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EFFECT OF PHOSPHATE FERTILIZATION ON GROWTH, YIELD AND SEED PHOSPHORUS CONTENT OF BAMBARA PEA (*VIGNA SUBTERRANEA*) LAND RACES

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ABSTRACT

Responses of three Bambara pea [*Vigna subterranea* (L.) Verdc.] landraces subjected to different phosphorus (P) levels (0, 50, 100, 150 and 200 kg P_2O_5.ha^{-1}) were investigated in research farm during the years 2015 and 2016 at Mendong and Soa districts (Cameroon). Treatments were arranged factorial completely randomized design with three replications. Some growth (shoot length, number of branches) and yield (seed diameter, number of pods plant^{-1}, pods weight plant^{-1}, seeds weight plant^{-1}, 100-grain weight and grain yield) parameters and seed P content were determined. P application led to a significant increase in all growth and yield parameters and seed P content in both years with the high values at 150 kg P_2O_5.ha^{-1} compared to control. The maximum grain yield (1.99 t ha^{-1}) was found in White Seed Coat with grey eyes (WSCge), which was statistically similar to White Seeds Coat (WSC) (1.85 t ha^{-1}) in 2015. Light Red Seed Coat (RSC) had the least grain yield (1.23 and 0.71 t ha^{-1}) during 2015 and 2016, respectively. WSCge and WSC can be cultivated successfully in the humid forest agro-ecological zone. A dose of 150 kg P_2O_5.ha^{-1} can be considered as the efficient fertilizer to improve significantly the Bambara pea growth and yield performance.

Key words: phosphate fertilizer; productivity; seed phosphorus content; *Vigna subterranea*.

INTRODUCTION

The major problem contributing to reduce land productivity in the humid forest agro-ecological zone of Cameroon is soil impoverishment caused by continuous cropping with inadequate use of chemical fertilizers, soil depletion in essential nutrients [Nitrogen (N) and phosphorus (P)] and the farmer's inability to replenish nutrients lost in the continuous cultivation (Lynch and Deikam, 1998; Jemo *et al.,* 2010). In this area, growth and biological N fixation of legumes such as Bambara pea are hampered by P deficiency due to high P sorption by Fe and Al oxides (Ssali *et al.,* 1996). P is one of the least available nutrients in many aquatic and terrestrial ecosystems, and plant-available P deficiency is a main feature of many soils in Sub-Saharan Africa (Buresh and Smithson, 1997). Soil-P availability during plant seedling development is an important determinant factor for plant growth, N_2 fixation and grain formation of legumes (Vance, 2001). Similarly, good supply of inorganic-P is usually associated to increased root density, soil porosity and proliferation which aid in extensive exploration and supply of nutrients and water to the growing plant parts, resulting in increased growth and yield traits. Selection of genotypes efficient in acquiring P from sparingly available sources and fix N_2 from the atmosphere will benefit subsequent crops and represent keys elements of sustainable cropping systems in such regions (Jemo *et al.,* 2010). In addition, global reserves of commercial phosphate (phosphate rock) at the current rate of extraction will be exhausted by 2050 and only Africa and Latino America still have potentially cultivable land (Cordell *et al*., 2009; Lambin *et al*., 2013). In developing countries, 12.9% of the population is undernourished and malnutrition is the cause of 45% of the deaths of children under 5 years (Anonymous, 2016). The challenge of agricultural research is therefore to contribute to increase crop yields and soil productivity while safeguarding the environment.

Bambara pea (*Vigna subterranea* (L.) Verdc.) is an indigenous African legume. The crop is similar to peanut and forms pods and seeds on the ground. It has been reported as drought tolerant crop (Tsoata *et al*., 2016, 2017 a, b; Temegne *et al*., 2018 a) which is capable of producing some yields where other crops such as groundnut fail to survive. Bambara pea is a rich source of protein which, together with other local sources of protein, can help mitigate the nutritional problem in poor tropical countries (Massawe *et al*., 2005, Temegne *et al*., 2015 a, 2018 a). The gross energy value of Bambara pea seed is greater than that of other common pulses such as lentil, cowpea and pigeon pea (Anonymous, 1982). This crop is useful in the cropping system and found intercropped with cereals, root and tuber crop. In Botswana and Burkina Faso, Bambara pea is intercropped with maize, millet and sorghum (Drabo *et al.,* 1997). It also has a high potential for attainment of food security and poverty alleviation in most countries of the African continent especially for women who form the bulk of producers (60%) (Berchie *et al.,* 2012). In Cameroon, this crop comes after peanut, soyabean and cowpea, the fourth most important leguminous (Anonymous, 2009). It's among the most tolerant legumes grown on infertile soil (Nweke and Emeh, 2009; Taffouo *et al*., 2010; Toungos *et al*., 2010; Jideani and Diederiks, 2014, Temegne *et al*., 2015 a, 2017 a, b). In sub-saharan Africa, Bambara pea is mainly grown by female on a small scale, in pure culture without improved techniques (Ntundu *et al.,* 2004). Research on Bambara pea has been very limited compared to investigation made on sorghum, millet, maize, peanut and cowpea (Drabo *et al.,* 1997). With rapidly changing climatic conditions such as global warming and its attendance effect on agriculture, the research effort to improve the growth and yield performance and acceptability of Bambara pea will be a major boost towards solving the problem of hunger and nutrition in most parts of Africa.

Improving cropping techniques, pest and disease control and using potential genetic resource could increase production and productivity of Bambara pea (Ouedraogo *et al.,* 2008). Therefore, the aim of this study was to study the comparative effects of different P fertilization levels on growth, yield, and seed P content of Bambara pea landraces.

MATERIALS AND METHODS

Study area: The study was conducted during the 2015 and 2016 cropping seasons at two research farms, Mendong and Soa districts, Centre Region, Cameroon. The previous crop in Mendong was rice (*Oryza sativa* L.) with a predominance of ruderal species such as *Chromolaena odorata* L. and *Imperata cylindrica* L. Soa was an old shrubby fallow. Mendong units is located between longitude 11°27 East, latitude 03°50 North, at an elevation of 717 meters above sea level while Soa experimental field is located between longitude 11°34 East, latitude 03°58 North, at an elevation of 680 meters above sea level. The daily average temperature of air varies from 23 to 24 °C. These areas belong to the humid forest agro-ecological zone, characterized by oxisol in the USA soil taxonomy or acidic ferrasols (World Reference Base) and Guinean equatorial climate. They are governed by a bimodal rainfall pattern with four seasons: a long rainy season from September to November, a long dry season from December to February, a short rainy season from March to June and a short dry season from July to August (Fig. 1).

Soil sampling: Composite sample of the top soils (0-15cm depth) from each site was taken with an auger before bed preparation following the transect method described by Okalebo *et al.* (2002). About 200 g of the samples were analyzed for physical and chemical properties in the International Institute of Tropical Agriculture (IITA) soil laboratory of Nkolbisson (Cameroon). Soils samples were air-dried and ground to pass through a 2 mm sieve. For carbon (C) and nitrogen (N) analysis, soils was further fine ground to pass through a 0.5 mm sieve. Soil pH in water, was determined in a 1:2.5 (w/v) soil: water suspension. Organic C is determined by chromic acid digestion and spectrophotometric analysis (Heanes, 1984). Total N determined from a wet acid digest (Buondonno *et al.,* 1995) and analyzed by colorimetric analysis (Anderson and Ingram, 1993). Available P was extracted using Bray extractant and the resulting extract analyzed using the molybdate blue procedure described by Murphy and Riley (1962). Exchangeable cations Ca, Mg, K and Na extracted using the ammonium acetate and determined by flame atomic absorption spectrophotometry. Cation exchange capacity (CEC) is determined using ammonium acetate. Results of the soil analysis are presented in Table 1.

Plant materials, growth conditions and phosphate fertilization treatments: Seeds of three Bambara pea landraces [White Seeds Coat (WSC), light Red Seeds Coat (RSC) and White Seeds Coat with grey eyes (WSCge)], collected from Agronomic Institute for Research and Development (IRAD, Dschang) were used. The study was carried out during 2015 and 2016 years. The treatments consisted of combinations of different P fertilization levels (0, 50, 100, 150 and 200 kg P ha^{-1}), three landraces (WSC, RSC and WSCge) and two sites (Mendong and Soa). P was applied as single superphosphate (20% P_2O_5). Experiment units were arranged factorial completely randomized design and replicated thrice. After clearing and plowing at 20 cm depth, plots were 2 m x 2 m surfaced. Plots were separated from each other by 0.5 m path and each block was separated by 0.5 m alley. The spacing between lines was 25 cm and the line spacing between plants was 25 cm. P fertilizers were applied to their respective plots two weeks after sowing (WAS). Nitrogen was applied as urea (46% N) at the rate of 25 $gm^{-2}plot^{-1}$ in each plot as blanket treatment 2 WAS to increase the vegetative growth of the crop. Four seeds of Bambara pea were sown together in the same hole at about 5 cm deep on September 13 and 26, 2015 in Mendong and Soa respectively for the first year and March 19 and 26, 2016 in Mendong and Soa respectively for the second year. The seedlings were thinned down to one plant per hill 2 weeks after sowing (WAS). Weeding was manually done using hoe and hand pulling at one to two weeks interval till harvest. Harvesting was done manually on December 15 and 26, 2015 in Mendong and Soa respectively for the first year; and June 25 in Mendong and July 9, 2016 in Soa for the second year at physiological maturity when the leaves had yellow and faded.

Phosphorus content: Seed P was extracted by dry ashing in a muffle furnace at 500ºC, diluted using a dilute acid mix of HCl/HNO_3 and analyzed using Murphy Riley reagent and read colorimetrically (Murphy and Riley, 1962; Benton and Vernon, 1990).

Growth and yield attributes: Plant growth traits (number of branches and shoot length) were evaluated every two weeks using ten plants randomly selected in each plot.The yield components (number of pods plant^{-1}, weight of pods plant^{-1}, seed weight plant^{-1}, 100-grain weight and grain yield) were recorded at harvesting following the standard procedures (Mohsin *et al.,* 2014).

Data analysis: The experiment units were arranged factorial completely randomized design. All the crop data collected was subjected to analysis of variance (ANOVA). Statistical differences between treatment means were established using the Fisher LSD test at $p < 0.05$. Multifactorial ANOVA was used to estimate whether P fertilization levels, landrace, site, alone or in interaction had a significant influence on the measured parameters.

RESULTS AND DISCUSSION

Growth characteristics of Bambara pea landraces: Bambara pea growth was estimated by measuring the number of branches and the shoot length of different landraces under different P fertilization levels at vegetative stage (8 WAS). The effect of P fertilizer on number of branches and shoot length of Bambara pea was found statistically significant during the both years 2015 and 2016 at 6 and 8 WAS (Table 2, Fig. 2 and 3). P application led to a significant increase in number of branches and shoot length compared to untreated plants. P fertilizer applied at 200 kg ha^{-1} showed significantly higher number of branches and shoot length during both the years 2015 and 2016 at 8 WAS compared to the plants fed with 50, 100 and 150 kg P_2O_5 ha^{-1} and untreated controls (Fig. 2 and 3). The highest increase of number of branches was found in 2015 while the one of shoot length was recorded only in 2016 (Fig. 2 and 3). According to analysis of variance (Table 2) the interaction between landraces, P fertilization and sites were highly significant. Numerous studies have reported that P fertilization increased growth by enhancing solubilization of P uptake (Nweke and Emeh, 2013; Temegne *et al*., 2017 a, 2018 a, b). N, P and K are among the essential elements required for plant metabolism. P is required in high amount, and it is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics (Jemo *et al.,* 2010). Since P is readily mobilized in the plant, when a deficiency occurs the P is translocated from older tissues to active meristematic tissues, resulting in foliar deficiency symptoms appearing on the lower portion of the plant. Soil-P availability during plant seedling development is an important determinant factor for plant growth, N_2 fixation and grain formation of legumes (Vance, 2001). In this study, the significant increase observed in growth parameters as a function of the doses of P fertilization levels could be also explained by the interaction between N and P in the soil rhizosphere. Similarly, Njukeng *et al*. (2017) and Kamtchoum *et al*. (2018) reported that inorganic fertilizer rapidly provides major elements at the early stage of growth and at the stage of plant development.

Morphological attributes of Bambara pea landraces over years: The number of branches and shoot length differed significantly between landraces and years (Table 3). Number of branches showed higher increase in 2016 compared to 2015 with the highest value (60.46) recorded in WSCge 8 WAS. Significant difference in shoot length between landraces was observed during both years (Table 3). The highest value of shoot length (35.19 cm) was found in RSC in 2015 8 WAS. This latter result can be explained by the fact that the experiment was carried out in 2015 during the long rainy season and in 2016 during the short rainy season (Fig. 1). The present results are in confirmation with that of Ramezan *et al.* (2009) where they reported significant genotypic variations in primary branches of tomato. Difference in number of branches in the genotypes may be due to its genetic potential. Some leguminous crops are known for N fixing ability; however their establishment with P fertilization enhances nodulation and hence fixation of atmospheric N (Masinde and Omolo, 2007). According to Taffouo *et al.* (2014), the process of foliar N mobilization is dependent on the amount of P uptake by plants.

Morphological attributes of Bambara pea over sites: The number of branches and shoot length were significantly affected in both sites during 2015 and 2016 (Table 4). The highest number of branches (59.48) occurred in 2016 at Mendong district while no significant difference in number of branches was observed at Mendong and Soa in 2015, 8 WAS (Table 4). The shoot length was higher (33.82 cm) at Mendong than Soa (28.96 cm) in 2015 8 WAS (Table 4). In contrast, Soa district showed higher shoot length (32.80 cm) than Mendong (29.12 cm) in 2016 (Table 4). This result can be explained by the physico-chemical composition of the soils of the two sites. Indeed, the soil of Mendong is richer in mineral elements than that of Soa (Table 1). Present results are in agreement with earlier reports on soil fertility management and seasonal variation in plant development (Choula *et al.,* 2017). Soil nutrients play a role in the life cycle of the plants and must be present for survival and successful growth. Elements such as carbon, nitrogen and hydrogen usually flow through the organic material, while potassium and phosphorus come from the mineral portion of the soil. Inorganic fertilization such as P and N can influence soil fertility, regeneration and growth of species on degraded sites in tropical rainforests (Choula *et al.,* 2017). In short supply, one or more nutrients can be the limiting factor to the growth and development of plants (Temegne *et al*., 2017 a, 2018 b).

Yield attributes of Bambara pea landraces under phosphate fertilization: Application of P fertilization at different levels led to a significant increase in seed diameter, 100-grain weight, number of pods and pod weight plant^{-1}, seed weight plant^{-1} and grain yield in the two cropping seasons compared to untreated plants (Table 5, Fig. 4). The highest yield components was found in 2016 for 100-grain weight at 200 kg P_2O_5 ha^{-1},while the highest number of pods and pod weight plant^{-1} was recorded at both 150 and 200 kg P ha^{-1}, (Fig. 4A, B, C and D). Although the seed weight plant^{-1} and grain yield showed higher values of yield components in 2015 than 2016 at both 150 and 200 kg P_2O_5 ha^{-1} (Fig. 4E and F). According to analysis of variance (Table 5) the interaction between landraces, P fertilization and sites were highly significant in both 2015 and 2016 cropping seasons except in 2015 for seed weight plant^{-1} and grain yield. Similar observations were reported by other researchers on various species, but the reported optimum rates at which yield parameters were maximized varied widely (Wamba *et al.,* 2012). This could be attributed to differences in nutrient inputs by the fertilizers and differences in nutrient demand by the crops. N, P and K are key elements in the production of leafy vegetables as they enhance yield by promoting cell division and expansion in leaves, and root development (Njukeng *et al*., 2017). Similarly, good supply of inorganic-P is usually associated to increased root density, soil porosity and proliferation which aid in extensive exploration and supply of nutrients and water to the growing plant parts, resulting in increased growth and yield traits related positive effects of P nutrition on plant growth to increased photosynthesis, root growth and nodulation.

Yield attributes of Bambara pea landraces over years: Yield components (Table 6) were recorded in Bambara pea landraces with application of P fertilization during 2015 and 2016. The highest values of seed diameter (14.4 cm) and 100-grain weight (117.56 g) were found in WSC in 2016 while those of the number of pods plant^{-1} (24.38), pod weight plant^{-1}(21.61 g), seed weight plant^{-1} (16.24 g) and grain yield (1.99 and 1.85 t ha^{-1}) were observed in WSCge and WSC landraces in 2015, respectively. The observed phenotype is generally the product of the genotype and the environment (soil, temperature, rainfall, etc. vary from year to year). The lowest values of yield components were recorded in RSC during the both years compared to WSC and WSCge (Table 6). The WSCge and WSC showed better growth and yield than RSC landrace in this condition revealing a greater response of those landraces to inorganic-P fertilization. Present results are in agreement with earlier reports of genotypic variation with regards to yield components by Wamba *et al.* (2012) and Temegne *et al*. (2015 b).

Yield attributes of Bambara pea over sites and years: A marked variation in the yield components was observed in different study sites during 2015 and 2016 (Table 7). The highest value of seed diameter (13.57 mm) was recorded at Soa district in 2016. Although the highest values of 100-grain weight (100.07), number of pods plant^{-1} (21.90), pod weight plant^{-1} (24.50 g), seed weight plant^{-1} (17.88 g) and grain yield (2.19 t ha^{-1}) were found at Mendong in 2015. The result is consistent with the results of Toungos *et al*. (2010) and Nweke and Emeh (2013). The results of the analysis of the soil (Table 1) showed that the soils of the Mendong and Soa districts are poor in P. Incorporation of inorganic-P fertilizer into soil promoted transformation and mineralization of less-labile inorganic and organic P into labile-P_i in the rhizosphere, which resulted in higher root P concentrations and higher total P uptake by plant (Waldrip *et al.,* 2011). P fertilization would have brought a nutritive balance which has increased the yield of the Bambara pea. The strong vegetative growth observed in 2016 would mean that the plant would have mobilized the majority of its resources for the growth of the shoot to the detriment of the underground part, and therefore to the detriment of pod production. The poor production of pods would have resulted in a low yield. The low yield observed in 2016 than 2015 could also be explained by the stormy rainfall observed during this period. These rainstorms would have caused the abortion of some flowers, which would have led to a decrease in pod production.

Correlation between studied traits: The grain yield (Table 8) was positively and significantly ($p<0.001$) correlated with seed weight plant^{-1} ($r = 0.99$), pod weight plant^{-1} ($r = 0.93$), number of pods plant^{-1} ($r = 0.78$) and 100-grain weight ($r = 0.16$) during both years of study. These finding are quite inconsonance with the outcomes of Mohsin *et al.* (2014). However, the grain yield was negatively and significantly ($p<0.001$) correlated with the seed P content ($r = -0.14$), the number of branches plant^{-1} ($r = -0.12$) and shoot length ($r = -0.08$).

Seed P content: Application of P fertilization led a significant ($p<0.001$) increase of the seed P content (Fig. 5). The highest seed P content was observed at 150 kg P_2O_5 ha^{-1} in 2015 (Fig. 5). WSCge and RSC landraces showed higher levels of P in their seeds than RSC (Table 6). Supply of P is usually associated to increased root density, which contribute to extensive exploration and supply of nutriments and water to the growing plant, resulting in increased growth, thereby ensuring more seed and dry matter yield (Wamba *et al.,* 2012).

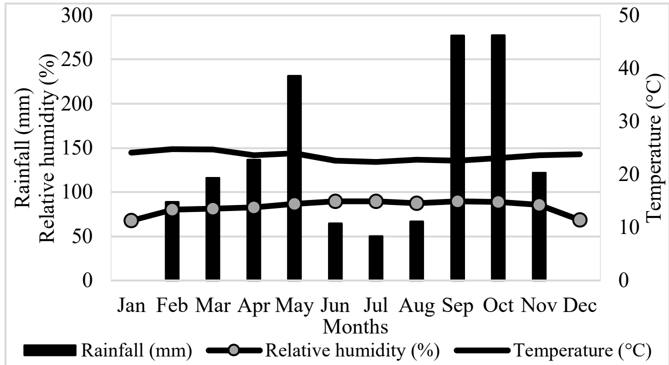

Fig. 1. Weather data for the study area (2015).

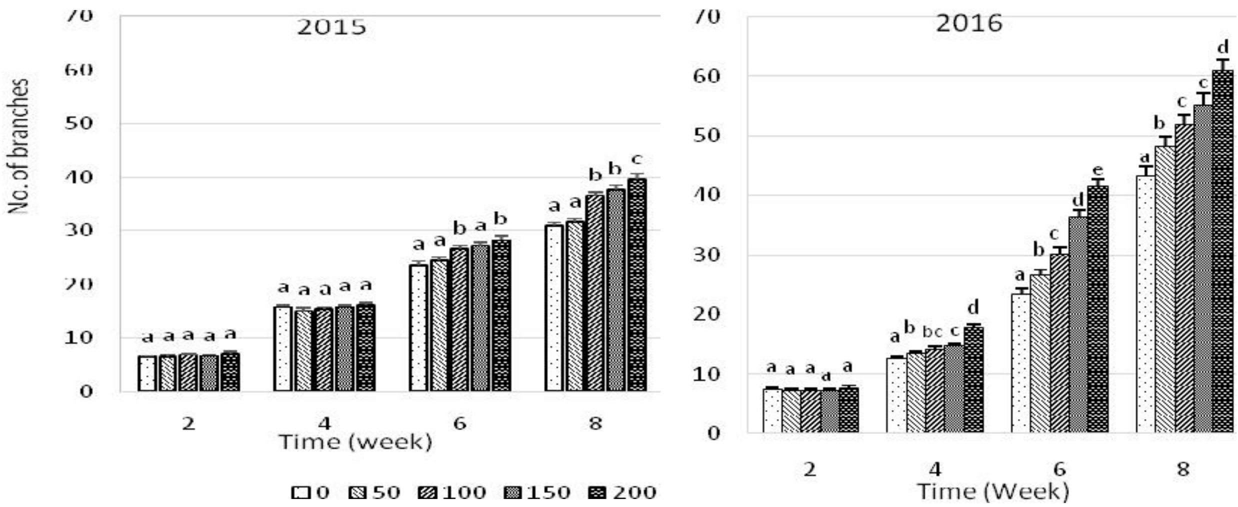

Fig. 2. Effect of phosphate fertilization (kg ha^{-1}) on number of branches of Bambara pea. Data were means±SE followed by different letters above the bars indicate significant differences between P fertilization and year using Fisher test ($p<0.05$).

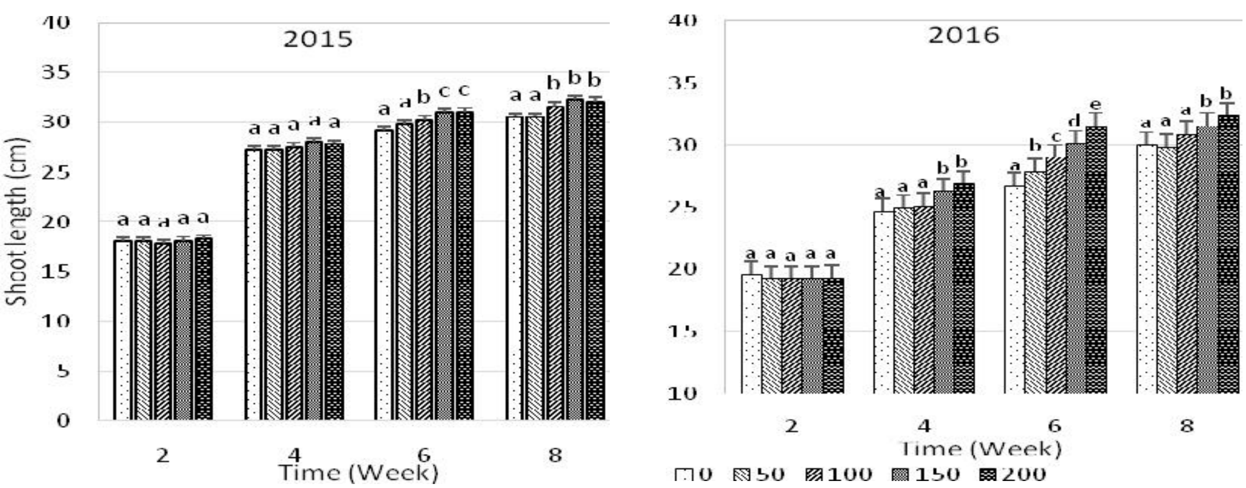

Fig. 3. Effect of phosphate fertilization (kg ha^{-1}) on shoot length of Bambara pea. Data were means±SE followed by different letters above the bars indicate significant differences between P fertilization and year using Fisher test ($p<0.05$).

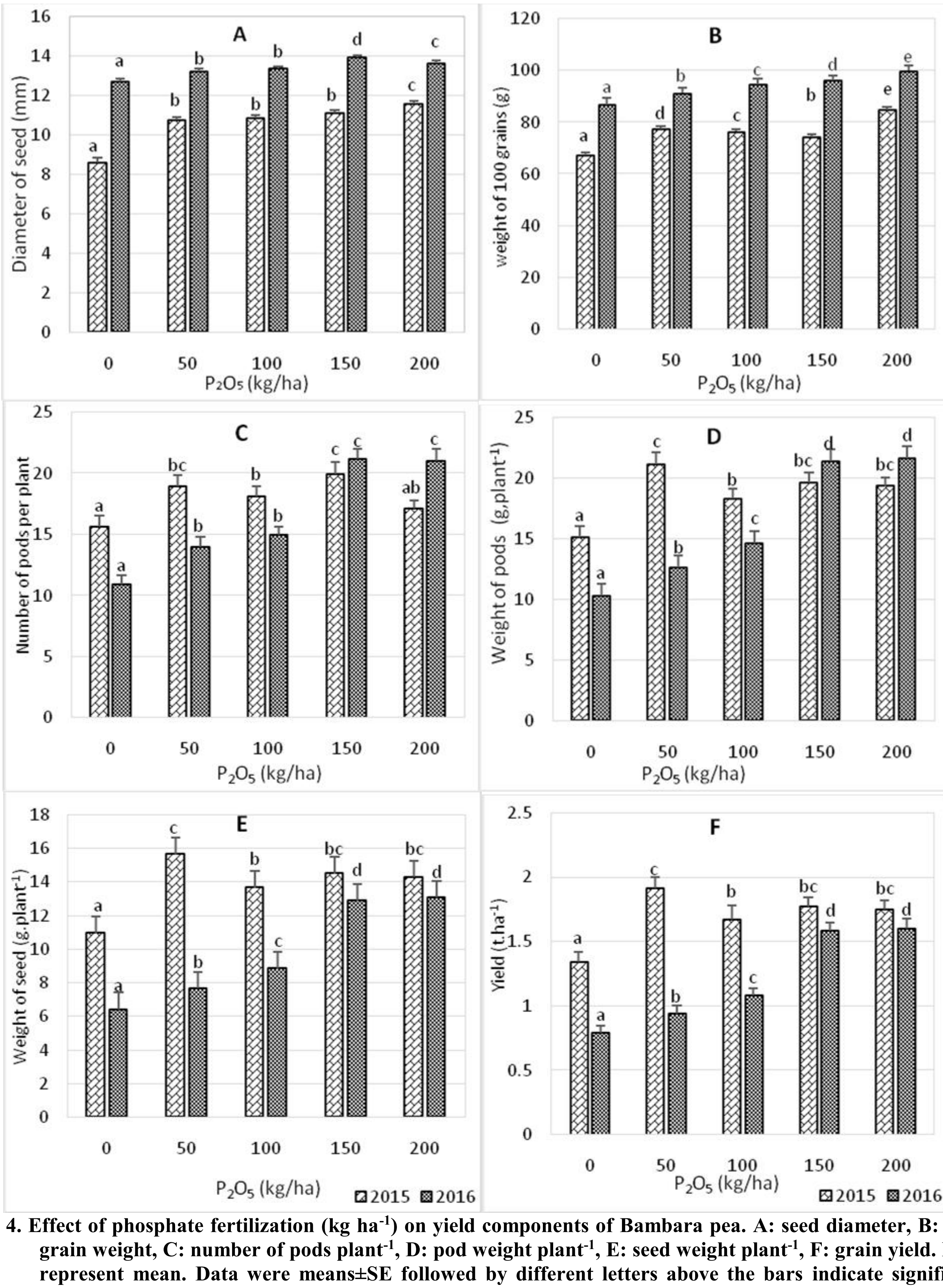

Fig. 4. Effect of phosphate fertilization (kg ha^{-1}) on yield components of Bambara pea. A: seed diameter, B: 100-grain weight, C: number of pods plant^{-1}, D: pod weight plant^{-1}, E: seed weight plant^{-1}, F: grain yield. Data represent mean. Data were means±SE followed by different letters above the bars indicate significant differences between P fertilization and year using Fisher test ($p<0.05$).

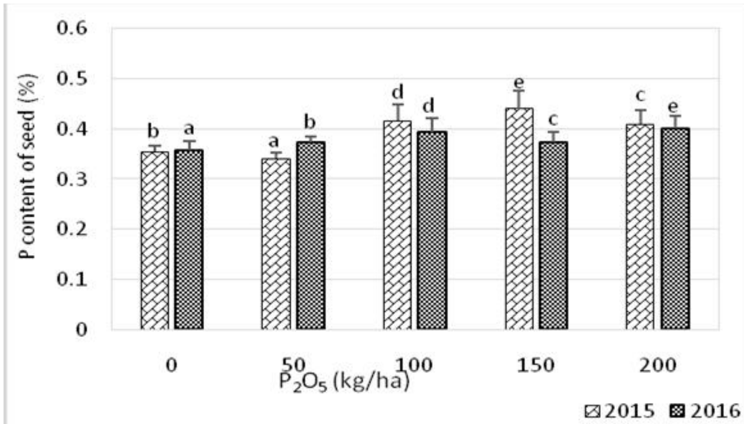

Fig. 5. Effect of phosphate fertilization (kg ha^{-1}) on P content of Bambara pea seed. Data represent mean±SE. Data values with the same letter are not significantly different at 5%.

Table 1. Physico-chemical characteristics of soils.

Parameters	Units	Mendong		Soa	
		2015	2016	2015	2016
Texture	-	Sandy loam	Sandy loam	Sandy loam	Sandy loam
C	(%)	2.498	2.488	2.539	1.756
Total N	(%)	0.212	0.218	0.205	0.193
C/N	-	11.813	11.428	12.363	9.102
pH	-	6.500	6.540	5.090	4.180
Ca	($cmolkg^{-1}$)	8.440	8.399	2.167	2.160
K	($cmolkg^{-1}$)	0.450	0.400	0.218	0.184
Bray P	(μgg^{-1})	2.915	3.738	1.813	2.089
Mg	($cmolkg^{-1}$)	1.916	1.899	1.296	1.288
Na	($cmolkg^{-1}$)	0.030	0.030	0.029	0.030
CEC	($cmolkg^{-1}$)	8.179	8.179	6.593	6.593

C: organic carbon, N: nitrogen, C/N: ratio organic carbon and nitrogen, P: available phosphorus, Ca: calcium, M: magnesium, K: potassium, Na: sodium.*: p<0.05. **: p<0.01. ***: p<0.001. ns: not significant.

Table 2. Extract from ANOVA of effect of landraces, sites and phosphate fertilization levels on number of branches and shoot length of Bambara pea.

Parameter	Source of variance	2015				2016			
		WAS				WAS			
		2	4	6	8	2	4	6	8
No. of branches	Landraces (L)	***	***	***	ns	***	***	***	***
	Sites (S)	***	***	***	ns	***	***	***	***
	P_2O_5 (P)	*	ns	***	***	*	***	***	***
	L×S	*	***	*	**	***	**	**	***
	L×P	ns	*	ns	**	**	***	***	**.
	S×P	ns	ns	***	***	ns	***	***	*
	L×S×P	ns	**	*	*	ns	*	**	***
Shoot length	Landraces (L)	***	***	***	***	***	***	***	***
	Sites (S)	***	***	***	***	***	***	***	***
	P_2O_5 (P)	ns	ns	***	***	ns	***	***	***
	L×S	**	ns	***	*	***	***	***	Ns
	L×P	ns	ns	**	***	*	ns	***	***.
	S×P	ns	ns	ns	ns	ns	***	ns	***
	L×S×P	**	ns	ns	***	*	ns	***	Ns

L: Landraces, S: sites, F: inorganic fertilizer, WAS: Week After Sowing, ns: not significant, *: Significant at p<0.05, **: Significant at p <0.01, ***: significant at p<0.001.

Table 3. Morphological attributes of Bambara pea landraces over years.

Year	Plant growth parameters	landraces	Times (Week)			
			2	4	6	8
2015	No. of branches	WSC	7.70^{c}	17.46^{b}	28.83^{b}	34.77^{a}
		RSC	5.21^{a}	14.52^{a}	24.62^{a}	36.18^{a}
		WSCge	7.14^{b}	14.89^{a}	24.71^{a}	34.92^{a}
	Shoot length (cm)	WSC	16.83^{a}	26.23^{a}	28.10^{a}	28.79^{a}
		RSC	18.46^{b}	30.86^{b}	33.54^{c}	35.19^{c}
		WSCge	18.95^{b}	25.67^{a}	29.18^{b}	30.19^{b}
2016	N. of branches	WSC	7.44^{b}	16.34^{b}	35.61^{b}	54.43^{b}
		RSC	6.44^{a}	11.25^{a}	24.1^{a}	41.10^{a}
		WSCge	8.33^{c}	16.21^{b}	35.43^{b}	60.46^{c}
	Shoot length (cm)	WSC	19.79^{b}	24.48^{a}	26.92^{a}	27.97^{a}
		RSC	19.77^{b}	27.82^{b}	31.64^{c}	31.64^{b}
		WSCge	18.51^{a}	24.54^{a}	28.72^{b}	33.28^{c}

Data represent mean, within row, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test.White Seeds Coat (WSC), light Red Seeds Coat (RSC) and White Seeds Coat with grey eyes (WSCbe).

Table 4. Morphological attributes of Bambara pea over sites.

Year	Plant growth parameters	Sites	Times (week)			
			2	4	6	8
2015	No. of branches	Mendong	8.42^{b}	18.77^{b}	29.68^{b}	34.80^{a}
		Soa	4.94^{a}	12.48^{a}	22.43^{a}	35.78^{a}
	Shoot length (cm)	Mendong	20.98^{b}	29.62^{b}	32.91^{b}	33.82^{b}
		Soa	15.18^{a}	25.55^{a}	27.64^{a}	28.96^{a}
2016	No. of branches	Mendong	5.75^{a}	15.42^{b}	34.75^{b}	59.48^{b}
		Soa	9.06^{b}	13.78^{a}	28.67^{a}	44.51^{a}
	Shoot length (cm)	Mendong	18.58^{a}	23.40^{a}	26.48^{a}	29.12^{a}
		Soa	20.13^{b}	27.83^{b}	31.7^{b}	32.80^{b}

Data represent mean, within row, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test.

Table 5. ANOVA p value of effect of phosphate fertilization on yield components of Bambara pea.

Years	Source of variation	yield components						
		Seed diameter (cm)	100 grains weight (g)	No. of pod plant^{-1}	Pod weight (g plant^{-1})	Seed weight (g plant^{-1})	Gain yield (t ha^{-1})	Seed P content (%)
2015	Landraces (L)	***	***	***	***	***	***	***
	Sites (S)	***	***	***	***	***	***	***
	P_2O_5 (P)	***	***	***	***	***	***	***
	L×S	***	***	***	***	***	***	***
	L×P	***	***	***	*	ns	ns	***
	S×P	ns	***	***	***	**	**	***
	L×S×P	***	***	**	**	ns	ns	***
2016	L	***	***	***	***	***	***	***
	S	***	***	***	***	***	***	***
	P	***	***	***	***	***	***	***
	L×S	***	***	***	ns	ns	ns	***
	L×P	***	***	***	***	***	***	***
	S×P	***	***	ns	ns	ns	ns	***
	L×S×P	***	***	***	***	***	*	***

The result of the three-way ANOVA analysis showing effects of inorganic fertilizer sources, landraces and sites, and their interaction (L×S×F) on the different plant growth and yield parameters. ns not significant, *Significant at $p<0.05$, **Significant at $p<0.01$, *** significant at $p<0.001$.

Table 6. Yield attributes of Bambara pea over years.

Yield components	Cropping seasons	Landraces		
		WSC	RSC	WSCge
Seed diameter (mm)	2015	10.61^b	10.24^a	10.79^b
100 grains weight (g)		93.04^c	64.55^a	70.56^b
No. of pods plant^{-1}		18.71^b	10.81^a	24.38^c
Pod weight (g plant^{-1})		20.59^b	13.81^a	21.61^b
Seed weight (g plant^{-1})		15.09^b	10.05^a	16.24^b
Grain yield (t ha^{-1})		1.85^b	1.23^a	1.99^b
Seeds P content (%)		0.34^a	0.41^b	0.42^c
Seed diameter (mm)	2016	14.40^c	12.37^a	13.23^b
100 grains weight (g)		117.56^c	74.02^a	89.51^b
No. of pods plant^{-1}		15.52^b	10.30^a	23.40^c
Pod weight (g plant^{-1})		18.16^b	10.03^a	20.00^c
Seed weight (g plant^{-1})		11.60^b	5.78^a	11.93^b
Grain yield (t ha^{-1})		1.42^b	0.71^a	1.46^b
Seeds P content (%)		0.32^a	0.40^b	0.41^b

Data represent mean, within row, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test. White Seeds Coat (WSC), light Red Seeds Coat (RSC) and White Seeds Coat with grey eyes (WSCbe).

Table 7. Yield attributes of Bambara pea over sites and years.

Yield components	Sites			
	Mendong	Soa	Mendong	Soa
	2015		2016	
Seed diameter (mm)	9.07^a	12.02^b	13.10^a	13.57^b
100 grains weight (g)	73.68^a	78.42^b	100.07^b	87.32^a
No. of pods plant^{-1}	21.90^b	14.02^a	19.12^b	13.69^a
Pod weight (g plant^{-1})	24.50^b	12.84^a	19.53^b	12.59^a
Seed weight (g plant^{-1})	17.88^b	9.70^a	12.04^b	7.50^a
Grain yield (t ha^{-1})	2.19^b	1.19^a	1.48^b	0.92^a
Seeds P content (%)	0.35^a	0.43^b	0.34^a	0.42^b

Data represent mean, within row, means followed by the same letter are not significantly different ($p<0.05$) by Fisher LSD test.

Table 8. Correlation matrix between studied traits in Bambara pea varieties under phosphate fertilization.

	SD (cm)	GW (g)	NP	PW (g)	SW (g)	Grain yield	Seed P (%)	NB	Shoot length
Seed diameter	1								
100-grain weight	0.535 ***	1							
No. of pods plant^{-1}	-0.071 *	0.127 ***	1						
Pod weight plant^{-1}	-0.088 **	0.241 ***	0.835 ***	1					
Seed weight plant^{-1}	-0.180 ***	0.160 ***	0.779 ***	0.932 ***	1				
Grain yield	-0.180 ***	0.160 ***	0.779 ***	0.932 ***	1.000 ***	1			
Seed P content	0.161 ***	-0.142 ***	-0.080 **	-0.137 ***	-0.143 ***	-0.143 ***	1		
No. of branches	0.327 ***	0.232 ***	-0.070 *	-0.031 ^{ns}	-0.124 ***	-0.124 ***	0.197***	1	
Shoot length	-0.051 ns	-0.242 ***	-0.044 ^{ns}	-0.056 ^{ns}	-0.076 **	-0.076 **	0.171***	0.04***	1

*: p<0,05. **: p<0,01. ***: p<0,001. ns: not significant (p>0,05). SD : Seed diameter, GW : 100-grain weight, NP: No. of pods plant^{-1}, PW: Pod weight plant^{-1}, SW: Seed weight plant^{-1}, NB: No. of branches.

Conclusion: It may be concluded that phosphatic fertilizers significantly improved the production of Bambara pea landraces. WSCge and WSC can be cultivated successfully in the humid forest agro-ecological zone. The rate of 150 kg P_2O_5 ha^{-1} can be considered as the efficient fertilizer to improve significantly the Bambara pea growth and yield performance.

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