



Effects of Spacing Between Stone-Rows on the Chemical and Biological Fertility of Lixisoils in Eastern Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. Author AC led the study and wrote the manuscript. Authors KFZ and COZ participated in the study and the drafting of the manuscript. Authors HO and DG contributed to the manuscript's revision. Authors EH and MM provided guidance for this work and reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed the effects of stone-rows spacing on soil fertility and the potential for a fertility gradient to occur in a farming setting. The study was conducted in a rural area of Sampieri, eastern Burkina Faso, within a Sudano-Sahelian environment on Lixisols with a medium slope of up to 5%. The experimental design included three plots, each with a different stone-rows spacing: 15.5 m (P1), 18.5 m (P2) and 22 m (P3). Soil samples were taken at depths of 0-10 and 10-20 cm, with interval ranging from 0 to 15 m from the rows. Soil organic carbon (C), total nitrogen (N), pH and soil microbiological activity were measured. The study showed that C, N, P and pH levels improved more on plots P2 and P1 than on plot P3. Although differences were noted for microbiology, they were not statistically significant. A correlation was found and most soil fertility parameters. However, no soil fertility gradient was evident as a function of slope when moving away from the first stone-rows line. It can be concluded that the optimal spacing between stone-rows is 18.5 m and that it is difficult to deduce a fertility gradient within this interval. However, further research is needed for validation and confirmation of these findings.

Keywords: *Agro-ecological; stone-rows; soil parameters; Lixisols; Burkina Faso.*

1. INTRODUCTION

In the Sudano-Sahelian region, recurrent droughts since the 1970s, demographic pressure, and extensive agro-pastoral production systems have all increased the vulnerability of agro-ecosystems. Indeed, the Green Revolution, a symbol of agricultural industrialized agricultural intensification based on tillage, the massive use of mineral and synthetic inputs (fertilizers, pesticides and energy) and a narrow genetic base of cultivated species, led to a significant increase in cereal crops yield (Sainju et al., 2003; Goïmiero, 2011; Goïta, 2014). Globally, this modernization resulted in a tenfold increase in cereal production yields and cultivated areas per farmer, a sharp increase in livestock production, and a more than hundredfold increase in gross agricultural labor productivity (Mazoyer et al., 2002). In Africa, this has resulted in an estimated 14% increase in yields, but with a parallel doubling of cultivated areas (Soule & Gansari, 2010). However, this type of agriculture often leads to a reduction in biodiversity, the degradation of arable land, the alteration of water quality and quantity, and a negative contribution to climate change (Gomiero et al. 2011). The most characteristic consequence is a continuous decline in land productivity, reflecting a complex process of deterioration in the chemical, physical, and biological properties of the soil (Hien, 2004). These dysfunctions are exacerbated by the impact of global climate change (Jauffret, 2009), whose predictive models agree on a likely increase in the instability worldwide, with catastrophic droughts or floods. In addition to the

impact of climate change and human activity on continental biogeosystems, it is important to consider the unique characteristics of tropical environments. These environments are often characterized by fragile soils and intense climates, which can further compound the effects of these disturbances. As a landlocked and ecologically fragile country, Burkina Faso is unfortunately not immune to this general trend in the agricultural world of the Sahel. It is even more exposed because its economy is primarily structured around its land and natural resources, which are undergoing worrying degradation due to the combined effects of climate and human activity, thus jeopardizing the country's socioeconomic development. Indeed, some studies (Gomgnimbou et al., 2010; Ouédraogo et al., 2019, Sanou et al. 2025) have shown that the degradation of terrestrial ecosystems and the environment in Burkina Faso is linked to anthropogenic factors, particularly agricultural activities. In addition, the slopes present a morpho-pedological heterogeneity from upstream to downstream, often marked by the presence of a shell or armor which limits the useful depth of the soil (80 and 100 cm maximum). The presence of this shallow shell or armor on nearly two-thirds of the glacia imposes constraints on water management and plant growth, as well as making the soils susceptible to runoff, regardless of their texture (Coulilaly et al., 2019). According to a 2010 assessment by INERA, about 24% of Burkina Faso's farmland is severely degraded. This poses a threat to the quality of the natural environment and the country's food security in the medium and long

term. Furthermore, the country's soils are characterized by their nutrient deficiencies, particularly in nitrogen and phosphorus (Dembélé & Somé, 1991). They are also rich in silt and fine sand with poor structural stability, low clay content, and low organic matter content (less than 3% under vegetation and 0.7% under crops) (Pieri, 1989).

To address these realities, scientific agronomic work combined with traditional knowledge has helped to identify and reveal innovative agro-ecological technical solutions. Based on the measured use of local resources, agro-ecology aims to integrate into its practice all the parameters of ecological management of cultivated areas, making it possible to reconcile productivity, sustainable management of natural resources, food security and human development while preserving the health of populations (Altieri, 2002; De Schutter, 2011; Dufumier, 2010; Van Walsum, et al., 2014; Francis et al., 2003). These advantages are therefore the foundations for building a more resilient agriculture (USAID, 2012). Stone bunds are, in this context, a promoted technique whose effects on soils and crop yields have been evaluated in the western, northern, and eastern regions of the country (Coulibaly et al., 2018; Yaméogo et al., 2013; Sawadogo et al., 2008, Douamba et al., 2011). However, little research has been conducted on the effectiveness of the technique when the spacing between stone-rows varies.

Hence, the interest of this study in this agro-ecological zone is evaluated the impact of spacing between stone-rows on the chemical and microbiological characteristics of soils, and to determine the optimal spacing.

2. MATERIALS AND METHODS

2.1 Site Description

The study was conducted in the eastern Burkina Faso in the village of Sampieri about 150 km east of Fada N'Gourma city and 20 km west of the commune of Kantchari (on the border with Niger). The climate in this area is Northern-

Sudanian, with a mean annual precipitation of 687 mm and a temperature of 29°C respectively. Geologically, Sampieri is located on a basement resulting from the alternation between Birrimian furrows and granitic terrains (Sattran & Wenmenga, 2002). Soils developed from the granitic bedrock were level subsequently altered, leading to the formation of plinthite or petro-plinthite or petro-plinthite layer. The main soils inventoried in the village are Lixisols (WRB, 2015), which ranged from slightly to highly leached and have a sandy, sandy-clayey or clayey-sandy texture. They are mainly characterized by low levels of nitrogen and phosphorus. Basic soil data for the Sampieri village are given in Table 1. Agriculture (a sorghum, millet, maize system) is the main activity and is family-based, with a set of small plots (about 3 ha) per farmer. Production is predominantly subsistence, but in recent years cash crops such as cotton and sesame have also been developed. The fields for this study had been cultivated for years before being gradually developed with into stone-rows and then amended with compost since 2006.

2.2 Methods

Stone-rows are obstacles constructed along a contour line to reduce runoff velocity and facilitate the sedimentation of soil particles (e.g., sand and organic matter). According to the farmer's organization, the plots on the average sloped terrain were subdivided into three plots P1, P2 and P3 (Fig. 1). These Plots had different stone-rows spacings: 15.5 m for P1, 18.5 m for P2, and 22 m for P3. Within each plot, soil samples were taken at regular ranging from 0 to 15 meters from the bunds. In addition, an extra sample was collected at the end of plots P2 and P3. Samples were taken at the 0-10 cm and 10-20 cm. layers. A total of 120 soil samples were collected from the areas delimited by the stone bunds: 36 samples for plot P1 and 42 samples each from plots P2 and P3. These elementary samples were used to create composite samples. The soil samples were then dried, sieved to 2 mm, and stored for physicochemical and microbiological analyses.

Table 1. Basic soil properties of Sampieri soil (Bunasols, 2008)

Parameter	Clay	Sand	Silt	C	N	C/N ratio	Pa	pH
Unit	%	%	%	mg.g ⁻¹	mg.g ⁻¹	-	ppm	-
Value	8-10	37-51	39-55	4.5	0.4	10-13	1.4	6-6.6

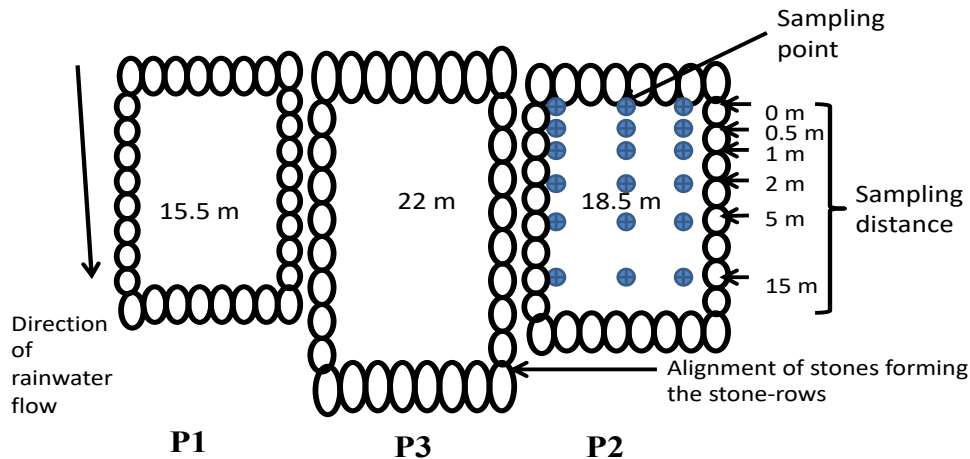


Fig. 1. Plots arranged in stone ridges and sampling plan

The experimental texture kit, Soil Texture Unit (code 1067) developed by LaMotte company (USA), was used to determine the particles size fractions of the soils after sieving at 2 mm. This test was designed to separate the fine earth into three basic mineral fractions (sand from 2 mm to 50 μm , silt from 50 μm to 2 μm and clay less than 2 μm), independent of coarse elements greater than 2 mm. Total nitrogen content was determined using a flash 2000 elementary analyzer (Thermo Fischer Scientific). For this analysis, soil samples were finely ground to a diameter less than 160 μm , placed in a tin capsule, and introduced into a high-temperature furnace (900 $^{\circ}\text{C}$). A helium current with an oxygen supply induced total combustion, and the resulting nitrogen content was quantified by gas chromatography. Total organic carbon content was determined by the Rock-Eval method (Disnar et al., 2003) using a Rock-Eval 6 Turbo (Vinci Technologies, France). This method consists of successively heating a 100 mg finely ground soil between 300 and 650 $^{\circ}\text{C}$ (pyrolysis) and 300 and 850 $^{\circ}\text{C}$ (oxidation). Microbial communities were characterized using the MicroRespTM technique (Campbell et al., 2003), which studies the functional diversity of soil without the need to cultivate microorganisms. This technique measures soil respiration by quantifying the CO_2 emitted. The principle is based on capturing the CO_2 released by the soils incubated in deep 96-well plates using cresol red placed in detection plates. Soil samples (approximately 0.4 g per well) were first moistened to about 60% of their maximum water-holding capacity. In addition to a blank (distilled water), 25 μL of 15 carbon substrates (added at 30 mg C g⁻¹ soil) were used to enrich the

incubated soils. The substrate including glucose, galactose, mannose, fructose, trehalose, sucrose, maltose, mannitol, sorbitol, inositol, glycine, proline, arginine, citrate and malate were chosen based on their complexity and diversity regarding their role in metabolism. Moreover, these substrates are representative of low molecular weight organic compounds released during the decomposition of plant residues and in root exudates (Campbell et al., 2003). All the carbon sources were obtained from Sigma-Aldrich (Saint-Quentin Fallavier, France). The CO_2 released by the soil, after six hours of incubation in the dark at 25 $^{\circ}\text{C}$ was captured by the gel. A chemical reaction occurs between the formed CO_2 and the HCO_3^- ion, which produces H^+ and decreases the pH. This decrease causes a color change in the indicator on the detection plate, from pink to yellow. The color change was measured using a spectrophotometer at the wavelength of 570 nm (Bio-Tek Instrument, Inc., $\mu\text{Quant} - \text{MQX} 200$). Both before and after the six-hour incubation period, to estimate the respiration rate for each well. The CO_2 respiration rate, expressed per gram of soil per hour, was calculated using the formula provided in the MicroRespTM manual (Macaulay Scientific Consulting, UK). The amount of CO_2 produced from the water-added wells was subtracted from the respiration in the substrate wells to accurately calculate the substrate-induced response (SIR). The basal respiration (BR) was calculated from data obtained after soil incubation with water added. Results were expressed in $\mu\text{g C-CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$. The microbial biomass (MB) was calculated from the respiration produced in the glucose amended wells using the equation from Anderson &

Domsch (1978). The metabolic quotient (qCO_2) was calculated according to the equation by Anderson and Domsch (1993): $qCO_2 = \text{basal respiration} / \text{microbial biomass}$. A higher qCO_2 indicated stress or exogenous disturbance (Anderson and Domsch, 1993). The Shannon-Weaver index (H') and equitability index (E) were also calculated to characterize the microbial community. All measurements were performed in six technical replicates.

2.3 Statistical Analysis

The data were compiled in an Excel spreadsheet and then analyzed using ANOVA from XLSTAT 7.5 software. Means were separated using a Tukey's post-hoc test at a 5% significance level. For the MicroResp data, a principal component analysis (PCA) using a correlation similarity matrix was performed to identify separate groups according to the different soil's treatments. For soil microbial diversity, two indices were calculated. The functional diversity, as measured by Shannon-Weaver index (H'), was calculated using the equation: $H' = \sum P_i (\ln P_i)$, where P_i was the ratio of the utilization rate of each C source to the sum of the utilization rate of all C source for each soil sample (Zak et al., 1994). Evenness (E), or Pielou's index was calculated based on the equation of $E = H' / H'_{\max} = H' / \ln S$, where $H_{\max}$ was the largest H' within a specific sample (Zhou et al., 2012) and S was the total number of species, represented here by the total number of substrates tested.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effects of spacing between stone-row lines on soil chemical characteristics

The pH values varied depending on the plot type and depth (Table 2). Thus, in the 0-10 cm layer, the highest values noted for plot P2 (6.89) and plot P1 (6.63), unlike plot P3, where the pH was 6.0. The same trend was observed in the 10-20

cm layer, with pH values of 5.87 for P1 and 6.16 for P2, which were clearly higher than that of P3 (5.2). The pH-KCl values followed the same trend as pH in both layers. For the 0-10 cm layer, the values were 5.98 for P1, 6.02 for P2, and 5.12 for P3. In the 10-20 cm layer, the values were 5.67, 5.95, and 4.46 for P1, P2, and P3, respectively. It was also noted that the pH and pH-KCl of plot P2 were higher than those of plot P1. Furthermore, according to the Tukey's test, significant differences were found between these treatments regardless of the layer (Table 2).

For electrical conductivity, in the 0-10 cm layer, the values were 247.47 $\mu S/cm$ for P2, 175.66 $\mu S/cm$ for P3, and 163.78 $\mu S/cm$ for P1. In the 10-20 cm layer, the same variation was observed, with 147 $\mu S/cm$ for P2, 78.86 $\mu S/cm$ for P3, and 74.83 $\mu S/cm$ for P1. No significant difference was found between the treatments in the 0-10 cm layer. However, in the 10-20 cm layer there was a significant difference between plot P2 and the other treatments (Table 2).

The carbon content of Plot P3 was low compared to that of Plots P1 and P2, regardless of the sampling layer (Fig. 2). The carbon content for Plot P3 varied from 4.23 mg g⁻¹ in the 0-10 cm horizon to 4.10 mg g⁻¹ in the 10-20 cm layer. For Plot P1, the 0-10 cm layer contained 9.18 mg g⁻¹, and the 10-20 cm layer contained 8.38 mg g⁻¹. For plot P2, the carbon content was 8.28 mg g⁻¹ in the 0-10 cm and 6.82 mg g⁻¹ in the 10-20 cm layer. The analysis of variance showed significant differences among Plots P1, P2 and P3, regardless of the layer (Table 3).

Nitrogen contents evolved across the plots and layers (Fig.3). For the 0-10 cm layer, values were 0.48 mg g⁻¹ for P3, 0.54 mg g⁻¹ for P2 and 0.56 mg g⁻¹ for P1. In the 10-20 cm layer, the values were 0.18 mg g⁻¹ for P3, 0.49 mg g⁻¹ for P1 and 0.50 mg g⁻¹ for P2. Analysis of variance showed no significant difference between plots P1 and P2 regardless of the sampling layer; However, both were significantly different from plot P3 on both layers (Table 3).

Table 1. pH; pH-KCl and electrical conductivity of the different plots

Plots	pH		pH-KCl		EC	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
P1	6.63 a	5.87 a	5.98 a	5.67 a	163.78 a	74.83 b
P2	6.89 a	6.16 a	6.02 a	5.95 a	247.47 a	147.00 a
P3	6.00 b	5.20 b	5.12 b	4.46 b	175.66 a	78.86 b

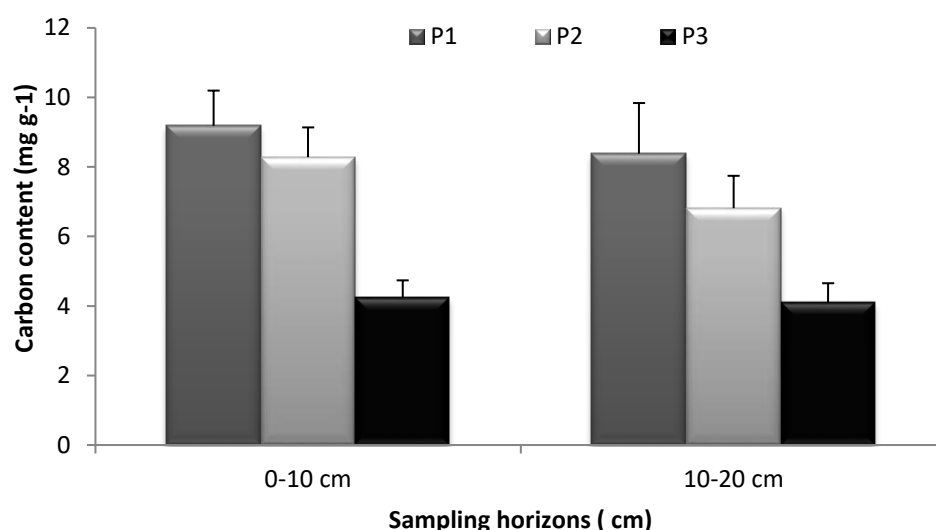


Fig. 2. Organic carbon content of different plots

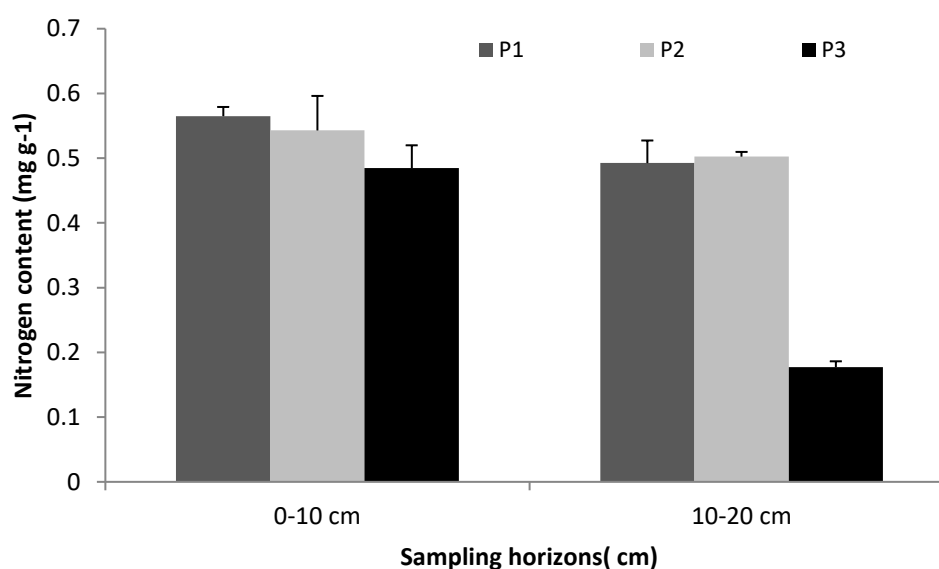


Fig. 3. Total nitrogen content of the different plots

The available phosphorus levels in the plots were generally low (Fig. 4). In the 0-10 cm layer, values of 0.04 mg g⁻¹ were recorded for P1, 0.08 mg g⁻¹ for P2 and 0.02 mg g⁻¹ for P3. These values all increased in the 10-20 cm layer, with P1 at 0.01 mg g⁻¹, P2 at 0.03 mg g⁻¹ and P3 at 0.01 mg g⁻¹. Furthermore, significant differences were observed between P2 and the other treatments at the 5% threshold according to Tukey's test, regardless of the layer (Table 3).

No significant differences were observed for Na⁺ and Mg²⁺ concentrations between the plots,

regardless of the sampling layer (Table 4). For K⁺, there was a significant difference between P1 and the other plots at the 5% threshold for both sampling layers. For Ca²⁺, only plot P2 differed significantly from the other treatments. Regarding cation exchange capacity (CEC), higher values were recorded for P1 and P2 compared to P3 in both layers. Significant differences were observed among P1, P2, and P3 in the 0-10 cm layer at the 5% threshold (Table 4). However, in the 10-20 cm layer, only treatment P2 was significantly different from treatment P3.

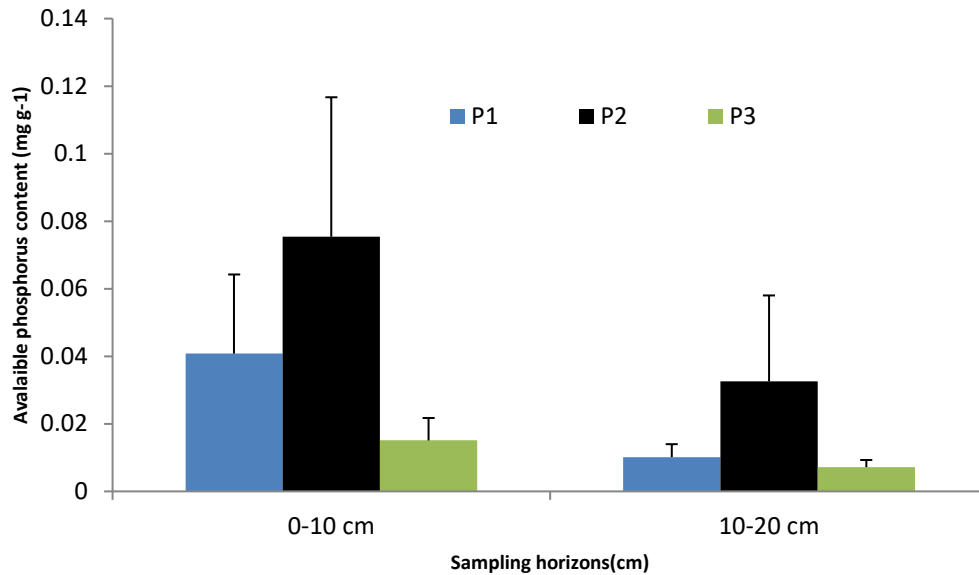


Fig. 4. Content of assimilable phosphorus of the different plots

Table 2. Comparison of average C, N, and Pa contents

Plots	N (mg.g ⁻¹)		C (mg.g ⁻¹)		Pa (mg.g ⁻¹)	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
P1	0.56 a	0.49 a	9.18 a	8.38 a	0.04 ab	0.01 b
P2	0.54 a	0.50 a	8.28 a	6.82 a	0.08 a	0.03 a
P3	0.48 b	0.18 b	4.23 b	4.10 b	0.02 b	0.01 b

Table 3. Exchangeable cations and cation exchange capacity of different plots

Exchangeable cations	Sampling depth	P1	P2	P3
Na ⁺ (meq/100g)	0-10 cm	1.100 a	0.296 a	0.751 a
	10-20 cm	0.313 a	0.893 a	0.407 a
Mg ²⁺ (meq/100g)	0-10 cm	3.000 a	1.972 a	2.138 a
	10-20 cm	3.740 a	2.929 a	2.783 a
K ⁺ (meq/100g)	0-10 cm	1.860 a	0.879 b	0.565 b
	10-20 cm	1.224 a	0.627 b	0.279 b
Ca ²⁺ (meq/100g)	0-10 cm	17.226 b	22.130 a	12.532 b
	10-20 cm	18.991 ab	29.784 a	18.054 b
Sum des EC	0-10 cm	23.186 a	25.277 a	15.986 b
	10-20 cm	24.268 ab	34.233 a	21.524 b
CEC (meq/100g))	0-10 cm	15.450 a	19.908 a	8.117 b
	10-20 cm	24.353 ab	29.412 a	16.187 b

3.1.2 Effects of spacing between stone-rows lines on soil microflora

The Basal Respiration (BR) values for plots P1, P2 and P3 were 0.194 $\mu\text{g C-CO}_2 \text{ g}^{-1} \text{ h}^{-1}$, 0.250 $\mu\text{g C-CO}_2 \text{ g}^{-1} \text{ h}^{-1}$ and 0.122 $\mu\text{g C-CO}_2 \text{ g}^{-1} \text{ h}^{-1}$ respectively. For microbial biomass (MB), a high value of 16.071 $\mu\text{g biomass-C g}^{-1}$ was

noted for plot P2, which was significantly higher than the values for treatments P1 (5.595 $\mu\text{g biomass-C g}^{-1}$) and P3 (6.324 $\mu\text{g biomass-C g}^{-1}$). The metabolic quotient ($q\text{CO}_2$) ranged from 0.031 $\mu\text{g C-CO}_2 \text{ biomass-C g}^{-1} \text{ h}^{-1}$ for P3 to 0.071 $\mu\text{g C-CO}_2 \text{ biomass-C g}^{-1} \text{ h}^{-1}$ for P1. Regarding the diversity index H' , the lowest value observed at plot P2 (2.144). Plots P1 and P3 had

diversity indices of 2.362 and 2.196, respectively. Similar to the diversity index H' , the equitability index was highest in P1, followed by P3, with the lowest value recorded in P2. Despite the observed differences in all these microflora parameters, statistical analysis did not reveal any significant difference between the treatments at the 5% threshold according to the Tukey's test.

3.1.3 Fertility Gradient with Slope

Following the initial results on plot sizes, we examined whether there was a soil fertility

gradient depending on the position within the plots. Tables 5 and 6 give the values of the various soil fertility parameters at the different sampling points. It should be noted that there was no discernable pattern based on the distance from the stone bund lines.

Furthermore, the results showed that there was no strong correlation between the contents of carbon, nitrogen, and the sampling distance regardless of the sampling layer (similar to pH, as shown in Fig. 5).

Table 4. pH and electrical conductivity

Distance to the stone-row line	pH		pH _{KCl}		EC	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
0	6.12	5.68	5.63	5.04	276.77	92.33
0.5	6.64	5.99	5.74	6.05	188.06	143.38
1	6.47	5.60	5.49	5.38	225.94	132.97
2	6.68	6.04	5.65	5.59	186.70	131.09
5	6.65	5.51	5.93	4.90	134.45	58.50
15	6.49	5.66	5.81	5.18	161.90	65.15

Table 5. Carbon, nitrogen and available phosphorus content

Distance to the stone-row line	N (mg.g ⁻¹)		C(mg.g ⁻¹)		Pa (mg.g ⁻¹)	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
0	0,505	0,384	7,67	5,83	0,034	0,017
0.5	0,523	0,400	6,83	7,17	0,055	0,015
1	0,557	0,377	7,37	6,90	0,051	0,030
2	0,552	0,383	7,03	5,87	0,052	0,019
5	0,515	0,386	7,40	6,67	0,025	0,010
15	0,535	0,415	7,10	6,17	0,045	0,010

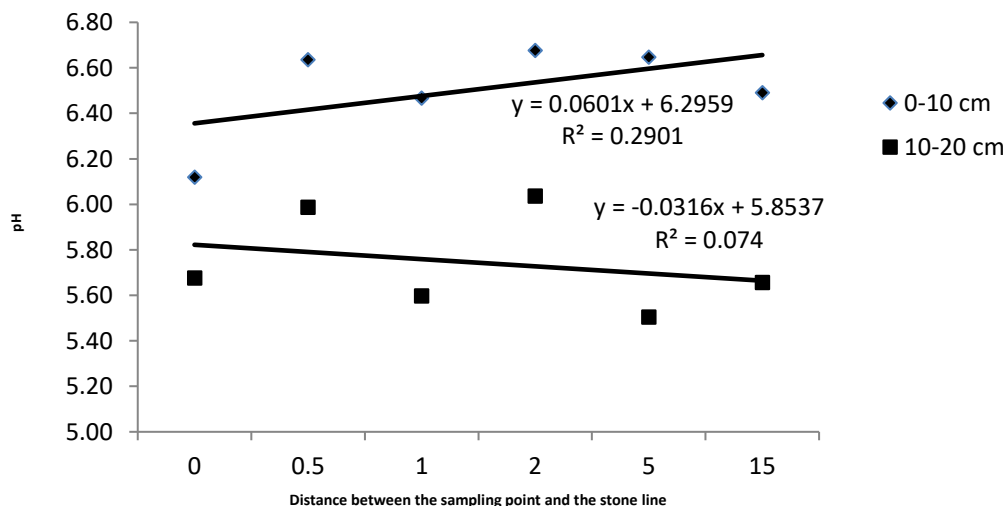


Fig. 5. Relationship between sampling distance and soil pH

The measured biological parameters, including basal respiration, microbial biomass, metabolic quotient, H' diversity and E equitability indices, showed significant variability depending on the sampling distances. For example, microbial biomass showed a variable trend with distance: increasing from 0 to 1 m; then decreasing at 2 m, followed by a considerable increase at 5 m, and a drastic decrease at 15 m. therefore, a clear fertility gradient was not established as a function of sampling distance.

3.2 Discussion

While very little work has been done exclusively on the effects of spacing between stone bunds, contrary to our expectations, we were unable to establish a soil fertility gradient from the top to the bottom of the plots along the slope, regardless of the parameters measured. This could be explained by the non-uniform distribution of organic matter inputs on these plots. Zougmore et al. (2004) had indeed proven the role of organic matter in the success of Soil and Water Conservation (SWC) techniques. Specifically, indeed, the mature compost is first deposited in piles in the fields before being spread and buried by surface plowing. This process may explain the differences observed within the same plot. This is all the more true since, at the scale of individual plots, we observed differences between treatments P1, P2 and P3 for physical and chemical parameters. We note a clear improvement in the effect of inputs on plots P1 and P2 compared to plot P3, which is larger. We could therefore conclude that the smaller the plot, the more controlled the inputs are and the more the effects are felt on the soil characteristics. However, the fact that there is no significant difference between P1 and P2 shows that there is a reasonable threshold (a profitability threshold of approximately 18.5 meters) beyond which the induced effect is no longer significant. Regarding the biological parameters there were no differences between plots P1, P2 and P3. In other studies, Ballo and al., (1994) already drew the attention of agronomists to the dimensions to be given to agricultural plots. Contrary to our results Kiema and t al., (2012) had shown that the positive effect induced by stone barriers is observable over a distance of 20 m. Similar studies have shown the beneficial effect of reducing the

distance between stone bund lines on runoff and agricultural production (Zougmore et al., 2000) and on the physical, chemical and biological characteristics of soils (Zougmore et al., 2002). Like Zougmore et al. (2000), Sanon in 2014 worked on spacings of 33 m and showed clear improvements in soil characteristics thanks to stone-rows.

As for the second part of this work, it should be noted that no prior work has been conducted on the subject. Nevertheless, like the internal work on the spacing of stone lines, it can be said that fertility is uniform in the space between the stones lines.

4. CONCLUSION

We can note that very little research has been devoted exclusively to investigating the effect of spacing between stone bunds on soil fertility parameters. However, our results have shown that the smaller the distance between rows, the more significant the effect on soil chemical parameters up to a spacing of 18.5 m between rows. This leads us to believe that this distance is a reasonable threshold for their implementation in this area. Additionally, the results of the fertility gradient test confirm this finding. Conversely, this is not the case for microbiological parameters, which highlights the need to further explore this work in this area. Furthermore, this work is in line with the policy of sustainable management of agricultural land in our country. This work thus proposes an alternative in the implementation of the National Strategy for the Recovery of Degraded Lands.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

The authors have declared that they have no known financial interests or personal relationships that could be construed as influencing the work reported in this paper.

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