Original Research Article

Burkina rock Phosphate fertilization increases nodulation and yield of cowpea under zaï cultivation in sahelian agro-ecosystem of Burkina Faso

ABSTRACT

Cowpea occupies a considerable place in the nutritional and economic balance of the rural population of Burkina Faso. However, its cultivation is marked by yield instability linked to soil depletion of nutrients, especially N and P, and irregular rains. The objective of this study was to evaluate the effect of phosphorus fertilization with the rock phosphate named BurkinaP, on the spatial and temporal variability of cowpea nodulation and yield. A multilocation test was conducted in 12 and 16 farmers'fields in 2013 and 2014, respectively, in 3 villages of 3 provinces of the northern region of Burkina Faso. Two treatments were compared: zaï without (ZS) and zaï with BurkinaP (ZP). Overall, dry weights of nodules and shoots at flowering stage, and grain at harvest, were significantly increased by BurkinaP. It is concluded that in soils where low availability of P limits crop yields of cowpea especially in arid sud-saharan areas of West Africa, the input of BurkinaP can improve cowpea N_2-fixation, and increase and stabilize cowpea yields.

Keywords: *Cowpea, grain yield, nodules dry weight, shoot dry weight, rhizobia, symbiosis.*

1. INTRODUCTION

Burkina Faso, like other sub-saharan countries is characterized by precarious climatic conditions, population pressure and low soil-fertility. Thus, the balance between the exploitation and regeneration of natural resources in time and in space is hard to maintain. The insufficiency and erratic rainfall, and the overuse of land have contributed to the depletion of soil in N and P as major factors limiting agricultural production [1,2]). These soils under tropical and sub-tropical climates are often extremely P deficient with high P fixation as mostly acidic [3,4].

Phosphorus is a critical nutrient for optimal plant growth and food adequate production. Phosphate fertilizers are most often used to correct soil P deficiencies. However, most developing countries import the P fertilizers, though in limited quantities with significant expenses for poor farmers [5,6]. An alternative may be the direct application of phosphate rock (PR) in agriculture [3,7]. PR deposits are found worldwide, but few are operated primarily as raw materials for phosphate fertilization, although it can improve soil P status [8,9]. Since PR chemical composition is highly variable and complex, PR may also be sources of nutrients other than P [7].

In northern region of Burkina Faso, farmers practice zaï, among various land restoration techniques. This technique, originating from Yatenga in Burkina Faso increases infiltration and water available in soil [10,11]. It improves soil fertility and recovers degraded land for agricultural use [12,13]. It consits in digging holes of 20 to 40 cm in diameter with a depth of 10 to 15 cm, approximately. The excavated soil is deposited in ascending order downstream of the hollow in order to collect runoff water. In these holes are trapped, sands, silt, organic matter transported by dry winds like Harmattan [10]. The zaï holes are dug during the dry season. Before the sowing period, such organic matter as manure or compost, is supplied in varying amounts according to farmers, an adult handshake corresponding to about 300 g per hole [14,15].

Zaï allows a reinstallation of agro-pastoral cover through the organic matter accumulation [12]. This latter contains the seeds of various species consumed by cattle whose stomach acids prepared them to germinate rapidly and benefit from the exceptional contribution of water. This doubles the grain yield and significantly increases the sorghum-straw production compared to the control on tropical ferruginous leached soil [16]. According to the interpretation standards of National Soil Office, the contents of total carbon, nitrogen and phosphorus, and inorganic phosphorus in these soils below 100; 0.6 mg g^{-1}; 200; 10 mg kg^{-1} soil, respectively, are considered low [17]. However, on degraded soil, increasing soil water conditions is not sufficient to improve the production of cereals. Zaï must be associated with the fertilisation to compensate the poor soil fertility.

In the context of soil depletion and climate risks, cowpea plays a strategic role in agricultural systems of Burkina-Faso. It is often cultivated in intercropping with cereals [14]. Cowpea areas of cultivation have increased during the 2000 up to nearly 1 500 000 ha in 2010, and the production of cowpea grain has also increased from 200 000 t worldwide in 1990 to 400 000 t in 2010 [18]. Protein-rich, the green pods and dry seeds are consumed or sold, and the straws are preserved as animal feed for the dry season. Cowpea through symbiotic nitrogen fixation (SNF) can improve soil fertility. However, SNF is influenced by several factors including the low P availability in soils. The objective of this study was to evaluate the effect of BurkinaP ferilization on nodulation and yield of cowpea under zaï cultivation in Sahelian agro-ecosystem of Burkina-Faso.

2. MATERIALS AND METHODS

2.1. Experimental sites

The study was conducted in representative villages of 3 provinces of the northern region of Burkina Faso: Poungyango (12°58'N, 2°08'W), Zindiguessé (13°16'N, 2°0'W) and Soumyaga (13°30'N, 2°24'W), representing the provinces of Passoré, Zondoma and Yatenga, respectively. The climate is sudano-sahelian, characterized by a short rainy season from June to September with a long dry season from October to May. During the period 2000-2014, annual rainfalls have varied from 505 to 983 mm (Figure 1).

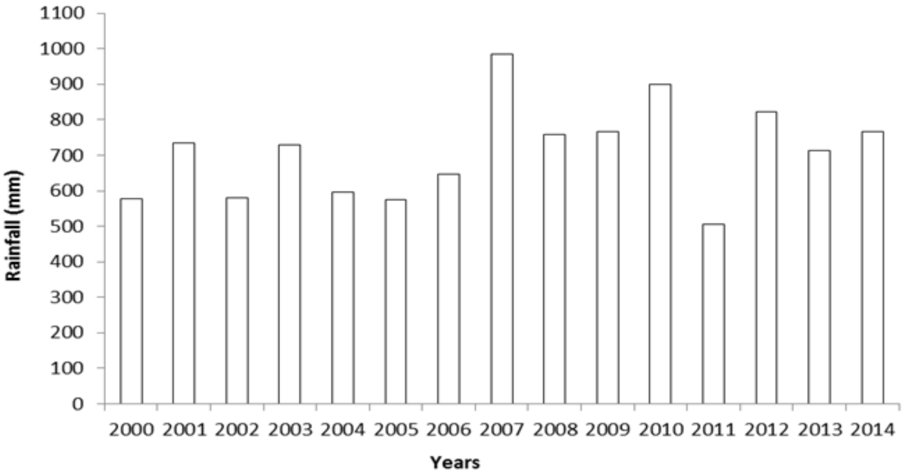

Figure 1. Total rainfall from 2000 to 2014 in the northern region of Burkina Faso

Data source: General Directorate of Meteorology of Burkina Faso

Soils are predominantly epipetric plinthosols, endo-petroplinthic and hypogleic lixisols [19]. They are very degraded surface-state as eroded and gravelly load. They are low in total organic matter (< 5.8 g kg^{-1}), nitrogen (< 0.3 g kg^{-1}), phosphorus (< 2 mg kg^{-1}) and acidic (water pH 5.5-6.5). These soils are subject to water and wind erosion because the scarce vegetation does not provide perfect coverage of the soil surface, although there are savanna shrubs and trees highly anthropized. Woody prevailing species as *Ziziphus mauritiana*, *Piliostigma reticulatum*, *Guiera senegalensis*, *Faidherbia albida, Vitellaria paradoxa*, *Lannea microcarpa*, *Tamarindus indica,* and various species of *Acacia*. The grass cover species are *Pennisetum pedicellatum*, *Andropogon gayanus*, *Corchorus olitorus*, *Ipomoae eriocarpa*, *Panicum laetum*, *Mitracarpus villosus* and *Microchloa indica.*

2.2. Experimental design

Two treatments were compared, namely simple Zaï (ZS) as control, and Zaï + 20 g of BurkinaP per hole (ZP), corresponding to 600 kg ha^{-1} following to national research recommendations. Chemical composition of BurkinaP was in %: P_2O5: 25.43; K_2O: 0.3; CaO: 34.61; MgO: 0.18; 0.03 water solubility. Before sowing, ZP was covered with a thin layer of soil to avoid direct contact between phosphate and seeds. To avoid contamination, the ZS were sown before ZP.

In 2013, 12 fields were selected in farmers' plots, on the basis of 4 sites per village. In 2014, 16 fields were used including 7 fields of 2013 for repeated test. There were 5 replications per field in 2013, but only 1 per field in 2014. Space between elementary site in each field was 1m. In 2014, 6 sites were located in Pougyango, 4 in Zindiguessé and 6 in Soumyaga. The surface of each site was 25 m^2 (5 m x 5 m). There was a 40 cm space between zaï holes on 7 rows with 80 cm space between rows. Zaï holes had diameter of 20 cm and depth of 15 cm.

2.3. Crop management

Cowpea was sown in intercropping with sorghum at the same time and in the same zaï hole during late June or early July. Sowing rate was 2 seeds per zaï hole of each cowpea, cultivar KVX 396-4-5-2D, and sorghum, cv Kapelga. These genotypes from the Institute of Environment and Agricultural Research (INERA) are adapted to the agro-climatic conditions of the region. Weeding was performed at 20 days after sowing (DAS). After thinning, 2 seedlings of cowpea and 2 of sorghum were left in the same zaï hole. Two weedings managed by the farmers according to their own practice.

2.4. Soils Sampling and analysis

Composite samples of rhizosphere soil at flowering stage were formed from elementary samples collected in 0-20 cm layer. These samples were sieved to 2mm diameter to separate coarse and fine particles. Thereafter, 100 g of each sample was ground to a mesh of 200 µm for analyzes of total carbon (C) and total nitrogen (N) by CHN method with microanalyzer NA-2000. Total and available phosphorus (P, Pi) was estimated by Olsen-Dabin method [20, 21]. Chemical analyses of rhizosphere soil were carried out at the laboratory of Joint Research Unit (UMR Eco&Sols) from Montpellier in France.

2.5. Data collection

In each site, considered as Fisher block of the multilocation test, 5 plants per treatment were harvested at early flowering stage when 50% of plants had emitted their first flower, around 45 DAS according to method described by Zongo et al. [15]. In fact, the roots were removed by clod with a cubic volume of soil of 20 cm each side. Cowpea roots were washed gently in a bucket of water to remove the adhering soil, enabling the detachment of nodules. Nodules were collected, counted and dried to constant weight upon filter paper in the open air. Shoot biomass of each plant was separated from the root biomass at the cotyledonary node and dried in an oven at 70 °C for 48 h. Nodules dry weight (NDW) and shoot dry weight (SDW) per plant of cowpea were measured. At harvest, the grain yield (GY) was measured on 2 m^2 areas in the middle of each elementary plot.

2.6. Statistical analysis

The statistical analysis of data was performed by ANOVA with R (2.15.1) software. The paired Student method was applied with P treatment as major factor, and site as interaction facteur. Each site was considered as a block according to Fisher methodology. The groups with significantly different means were established with the Tukey test at 5% de probability. The relation between two parameters were established by the regression method of Pearson.

3. RESULTS

3.1. Chemical properties of rhizosphere of soils of experimental sites at flowering stage

In table I, C contents of rhizosphere soils chemical properties of experimental sites at flowering stage varied of 4,30 (E10) to 10.70 mg kg^{-1} under ZS treatment, and under ZP it varied of 3.80 (E10) to 10.90 mg kg^{-1} (E19). N content of soil was between 0,20 (E13, E15) to 0.80 mg kg^{-1} (E2) under ZS and 0.20 in E13 to 0,90 mg kg^{-1} soil in E19 under ZP treatment. C/N ratio was around 11 (E10, E11) under ZS and ZP to 31 (E15) and 23 (E13) under ZS and ZP respectively. P of rhizosphere soil varied of 2.57 (E11) to 44.75 mg kg^{-1} (E15) under ZS, and 3,38 (E13) to 32,38 mg kg^{-1} (E16) under ZP. Pi varied between 0,34 (E13) to 3,78 mg kg^{-1} (E16) under ZS, at range of 0,31 (E13) to 6.30 mg kg^{-1} (E12) under ZP.

Table I: Chemical properties of rhizosphere soils collected of experimental sites at flowering stage

Sites	ZS	ZP	ZS	ZP	ZS	ZP	ZS	ZP	ZS	ZP
	C		N		C/N		P		Pi	
	mg kg^{-1}soil						mg kg^{-1}soil			
E02	7.80	6.10	0.50	0.40	16	15	9.91	6.44	1.25	2.60
E04	5.70	5.10	0.50	0.40	11	13	2.97	4.09	1.69	2.90
E05	5.30	5.90	0.40	0.50	13	12	10.63	9.15	2.48	4.70
E06	5.20	5.60	0.40	0.50	13	11	6.32	14.2	1.93	4.40
E10	4.30	3.80	0.40	0.40	11	10	5.97	9.72	2.69	2.80
E11	4.40	5.70	0.40	0.50	11	11	2.57	5.98	1.25	4.40
E12	7.70	7.40	0.60	0.60	13	12	6.43	23.60	2.71	6.30
E13	4.50	4.60	0.20	0.20	23	23	4.57	3.38	0.34	0.31
E14	5.60	6.40	0.30	0.40	19	16	6.15	9.01	1.47	3.40
E15	6.20	5.80	0.20	0.30	31	19	44.75	16.18	2.53	5.10
E16	5.90	6.10	0.30	0.50	20	12	9.04	32.38	3.78	3.19
E17	4.90	4.60	0.40	0.40	12	12	9.45	9.27	2.56	6.10
E18	5.40	5.30	0.40	0.40	14	13	5.21	6.03	1.42	1.60
E19	6.70	10.9	0.50	0.90	13	12	3.62	7.73	1.19	3.30
E20	5.80	5.30	0.50	0.50	12	11	33.07	7.61	0.94	4.77
E21	10.70	9.60	0.80	0.80	13	12	6.97	7.38	2.35	3.09

ZS = Simple Zaï ; ZP= Zaï+Burkina phosphate; C = total carbon; N = total nitrogen ; P = total phosphorus ; Pi = inorganic phosphorus.

3.2. Nodulation

Data in figure 2 show that nodule dry weight (NDW) varied among sites under ZS treatment. In 2013, 2 groups of sites were distinguished following to nodules production: i) E06 and E04 with high NDW of 64.1±37.6 and 49.9±47.9 mg NDW plant^{-1}, respectively; ii) other sites with significantly lower NDW varying from 23.0±19.4 to 5.9±6.0 mg NDW plant^{-1}. In 2014, 3 groups were distinguished: i) E04 with the significantly highest nodulation of 92.9±9.0 mg NDW plant^{-1}; ii) E20, E05 and E19 with low nodulation from 11.5±10.6 to 7.4±6.2 mg NDW plant^{-1}; iii) an intermediary group constituted by other sites from 79.1±44.7 to 14.4±6.4 mg NDW plant^{-1}. Overall, a significant positive effect of BurkinaP was observed on NDW though this effect varied among sites. Under ZP treatment in 2013 for the first site group (E06 and E04), no difference was observed between ZP and ZS treatments with 61.2±41.6 *vs* 64.1±37.6 and 51.4±49.6 *vs* 49.9±47.9 mg NDW plant^{-1}, respectively for ZP vs ZS. For the second group, NDW increased significantly under ZP for E01, E09 and E10 sites with 33.9±28.1 *vs* 12.6±10.8; 13.8±12.6 *vs* 5.9±6.0 and 42.6±39.2 *vs* 19.5±21.0 mg NDW plant^{-1}, respectively. In 2014, NDW increased significantly under ZP in E05, E18, E20 and E21 with 16.6±6.5 *vs* 7.7±3.4; 108.9±65.4 *vs* 26.9±9.7; 42.6±28.0 *vs* 11.5±10.6 and 53.7±32.5 *vs* 14.4±6.4 mg NDW plant^{-1}, respectively. Also, NDW increased significantly from 2013 to 2014 for E06, E04, E12 and E02 sites with 61.2±41.6 to 73.9±90.1; 51.4±49.6 to 115.2±71.2; 28.3±40.9 to 43.3±26.1 and 17.2±22.9 *to* 56.2±21.3 mg NDW plant^{-1}, respectively.

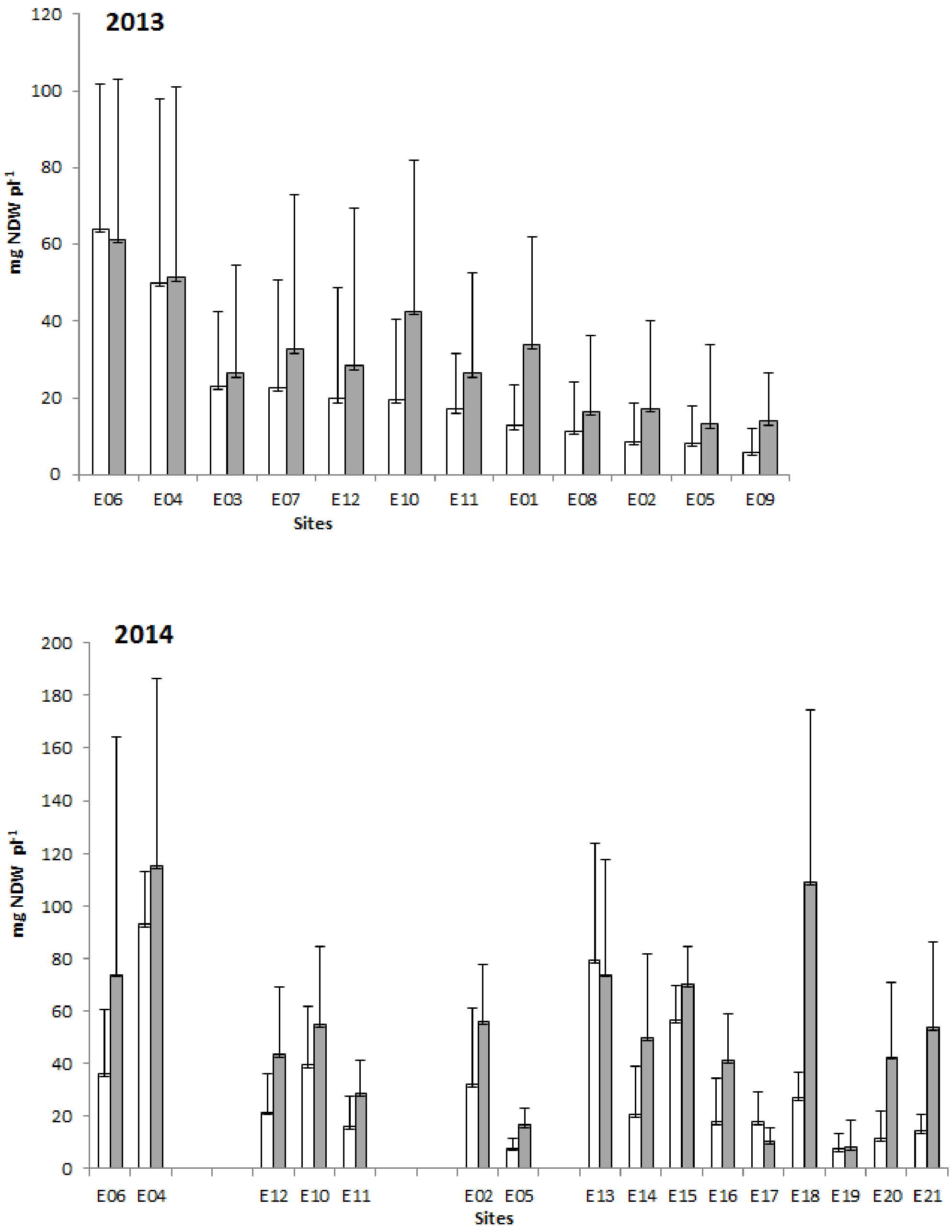

Figure 2. Nodules dry weight per plant. Sites 1 to 12 were observed in 2013 and 2014 whereas sites from 13 to 21 were observed only in 2014. *Data are means ± Sd of 20 replicates in 2013 and 5 in replicates in 2014, harvested at flowering stage. ☐ control ■ Burkina phosphate.*

3.3. Plant growth

Data in figure 3 show that SDW varied among sites under ZS treatment. In 2013, 3 groups were distinguished: i) E06 with high growth of 15.2±8.0 g SDW plant^{-1}; ii) E08 with low growth of 3.6±3.3 g SDW plant^{-1}; iii) an intermediary group constituted by other sites from 14.4±6.5 to 4.6±1.9 g SDW plant^{-1}. Variability was not observed among provinces around an overall mean of 10.0±6.6 g SDW plant^{-1}.

In 2014, 4 groups were distinguished: i) E15 with high growth of 19.1±6.1 SDW g plant^{-1}; ii) E04 with medium growth of 10.6±2.4 g SDW plant^{-1}; iii) E20 with low growth of 0.6±0.4 g plant^{-1}; iv) an intermediary group constituted by other sites with SDW varying from 9.7±5.5 to 0.9±0.7 g SDW plant^{-1}. Overall, a significant positive effect of BurkinaP was observed on plant growth. This effect varied among sites. In 2013, no difference was observed between ZP *vs* ZS for sites E06 with 16.7±8.8 *vs* 15.3±8.0 g SDW plant^{-1}and E08 with 5.4±5.0 *vs* 3.6±3.3 g SDW plant^{-1}. For intermediary groups SDW increased significantly under ZP *vs* ZS for E02, E10, E11 and E12 sites with 20.1±10.1 *vs* 11.9±8.9, 19.1±11.8 *vs* 11.3±5.8; 19.2±7.7 *vs* 14.4±6.5 and 11.5±6.6 *vs* 7.1±4.7 g SDW plant^{-1}, respectively. In 2014, no difference was observed for E15 whereas for other groups, SDW increased significantly under ZP for E05, E06, E12, E17 and E18 with 20.3±12.2 *vs* 2.0±0.4, 13.2±6.2 *vs* 5.2±2.5, 11.7±5.7 *vs* 5.3±1.3, 6.4±3.1 *vs* 3.0±1.0 and 12.7±4.9 *vs* 5.0±1.5 g SDW plant^{-1}, respectively. SDW varied also under ZP among years, with more shoot production during 2013 than 2014, especially for E02, E10 and E11 with 20.1±10.1 vs 6.6±4.0, 19.1±11.8 vs 6.2±2.7, and 19.2±7.7 vs 0.7±0.3 g plant^{-1}, respectively.

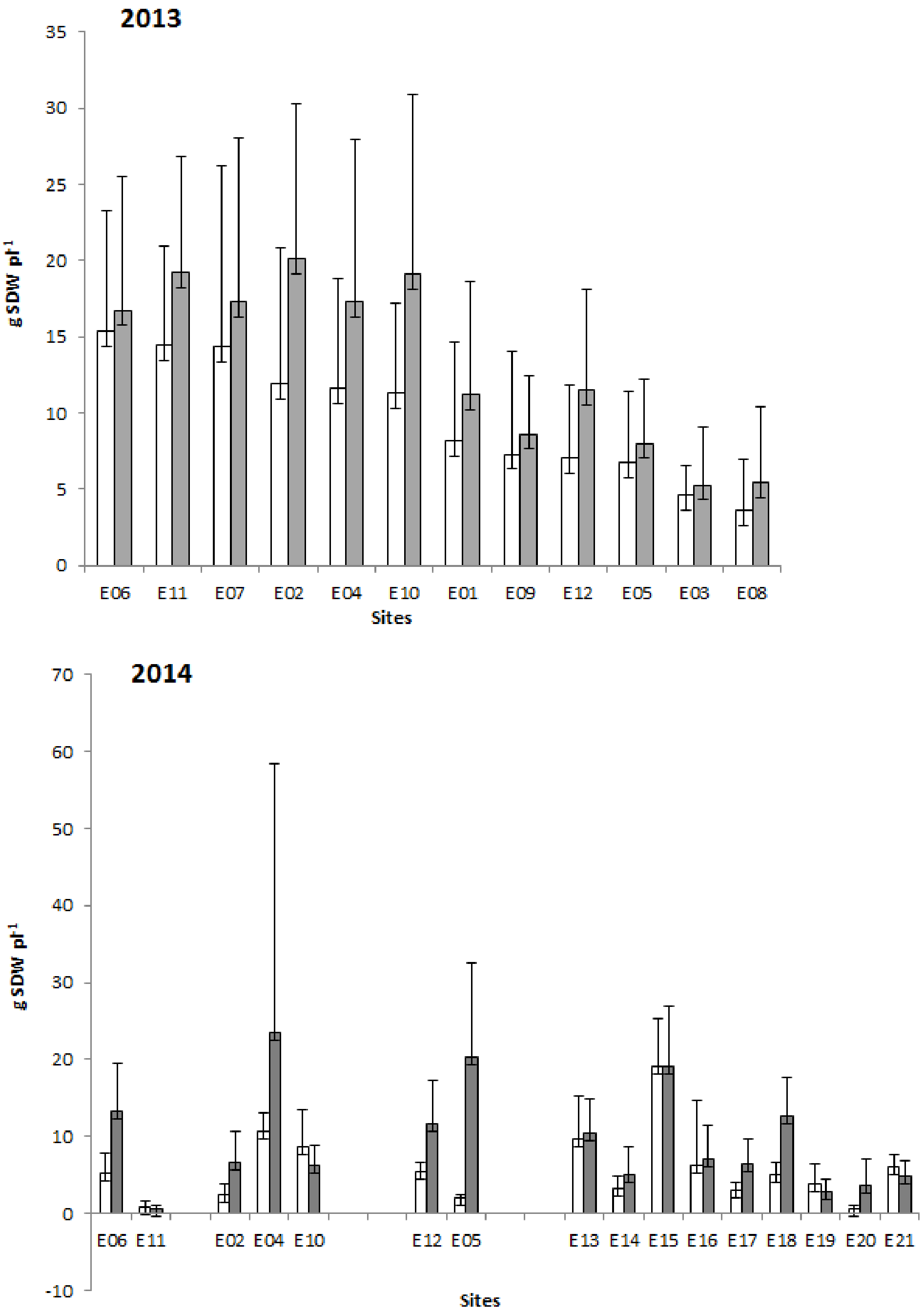

Figure 3: Shoot dry weight per plant. Sites 1 to 12 were observed in 2013 and 2014 whereas sites from 13 to 21 were observed only in 2014. *Data are means ± Sd of 20 replicates in 2013 and 5 in replicates in 2014, harvested at flowering stage.* □ *control* ■ *Burkina phosphate.*

3.4. Efficiency in use of rhizobial symbiosis

In order to assess the effectiveness of the symbiosis for the plant growth, the mean values of SDW per treatment for each site were plotted as a function of NDW in figure 4. NDW and SDW were significantly correlated under ZS *vs* ZP with R^2 of 0.80 *vs* 0.78 in 2013 (Figure 5a & 5b), and 0.70 *vs* 0.67 in 2014 (Figure 4c & 4d), respectively.

The regression-slope, i.e., the efficiency in use of rhizobial symbiosis (EURS), was 0.13 *vs* 0.60 g SDW g^{-1} NDW in 2013 (Figure 4a & 4b) and 0.23 *vs* 0.11 g SDW g^{-1}NDW in 2014 (Figure 5c & 5d), respectively. However, the following sites strayed from the model: For ZS during 2013, E02, E07, E11 strayed significantly above the model (Figure 4a & 4b) and during 2014, E02, E03 and E08 strayed significantly below, whereas E15 strayed above the model (Figure 4c & 4d). For ZP during 2013(Figure 4a & 4b), E02, E11 strayed above and E03 below the model, whereas during 2014(Figure 4c & 4d), E05 and E15 strayed above the model.

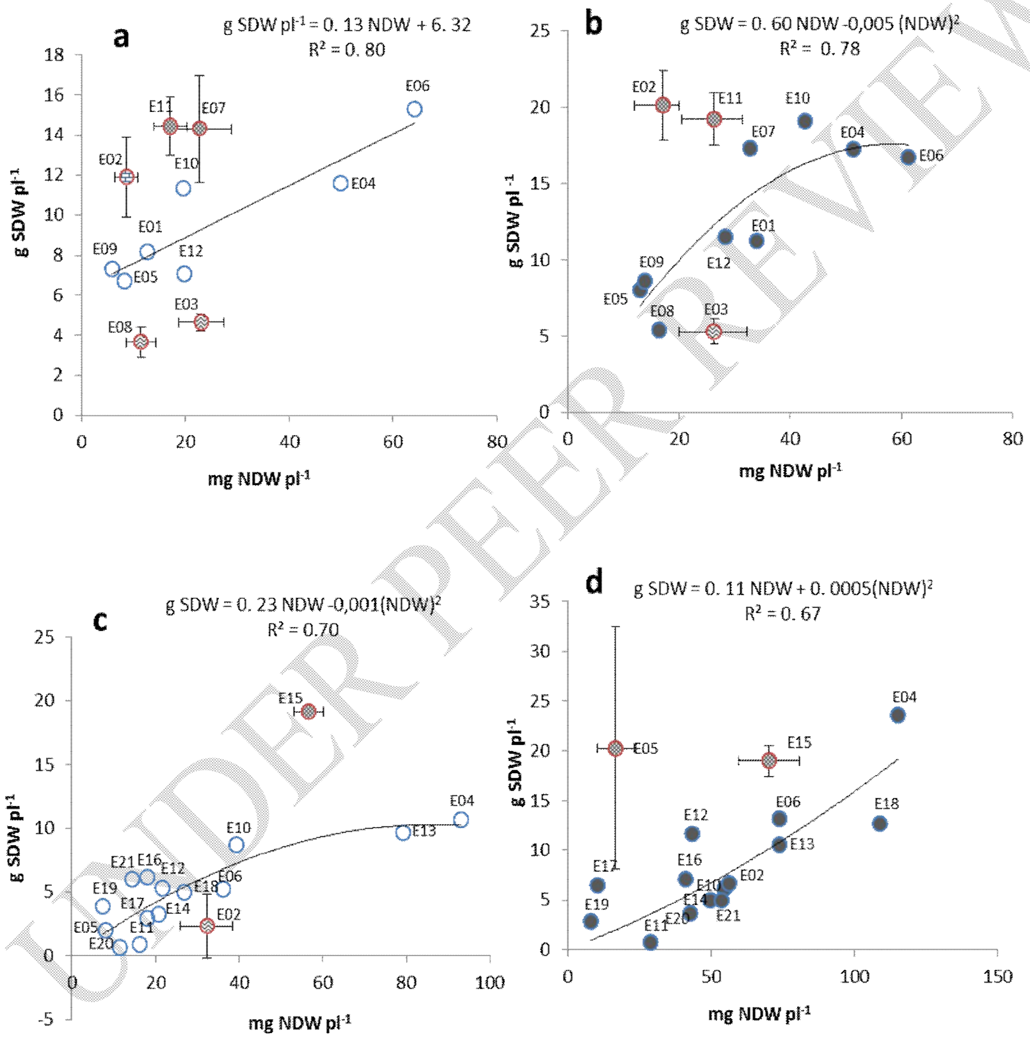

Figure 4: Relationship between nodules dry weight and shoots dry weight per plant

(a) 2013 control (b) 2013 Burkina phosphate; (c) 2014 control (d) 2014 Burkina phosphate; E: sites.

Data in figure 5 show that grain yield (GY) varied among sites under ZS treatment. In 2013, 3 groups could be distinguished: i) E06, E01 and E02 with high mean GY of 941.3±174.8 kg ha^{-1}, respectively;

ii) E04, E10, E03, E12 and E05 with low GY from 445.2±235.4 to 267.2±217.4 kg ha^{-1}; iii) an intermediary group was constituted by other sites from 596.1±240.7 to 447.2±301.3 kg ha^{-1}. In 2014, GY varied also among sites from 2463.3 to 17.2 kg ha^{-1}, but not among province.

Overall, a significant positive effect of BurkinaP was observed on GY. In 2013, GY increased under ZP *vs* ZS for E01, E02, E05, E06 and E10 sites with 1087.7 ± 324.0 *vs* 948.7 ± 181.8; 1319.6 ± 426.1 *vs* 925.1 ± 331.8; 577.2 ± 585.4 *vs* 267.2 ± 217.4; 1234.3 ± 153.1 *vs* 953.1 ± 232.0 and 501.8 ± 268.8 *vs* 394.0 ± 85.3, respectively. In 2014, statistical analysis with the paired Student-test showed that the GY increased significantly under ZP *vs* ZS (*p = 0.004*) with values per site varying from 2415.6 *vs* 1336.7 in E18 to 759.4 *vs* 118.8 in E21. There was more grain production in 2014 than in 2013, especially for E02, E04, E05, E06, E10 and E12 sites.

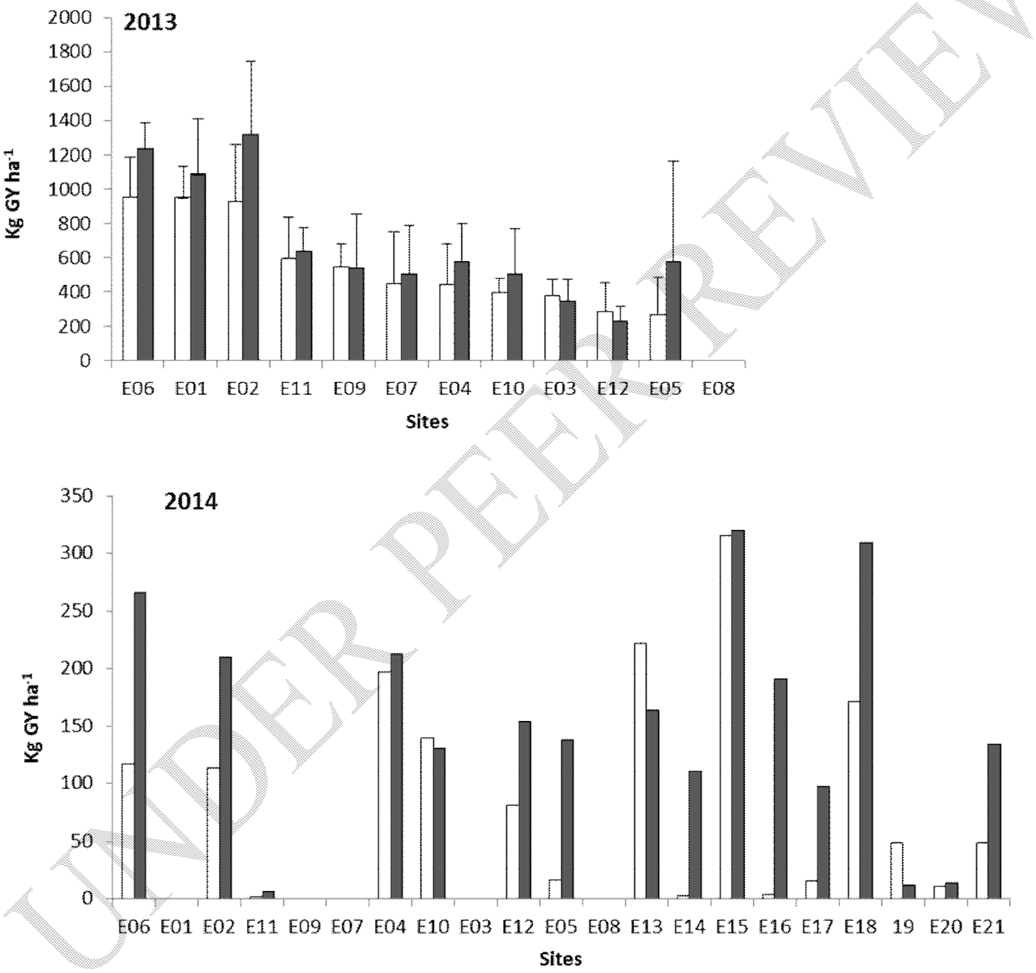

Figure 5: Grain yield per hectare. Sites 1 to 12 were observed in 2013 and 2014 whereas sites from 13 to 21 were observed only in 2014. *Data are means ± Sd of 5 replicates in 2013 and 1 replicate in 2014 harvesting.* □ *control* ■ *phosphate.*

4. DISCUSSION

The analysis of the results showed that the increase in nodules, plant growth and the efficiency in use of rhizobial symbiosis of cowpea are not specifically linked to various chemical properties of experimental sites soils but instead to BurkinaP supply. Mineral contents among carbon, nitrogen and phosphorus of theses soils are considered low according to the interpretation standards of the National Soil Office [22]. The significant positive effect of BurkinaP on NDW in 2013 and 2014 compared to control (Figure 3) could be explained by the phosphorus contribution to the formation of nodules and their function which requires a high energy consumption of at least 16 ATP per molecule of N2 reduced by nitrogenase [23]. It agrees with previous works in sub-saharan zones where the soils are characterized by their deficiency of N and P which are the factors limiting crop production [24,25], and where phosphorus improved SNF through increased nodulation [26]. Our results confirm those of Singh and Singh [27] who have shown that the application of Mussorie rock phosphate significantly increased soybean nodulation on a sandy loam soil. Similarly, on a sandy soil, Kasongo et al. [28] showed that the application of Kanzi rock phosphate significantly increased soybean nodulation. Nodulation of cowpea was significantly increased at supplying of 30 kg P ha^{-1} single superphosphate in Nigeria [29]. Somé et al. [13,16] reported that, in a field agronomic trial, the supply of BurkinaP under cowpea cropping can increase the SNF by 50%, compared to mineral fertilizer. Nevertheless, our results are the first obtained in multilocation field tests. The highest phosphate effect in 2014 than in 2013 without phosphate effect, e.g., in E06 and E04 sites could be explained by the higher dissolution of rock phosphate due to the higher average rainfall observed in 2014 than in 2013, since increasing the soil water content can increase the dissolution of rock phosphate [30,31,32]. In 2013, the rainy season was delayed, and followed with abundant and regular rains, whereas in 2014, it rained profusely which hindered the early development of plants.

The positive and significant correlation per site of SDW as a function of NDW in 2013 and 2014 for both ZS and ZP treatments could be explained by the efficiency of rhizobial symbiosis in plant growth. Indeed, Singleton and Tavares [33] showed that improved SNF after rhizobial inoculation was related to an increase in nodule dry weight for *Glycine max*, *Vigna unguiculata*, *Leucaena leucocephala*, *Arachis hypogaea*, and *Phaseolus vulgaris*. Similarly, Thies et al. [34] reported that the abundance of indigenous population of rhizobia has a direct influence on nodulation and SNF by legumes. Combined native rhizobia strain (SAMFIX 286) inoculation with 250 kg (Ca $(OH)_2$) ha^{-1}, and 30 kg P ha^{-1} single superphosphate increased N concentration by 31.9% and N derived from atmosphere (Ndfa) by 16.3% of cowpea compared to the un-inoculated treatment in Nigeria [29]. The sites below the regression models for both treatments like E03 and E08 in 2013 and E02 in 2014 could be explained by soil limitation of EURS. These soils are sandy loam or loamy sand in upper horizons, and clay in depth. Also, the geomorphological position of these sites next to slope caused stagnant rainwater and waterlogging, and plants cowpea especially does not like large amounts of water [15,35]; In fact, plants subjected to severe and/or prolonged waterlogging have significantly declined their carbon assimilation ratedue to reactive oxygen species accumulation, resulting in reduced growth and productivity [36].

Those sites above the regression model may benefit of most efficient rhizobia. Thus, Sacko et al. [37] found PCR-RFLP profiles of 16S-23S for rhizobia genotype -groups specifically encountered in the nodules of Sesbania under treatments of Tilemsi phosphate. Singh and Singh [27] showed that the application of phosphate Mussorie significantly increased the population of microorganisms solubilizing the phosphorus in the soil. Rock phosphate application can stimulate plant-growth-promoting rhizobacteria that can induce an improvement in growth [38]) and protect the plant against some parasitic infections [39].

As a consequence, the significant positive effect of BurkinaP on SDW in 2013 and 2014 concluded that phosphorus deficiency limits the growth of the plant but also nodular activity. Thus, our results confirm the conclusions of Nwoke et al. [40] that the supply of rock phosphate increases the dry matter yield of cowpea, like triple superphosphate, on low P soils in the Nigeria savannah. Also, application of 40 kg P_2O_5 ha^{-1} was the best rate for good growth and yield of cowpea in north of plateau state of Nigeria [41]. Somé et al. [13] showed that BurkinaP increased the growth and yield of cowpea on zipellés in Passoré Province and also contributed to the restoration of soil by increasing their phosphorus content. Root secretions and those caused by microorganisms including protons, hydroxyl and organic acids can influence the pH and increase the availability of P, the production of enzymes capable of hydrolyzing the organic forms of P also participates in the bioavailability of P in the rhizosphere (Hinsinger et al., 2007[42]).

Overall our result confirm that direct application of rock phosphate can increase biomass production of cowpea in acidic soils, like most plants [43,44]; Kasongo et al. [28]) including *Ziziphus mauritiana* [45]). The subsequent positive effects of phosphate on grain yield confirm those of Somé et al. [13] with BurkinaP, and Sokoto and Singh [44] with Sokoto phosphate at 25 kg ha^{-1} in the semi-arid soils of Sokoto in Nigeria.

5. CONCLUSION

Overall, a significant positive effect of BurkinaP was observed on nodule dry weight, plant growth and grain yield in 2013 and 2014. In sub-Saharan areas where P is one of the factors limiting agricultural production, the use of chemical fertilizers is not accessible to all farmers because these fertilizers are very expensive and farmers are poor. These fertilizers can also cause environmental degradation. An alternative may be the direct application of PR in agriculture. This has the advantage of contributing to the restoration of soils, increasing yields crops, and mainly to help ease the costs of farmers for fertilizing fields. It would be interesting to see the possibilities of combinations BurkinaP with local fertilization practices of farmers, including organic manure.

REFERENCES

1. Pallo FJP, Asimi S, Assa A, Sedogo PM, Sawadogo N. Statut de la matière organique des sols de la région sahélienne du Burkina Faso. Étude et Gestion des Sols. 2006 ;13: 289-304.
2. Bationo A, Kihara, J, Waswa B, Ouattara B, Vanlauwe B. Technologies for sustainable management of sandy Sahelian soils. In: Management of Tropical Sandy soils for sustainable agricultura. A holistic approach for sustainable development of problema soils in the tropics. FAO Regional Office for Asia and the Pacific. Bangkok: pp 414-429: 2014.
3. Chien SH, Prochnow LI, Mikkelsen R. Agronomic Use of Phosphate Rock for Direct Application: Better Crops. 2010; 94 (4): 21-23.

4. Rafael RBA, Fernández-Marcos ML, Cocco S, Ruello ML, Weindorf DC, Cardelli V, Corti G. Assessment of potential nutrient release from phosphate rock and dolostone for application in acid soils. Pedosphere ; 2018; 28 (1) : 44–58.
5. Chianu J, Chianu J, Mairura. Mineral fertilizers in the farming systems of sub-Saharan Africa. A review. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA; 2012; 32 (2): 545-566.
6. Alewell C, Ringeval B, Ballabio C, Robinson D A, Panagos P and Borrelli P. Global phosphorus shortage will be aggravated by soil erosion. Nat Commun. 2020; 11:4546.
7. Hellal F, El-Sayed S, Zewainy R, Amer A. Importance of phosphate pock application for sustaining agricultural production in Egypt. Bull Natl Res Cent. 2019 :43-11.
8. FAO. Utilisation des phosphates naturels pour une agriculture durable. Bulletin Fao Engrais et Nutrition Végétale. 13 :11-15 :2004
9. Elmaadawy KHG, Ezz El, Din M, Khalid AM, Abouzeid AZM. Ineral Industry in Egypt–Part II non-metallic commodities phosphate rocks. J Mining World Express: 2015;4:1–18.
10. Roose E, Kabore V and Guenat C. 1993. Le zaï: fonctionnement, limites et amélioration d'une pratique traditionnelle africaine de réhabilitation de la végétation et de la productivité des terres dégradées en région soudano-sahélienne (Burkina Faso). Cahiers-ORSTOM. Pédologie, 28 :159-173.
11. Zougmoré R, Zida Z and Kambou N 1999. Réhabilitation des sols dégradés : rôles des amendements dans le succès des techniques de demi-lune et de zaï au Sahel. Bull. Rés. Érosion,19 :536-550.
12. Roose E, Kaboré V, Guenat C. Le zaï, une technique traditionnelle africaine de réhabilitation des terres dégradées de la région soudano-sahélienne (Burkina-Faso). John Libbey Eurotext.1995 ;249-265.
13. Somé D, Zombré PN, Zombré G,Macauley HR. Impact de la technique du zaï sur la production du niébé et sur l'évolution des caractéristiques chimiques des sols très dégradés (zipellés) du Burkina Faso. Science, Changements Planétaires et Sécheresse.2004 ;15 :263-269.
14. Zongo KF, Hien E, Drevon JJ, Blavet D, Masse D,Clermont-Dauphin C. Typologie et logique socio-économique des systèmes de culture associant céréales et légumineuses dans les agro-écosystèmes Soudano-Sahéliens du Burkina Faso. Int. J. Biol. Chem. Sci. 2016 ;10(1): 290-312.
15. Zongo KF, Traoré M, Hien E, Blavet D, Clermont-Dauphin C and Drevon JJ: Variability of cowpea (*Vigna unguiculata L.*) nodulation: what efficiency in use of the rhizobial symbiosis for plant growth under zaï cultivation in Sub-Saharan agro-ecosystem of Burkina Faso? I.J.C.A.R. 2017a;6(03): 2759-2767.
16. Somé D, Hien E, Assigbetse K, Drevon JJ, Masse D. Culture d'une légumineuse et d'une céréale dans le système zaï avec différents amendements organo-minéraux – productivité et impact sur les propriétés biologiques d'un sol ferrugineux dégradé dénudé en Région nord soudanienne au Burkina Faso Tropicultura.2016 ;34 : 56-68.
17. Zongo KF. Déterminants des performances des associations céréales-légumineuses dans les agroécosystèmes soudano-sahéliens du Burkina Faso. Thèse de Doctorat, Université Ouaga I Pr Joseph KI-ZERBO, Burkina Faso. 2017b :186 p.
18. Dabat MH, Lahmar R, Guissou R. La culture du niébé au Burkina Faso : une voie d'adaptation de la petite agriculture à son environnement ? ». Autrepart. 2012 ; 62 : 95-114.
19. WRB : Base de référence mondiale pour les ressources en sols 2014. Système international de classification des sols pour nommer les sols et élaborer des légendes de cartes pédologiques. Mise à jour 2015. 203 p. Classification, corrélation and communication, 2nd édition. World Soil Resources Reports No. 103, FAO, Rome, 2015 ; 145 p.
20. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. 939:1954.
21. Dabin B. Sur une méthode d'analyse du phosphore dans les sols tropicaux. Colloque sur la fertilité des Sols Tropicaux. Tananarive, 19-25 Nov. 1967 ; I:99-115.
22. BUNASOLS, Bureau National des sols. Manuel pour l'évaluation des terres, documentions techniques n° 6, BUNASOLS/ Ouagadougou, Burkina Faso, 1990 ;181p.
23. Othman WW, Lie TA, Wassink GY. Low level phosphorus supply affecting nodulation, N2 fixation and growth of cowpea (*Vigna unguiculata* L. Walp). Plant and Soil.1991;135: 67-74.
24. Stroosnijder L. Modelling the effect of grazing on infiltration, runoff and primary production in the Sahel. Ecological Modelling.1996;92: 79-88.
25. Pekka N, Vaillant V, Desfontaine L, Cruz P and Domenach AM 2000. Effets of nitrogen source and defoliation on growth and biological denitrogen fixation of Gliricidia sepium seedlings.Tree physiology, 20: 33-40.

26. Owolade OF, Akande MO, Alabi BS and Adediran JA. Phosphorus level affects brown blotch disease, development and yield of cowpea. World Journal of Agricultural Sciences. 2006; 2 :105-108.
27. Singh HP, Singh TA. The interaction of rockphosphate, Bradyrhizobium, vesicular-arbuscular mycorrhizae and phosphate-solubilizing microbes on soybean grown in a sub-Himalayan mollisol. Mycorrhiza. 1993;4: 37-43.
28. Kasongo RK, Van Ranst E, Kanyankogote P, Verdoodt A, Baert G. Réponse du soja (Glycine max) à l'application de phosphate de Kanzi et de dolomie rose de Kimpese sur sol sableux en RD Congo. Canadian Journal of Soil Science;2012;92: 905-916.
29. Bello SK, Yusuf AA, Cargele M. Performance of cowpea as influenced by native strain of rhizobia, lime and phosphorus in Samaru, Nigeria. Symbiosis. 2018;75: 167–176.
30. Weil S, Gregg PEH, Bolan NS. Influence of soil moisture on the dissolution of reactive phosphate rocks. The efficient use of fertilizers in a changing environment: reconciling productivity and sustainability. Occasional Report.1994;7: 75-81.
31. Sale PG, Gilkes RJ, Bolland MDA, Simpson PG, Lewis DC, Ratkowsky DA, Johnson D.The agronomic effectiveness of reactive phosphate rocks 1. Effect of the pasture environment. Animal Production Science.1997;37: 921-936.
32. Mutuo PK, Smithson PC, Buresh RJ, Okalebo RJ. Comparison of phosphate rock and triple superphosphate on a phosphorus-deficient Kenyan soil. Communications in Soil Science and Plant Analysis.1999;30:1091-1103.
33. Singleton PW, Tavares JW. Inoculation response of legumes in relation to the number and effectiveness of indigenous Rhizobium populations. Applied and Environmental Microbiology. 1986; 51:1013-1018.
34. Thies JE, Bohlool BB, Singleton PW. Environmental effects on competition for nodule occupancy between introduced and indigenous rhizobia and among introduced strains. Canadian Journal of Microbiology. 1992; 3:493-500.
35. Hong TD, Minchin FR, Summerfield RJ. Recovery of nodulated cowpea plants (*Vigna unguiculata* (L.) Walp.) from waterlogging during vegetative growth. Plant and Soil. 1977; 48: 661-672.
36. Pan J, Sharif R, Xu X, Chen X.Mechanisms of Waterlogging Tolerance in Plants: Research Progress and Prospects. Front. Plant Sci. 2021; 11:627331.
37. Sacko O, Yattara II, Lahbib M, Neyra M. Effects of a rock phosphate on indigenous rhizobia associated with *Sesbania sesban*. Journal of Environmental Management, 95: 265-268.
38. Beauchamp CJ 1993: Mode of action of plant growth-promoting rhizobacteria and their potential use as biological control agent. Phytoprotection.2012;74: 19-28.
39. Geetha K, Rajithasri AB, Bhadraiah B. Isolation of Plant growth promoting rhizo bacteria from rhizosphere soils of green gram, biochemical characterization and screening for antifungal activity against pathogenic fungi. International Journal of Pharmaceutical Science Invention. ISSN (Print) 2014: 2319 – 670X.
40. Nwoke OC, Diels J, Abaidoo R, Sanginga N. Low phosphorus availability in West African moist savanna soils: effect of sparing soluble P sources on growth of soybean, cowpea and maize. In African Crop Science Conference Proceedings. 2005; 7:1157-1161.
41. Iro II, Auwalu BM, Sabo MU. Effect of phosphorous rates on growth and yield of cowpea [Vigna unguiculata (L.) Walph.] Varieties in jos north, plateau state, Nigeria. Journal of Agripreneurship and Sustainable Development (JASD). 2022 ;5 (2):2651-6144;
42. Hinsinger P, Jaillard B, Le Cadre E, Plassard C. Spéciation et biodisponibilité du phosphore dans la rhizosphère. Océanis. 2007 ;33: 37-50.
43. Rahmoune C, Maâlem S and Bennaceur M 2004. Effets comparés de la fertilisation phosphatée sur l'atriplex cultivé en zone semi -aride du nord-est algérien. Options Méditerranéennes, 60 : 213-216.
44. Sokoto AL, Singh A. Yield and yield components of cowpea (*Vigna unguiculata* (L.) Walp.) as influenced by Sokoto phosphate rock and placement methods in the semi-arid zone of Nigeria. Nutrient Cycling in Agroecosystems. 2008; 81 :255-265.
45. Guissou T, Bâ AM, Guinko S, Duponnois R, Plenchette C. Influence des phosphates naturels et des mycorhizes à vésicules et à arbuscules sur la croissance et la nutrition minérale de *Zizyphus mauritiana* Lam. dans un sol à pH alcalin. Annales des Sciences Forestières 1998 ;5 :925-931.