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RESPONSE OF GROUNDNUT (*Arachis hypogaea L.*) TO EXOGENOUS *Bradyrhizobium sp* STRAINS INOCULATION AND PHOSPHORUS SUPPLY IN TWO AGRO-ECOLOGICAL ZONES OF BENIN, WEST AFRICA

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ABSTRACT

The aim of this study was to assess the response of phosphorus and some *Bradyrhizobium sp* strains inoculation on the growth and development of *Arachis hypogaea L.* Fields trials were carried out in twelve farms located in the north and center of Benin. The experimental design is a randomized complete block with two factors dispersed to six repetitions. The first factor is inoculation of *Bradyrhizobium* with four levels (control, STM 5945, STM 5894 and WSM 4412) and second factor is phosphorus with two levels (0 and 50 $Kg.ha^{-1}$). After 50 days of sowing, parameters related to growth, nodulation and nitrogen accumulation in aerial biomass were collected. After harvesting, fallen leaves yields biomass and pods yield have been assessed. The best height was obtained in treatment containing rhizobial STM 5945 and it was 25 % higher than the control. In case of number of leaves, there were an increase of 79% in treatment containing WSM 4412 + Phosphorus while this number was 63% higher in treatment having STM 5894 + Phosphorus whereas the single treatment of strains induce 38% (STM 5894) and 33% (WSM 4412) increases over the control. In the center, the pods yields were increased 135% (WSM 4412 + phosphorus) and 113% (STM 5945+phosphorus) over the control. In the north, the treatments with STM 5945 strains only induce pods increase of 51 % and 21 % for WSM 4412. In the north, the best increase of nitrogen accumulation was 196% in the combination of WSM 4412 + phosphorus as compared to the control. These results augur the possibility to use these *Bradyrhizobiums* strains as biologic fertilizer to increase the growth and the productivity of the groundnut in Benin.

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1 Introduction

Groundnut (*Arachis hypogaea L.*) is one of the most important oleaginous plants cultivated all over the world and particularly in tropical and subtropical areas (Shiyam, 2010). This crop is commonly cultivated in arid and semi-arid regions of Africa (Clavel & Gautreau, 1997) where it plays an important socio-economical role. Indeed, in many developing countries such as Benin, it is cultivated both for exportation and local consummation. It contains proteins and is one of the major oil yielding crops used in traditional and industrial transformation factories. Although, cultivated areas increased from 2000 to 2012 (from 80.000 to 100.000 ha) but still the yields remain very low (600 to 800 $kg.ha^{-1}$) (MAEP, 2012). There is a continuous degradation in the determining factors of soil fertility with reduction of fallow and fertilizers uses at low level. One of the main constraints for a good productivity of this crop is the nitrogen deficiency in soils (Mohamed & Abdalla, 2013) followed by phosphorus low level in soils (Maheswar & Sathiyavani, 2012).

To overcome this problem of crop yield reduction, many farmers used chemical fertilizers. Although the chemical fertilizers helped in increasing the yield but, they are commonly associated with soil pollution and their high costs making them unaffordable to smallholder African farmers (Plenchette et al. 2005; Perem, 2011). Apart of the chemical fertilizers, it can be noticed, the uses of bacteria that are able to fixe atmospheric nitrogen in appropriate climatic and pedological conditions (Kishinevsky et al., 1984). Indeed, it has been estimated that leguminous plant with symbiotic nitrogen fixing bacteria, are able to fix about 15 to 210 $kg.ha^{-1}$ of nitrogen per season in Africa (Dakora & Keya, 1997). In many traditional farming systems, crop rotation with groundnut make possible to increase the yield of crop (Nwaga & Ngo Nkot, 1998) because it may highly contribute to increase the soil nitrogen contents (FAO, 1991). The symbiosis of *Rhizobium* and groundnut fixed 70% - 80% nitrogen and fulfill the demand of groundnut nitrogen (Adlan & Mukhtar, 2004). Thus, the inoculation of groundnut with competitive rhizobia revealed to be a beneficial technique (Nwaga et al., 2000; Sharma et al., 2011) because it can considerably improve the growth and productivity and symbiotic parameters of groundnut (Sajid et al., 2011; Mohamed & Abdalla, 2013). Indeed, Sajid et al. (2011) and Hoque & Hashem, (1991) were conducted field experiments with soybean and groundnut for selection of suitable Rhizobium strains for inoculum production. They obtained good results for various crop parameters such as nodule number; nodule weight and root dry matter etc. during vegetative growth of the crops and increase the yield at maturity. Elsewhere, the response of a promiscuous soybean cultivar to Rhizobial inoculation and phosphorus are study by Muhammad, (2010) in the Nigeria and reported that the four Rhizobial inoculants (R25B, IRj 2180A, IRc 461 and IRc 291) were found to increase the parameters as the number of nodules, dry shoot biomass, grain yield, grain N and haulm N content.

Apart of the nitrogen, phosphorus is also an essential nutrient for an efficient growth and yield improvement of the groundnut (Hemalatha et al., 2013). Also, the phosphorus can not only increase of the crop nitrogen fixation rate (Jones, 1982) but also increased the nodulation of roots (Nwaga & Ngo Nkot, 1998). The competition observed among soil native bacteria strains is minimized with an appropriate dose of phosphorus (Basu & Bhadoria, 2008; Basu, 2011). It included in the cropping system, groundnut is known to help phosphorus solubilization in soils, with this it can improve the soil physical environment, and soil microbial activity to restore most of it organic matters (Ghosh et al., 2007).

The adoption of sustainable production systems using less or no chemical inputs and the valorization of nitrogen fixing bacteria in association with phosphorus supply may be an appropriate way for improving groundnut productivity in Benin. Unfortunately, there is a lake of information related to rhizobial inoculation responses of groundnuts in Benin. Thus, the aim of the present study was to assess the performance of introduced strains of *Bradyrhizobium sp* in association with phosphorus application on the productivity of groundnut in two agro-ecological zones of Benin.

2 Materials and Methods

2.1 Study area

Farm experiment was carried out from July 2013 to October 2013 in two agro-ecological zones (zone III in the northern part and zone V in the center) of Benin, West Africa (Figure 1). The agro-ecological zones III (located between 1°10- 3°45-E and 9°45-12°25-N) is characterized by a soudano-guinean climate with an average rainfall of 1100 to 1200 mm/year. In this zone, the experiment were installed at Ina (9°57’51’’N, 2°43’34”E) located in the commune of Bemberekè and Tamarou (9°44’11”N, 2°41’50”E)in the commune of N’dali (Figure 1). The agro-ecological zones V (1°45- 2°24-E and 6°25-7°30-N) is characterized by subequatorial climate with an annual rainfall around 1100 mm. In this zone V, localities such as Yawa (7°57’-1°03-N and 2°12’-9°65-E) in the commune of Glazoué (Yawa) and Gobé (8°00’-4°89-N and 2°25’-8°64’-E) in Savè were chosen to shelter the experimentation. During the experiment period, the climatic parameters were 75mm for annual rainfall, and temperature was between 32°C to 22°C while in zone III while in zone V annual rainfall was 70 mm, temperature reported between 33°C to 22°C.

2.2 Sampling and soils analysis

Soil samples (500 g) were collected from each experimental field before sowing. Once collected, the samples were aliquot for the physico-chemical analysis. The Robinson’s pipette was used to determine the granulometry (Gee & Bauder, 1986).

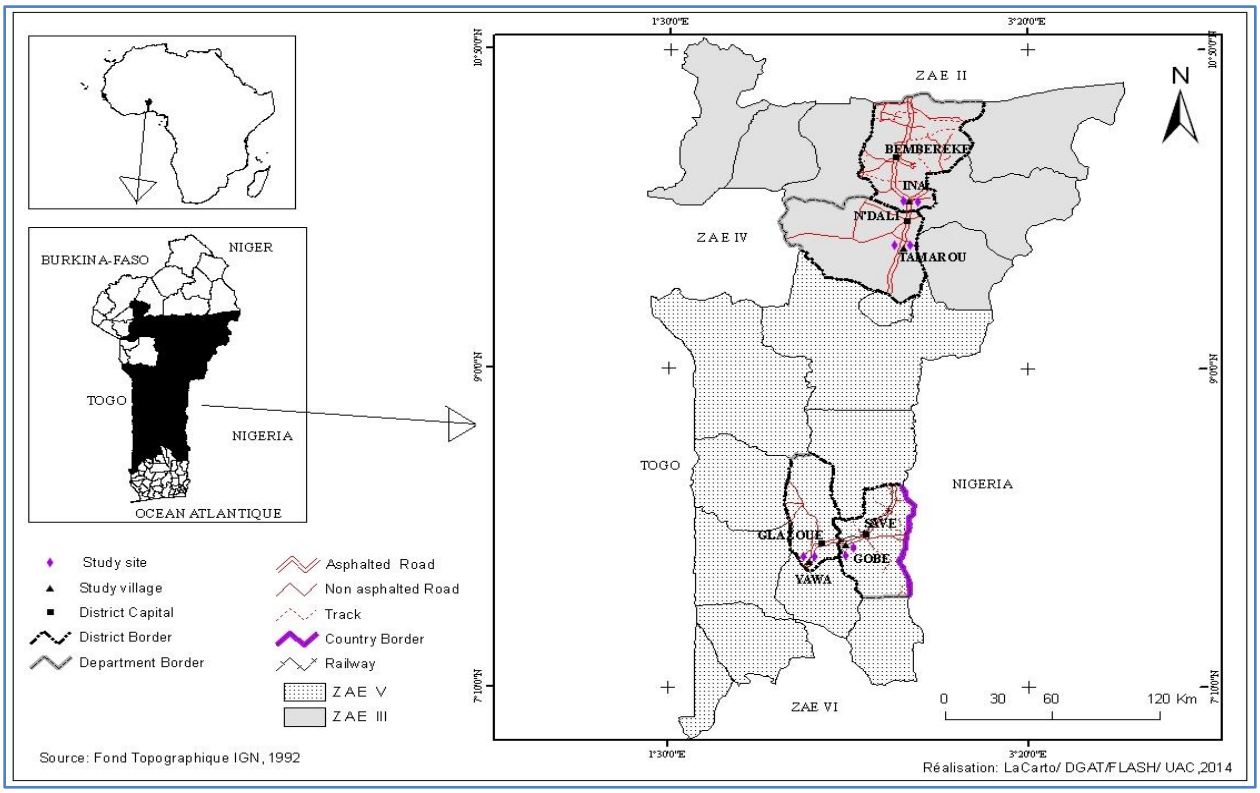


Figure 1 Localization of the two agro-ecological zones of study in Benin.

The pH was measured in water (soil: water ratio 1:2.5) and KCl (1:2.5) with a digital pH meter (Black, 1965) whereas the organic carbon was determined by the acid digestion method (Walkley & Black, 1934) and the total nitrogen was determined using auto-analyzer (Bremner & Mulvaney, 1982). The Cation Exchange Capacity (CEC) was determined by Metson method (Baize, 2000) and the phosphorus (total and available) were determine using the method of Duval (Bray & Kurtz, 1945).

2.3 Plant material

The groundnut variety TS 32-1 was collected from National Institute of Agricultural Research (INRAB) and used for the present trials. This variety become semi-mature in 90 days and usually cultivated in localities with short rainy season (Bockelee-Morvan, 1983). In addition, the variety have very high germination rate (about 80 %) with a yield of 3 t/ha and the weight of 100 grains is evaluated to 35-38g.

2.4 Rhizobium inoculum

Three *Rhizobium* strains namely STM 5945, STM 5894 and WSM 4412 were used for experimentations. The peat was used as carrier for the inoculum preparation it is neutralized by 0.30% of $CaCO_3$.The mixture was sterilized at 121°C for 1hrs (Menaka & Alagawadi, 2007). Twenty (20) ml of each bacterial strain suspension were used to inoculate in 75g of peats packaged in thermo-resistant polypropylene bags in aim to obtain 2.8 x 10^8 CFU/g. The groundnut seeds (15 kg) were coated with a melting of arabic gum (300 ml) and appropriate strains inoculation (100 g) (Nwaga, 2008).

2.5 Experimental design and grain inoculation

The experiments were led out in a randomized block design on two factors with three replicates per communes. Each block had eight plots amongst them one plots did not have any supply or inoculation (T0) and serve as a control, while the rest 7 plots were inoculated with various treatments (T1-T7). A surface covered by a single plot was 64 m^2 (10 m x 6.40 m) and two consecutive plots were spaced by 0.80 m. The treatments were: (i) Control (T0),(ii) plants supplied with50 kg $P_2O_5.ha^{-1}$ (T1), (iii) plants inoculated with STM 5945(T2), (iv) plants inoculated with STM 5945 and supplied with 50 kg $P_2O_5.ha^{-1}$(T3),(v)plants inoculated with STM 5894 (T4), (vi) plants inoculated with STM 5894 and supplied with 50 kg $P_2O_5.ha^{-1}$ **(**T5**)**, (vii) plants inoculated with WSM 4412 (T6),: (viii) plants inoculated with WSM 4412 and supplied with50 kg $P_2O_5.ha^{-1}$ **(**T7**)**.

2.6 Measurement of plants Parameters

2.6.1 Growth and vegetative parameters

At the flowering stage, samples of 12 plants were collected randomly from a square (1 m²) to evaluate their height, number of branches and number of leaves following the method described by Sharma et al. (2011). The dry matter was estimated by drying the aerial and underground plants parts at 65°C for 72 h (Yadav et al., 2010).

2.6.2 Symbiotic and chemical parameters

The randomly selected plants were separated into shoots and roots. Soil was carefully washed from the roots. The nodules on the each root system were picked carefully and their number and dry weight recorded. The total nitrogen content in the aerial biomass was determined using the Kjeldahl method (Bremner, 1965).

2.6.3 Production parameters

In a field, a surface of 9 m^2 per treatment was harvested for the estimation of the yield in leaves biomass and pods.

2.7 Statistical analysis

The statistical analyses were carried out using Statistical Analysis System (SAS) version 9.2 software. The collected data were subject to an analysis of variance (ANOVA) and to means structuring (Student test Newman-Keuls) of parameters.

3 Results

3.1 Soil characteristics

Results obtained on physical and chemical characteristics of soils showed a high pedological diversity among the sampling regions (Table 1). Thus, soils sampled at Yawa (center), Tamarou and Ina (North) has sandy loam texture while the sample collected from Gobé has loamy sand characteristic. The pH values obtained from the study shows that soils were light acidic ($5<pH_{(water)}< 6.50$) and potentially poor in nutrients (OM < 3 % and the CEC < 25 méq/100g).

Concerning organic carbon contents of soils, it varies from 0.8% to 1.2%. The highest average contents were observed at Tamarou (1.26 %). Soils of the center zone (zone V) were poor in total nitrogen contents (%N-total < 0.08%) whereas those of the north zone (zone III) were moderately provided in nitrogen (%N-total < 0.13%). Similarly, great variability was reported in the content of available phosphorus with a percentage of 22 to 55 %.

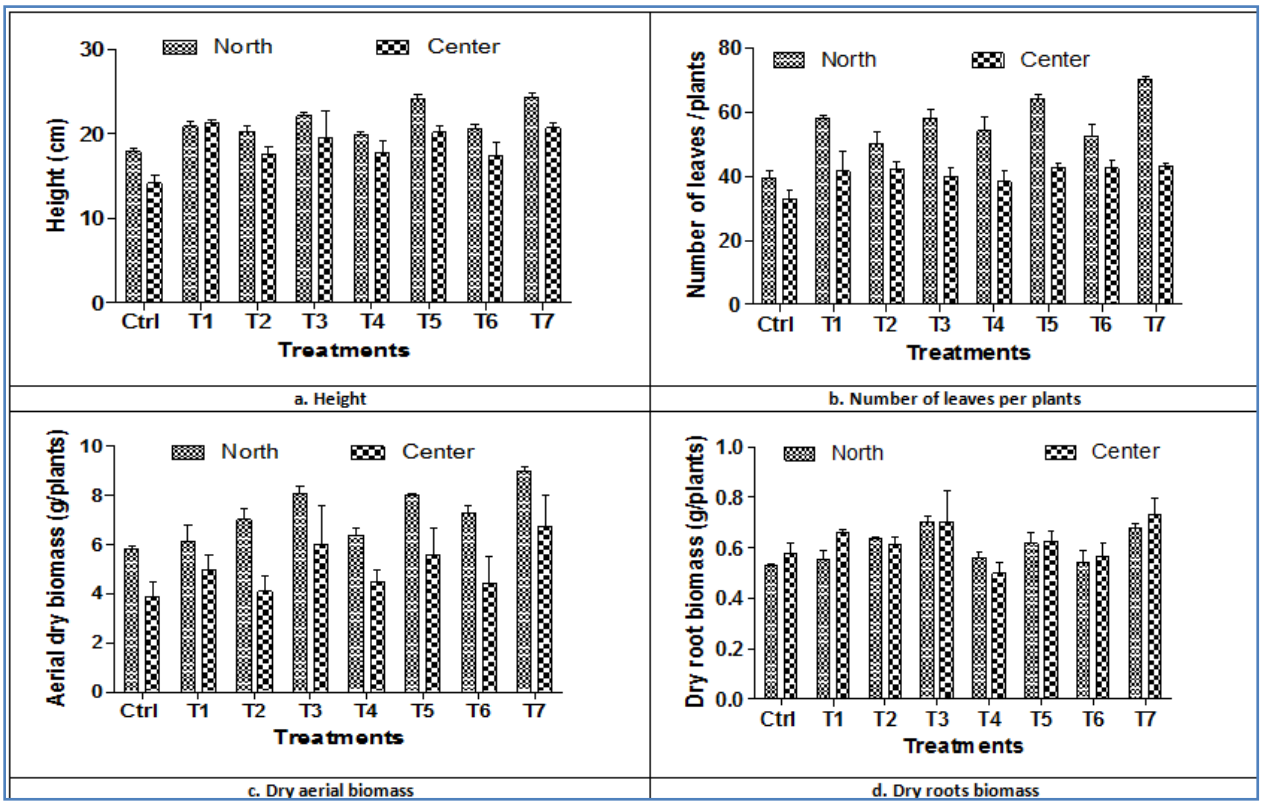
3.2 Plant height

The effect of treatments on the height of groundnut plants has revealed to be highly significant in the north zone experimentations ($p<0.001$) while it is significant ($p<0.05$) with the center's zone experimentations (Figure 2a). Independently to the experimentation area, the most important height averages were observed with the treatment T5 and T7. These treatment, induced a significant growth of the plants as compared to the control ($p<0.001$).

Table 1 Physicochemical characteristics of soil prior to tests.

Physicochemical parameters		AEZ V		AEZ III	
		Centre		North	
		Glazoue	Save	N'dali	Bembereke
	Clay (%)	12.06±2.02	8.33±0.72	12.46±0.58	11.40±0.5
Texture	Silt (%)	20.40±7.88	7.96±1.02	10.70±1.45	15.46±1.19
	Sand (%)	65.86±9.00	82.73±1.33	76.13±2.15	72.20±2.87
		Ls	Sl	Ls	Ls
pH	pH (Water)	6.20±0.25	6.50±0.12	6.40±0.15	6.10±0.08
	pH (KCl)	5.90±0.23	6.23±0.08	6.03±0.12	5.86±0.06
	OM (%)	1.48±0.13	1.46±0.33	2.18±1.17	1.55±0.43
	C-org (%)	0.86±0.04	0.85±0.11	1.26±0.39	0.90±0.14
	N total (%)	0.05±0.00	0.07±0.00	0.09±0.01	0.09±0.00
	C/N	15.16±1.96	12.23±2.61	13.38±2.99	9.84±1.19
	P-total (ppm)	86.68±12.73	91.84±12.46	87.07±14.35	110.91±3.60
	P-ass (ppm)	26.60±1.44	33.17±2.88	29.68±1.50	27.14±0.74
	CEC (meq/100g)	19.16±2.20	19.37±4.16	24.37±2.25	13.33±3.00

***Ls**: Silty-sandy; **Sl**: Sandy-silty*



Ctrl: control**, T1:** plants supplied with50 kg $P_2O_5.ha^{-1}$**, T2:** plants inoculated with STM 5945**, T3:** plants inoculated with STM 5945 and supplied with 50 kg $P_2O_5.ha^{-1}$**, T4:** plants inoculated with STM 5894**, T5:** plants inoculated with STM 5894 and supplied with 50 kg $P_2O_5.ha^{-1}$**, T6:** plants inoculated with WSM 4412**, T7:** plants inoculated with WSM 4412 and supplied with50 kg $P_2O_5.ha^{-1}$**.**

Figure 2 Estimation of the growth and vegetative parameters recorded after phosphorus supply and strains inoculations.

But the height recorded within the treatment T2, T4 and T6 and only in the phosphorus (T1) are not statistically different then the control (Figure 2 a).

3.3 Number of leaves per plant

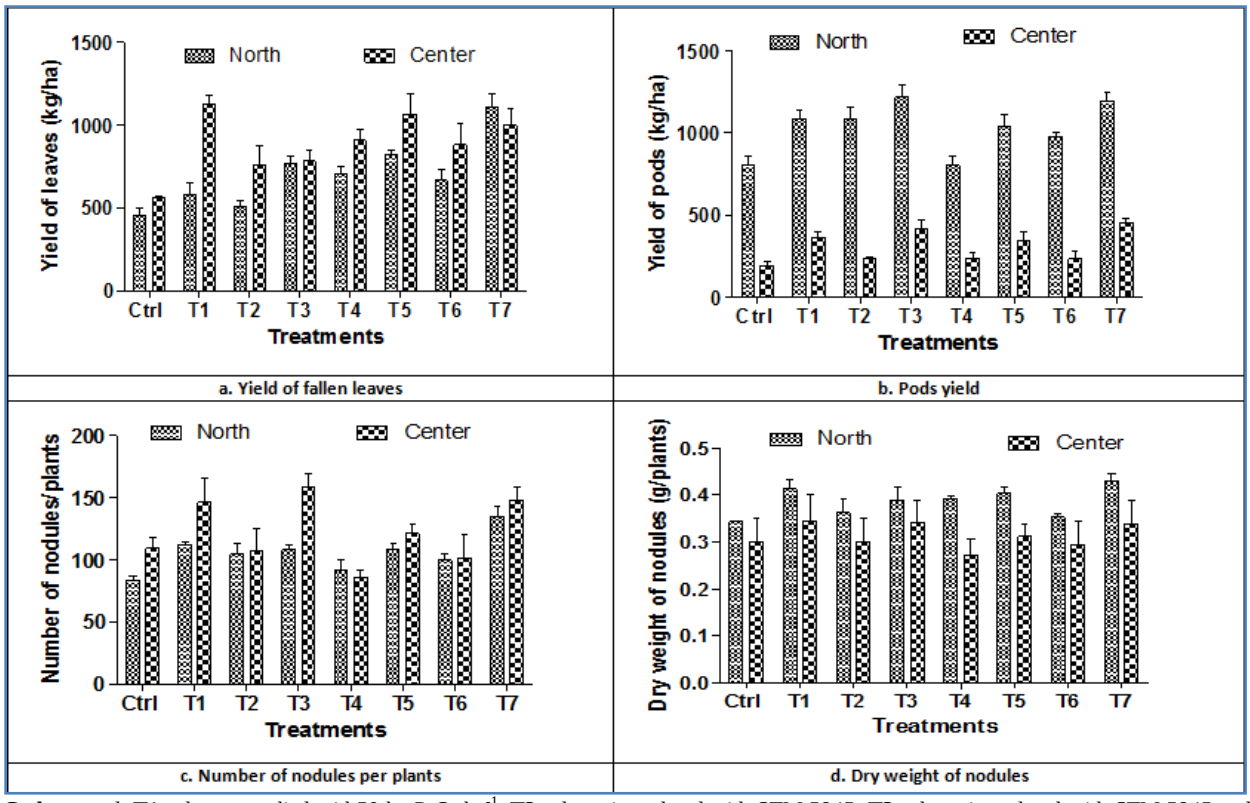
In comparison to the control, all the treatment displays significant increases in the average number of leaves in the north zone (p< 0.001). In the central area, slight difference was reported only in treatment T5 and T7 (p<0.05). In the north zone, the highest average numbers (Figure 2b) of leaves were observed with the treatments supplied with phosphorus (T1, T3, T5 and T7). Among the tested strains, the one which improved the number of leaves highest are STM 5894 (54.23±7.15) and WSM 4412 (52.54±6.51).

3.3 Dry aerial biomass per plant

The Figure 2c compiled the average values of aerial dry biomass. It clearly shows that the parameter related to dry aerial biomass per plant was better in the northen zone as compare to the center zone (p<0.001). Both in the north and the center, the most significant biomass was observed with the treatment T7 (p< 0.05). For the other treatment, the recorded biomass difference was not significant (p> 0.05). Considering the treatment with strains only, the highest biomass were observed with WSM 4412 (7.29±0.44 g/plants) followed by STM 5945 (7.01±0.77 g/plants) and then STM 5894 (6.36±0.50 g/plants) in the north experimentations. Globally, the treatments of strains supplied with phosphorus produced the better weigh of aerial biomass in both experimental areas (Figure 2c).

3.4 Dry root biomass per plant

The recorded data in the north and center zone were not statistically different (p> 0.05). Nevertheless, in comparison with the control (0.53± 0.01 g/plants), the weight of the roots recorded in the north was statistically high for the strains STM 5945 + phosphorus (0.71± 0.04 g/plants) (p< 0.05). While In the center, the roots dry matter's weight for strains WSM 4412+phosphorus (0.73±0.11 g/plants) was higher than the one recorded with the treatment of the strains (0.57±0.10 g/plants) only (Figure 2d).



Ctrl: control, **T1:** plants supplied with50 kg $P_2O_5.ha^{-1}$, **T2:** plants inoculated with STM 5945, **T3:** plants inoculated with STM 5945 and supplied with 50 kg $P_2O_5.ha^{-1}$, **T4:** plants inoculated with STM 5894, **T5:** plants inoculated with STM 5894 and supplied with 50 kg $P_2O_5.ha^{-1}$, **T6:** plants inoculated with WSM 4412, **T7:** plants inoculated with WSM 4412 and supplied with50 kg $P_2O_5.ha^{-1}$.

Figure 3 Estimation of symbiotic and nodules parameters recorded after phosphorus supply and strains inoculations.

3.5 Fallen leaves yield per hectare

The Figure 3a shows the existence of a highly significant effect of treatments on fallen leaves yield in the groundnut. In the north, the combined treatment T7 (WSM 4412 + phosphorus) clearly displays the best yield of fallen leaves biomass. Thus, the weight of fallen leaves in treatment T7 (1110.37±136.29 kg/ha) were assays significantly higher than those with a single treatment of WSM 4412 only (666.64±117.04 kg/ha) (p<0.001). In the center, the highest fallen leaves biomass was observed with the treatments made exclusively of phosphorus (1132.34±82.80 kg/ha) followed by the T5 (1068.63 ± 209.52 kg/ha) and T7 (1002.32±179.91 kg/ha).

3.6 Pod yield per hectare

The data displays in the Figure 3b indicate that the pods yield was reported higher in the north zone than the center (p< 0.001). In the north, although all the treatments induce a significant increases in the number of pods (p< 0.001) and the highest pod yields were reported form the treatments T3 (1220.97±126.55 kg/ha) and T7 (1195.90±83.86 kg/ha). Considering the tested strains, STM 5945 (1086.21±128.23 kg/ha) and WSM 4412 (980.03±47.56 kg/ha) induced the highest pod yields. While for the center zone, all the treatments were recorded with lowest values in comparison to those of the north (Figure 3b).

3.7 Number of nodules per plant

The number of nodules per plants were not showing any significant different between the north and the center assays for all the treatments (p>0.05) (Figure 3c). Nevertheless, the biggest values were recorded with the treatments led in the center. In the center, compared with the control (109.50±14.53), the significantly highest number of nodules were recorded with the T3 (159.00±17.32; p<0.01), T7 (148.50±17.52; p<0.05) and T1 (146.83±33.67; p< 0.05). Whereas in the north, only T7 (134.67±14.21) was significantly very different (p< 0.01) to the control (83.61±6.08).

3.8 Dry weight of nodules per plant

The data concerning to the dry weight of nodules are compiled and displayed in the Figure 3d. This figure shows that there is not a significant difference between the data of the north and center (p> 0.05). Also, in comparison with the control, there not any significant difference of weight independently to the kind of treatment.

3.9 Nitrogen accumulation

The Figure 4 shows the nitrogen content and it was highly accumulated in all the treatments of the north. Globally, all the treatment of strains supplies with phosphorus induced the best nitrogen accumulation rates. Thus, in the north, the highest accumulation was reported in the treatment containing WSM 4412 + phosphorus (3.98%±0.33) and in the center a nitrogen accumulation of 3.19%±0.21 was recorded with STM 5945 +phosphorus. Considering the treatment of rhizobium strains only, various treatments can be classified in the north is as follows: STM 5894 (2.49±0.55), WSM 4412 (2.39%±0.05), STM 5945 (2.36%±0.85). For the center experimentation, STM 5945 (2.11%±0.14) induce the best nitrogen accumulation followed by WSM 4412 (1.81%±0.62) and STM 5894 (1.7%±0.23).

Discussions

The present study shows that the supply of phosphorus and the inoculation of rhizobium bacteria have positive impact on the groundnut growth parameter. Nevertheless, for most of the recorded parameters, the data collected from the north experimentation are considerably higher than those of the center. After analyzing soils, variability in the composition of soil was denoted. The difference indicates in texture of soil, sandy loam type of soil was reported from the north zone while loamy sands type of soil was reported from the center zones. Thus, the loamy sand may be disadvantageous for the groundnut cultivation. With reference to the study of Martin & Nolin (1991), the tested soils are not very rich in nutritive matters although the soils collected from the north content were have more nutritive matter than those collected in the center. Nevertheless, the low acidity is not disadvantageous to the growth of bacteria such as rhizobium (Schilling, 2003). In addition, the bad climatic condition (particularly rain) recorded during study may negatively act on the growth parameters of groundnut. Indeed, during present experimentations, there was a lake of rain in the center of Benin. Thus, the low recorded parameters were recorded at the low pluviometry level that may handicap the bacteria expression and phosphorus availability. Some authors recorded a decrease of rhizobial activity and groundnut growth during a long period of dryness (Venkateswaralu, 1997; Perem, 2011).

Globally, the effect of treatments on the height of groundnut plants was higher than the control (p<0.001) (Figure 2a). Result of the present study are corroborate with Shaheen & Rahmatullah (1994) and Basu et al. (2006)those who reported a positive effect on rhizobial inoculation on the height of groundnut plants. In comparison to the control, the height was increase about 23% (WSM 4412) and 25% (STM 5894 and STM5945) in the center experimentations.

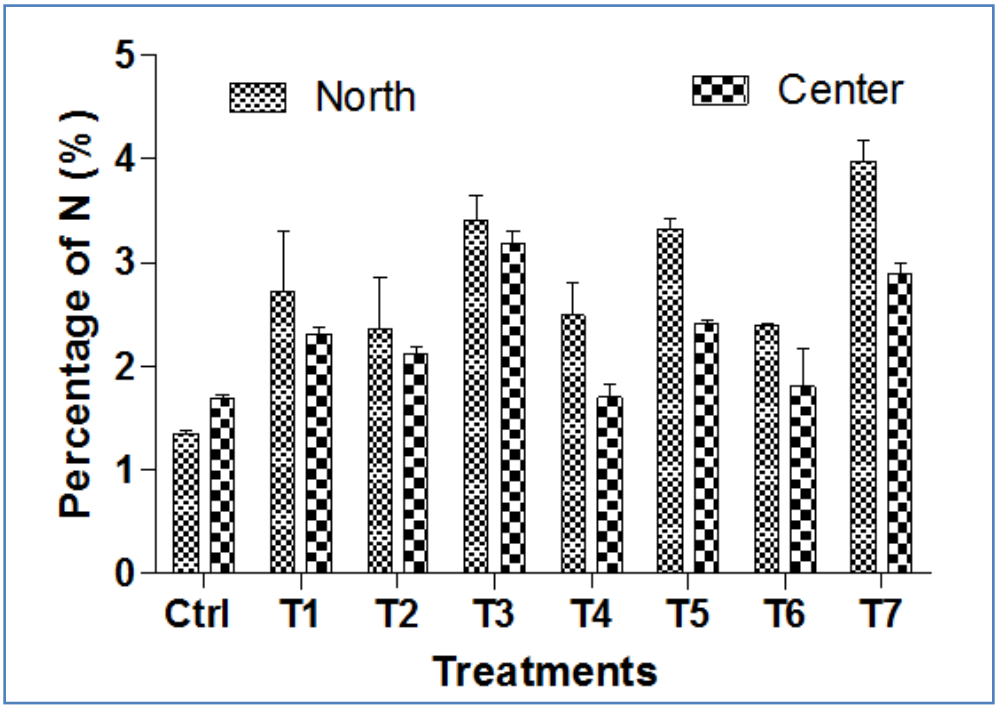


Figure 4 Variation of the nitrogen accumulation rate after phosphorus supply and strains inoculations.

Though the same plants speculations were used but the percentages of increase are lower than the 56.78% as recorded by Sajid et al. (2011) in Pakistan. The difference observed may be due to the difference in cultivation soils and used strains. In this study, the best height was obtained with the treatments of strains supplied with phosphorus. Thus it can be conclude that there is a synergetic effect between rhizobacteria and the phosphorus. This combination promotes the growth of the groundnut.

A significant increase in the average number of leaves in the north ($p< 0.001$) and globally the treatment with strains only induce the increase of leaves numbers. This observation suggests the benefic effect on leaves production of rhizobial strains. The optimum effect were observed after a supply, to rhizobial, of phosphorus (Figure 2b) suggesting a symbiotic action between the bacteria and the mineral element. Then, an increase of 79% (WSM 4412+P) and 63% (STM 5894+P) of leaves number were observed in the combination whereas the single treatment of strains induce 38% (STM 5894) and 33% (WSM 4412) of increases. This increases recorded with the treatment of strains were only similar to those reported by Sajid et al.(2011) in Pakistan. As for the number of leaves, the aerial dry biomass is better in the north than in the center ($p<0.001$). However, in both north and center, the most significant biomass was observed with the treatment WSM 4412+P ($p< 0.05$) and generally with the treatments of strains supplied by phosphorus (Figure 2c). The treatment with strains only, the biomass were increased at 25% (WSM 4412), 20% (STM 5945) and 9% (STM 5894) in the north experimentations. Those results concerning the aerial dry biomass are lower than 51% reported by Basu et al. (2006) during their experiment on groundnut with a unique application of strains. The difference in the results in comparison to those of Basu et al. (2006) may be due to the difference of strains used in the two studies.

The roots dry biomass was not statistically different ($p> 0.05$) between experiments of the north and those of the center. However the best roots dry biomass was recorded with strains WSM 4412 + phosphorus (0.73±0.11 g/plants) for the center zone while the best strain for the north experimentation was STM 5945 + phosphorus (0.71±0.04 g/plants). Significant effect of bacterial stain on the root dry weight was reported by various researchers (Sharma et al., 2011; Mohamed & Abdalla, 2013). Thus the single treatment of strains shows an increase of 20% with STM 5945 in the north (Figure 2d). Independently to the area, STM 5945 was the only one strain that permitted to have over 10% of dry roots biomass increase.

The weight of groundnut's fallen leaves was significantly increases with the treatment of strains and/or phosphorus supply. The highest improvement (146%) as compared to the control was observed with the treatment of WSM 4412 + phosphorus in the north. In the same area, the treatments with bacterial strains induced an increase of 56% (STM 5894), 48% (WSM 4412) and 12% (STM 5894) respectively. The same tendency was observed in the center with respectively 61% (STM 5894), 56% and 35% (STM 5894). The increase of the fallen leaves biomass among the treatment of strains can be due to the ability of those strains to fixe atmospheric nitrogen (Mohamed & Abdalla, 2013). This ability to fixe nitrogen is considerably strong then by a supply in phosphorus. The values recorded in present study for most of the strains, superior to the 21% obtained by Ndiaye (1986) with the strain CB 756 on at Louga (Senegal). The recorded difference may be due to the used strains and to the climatic conditions.

The treatments induce a significant increases of pods ($p< 0.001$), the highest yields was recorded in the treatments supplied by phosphorus. In the center, there was an increase of 135% (WSM 4412+phosphorus) and 113% (STM 5945+phosphorus). Results of the present study are higher than those of Basu & Bhadoria (2008) those who obtained a yield of 38.20 % induced by the combination of phosphorus and an inoculum. In the north, the treatments with bacterial strains only induced an increase of 51% (STM 5945) and 21% (WSM 4412). The positive effect of phosphorus fertilizer in association with rhizobium strains on the pod yield has been recently demonstrated on *Vigna radiate* (Hussain et al. 2010) and on groundnut (Basu & Bhadoria, 2008). In the center, all the treatments of strains only induce an increase of about 20%. The positive effect of the rhizobium strains in the pod yield has already been reported in cops such as groundnut and *Vigna radiata* (Mohamed & Abdalla, 2013; Sajid et al. 2011). The increase of the pod yield may be the output of the fixation of the tested strains on the roots of the groundnut.

Various treatments affect the number of nodules per plants at the two experimentation areas. In the north, compared with the control, an increase in the nodules number was denoted and this improvement was up to 61% (WSM 4412 + phosphorus) while for the center it is up to 45% (STM 5945 + phosphorus). The improvement in nodules number after rhizobium inoculation was already reported by Mohamed & Abdalla (2013). But in present study a better action was denote after supplying the strains by phosphorus in contrast of the observations of the previously cited authors. As for the numbers, the weight of the nodules varies according to the treatment and the experimentation area. Thus, in the north the highest increase was recorded with the treatment of WSM 4412 + phosphorus (26%) whereas in the center it was the treatment of phosphorus only (15%) that displays the biggest nodules weight. Those results are similar to the observations made in Soudan by Mohamed & Abdalla (2013) when the inoculated groundnut with Rhizobium TAL 169 + phosphorus (50 $kg.ha^{-1}$). Moreover, Son et al. (2007) demonstrated that the application of a *Bradyrhizobium japonicum*s train + phosphate (60 kg of P_2O_5) in soya improves the number and dry weight of nodules in comparison with different conventional fertilizing methods used by farmers.

The nitrogen accumulation rates was increase by all the treatment of strains supplies with phosphorus. In comparison to the control, the treatments of strains + phosphorus accumulate nitrogen better than the single treatment of strains.

Thus, the best increase was near to 200% (WSM 4412 + phosphorus) and the low increase with the combination (strains + phosphorus) was recorded with STM 5894 +phosphorus (146%). In the north, this value increased with the increasing rate of application and with the strains only, these were in crescent order 75% (STM 5894), 77% (WSM 4412) and 84% (STM 5945). Those rates are higher than the values of 39.00% (Yakubu et al. 2010) and 30.00 % (Mohamed & Abdalla, 2013) in Soudan obtained respectively on sandy soil and on groundnut using inoculation combined to doses of phosphorus (50 $kg.ha^{-1}$). More interesting results were observed (135 %) in Senegal by Gueye, (1986) on Bambara groundnut.

Looking out all the studied parameters, it can be conclude that the establishment of the symbiosis between the groundnuts plants and bacteria strains depends on interactions among micro and macro-symbionte.

Conclusion

Present study confirms the promoter effect of rhizobium strains and their combination with phosphorus on many parameters such as symbiotic, growth and productivity of groundnut. It also appears that among the three tested strains STM 5945 and WSM 4412 were the better in all the investigated parameter than the strain STM 5894 was indifferently to the tested area. The best activity on the treatment was recorded if there is a good pluviometry. In addition, phosphorus application are significantly increased the effectiveness of rhizobial strains introduced that has induced good performance of peanut.

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