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Assessment of the Influence of *zaï*, Stone Rows, and Organo-mineral Fertiliser on Soil Properties and Groundnut Yields Performances in Sudan Sahelian Zone of Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundnut occupies a vital position in oilseed crop production in Burkina Faso, with current production at 630,526 tonnes. However, its production faces threats from drought and low soil fertility. This study aims to determine the influence of zaï, stone rows, ridge tillage, and mineral fertilisation on soil health and on groundnut yields performances in Sudan Sahelian zone of Burkina Faso. Experimental treatments were distributed randomly following a Fisher block design, comprising four treatments and five replications, in the village of *Sandogo*. Data on soil properties, plant growth, and yields were analysed using variance analysis in R software.

The results indicate significant influences of the treatments on carbon content, nitrogen content, phosphorus content, pH values, soil moisture content, soil carbon dioxide release, and soil macrofauna. Moreover, notable effects were observed on the number of nodules, drier nodule weight, number of leaves and branches, pod load, pod and straw yields, and the weight of 100-pods. The highest carbon content (0.857; 0.861%), nitrogen content (0.081%; 0.087%), phosphorus content (7.488; 7.735 mg.kg^{-1}), pH values (6.43; 6.54), and soil moisture content (24.80; 25.27%) were recorded in the homogeneous group of *zaï* and *zaï* associated to stone rows. The highest carbon dioxide release (2863.33 ppm) was recorded in plots treated with stone rows. Ants were the most widely encountered macrofauna, whereas no earthworms were recorded. The highest performance in terms of the number of nodules (84.76; 87.88), dry nodule weight (0.0893; 0.0886 g/plant), number of leaves (40; 40), number of branches (6; 6), pod load (25; 25), weight of 100-pods (112.90; 111.98 g), straw yields (1673.28; 1664.87 kg.ha^{-1}), and pod yields (2122.32; 2161.96 kg.ha^{-1}) were achieved with *zaï* and *zaï* combined with stone rows.

Zaï and *zaï* combined with stone rows can therefore be used as effective alternatives to improve groundnut production in the Sudan Sahelian zone of Burkina Faso in a context of climate change, while protecting the environment.

Keywords: Agroecology; ants; earthworms; nodules; stone rows; termites; zaï.

1. INTRODUCTION

In Burkina Faso, groundnut (*Arachis hypogaea* L.) is an important annual legume produced throughout the country. It occupies a major place in the cash crop sector with production doubling over the decade. Thus, it increased from 265,322 tonnes in 2011 to 646,303 tons in 2021 [1,2]. The area under groundnut has increased from 388,704 hectares in 2011 to 670,798 hectares in 2020. Groundnut is an improver of nutritional quality and human health due to its richness in digestible proteins (25-30%), high quality and content oils (35-56%), carbohydrates (9.5-19%), minerals elements (P, Ca, Mg, K, Zn and Fe) and vitamins [3]. Groundnut is widely grown thanks to its wide adaptability useful for ecosystem (soil health improvement through crop rotation, intercropping, and nitrogen fixation) and multiple uses by both human, and animal: food, feed, paints, lubricants, insecticides [4,5]. Like other countries [6], Burkina Faso exports groundnut mainly in the form of pods, kernels, and oil cakes. Yields have varied from 671 kg.ha^{-1} to 917 kg.ha^{-1} from 2011 to 2020 but remain lower than the Sub-Saharan Africa average (964 kg.ha^{-1}), its potential (2500 kg.ha^{-1}), and those in developed countries (4,500 kg.ha^{-1} in the United States and 3,810 kg.ha^{-1} in China) [7]. This low yield level in Burkina Faso is attributable to various constraints such as frequent droughts, low soil fertility, climate change, lack of financial and technical support, lack of promotion of the crop, pest and diseases, and poor crop management. Regarding soil fertility and drought problems, several studies have shown the impacts of *zaï*, stone rows, ridge tillage and fertilizer microdosing practices on both the soil chemical and physical properties, and on crop yields. *Zaï* is an ancient peasant technique rediscovered after the great drought of 1973/1974 and then developed by various stakeholders working with farmers. It involves digging sowing pits about 30 to 40 cm in diameter and 10 to 15 cm deep. The distance between the holes is 70 to 80 cm. The pits are dug perpendicular to the slope and staggered rows. *Zaï* technology is most practiced in Burkina Faso, Ethiopia, Mali and Niger [8,9]. It also is called “Tassa” in Niger and is an intervention that improves precipitation capture, reduces runoff and evaporation, and increases agricultural productivity [10,9]. According to Oduoret al [11], *zaï* combined with manure can lead to improved soil chemistry (nitrogen and phosphorus) and an increase in crop yields. Stone rows are anti-erosive devices built of blocks of rubble assembled by series of two to three. They are constructed in lines along a contour after stripping 10 to 15 cm of soil along the line. The tops of the stones reach a height of 20-30 cm from the ground. The distance between the stone rows is 20-50 m depending on the slope. Stone rows help to combat water erosion by slowing down runoff. This benefits water infiltration and prevents the loss of rainwater. They also promote the sedimentation of fine soil particles carried along by water and manure. The application of compost with stone rows reduce runoff and increase soil water storage and sorghum biomass production [12]. Ridging is a ploughing technique that results in the formation of a series of ridges called "*ados*". The ridging is done perpendicular to the slope. These ridges are made with a gentle slope (0.1 to 0.2%) to avoid overflow during heavy rainfall. The distance between two ridges is 0.60 m for groundnuts. The prowess of ridging on crop yields and soil has been widely mentioned by some authors. Indeed, the ridging technique had a positive effect on the production of fresh tuberised roots by an increase of 62.79% [13]. Ridging improves maize productivity compared to direct seeding. Indeed, the best indices (foliar, harvest), growth rates and yields (grains, stalks, spathes, straw) were obtained with ridging [14]. Microdosing is a strategic application of small quantities of fertilizers in the planting pit or to the base of the plants shortly after planting. It is promising in terms of the plant fertilizer use efficiency and the input optimization by its application directly in the root zone leading to enhanced nutrient extraction by the crop [15]. This technique showed good results in West Africa (Burkina Faso, Mali and Niger) by increasing yield of pearl millet and sorghum (44-120%) [16], cowpea (97%), groundnut (26%) and sesame (42%) [15]. Since pockets of *zaï* make it possible to improve water infiltration and store the organic matter resulting from the application of manure, and the stone rows reduced the speed of water run-off, thereby reducing erosion and encouraging the retention of organic manure applied around the rows. Their effects, combined with the application of mineral fertilizer using the microdose technique, help to ensure the availability of the nutrients needed by plants, while conserving the soil and environment. However, the effects of *zaï* and stone rows on groundnut and soil biological properties are either almost nonexistent or have been scarcely investigated. In the context of climate change and the importance of groundnuts and their derivate products, an investigation should focus on the response of groundnut to indigenous soil and water conservation techniques combined with soil fertility management options. Our study aimed to determine the influence of *zaï*, stone rows, and ridge tillage combined with manure and mineral fertilizer microdosing on soil properties, nodulation, growth, and yield component of groundnut.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was carried out in the village of *Sandogo*, located in the Plateau Central region of Burkina Faso. The site is positioned on an upper slope at coordinates 30P 0648463, UTM 1397258. *Sandogo* falls within the Sudanese-Sahelian climate zone, featuring an annual rainfall between 600 mm and 900 mm. The rainy season is short, not exceeding four months (June to September), and is characterized by average annual thermal amplitudes, followed by a dry season of 8 months (October to May). Over the past 30 years (1991-2020), the rainy season has shown significant inter-annual variability in time and space with an average annual rainfall of 780.91 mm. Temperature maxima have ranged from 34.49 to 36.04 ℃, and minima from 21.54 to 23.46 ℃. Wind speeds have varied from 1,486 to 3,151 $m.s^{-1}$, and average humidity from 47.61 to 52.71%. Evapotranspiration (ETP) rates have fluctuated between 5.32 mm and 6.17 mm (ANAM, 2020). The soil is classified as moderately fertile (Table 1).

2.2 Experimental Design and Crop Management

The trial was arranged in a randomized Fisher bloc design with four treatments (Table 2) and five replications. The blocks, made up of groups of homogeneous experimental units, were oriented perpendicular to the slope. The treatments were composed of Ridge tillage as a control, *Zaï*, Stone Rows, *Zaï* + Stone Rows. Organic manure was applied at a dose of 5,000 kg. ha^{-1}. Groundnut was sown at 0.6 m x 0.15 m spacing, *i.e.* 110,000 plants per hectare at a rate of 60 kg. ha^{-1}. The treatments were applied on plots of 20 m x 3.5 m size separated at intervals of 1 m x 10 m. The complex fertilizer NPKSB was applied 21 days after sowing in a microdose, *i.e.* 0.57g/plot. Weeding was conducted manually. Harvesting of groundnut took place 96 days after sowing (DAS) in 2021 and 105 DAS in 2022.

2.3 Agronomic Practices

Prior to the experimental design implementation, we conducted a field investigation based on both pedological pit description and soil sampling. For pedological pits, soil descriptions and classification were conducted following the guidelines for soil description by the FAO and adapted by BUNASOLS to the agro-climatic conditions of Burkina Faso. One soil sample was collected from a pedological pit within the 0-15 cm horizon and analysed for the following parameters: cation exchange capacity (CEC), pF (2.5 and 4.2), texture, pH, soil organic carbon, total nitrogen, total phosphorus, available phosphorus, total potassium, available potassium, exchangeable bases, and particle size distribution (Table 1).

Table 1. Soil chemical and physical properties before planting groundnut

Parameter	Value	Quotation
Organic Matter (%)	1.35	3
Total Nitrogen (%)	0.08	3
Total potassium (ppm)	982.86	2.75
Available potassium (ppm)	80.90	3
Total phosphorus (ppm)	30.90	2.5
Available phosphorus (ppm)	5.43	2.5
Cation Exchange Capacity (CEC) (méq/100g)	6.45	2.5
Sum of Exchangeable Bases (SEB) (méq/100g)	3.77	2
Base saturation (BS) (%)	58	3
pH_{H2O}	5.79	4
Total cotation		28.25
Class of Fertility	Medium	
Sand (%)	70.59	
Silt (%)	13.72	
Clay (%)	15.69	
Texture class	Loam-sandy	

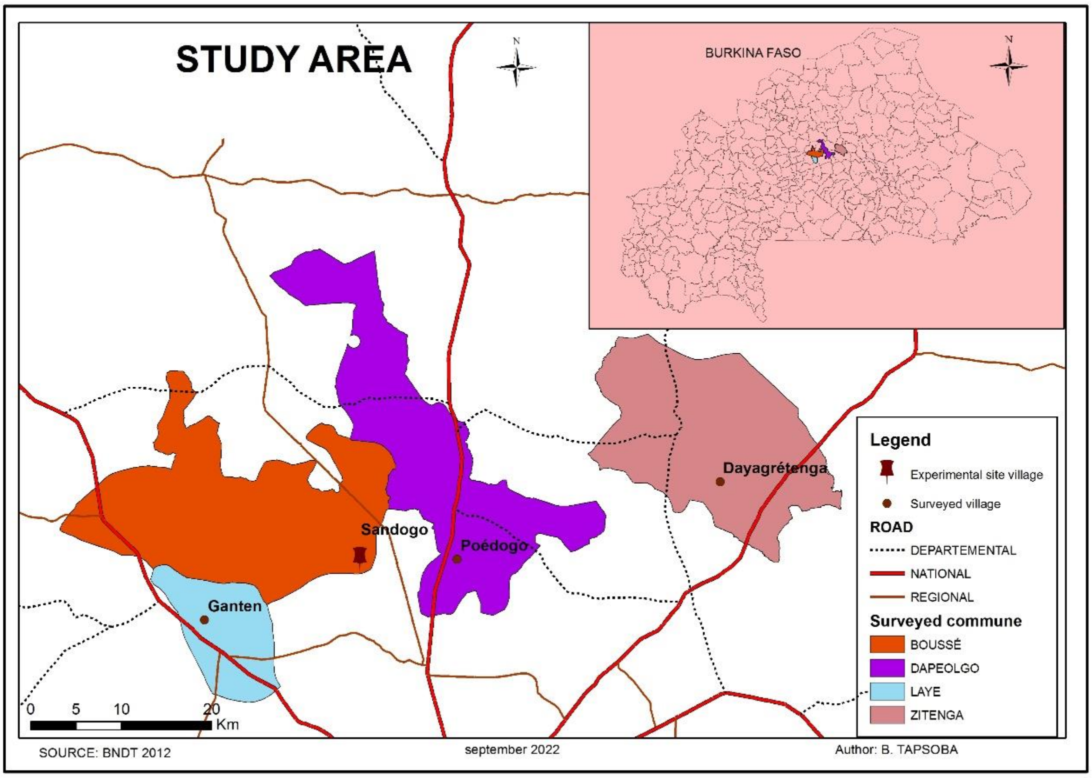

Fig. 1. Map of the study area

2.4 Plant Data Collection

Number of leaves, branches, and flowers: Five plants were selected from each elementary plot. The number of leaves, flowers, and branches was carefully counted. The number of flowers was counted before the plants were uprooted. The counting of leaves and branches was done after the uprooting.

Nodulation: From the row next to the two border rows, five plants were selected. These plants were carefully uprooted with a pickaxe, and their roots were washed on a sieve under running water. The plants were then placed on a paper towel in the shade to air dry. Subsequently, the nodules were carefully detached from the roots by hand and left to dry in ambient air for two weeks. The total number of nodules from the five plants was divided by 5 to obtain the number of nodules per plant, and the corresponding weight was divided by 5 to obtain the dry weight of nodules per plant.

Pod yield: Plants in the valuable surface of each plot were harvested and the pods picked from the roots and dried in the sun on a concrete floor for a sufficient number of days and then weighed using a digital balance.

Pod load: Five plants were randomly selected from the harvested lot and their pods were detached, counted and the number recorded. This value was averaged over the five plants to obtain the pod load, which is defined as the average number of pods produced by one plant.

Seed-weight: In order to determine the average seed size/weight, about 100 pods were randomly selected per treatment, shelled and the seeds were mixed; from this number 100 seeds were picked and weighed to estimate the average seed weight.

Haulm yield: After pod removal from the harvested plants from the relevant surface, the remaining biomass was weighed and recorded as the field weight. In order to determine the moisture content of each lot of haulm, aliquots of fresh biomass were taken and transported to the laboratory; they were weighed, air-dried for two weeks and then reweighed to obtain the quantity of dry matter with a constant weight. The percent moisture content of the sub-sample and the field weight of the bulk haulm were used to calculate the dry weight of the bulk haulm. This value was used as the basis for calculations to obtain the average yields in t ha^{-1} of groundnut per treatment.

2.5 Soil Data Collection

Soil moisture content was measured using a portable moisture meter. Soil texture was determined through the study of the granulometric fractions (3 fractions) which was determined by the international Robinson pipette method. Soil macrofauna assessment was realized using the Tropical Soil Biology and Fertility method [17]. Soil respiration was measured to assess the potential of the biological activity of the soil by using an IRGA respirometer. Soil pH was measured with a glass electrode using a 1:2.5 soil to water ratio by AFNOR [18] method. Soil organic carbon (SOC) was determined by Walkley et al [19] method. Soil total nitrogen (N) was determined by Kjeldahl method taken back by Novozamsky et al [20]. Soil available phosphorus was measured by Bray and Kurtz [21]. Soil cation exchange capacity (CEC) and exchangeable cations were determined by using the silver thiourea acid (AgTu) method at a concentration of 0.1 M silver thiourea acid (AgTu) with a concentration of 0.1 M $(AgH_2\ NCS\ NH_2)_2^+$. Total phosphorus was quantified after a mineralisation with perchloric acid ($HClO_4$) using spectrophotometry. Total potassium was analysed by flame photometry following mineralization.

2.6 Data Analysis

The data obtained were subjected to analysis of variance (ANOVA) using R.4.2.1 and significantly different treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance. Several parameters were used to describe the macrofauna of the sites: specific diversity, equitability index (EI), number, and biomass. The Shannon Index expressed specific diversity: $H' = -\Sigma\ (pi\ \ln\ pi)$, where H': Shannon's biodiversity index, i: a species in the study area, pi: the proportion of a species i to the total number of species (S) in the study area (or species richness of the area), which is calculated as follows: $p(i) = ni / N$ where ni is the number of individuals for species i and N is the total number of individuals (individuals of all species). The Equitability Index (IE) translates the relative abundance of the different species within the stand: $IE = H'/\ln S$, where S is the specific richness of the population. Abundance was used to express the number of individuals of a species per unit area. Finally, biomass, the total mass of living macrofauna present in a unit area, was used to express the importance of the different species on the sites.

3. RESULTS AND DISCUSSION

3.1 Biological, Chemical and Physical Properties of the Experimental Soil

Based on the description of the open soil profile, the type of soil identified is indurated leached tropical ferruginous soil. This soil belongs to the class of soils with iron and/or manganese sesquioxide [22]. The soil has a depth limited to 35 cm by a ferruginous shell. The colour is brown (10YR 5/3) when dry and dark yellowish brown (10YR 3/4) when wet down to 15 cm. The texture is silty-sandy from 0 to 15 cm and silty-clay-sandy from 15 to 35 cm. There is 50% ferruginous gravel on the useful 15 cm. The drainage is moderate. The structure is weakly developed with polyhedral and subangular aggregates. The consistency is soft on the surface and hard at depth. Roots are numerous. The soil has good porosity and biological activity and is well developed. Variations within the profile include the type of induration (plinthite or petroplinthite), the depth at which induration appears (less than 40 cm), and the coarse element content varying between 50 and more than 70%. There are numerous spreads of gravel and ferruginous pebbles. The analysis reveals that this upper slope soil has a high organic matter (OM) content (2.674%) but is highly mineralized (C/N= 12). The cation exchange capacity (6.45 $cmol^+.kg^{-1}$) and the sum of exchangeable bases (3.77 $cmol^+.kg^{-1}$) are low, with an average saturation rate of 58%. The soil has a high level of nitrogen (0.125%), and an average level of available potassium (80.90 $mg.Kg^{-1}$), but low levels of available phosphorus (3.99 ppm). The soil is highly acidic (pH-H_2O=5.22) with a cumulative carbon dioxide release of 5,670 ppm.

3.2 Effects of Soil Management on Soil Properties

3.2.1 Effects of soil management on soil moisture content

The soil and water conservation practices had a significantly high effect on soil moisture content. From 40 DAS to 80 DAS and during 2021 and 2022 (Table 2 and Table 3), the treatments Z and Z_SR showed higher moisture content than Stone rows (SR) and Ridge tillage (RT). The moisture content in *zaï* pits was accentuated byh the combination with stone rows, though statically not significant. From 50 DAS to 80 DAS, the moisture content was almost the same across all treatments. Compared to RT at 40 DAS, SR, Z, and Z_SR increased the moisture content by 1.66%, 27.77%, and 29.66%, respectively. Compared to RT at 40 DAS, SR, Z, and Z_SR increased the moisture content by 8.13%, 18.93%, and 22.73%, respectively in 2022. The increases of moisture content due to SR, Z, and Z_SR were 2.09%, 19.53%, and 20.15%, respectively at 50 DAS. The increases in soil moisture content were 3.25% for SR, 15.40% for Z, and 19.85% for Z_SR at 60 DAS compared to RT. Z and Z_SR increased the moisture content by 14.95% and 14.09%, respectively on 70 DAS, and SR showed a moisture content less than RT. At 80 DAS, Z and Z_SR increased the moisture content by 12.37% and 14.50%.

The results showed a significant increase in surface soil moisture within the seed-hole compared to ridge tillage and stone rows. These results show that *zaï* pits play an important role in soil moisture quality. The Z and Z_SR record the highest moisture levels. That situation is due to *zaï* pits that have been amended with organic fertilizer and increased fine particles caused by the soil engineers [23]. This mixture of organic manure and fine soil limits water losses by filtration as well as evaporation losses. This corroborates the results of Kebenei et al [24], who found that *zaï* holes, by capturing water, significantly improve the amount of water available in the soil and thus increase the water retention and infiltration capacity of the soil. The low water content noted on the ridge-plowed soils could be explained by runoff due to the lack of organic inputs. Indeed, organic matter increases the water retention capacity of the soil [25]. In addition, it is this manure supply associated with ridging that has led to higher moisture in stone strips than in ridge plowing.

3.2.2 Effects of stone rows and *zaï* on soil carbon dioxide release variability

There was a strong effect of soil management on cumulative CO2 emissions in 2021 (P=0.0131). Two homogeneous groups pointed out: the first group formed by the soils under SR treatment (5203.33 ppm); the second group is formed by soils under RT (2620 ppm), Z (2752 ppm), and Z_SR (3307.33 ppm) treatments. The highest clearance was recorded in the stone rows soil (Table 4). The ridge tillage soil had the lowest cumulative CO2 release, and statistically similar to Z and Z_SR. Thus, outside of the *zaï* pits, soil respiration does not differ from that of the ridges and stone rows. There was no influence of practices on CO2 release in 2022 (P=0.76). All treatments, statistically, recorded the similar soil respiration. Our results showed a significant difference between soil CO_2 release under the four treatments in 2021 and not significant in 2022. In 2021, the SR treatment recorded more cumulative CO_2 than the other treatments. Then, the stone cordon arrangements stimulated higher carbon dioxide release than the other treatments. This is explained by the organic manure input and the ridging, which increased the organic matter content of the soil, as organic inputs and tillage condition the dynamics of the soil's biological activity potential [26]. The higher water retention capacity of the soil can also explain our results under stone rows, as water availability has a positive influence on soil respiration [27–29]. Thus, organic inputs, ridging, stone cordons, and soil water content positively influence soil biological activity.

3.3 Effects of Soil Management on Soil Macrofauna

The inventory carried out allowed the identification of forty-five (45) species under the four (4) treatments applied to groundnut. These identified species belong to twelve (12) orders and thirty-four (34) families. In both seasons, there was no significant difference in the number of macrofauna between the treatments. The diversities remained low during the two years of experimentation, with Shannon's diversities index below 3. In 2021, the Shannon diversity index showed that RT and Z had the richest macrofauna community with IS = 1.3863 each (Table 5). These treatments are followed by SR, Z_SR with IS values of 0.9404 and 0.6365, respectively. In 2022, the Shannon diversity index showed that the ridge tillage stimulated macrofauna richness (H'=2.8804). It is followed by *zaï associated with stone rows*

Table 2. Effects of *Zaï, stone rows and Ridge tillage* on soil moisture content in 2021

Treatment	40_DAS	50_DAS	60_DAS	70_DAS	80_DAS
RT	5.368±0.38**b**	5.067±0.36**b**	5.795±0.39**b**	5.745±0.41**c**	5.384±0.34**d**
SR	5.457±0.63**b**	5.176±0.55**b**	5.966±0.47**b**	5.894±0.43**c**	5.694±0.35**c**
Z	6.859±0.46**a**	6.423±0.48**a**	6.981±0.40**a**	6.854±0.37**ab**	6.647±0.34**a**
SR_Z	6.960±0.47**a**	6.462±0.45**a**	7.193±0.24**a**	7.107±0.21**a**	6.873±0.19**a**
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Signification	***	***	***	***	***

Table 3. Effects of *Zaï*, Stone rows (SR) and Ridge tillage (RT) on soil moisture content in 2022

Treatment	40_DAS	50_DAS	60_DAS	70_DAS	80_DAS
RT	22.87±1.80**c**	22.53±1.39**b**	22.47±1.12**bc**	23.20±0.51**b**	22.07±0.72**b**
SR	24.73±1.09**b**	23.00±1.25**b**	23.20±1.15**b**	21.87±1.50**c**	20.73±1.04**b**
Z	27.20±1.52**a**	26.93±0.72**a**	25.93±0.43**a**	26.67±1.18**a**	24.80±0.77**a**
Z_SR	28.07±1.64**a**	27.07±0.83**a**	26.93±1.36**a**	26.47±0.87**a**	25.27±1.16**a**
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Signification	***	***	***	***	***

Table 4. Dynamic of soil carbon dioxide release under groundnut production

Treatment	Groundnut (means± stdev)	
	2021	2022
RT	2620±319.56**b**	2352.00**a**
SR	5203.33±393.03**a**	2863.332**a**
Z	2752±245.82**b**	2826.00**a**
Z_SR	3087.33±205.80**b**	2720.00**a**
P-value	0.0131	0.76
Signification	*	**NS**

RT= Ridge Tillage, SR= Stone Rows, Z= Zaï, Z_SR= Zaï Associated with STONE Rows. n=5; stdev = Standard Deviation, means with the same letter are not significantly different at threshold 5%

(2.8704), stone rows (2.5943) and *zaï* with H'=2.4904 (Table 5). Three (3) species of ants were recorded. These species are: *Pogonomyrmex sp.*, *Monomorium pharaonis*, and *Camponotus pennsylvanicus.* The Tramp ants (*Monomorium pharaonis*) remained the most numerous. Three (3) species of termites were recorded: *Microtermes upembae, Odontotermes mukimbunginis* and *Macrotermes sp.* These termites were essentially mushroom termites and were recorded on soils under the stone rows treatment. The environment created by stone rows is propitious for termites' development. Outside *zaï* pits, the environment is not suitable for termites' productivity. No earthworms were identified. Only the SR treatment recorded termites. Ants were more numerous in the SR, RT, and Z_SR treatments. The groundnut crop may not be conducive to the development of earthworms. The families of termites and ants encountered are Termitidae and Formicidae. These families feed more on foods rich in cellulose and lignin. Their presence can be explained by the availability of additional food constituted by the cellulose and lignin brought by the organic matter [30] resulting from the contribution of organic manure. Earthworms' non-existence in our soil could be due to the combination of soil and nitrogen from NPK fertiliser and groundnuts. Indeed, deep, silty soils with good water retention capacity and rich in organic matter are suitable for the development of earthworms [7,31,32].

3.4 Effects on Soil Carbon, Nitrogen, Available Phosphorus Content, and pH

Z, Z_SR and SR treatments positively influenced C, N, P and pH values. Treatments significantly affected the variation in total carbon ($p<0.001$), total nitrogen ($p<0.001$) and available phosphorus ($p<0.001$), and pH values ($p<0.001$). However, C/N ratio was not influenced ($p=0.417$). The analysis of variance (ANOVA) of C, N, and P results showed three statistically different homogeneous groups (Fig. 2a; Fig. 2b and Fig. 2c): Z and Z_SR form the first group. The second group contains the SR and RT represents the third group. The pH results reveal two statistically different homogeneous groups. Z and Z_SR form the first group. The second group contains the SR and RT treatments. The highest C, N, P content, and pH values were recorded under the Z and Z_SR treatments, which form a homogeneous group. The lowest nutrients content and pH values were recorded with RT treatment (Fig. 2e). This is due to manure, chemical fertilizers, *zaï* pits, and biomass input from groundnut. Indeed, the fall of groundnut biomass provides the soil with huge amounts of organic matter after their mineralization [33] and can provide important nutrients to the soil including C, P, and N, basic elements of plant tissues as well as exchangeable soil cations such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. In addition, Tanoh et al. [34] had mentioned the reduction of nitrogen leaching by the accumulation of organic matter by *zaï* pits. Furthermore, the decomposition of the manure provided would increase the organic matter content. This increase in the organic matter would contribute to improved soil organic carbon content, fertilizer element contents, and higher pH values [35]. *Zaï* pits combined with manure and micro-dose fertilizer on groundnut could be a form of adaptation to the adverse effects of drought sequences.

3.5 Effects of Soil Management on Agronomic Parameters of Groundnut

3.5.1 Effects of soil management on pods loads, nodules, leaves, and branches

Analysis of variance indicated that the treatments had significance influence (Table 6) on pod loads ($P = 0.0061$), nodulation ($P = 0.0001$), drier nodule weight ($P = 0.0008$), leaf formation ($P = 0.0015$), and number of branches ($P = 0.0137$).

Table 5. Effects of *Zaï, stone rows and Ridge tillage* on Shannon diversity Index and Equitability Index of macrofauna

Treatment	RT		SR		Z		Z_SR	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
H'	1.3863	2.8804	0.9404	2.5943	1.3863	2.4904	0.6365	2.8704
IE	0.5438	0.6000	0.2714	0.5434	0.5438	0.5278	0.2814	0.5886

H'= Shannon Diversity Index, IE= Equitability Index, RT= Ridge Tillage, SR= Stone Rows, Z= Zaï, Z_SR= Zaï Associated with Stone Rows

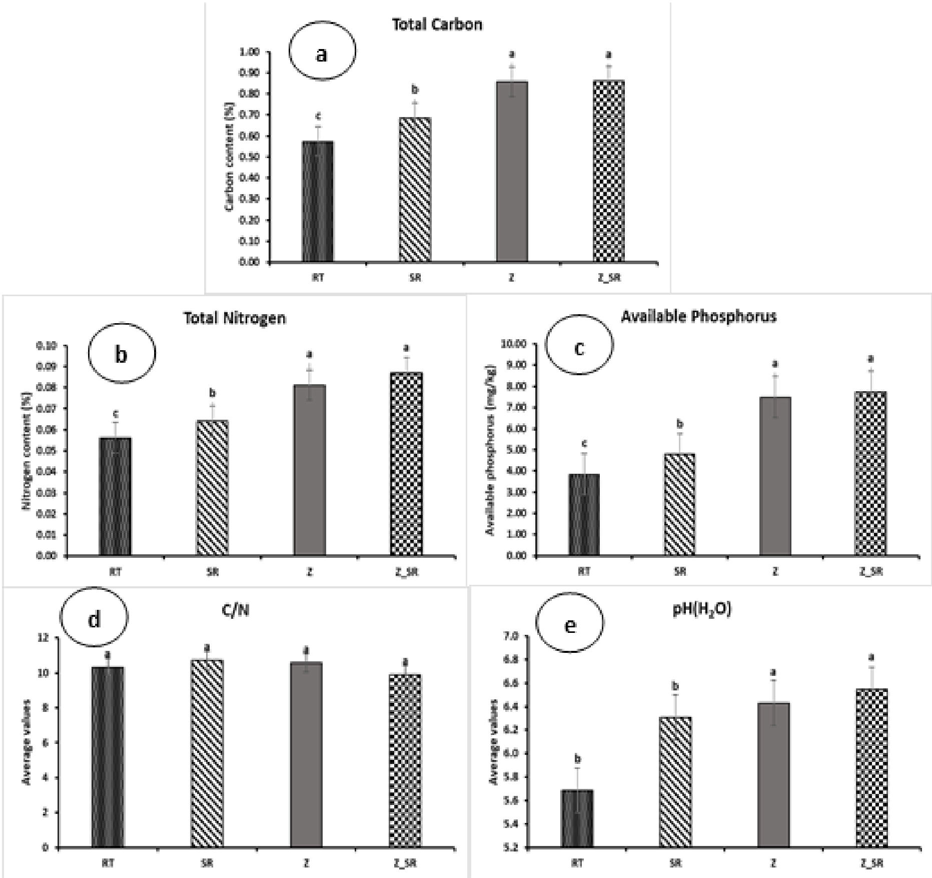

Fig. 2. Effects of *Zaï*, Stone rows (SR) and Ridge tillage (RT) on soil chemical properties

Table 6. Effects of *Zaï,* Stone rows (SR) and Ridge tillage (RT) on agromorphologic parameters

Treatment	Pod Load/Plant	Nodule Number/Plant	Nodule Dry Weight (g/plant	Leaf Number/Plant	Branch Number/Plant
RT	17.92±1.42**b**	58.48±14.30**c**	0.0411±0.01**b**	31.20±2.78**b**	5.24±0.17**b**
SR	17.24±1.60**b**	70.40±11.84**b**	0.0672±0.02**a**	37.56±2.77**a**	5.92±0.30**a**
Z	25.44±5.95**a**	84.76±15.88**a**	0.0893±0.01**a**	39.80±1.08**a**	6.08±0.66**a**
Z_SR	25.24±5.21**a**	87.88±14.09**a**	0.0886±0.02**a**	40.20±5.05**a**	6.32±0.58**a**
P-value	0.0061	<0.0001	0.0008	0.0015	0.0137
Signification	**	***	***	**	*

RT= Ridge Tillage, SR= Stone Rows, Z= Zaï Pit, Z_SR= Zaï Pits Combines to Stone Rows. n=5; stdev = Standard Deviation, mean with same letter are not significantly different at threshold

Table 7. Effects of *Zaï,* Stone rows (SR) and Ridge tillage (RT) on Pod yields and 100-seed weight

Treatment	Pod Yield (kg ha^{-1})		100-Seed WEIGHT (g)	
	2021	2022	2021	2022
RT	392.54±3.96**b**	1645.31±28.15**b**	69.78±.3.49**c**	91.56±1.23**b**
SR	397.48±.4.35**b**	1641.95±17.20**b**	75.84±1.86**b**	94.02±2.44**b**
Z	1124.65±.3.76**a**	2122.32±38.02**a**	90.38±1.91**a**	112.90±2.64**a**
Z_SR	1126.67±.5.11**a**	2161.96±36.52**a**	88.76±1.87**a**	111.98±4.65**a**
P-value	0.0001	<0.0001	<0.0001	<0.0001
Signification	*******	***	*******	***

RT= Ridge Tillage, SR= Stone Rows, Z= Zaï Pit, Z_SR= Zaï Pits Combined with Stone Rows. n=5; stdev = Standard Deviation, means with the same letter are not significantly different

Pod load: The treatments had significant effect on pod load. Two homogenous group are perceptible; the first group formed by zaï and zaï combined with stone rows. The second group constituted of ridge tillage and stone rows. Zaï pits stimulated the pods formation increase.

Number of nodules: The effect of treatment on nodules formation was significant at p<0.05. This nodule formation responded identically to the treatments SR, Z and Z_SR. Z_SR produced the highest number of nodules (89.88), which was statistically like Z (80.76) and SR (70.20). These increases were 53%, 76% and 95.90%, for respectively SR, Z, Z_SR compared to RT.

Nodule dry weight: The nodule dry weight was significantly influenced by all the treatments at p<0.05. The treatments SR, Z, and Z_SR formed a homogenous group. Z stimulated the highest nodule dry weight production (0.0893), but his result was statistically similar to SR and Z_SR. The nodule dry weight increased by 63.50%, 115.57%, and 117.27%, respectively by SR, Z_SR, and Z compared to RT (0.0411).

Leaf and branches number: All the treatments had significant influence on vegetative parameters at p<0.05. The number of leaves and branches had a similar direction. The higher numbers of leaves (39.80) and branches (6.08) were produced by Z_SR, which were statistically similar to the numbers of leaves and branched produced by SR and Z. SR, Z, and Z-SR induced the leaves' formation by 20.38%, 27.56%, and 28.84%, respectively over the RT (31.20). Similar to that situation, the SR, Z, and Z_SR induced the formation of branches by 12.98%, 16.03%, and 20.61%, respectively over the RT (5.24).

The results show that the treatments had a significant impact on pods, nodules, weight of dry nodules, leaves, and branches. The pods load was higher with the Z and Z_SR treatments compared to the control, which is the ridge tillage and more practiced in the area. In addition, the SR, Z and Z_SR treatments stimulated more nodule formation, more dry nodule weight, more leaves and branches formation than the ridge tillage. These increases in the pods load under Z and Z_SR, the number of nodules, the weight of drier nodules, the number of leaves and the number of branches under the SR, Z and Z_SR treatments show that groundnut responds better to these techniques compared to ridge tillage at the upper-slope for its nodulation and vegetative development. An improvement in water and chemical conditions could justify this increase. Indeed, the *zaï* pits and the stone rows contribute to improve the rate of water infiltration in the soil and the content of fine soil and fertilizing elements necessary for the nutrition of the plant. The work of Zongo [36] and Guébré [32] showed a significant effect of *zaï* with organic fertilizer on the nodulation capacity of the cowpea. As groundnut is also a legume, it is possible that these significant effects of *zaï* positively influence the nodulation capacity of groundnut.

3.5.2 Effect of soil management on groundnut productivity

The statistical analysis shows that the treatments had a significant effect on pod yield (p<0.0001), 100-seeds weight (p<0.0001) (Table 7), pod weight (p<0.0001), and haulm yield (p<0.0001) (Table 7). Z_SR induced the highest yield and weight, but it was similar to Z. The treatments Z and Z_SR produced the highest pod yield, 100-seed weight, pod weight, and haulm yield. In 2021, SR, Z, and Z_SR increased the pod yield by 1.26%, 186.50%, and 187.02% respectively compared to RT. In 2022, Z and Z_SR increased the pod yield by 29% and 31.40% respectively compared to RT. On the other hand, SR had yield less than RT. The weight of 100 seeds of RT increased by 8.68%, 27.20%, and 29.52%, respectively by SR, Z_SR, and Z in 2021. This trend is also noted in 2022. Biomass yields follow the same trend and vary from 586 $kg.ha^{-1}$ (RT) to 2011 kg/ha (Z_SR) in 2021 and from 1134 $kg.ha^{-1}$ (RT) to 1753 $kg.ha^{-1}$ (Z) in 2022. Pod yields in 2022 were about 1.9 to 4 times higher than in 2021. Haulm yields almost doubled in 2022 for the stone rows (1.9 times) and ridge tillage (1.9 times) techniques. In contrast, for Z and Z_SR the dry haulm in 2021 remained higher than in 2022 (Table 8). This increase in values in 2022 remains similar for the 100-pods weight and the weight per hole.

The results of our study show that *zaï*, stone rows and *zaï* combined with stone rows had significant effects on pod and straw yields and on 100-pod weight and pod weight per plant. These treatments stimulated these different parameters compared to ridge tillage. The Z and Z_SR treatments stimulated more pod and straw production and more pod filling. The *zaï* and the stone rows, by improving the soil parameters, contributed to improve these different plant parameters. According to Oduor et al [11], *zaï* holes improve soil chemical properties and

Table 8. Effects of *Zaï,* Stone rows (SR) and Ridge tillage (RT) on Pod weight and haulm yields

Treatment	Pod Weight (g/seed hole)		Haulm Yield (kg ha^{-1})	
	2021	2022	2021	2022
RT	2.93±0.23**b**	15.101±1.37**b**	586.57±32.93**b**	1134.43±11.76**b**
SR	3.60±0.57**b**	13.705±1.79**b**	596.23±98.05**b**	1176.78±70.63**b**
Z	9.45±1.09**a**	19.112±3.21**a**	1917.02±89.54**a**	1753.28±77.33**a**
Z_SR	10.33±0.88**a**	19.836±3.07**a**	2011.79±144.39**a**	1686.87±79.46**a**
P-value	<0.0001	0.0028	<0.0001	<0.0001
Signification	***	**	***	***

RT= Ridge Tillage, SR= Stone Rows, Z= Zaï Pit, Z_SR= Zaï Pits Combined with Stone Rows. n=5; stdev = Standard Deviation, means with same letter are not significantly different at threshold 5%

according to Partey et al [9], *zaï* increases water infiltration and reduces water evaporation. These actions contribute to increased yields and weights of groundnut pods and straws. The results are confirmed by surface moistures, which are higher in *zaï* and stone rows than in ridge tillage. The reduction of runoff and the improvement of soil water retention capacity by *zaï* [10,9] may have provided or retained nutrients necessary for groundnut development and productivity. In fact, organic manure must have stimulated the activities of microorganisms that made the plant nutrients readily available to the crops which augmented pod yield of groundnut [37]. Also, this increase in straw and pod yields could be explained by the contribution of organic matter. Organic fertilization that is associated with nitrogen synthesis by plants, as shown by other authors [38,39] can lead to an increase in peanut yields.

4. CONCLUSION

This study aimed to investigate the influence of *zaï*, stone rows, ridge tillage and *zaï* combined with stone rows on soil properties and groundnut development and yield parameters. Compared to ridge tillage, *zaï*, stone rows and *zaï* combined with stone rows significantly stimulated carbon content, total nitrogen, available phosphorus content, and pH values of soil. *Zaï* and *zaï* combined with stone rows significantly stimulated soil moisture content than ridge tillage and stone rows. Termites were recorded under stone rows. None of the treatments were able to promote the development of earthworms in this soil under the soil and environmental conditions present. In conclusion, *zaï*, stone rows, and *zaï* combined with stone rows improved selected chemical, physical and biological soil properties. Furthermore, *zaï*, stone rows, and their combination improved groundnut yields performances by increasing growth (leaves, branches, nodules), and yields (pod and haulm yields, 100-pods weight, pods load, weight of pods/hole) in Sudan Sahelian zone of Burkina Faso in a context of climate change, while protecting the environment.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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