à 1.5	>2.5	
Av. P ($mg \cdot kg^{-1}$)	<15	15 à 25	25 à 50	>100	
SOC ($g \cdot kg^{-1}$)	<0.5	0.5 à 1	1 à 1.5	>2.5	
ExK ($cmol \cdot kg^{-1}$)	<0.1	0.1 à 0.15	0.15 à 0.40	>15	
ExCa ($cmol \cdot kg^{-1}$)	<1.0	1 à 2.5	2.5 à 3.5	>7.0	
ExMg ($cmol \cdot kg^{-1}$)	<0.5	0.5 à 1.0	1.0 à 1.5	>3.0	
CEC ($cmol \cdot kg^{-1}$)	<2	2 à 3	3 à 8	8 à 15	>15

Source: [25].

3. Results and Discussion

3.1. Results

3.1.1. Soil Chemical Properties

1) Soil pH (H_2O) and SOC, TN and Av.P Cation Exchange Capacity (CEC)

On the one hand, the variations in soil pH were statistically significant ($p \leq 0.05$) in under the initiation of the expreiment and the experimental trials in the subsequent year (Table 3). The overall mean value of soil pH (H_2O) was found to be low (from 5 to 5.6, medium acidic, Figure 2) prior the initiation of the experiment, and high pH (H_2O) in the experimental trials in the subsequent year (5.7 - 6.1: slightly acidic). Under stone lines soil pH increased (Figure 2). The difference in pH across the experiment was also associated with the distribution of Av.P, which is positively and significantly correlated. Soil organic carbon (SOC) and Total Nitrogen (TN) showed a statistically no significant difference ($p > 0.05$) between the initiation and treated fields the subsequent year (Table 3).

2) Soil Cation exchange capacity (CEC) and Exchangeable bases (N = 30)

Cation Exchange Capacity (CEC) showed a statistically no significant difference ($p > 0.05$) between the initiation and treated fields the subsequent year (Table 4). Soils in the treated fields showed significantly higher CEC than the untreated fields. Exchangeable calcium and magnesium (ExCa and ExMg) showed a statistically significant difference between treated and untreated fields ($p < 0.05$; Table 4). Higher ExCa and ExMg were recorded in the subsequent year. Mean values of ExCa and ExMg content increased ranged from 1.3 $cmol \cdot kg^{-1}$

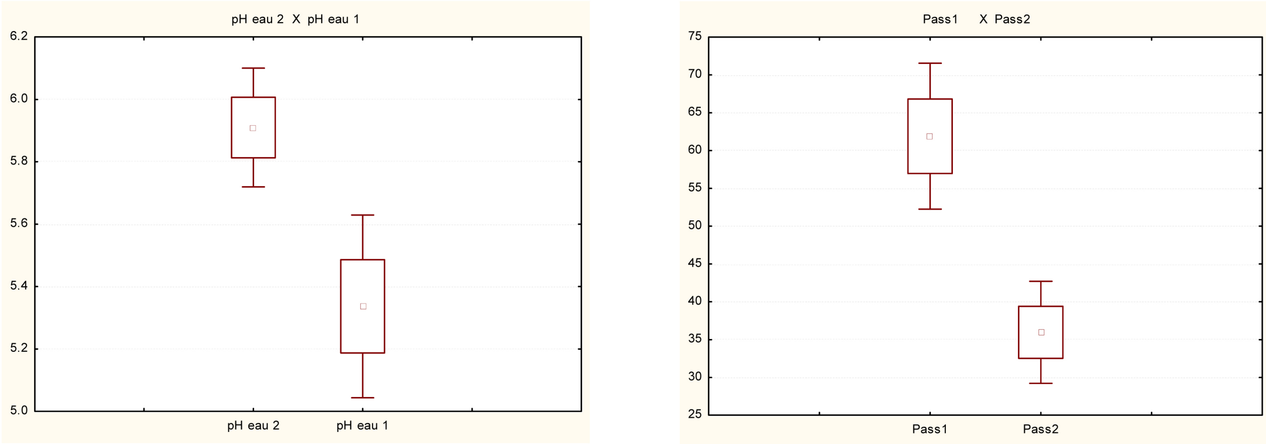

Figure 2. Boxplots for paired samples t test showing a significant difference in the pH (H_2O) and Av.P, prior and after stone lines installed. 1: prior the initiation of the experiment or observation 2: experimental trials in the subsequent year; pH eau: pH (H_2O), Pass = Av.P.

Table 3. Comparison of paired samples t test and performance of experimental trials in the subsequent year for pH (H_2O), SOC, TN and Av.P (N = 30).

Variables	Units	Difference	S.D* difference	t	df	p-value
pH $(H_2O)_1$ & pH $(H_2O)_2$		0.573333	1.014357	3.0958	29	0.0043
SOC_1 & SOC_2	g·kg^{-1}	0.027000	0.514253	0.2876	29	0.7757
TN_1 & TN_2	g·kg^{-1}	−0.007013	0.048189	−0.7971	29	0.4318
$Av.P_1$ & $Av.P_2$	mg·kg^{-1}	25.92667	35.37527	4.0143	29	0.0003

*Standard Deviation. 1: prior to the initiation of the experiment or observation 2: experimental trials in the subsequent year.

Table 4. Comparison of paired samples t test and performance of experimental trials in the subsequent year for CEC and Exchangeable Ca^{2+}, K^+, Mg^{2+} and Na^+ (N = 30).

Variables	Unité	Difference	S.D* difference	t	df	p-value
CEC_1 & CEC_2	cmol·kg^{-1}	−1.08533	5.017286	−1.184	29	0.2457
$ExCa_1$ & $ExCa_2$	cmol·kg^{-1}	−1.39862	1.711548	−4.475	29	0.0001
ExK_1 & ExK_2	cmol·kg^{-1}	−0.052086	0.173850	−1.641	29	0.1116
$ExMg_1$ & $ExMg_2$	cmol·kg^{-1}	−0.258967	0.284943	−4.9779	29	0.0000
$ExNa_1$ & $ExNa_2$	cmol·kg^{-1}	0.025433	0.175105	0.7955	29	0.4327

*Standard Deviation. 1: prior to the initiation of the experiment or observation 2: experimental trials in the subsequent year.

(poor) to 2.7 cmol·kg^{-1} (satisfactory) and de 0.57 (poor) to 0.84 (satisfactory), respectively. In contrast to this, in the study area, northern Côte d'Ivoire revealed that ExK and $ExNa^+$ didn't show a significant difference ($p > 0.05$) at different experiment fields (Figure 3).

3.1.2. Soil Textural Fraction

Table 5 shows the results of comparing the contents of clay, fine silt, coarse silt, fine sand and coarse sand.

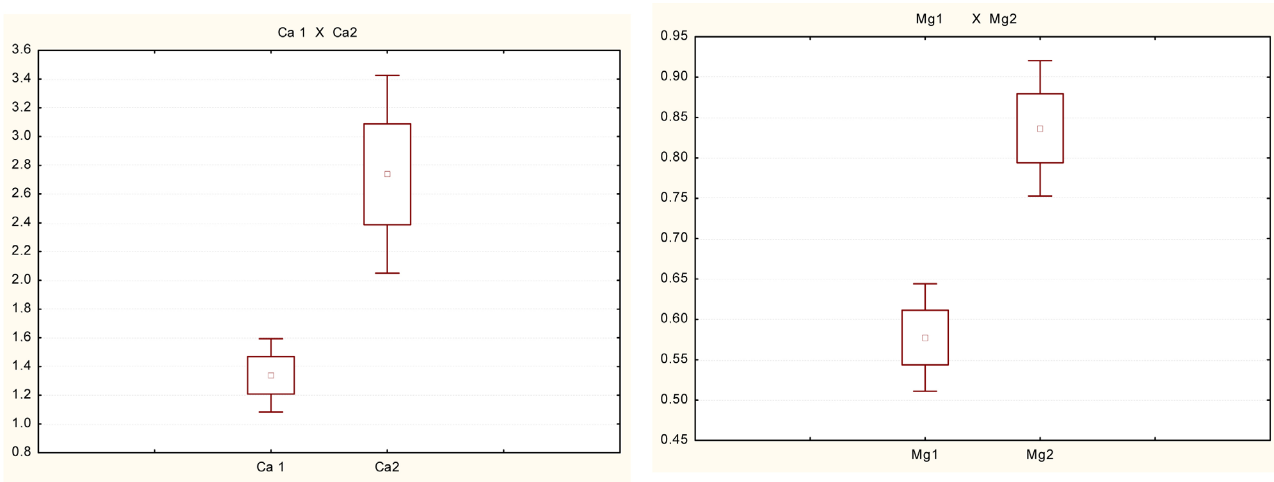

Figure 3. Boxplots for paired samples t test showing a significant difference in the Exchangeable Ca^{2+} and Mg^{2+}, prior and after stone lines installed. 1: prior to the initiation of the experiment or observation; 2: experimental trials in the subsequent year.

Table 5. Summary comparison of paired samples t test for soil textural fractions under conserved under stone lines farm plots (SD = standard deviation, N = 30).

Variables	Units	Difference	SD difference	t	df	p-value
$Clay_1$ & $Clay_2$ ($A_1 \times A_2$)	$g \cdot kg^{-1}$	10.97533	6.469389	9.292	29	0.0000
Fine $Silt_1$ & Fine $Silt_2$	$g \cdot kg^{-1}$	1.203333	5.172656	1.274	29	0.2127
Coarse $Silt_1$ & Coarse $Silt_2$ ($Lg_1 \times Lg_2$)	$g \cdot kg^{-1}$	−3.52667	7.180322	−2.690	29	0.0117
Fine $sand_1$ & fine $sand_2$ ($Sf_1 \times Sf_2$)	$g \cdot kg^{-1}$	9.367000	7.412921	6.921	29	0.0000
Coarse $sand_1$ & Coarse $sand_2$ ($Sg_1 \times Sg_2$)	$g \cdot kg^{-1}$	−17.5967	15.08434	−6.389	29	0.0000

On the other hand, Clay, silt (coarse) and sand fractions (fine and coarse) were significantly affected ($p \leq 0.05$) by stone-barriers (Table 5, Figure 4).

Prior of the experiment, the overall mean clay and fine sand content were found to be higher than in the 1-year old experiment (Table 5), while the coarse silt and coarse sand contents were higher in the 1-year old experiment. Results showed that stone lines reduced runoff effects, which affected performance of experimental trials in the subsequent year on soil textural fraction level (Figure 4). This result showed that coarse silt and coarse sand contents were, consequently, higher in soils under stone lines farm plots.

Before the stone bunds, 30% of the studied soils had a silty-clay-sandy texture, 53% silty-sandy and 17% sandy-silty. After the installation of the stone bunds, the percentage of silty-clay-sandy soils fell from 30 to zero, silty-sandy soils from 53 to 70, sandy-silty soils from 17 to 27 and sandy soils from 0 to 3 (Figure 5).

3.2. Discussion

As the stone barriers installed, soil pH increased. This might be due to the influence of the stone lines through its effect of limiting soil erosion and the leaching of soluble base cations, which in turn decreased the concentration of H^+

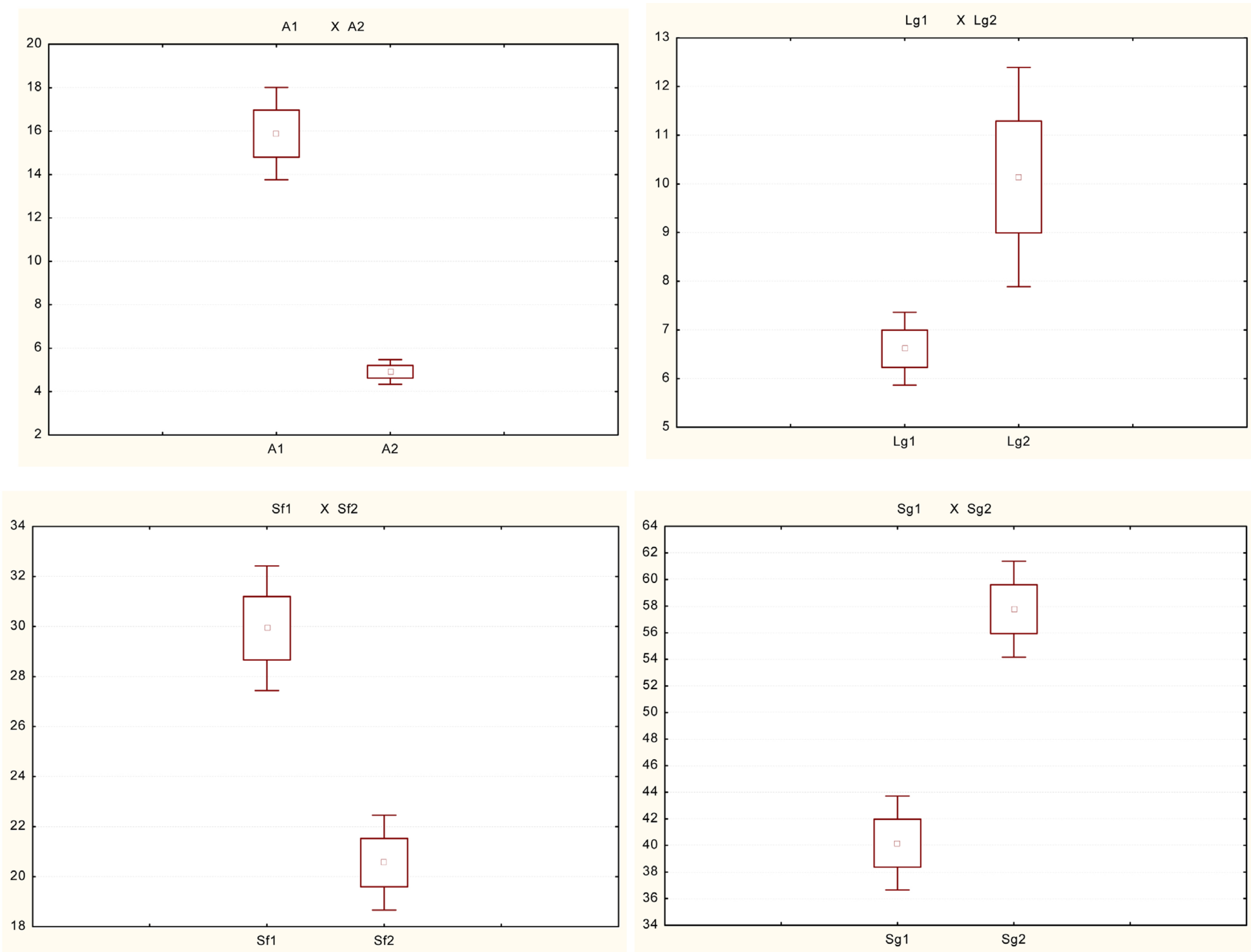

Figure 4. Boxplots for paired samples t test showing a significant difference in the Clay (A), silt (Lg), sand (S), prior and after stone lines installed.

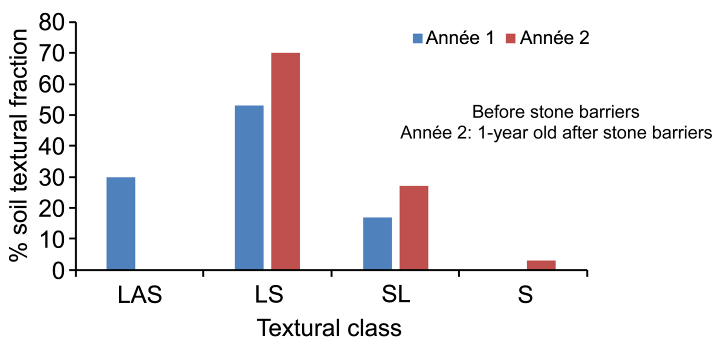

Figure 5. Evolution of the soil textural under experimental design in farm plots. LAS: silty-clay-sandy LS: silty-sandy SL: sandy-silty S: sandy.

ion in the soil solution and increased soil pH. Indeed, the soils in the study areas are naturally acidic to slightly acidic [9]. Acidification is a phenomenon that occurs naturally in humid tropical soils. The causes are linked. In general, low basic cation content in soils [27] due to runoff erosion. In the North of the Côte d'Ivoire, the aggressiveness of the climate is quite strong even on gentle slopes

[13]. Extensive monoculture cotton production increased the vulnerability of soils to erosion, degradation, which is facilitating the low fertility. This result agreed with the findings of [14]. The difference in pH H_2O across the experiment design could also be associated with the distribution of exchangeable Ca and Mg, as pH is positively and significantly correlated with CEC.

Soil organic carbon (SOC) showed a statistically no significant difference between the treated and untreated fields, which might not be associated with sediment accumulation in the treated fields. In general, as per the ratings of SOC content was found to be low in the land of cotton cropping, which might be due to intensive tillage, continuous cropping, and the removal of crop residues. This result might be associated with the removal of organic matter from the surface areas and via water erosion. Total Nitrogen (TN) showed a statistically no significant difference at different levels of experimental design. This might be due to the removal of organic matter from the Av.P horizon via soil erosion. Similar results were reported by [8] in the cotton production savannah area, northern Côte d'Ivoire.

Available Phosphorus (Av.P) showed a statistically significant difference between the treated and untreated fields. Low Av.P from treated fields was due to extractive crops biomass harvest. This may result in only a temporary decrease in plant availability. Indeed, there is a reversible transfer of P between available and non-available forms, whose are responsible for the re-assessment developed in this work. The low value of P content was retained by soil components. Plant roots take up P from the soil solution as orthophosphate ions, principally $H_2PO_4^-$ and to a lesser extent HPO_4^{2-}, except in calcareous and saline soils. Plant roots can absorb P from soil solutions having very low P concentrations [28], in which case P uptake is against a very steep P concentration gradient. In tropical soils, only a few kilograms of P are available in soils solution in the anionic form contents such as $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}, available for plants [29]. This is because the P content of root cells larger than that of the soil solution. In Côte d'Ivoire, soil acidity and phosphorus deficiency are some of the constraints hampering agricultural production in tropical regions. The prevalence of soil acidity is associated with phosphorus (p) insufficiency and aluminum saturation [30]. The level of availability of different forms of orthophosphates varies widely. Some find themselves quickly in solution, others migrate more slowly, from the solid phase to the solution and others only dissolve with the activity of living organisms [31].

The activity of microorganisms increases with the level of organic carbon in soils. The stone lines did not increase the organic carbon level in the top three inches of the soils studied. The stone bunds enriched the first thirty centimeters of the soil with coarse silt and sand. The accumulation of coarse silt and sand in the inter-stone lines spaces were relative. These particles come from the soils located upstream of the studied plots. During their migration, the stone lines acted as a filter. They allow the finest particles to pass and retain coarse ones. The coarse particles come from the minerals of the source rocks which are generally granitoids, gneisses and schists. These rocks are rich in quartz which weathering produces coarse particles such as sand and coarse silt [8].

4. Conclusions & Recommandations

Stone barriers in the central pivot cotton production savannah area, north of Cote d'Ivoire, positively influenced the physicochemical properties of soils, such as properties (soil texture, pH H_2O, Av.P, ExCa and ExMg). A statistically significant difference was shown between the treated with stone barriers and untreated fields. pH H_2O and coarse silt and sand were found to be high in fields having stone lines installed than in fields in the initiation of experiment. Soils of the study area were found to be slightly acidic (5.7 - 6.1; pH H_2O) in the experimental trials in the subsequent year. This means that stone lines practice could improve the fertility of the soil by limiting nutrient losses. This practice was carried out in 1-year-old. To evaluate the impacts old stone barriers on Organic matter (OM), cation exchange capacity (CEC), available potassium (K^+), crop yield and others, another study could be conducted at least 5-year old.

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Conflicts of Interest

The authors declare no conflict of interest.

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