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Improvement of Bambara Groundnut Productivity using Organic Manure Fertilization Doses on Plinthite Soil in sub-Saharan Agrosystem of Burkina Faso

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Abstract
Bambara groundnut (*Vigna subterranea* [L.] Verdc.) is a seed legume native to West Africa with significant agronomic, nutritional, economic and socio-cultural potential. In Burkina Faso, its cropping faces enormous constraints from poor soil fertility and poor nutrient management practices. This study aimed to evaluate the effects of different doses of organic manure on Bambara groundnut production. Experiment was conducted in experiment site of Tenkodogo University Center from July to October 2021. The treatments consisted of 0; 2; 3; 4; 5 t ha^{-1} of cow dung. Experimental design consisted of the trial following a completely randomized block design with four replications. Crop management consisted of a flat plowing, direct application of organic manure, sowing distances of 0.40 m x 0.20 m and ridging at 49 days after sowing. Compared to the control, results showed that application of 5 and 4 t ha^{-1} of organic manure significantly increased plant heights of Bambara groundnut by 19 and 20% ($P < 0.001$); 4 t ha^{-1} of organic manure treatment increased plant widths by 19% ($P < 0.001$); 5 and 4 t ha^{-1} of organic manure significantly increased the Bambara groundnut haulm yields by 37 and 30 % ($P < 0.05$) respectively. Significant improvement by 25% ($P < 0.05$) of nodules dry weight was observed under 2 t ha^{-1} of organic manure application. However, no significant correlations between plant biomass and numbers or weight of nodules was recorded. Thus, application of 2 t ha^{-1} of organic manure should be able necessary for Bambara groundnut nodulation and 4 or 5 t ha^{-1} of organic manure for high growth and haulm production of Bambara groundnut. Further investigations are needed to better understand the combined effects of soils and organic fertilizer interactions on Bambara groundnut productivity and soil fertility.

Keywords: Bambara groundnut, organic manure, nodulation, growth, yield, Burkina Faso

Introduction
Agriculture in sub-Saharan Africa is subject to unfavorable soil and climate conditions, including continuous soil degradation, irregular and low rainfalls, which make the agricultural sector underperform with low crop yields (Diop *et al*., 2022). Approximately 65% of the total area of degraded cropland is in Africa (Thiombiano and Tourino-Soto, 2007), affecting crop productivity and causing food insecurity. Food security is thus becoming a major challenge. It is imperative to promote certain neglected crops in order to mitigate food insecurity. Among these crops, there are seed legumes, particularly Bambara groundnut, which can promote sustainable agriculture. Bambara groundnut is the third most important food legume in Sub-saharan Africa after cowpea and groundnut (Yaya *et al*., 2013; Touré et al., 2013; Khan et al., 2021). It can contribute to achieving food security and economic development of poor people living in the marginal environment (Mkandawire, 2007). The crop is more tolerant than other companion crops and can be produced in difficult soil and climate conditions, where other pulses fail to

survive (Akpalu *et al*., 2013; Mabhaudhi *et al*., 2013). Bambara groundnut can fix atmospheric nitrogen for growth. It fixes 20 to 100 kg N ha^{-1} (Musa *et al*., 2016) and improves soil nutrient status, especially nitrogen, through its nodulation process. This process known from legumes improve the nitrogen and phosphorus pools of the rhizosphere, which through several mechanisms would increase *in situ* and subsequent crop yields (Bado *et al*., 2006; Fustec *et al*., 2010, 2011; Latati *et al*., 2016). Thus, on degraded and low fertility soils, Bambara groundnut can improve soil characteristics and also is a good source of N, P and K for the plant (Aziz *et al*., 2017). Moreover, it is a nutrient-dense legume and is sometimes termed a "complete food" due to its balanced macronutrient composition. It contains 64.4% carbohydrate, 23.6% protein, 6.5% fat, and 5.5% fiber and is rich in minerals (Mwangwela *et al*., 2012; Hasan *et al*., 2018; Azman *et al*., 2019; Hasan *et al*., 2021a). Bambara groundnut is thus a species that could be used to promote sustainable agriculture in a context of climate change marked by poor soils and insufficient rainfalls, and farmer resilience.

In Burkina Faso, little effort is devoted to develop Bambara groundnut production. Hence, the major constraint of Bambara groundnut production in the country includes the knowledge gap in agronomic practices. Very few references exist on the improvement of pedoclimatic conditions in order to increase Bambara groundnut production. Thus, a reasoned and optimal organic fertilization use could constitute an essential lever for improving Bambara groundnut productivity and for better capitalization of organic substrates that are becoming scarce. The present study evaluates the effects of different doses of cow dung on the productivity of Bambara groundnut.

Material and Methods

Experimental site

Experiment was carried out during the rainy season in the experimental field of Tenkodogo University Center (11°48'37"N, 0°22'19"W) located in East-center region of Burkina Faso. Climate is Sudano-sahelian. Conferred to data of meteorological station in this region, annual rainfalls are comprised between 600 and 900 mm and average minimum temperature around 33 °C and maximum temperature can reach 41 °C. Insolation is 7 – 8 h day^{-1} with low humidity. In 2021, 52.2 mm of rainfall (May) was recorded against 249.5 mm (August); Temperature was ranged from 26 °C (August) to 31 °C (May). In Table 1, according to FAO (1994) soil description guidelines, experimental site soil has a sandy texture in the 0-16 cm depth and sandy-clay in the 16-36 cm depth, all supported by a plinthite (Zongo et *al*., 2023). The drainage is excessive to perfect. The soil belongs to the class of iron and manganese sesquioxide soils and more specifically to a shallow leached ferruginous tropical soil according to the French classification (CPCS, 1967), and would corresponding an *endo-petroplinthic Lixisol* (WRB, 2015). The soil is acidic and characterized by low content of total carbon, nitrogen, phosphorus, potassium according to interpretation standards of Burkina Faso National Soil Office (BUNASOLS, 1990). The texture of the soil makes it potentially suitable for Bambara groundnut cultivation because it is better drained and favors the penetration of the pods into the soil. On well-drained, light, sandy and loamy soils with a pH of 5.0 to 6.5 are more suitable for Bambara groundnut cultivation (Basu *et al*., 2007; Hasan *et al*., 2018; Zongo et *al*., 2023).

Test crop and fertilizer

The test crop used was a cream-colored variety of Bambara groundnut (*KVS235)*, with black markings released by the Institute of Environment and Agricultural Research (INERA) of Burkina Faso. The cycle of this variety is 90 days. Fertilizer used is cow dung. It is a more or less decomposed mixture of carbonaceous litter (straw) and excreta (cow faces and urine). Cow dung manure pellets sourced from the farm were dried, crushed mechanically into powder before the application. The chemical properties of cow dung were consigned in Table 2.

Experimental design, treatments and crop management

Experimental design was a completely randomized block design with four replications. It consisted of four blocks arranged along the length of the slope of the land. The dimensions of the design were 11 m long and 9.2 m large. In total, there were 20 elementary plots of 1.2 m of wide and 2 m of long each. The intervals between elementary plot were 0.8 m and alley of 1 m between blocks. The treatments were composed of five doses of cow manure applied at 0 t ha-^{1} (M-0); 2 t ha-^{1} (M-2000); 3 t ha-^{1} (M-4000); 4 t ha-^{1} (M-4000); and 5 t kg ha-^{1} (M-5000) of cow dung. Seedbed preparation consisted of a plane tillage with a disc harrow connected to a tractor. Different doses of organic manure were applied at basal (spreading and burying method). Sowing was done on July 7, 2021 with one seed per hole. Spacing of sowing was 40 cm between the line and 20 cm between sowing hole. Two manual weeding were carried out respectively the 15 and 30 days after sowing (DAS) to reduce the competition between crop and weeds for soil resource. A mounding was carried out manually the 49 DAS in all elementary plots. The aim was to favor the burying of young pods in formation and their development.

Data collection

Growth and yield parameters were collected according to the Bambara groundnut descriptor (IPGRI *et al*., 2000).

- Plant height (PlH) and Plant Spread (PlS) were recorded on five plants in cm per treatment at 70 DAS with a graduated ruler; PlH per plant was measured from the ground to the last leaf of the plant crown. PlS per plant was measured from the horizontal extremity of the plant's crown of the plant crown. Pod length (PLen), width (PWid) of 10 randomly selected pods and seed length (SLen) and width (SWid) in mm of corresponding of 10 seeds from the pods were measured using an electronic caliper.

- Yield parameters are nodule numbers (NN) and dry weights (NDW) in mg; biomass dry weight at flowering stage in g (PDWf); Haulm yields at harvest stage (HY), pods yield at harvest stage (PY) and seeds (SY) yields in t ha^{-1} at harvest stage. Assessment of NN, NDW and PDWf consisted of careful digging of three Bambara groundnut plants per unit plot at the stage when 50% of the plants had emitted their first flower. The nodules were detached, counted and dried in filter papers and the biomass at flowering (shoot and root biomass) was sun-dried. At maturity, the haulm (shoot and root biomass) and pods per unit plot were harvested, sun-dried for three weeks and weighed. At maturity, haulm and pods per treatment were harvested, sun-dried for three weeks and weighed. The seeds were obtained by destoning and weighing. All dry measurements were made to ensure that each sample had a constant weight.

Statistical analysis

Statistical analysis of data including analysis of variance (ANOVA) and comparison of means at TukeyHSD test and Pearson correlation at 5% significance level was performed using XLSTAT 2021 4.1 (ADDINSOFT, 2021).

Results and Discussion

Effect of treatments on vegetative growth of Bambara groundnut

Table 3 presents the effects of the treatments on the growth parameters of Bambara groundnut. The plant heights (PlH) were significantly increased by 20 and 19 % respectively under M-4000 and M-5000 treatment compared to control M-0. The plant width (PIS) under M-4000 were also significantly improved by 19% ($P \leq 0.001$) compared to control M-0. In the coastal region of Cameroon, application of 12 t ha^{-1} poultry manure was found to increase seed weight, number of pods per plant, 1000-grain weight, pod yield as well as grain yield in Bambara groundnut (Wamba *et al*., 2012). Also, Goat manure applied at 5 and 10 t ha^{-1} significantly increased plant height, number of leaves, number of pods, shelling percentage, pod and seed yield of groundnut cultivated on sandy clay loam soil with a pH of 5.2, which is moderately acidic in Nigeria (Effa *et al*., 2022).The growth and yield differences among the chemical and organic treatments have been related to N, P and K availability to crops and release pattern by organic residues (Leconte *et al*., 2011; Hasan et al., 2018; Khan *et al.*, 2018). This is especially true since the cow dung used will add 31.11% C; 2.03% N; 15.33% C/N; 1.30% P;1.78% K to the soil's initial content of these elements. The application of 4 t ha^{-1} (M-4000) significantly improved the length and width of plants compared to the control. The improvement of the growth parameters of Bambara groundnut under organic manure supply compared to the control can be attributable to the role organic manure plays in improving soil fertility by promoting hydromineral nutrition of the crops. The cow dung used in experiment was be rich in nitrogen (2,03%) that is essential for plant growth. Contrary, Bakayoko *et al*. (2019) showed in Ivoiry Cost that cow dung can contain 0.92% N. Vecchia *et al.* (2001) stated that nitrogen is a major determinant of yield because of its favorable influence on the growth of the vegetative system. Adequate nitrogen supply has been shown to benefit carbohydrate and protein metabolism, thereby promoting plant growth (Shehu *et al*., 2010). Vegetative growth of the plant tended to enlarge with an increase in different levels of nitrogen fertilizer (Uddin *et al*., 2017).

Effect of treatments on yield and yield-related traits of Bambara groundnut

The results of the statistical analysis showed that the M-2000 treatments significantly increased ($P < 0.05$) the nodule dry weight (NDW) by 25% compared to the control M-0 (Table 4). Compared to the control (M-0), and other organic manure fertilization, M-2000 treatment are better increasing NN and NDW at flowering stage. This better nodulation performance confirms the good response of legumes for nodule production under low soil nitrogen levels. Bambara groundnut being a legume, improves soil fertility through nitrogen fixing present in its root nodules, but this is not sufficient to meet the nitrogen requirements of the plant (Chiezey *et al*., 1991). It is therefore necessary to provide additional nitrogen to stimulate nodulation for optimal production (Toungos *et al*., 2010). When N is released into the soil, it helps the roots development of Bambara groundnut while also assisting in N_2 fixation (Hasan *et al*., 2021b). However, this nitrogen dose should be higher than the starter dose and lower than the inhibitor dose. Nitrate inhibition of symbiotic nitrogen fixation was absolute when mineral N at sowing was over 380 kg N ha^{-1} and not initiated unless nitrate availability in the soil dropped below 56 kg N ha^{-1} for pea cropping (Voisin *et al*., 2002). Also, an increase in the rate of atmospheric N fixed by cowpea in the farming environment, which is explained by the "starter" effect of these fertilizers when applied at low doses (Bado *et al*., 2006). Indeed, high doses of nitrogen inhibit nodulation and nitrogen fixation. In fact, Argaw and Akuma (2015) reported decrease of nodules number and nodules dry weight with increased rates of nitrogen fertilizer (20, 40 60, 80, and 100 kg ha^{-1}) in bean (with or without inoculation). Evaluating of the 16 common bean genotypes under four nitrogen treatments [not inoculated low N (30 kg ha^{-1}) and high N (100 kg ha^{-1}) and two rhizobia strains], Akter *et al*. (2018) confirmed inhibition of nitrogen fixation by a high amount of nitrogen fertilizer. Low amount of nitrogen and even its absence led to good nodulation in nitrogen-deficient soils. In Kenya, nodulation of 6 grains Legumes was not improved by application of 26 kg N ha^{-1} as starter-N in the soil characterized by acidic humic topsoil (humic NITOSOLS) that contained the initial soil N, P and soil organic carbon levels about 2 g kg^{-1}, 20 mg kg^{-1} and 35 g kg^{-1}, respectively (Chemining`wa *et al*., 2007). This is because when the plant received a large amount of nitrogen, it no longer needs to develop nodules. When nitrogen is lacking or in low quantities, the plants develop symbiosis and to favor the development of nodules to fix atmospheric nitrogen in order to cover its needs. M-5000 and M-4000 treatments significantly increased the haulm yields at harvest (HY) by 37 and 30% ($P < 0.05$), respectively, compared to the control (M-0). This indicates that these inputs were necessary to increase Bambara groundnut haulm yield. These treatments were the most effective in terms of Bambara groundnut production at harvest. It could be explained by the positive effect of organic manure on soil properties and its ability to restore soil fertility with subsequent restoration of mineral elements in soil. This restoration of mineral elements in the soil could, under normal water conditions, promote a better assimilation of mineral elements by the plants, thus increasing yields at flowering and harvest stage.

Correlation among growth and yields parameters of Bambara groundnut

Pearson correlation matrix showed positive correlations at the 5% threshold among growth and yields parameters (Table 5). There are a positive and significant correlations between plant height and plant width (r = 0.77); plant dry weight at flowering (r = 0.52) and plant yields (r = 0.51). Moreover, significant and positive correlations were observed between pods width and seeds width (r = 0.54), seeds length (r = 0.77), pods length (r = 0.81); seeds width and seeds length (r = 0.73); plant width and pods length (r = 0.52), seeds length (r = 0.52) plant yield (r = 0.48); pod lengths and seed lengths (r = 0.79); nodules numbers and nodules dry weight (r = 0.89). In addition, pod yields were significantly correlated with plant dry weight at flowering stage (r = 0.47), Haulm yields at harvest (r = 0.58) and seed yields (r = 0.98). Plant dry weight at flowering stage and plant yield (r = 0.48); plant yields at harvest and seed yield (r = 0.56) was correlated. The significant and positive correlations between the growth and yield parameters of Bambara groundnut showed that they are dependent. In fact, correlations between growth parameters on the one hand, and between the yield parameters on the other hand, show that the good growth of Bambara groundnut would be the interrelated result to these parameters. However, correlations between growth and yield parameters of Bambara groundnut indicates that the improvement of its yield would be linked to its good growth. Indeed, part of our results coincide with those of Khan *et al*. (2021) who showed that some relevant parameters of Bambara groundnut were related to pod yield. Significant correlations were also found between yield and yield-related traits of Bambara groundnut (Oyiga and Uguru, 2011) and other legumes such as soybean (Kasu-Bandi *et al.*, 2019) and cowpea (Ofori, 2016; Kyei-Boahen *et al*., 2017). Also, the non-significant correlation between plant biomass and numbers or weight of nodules indicates that plant growth is not always the result of good nodulation (Ndiang *et al*., 2022). In the process of improving Bambara groundnut production, these characteristics must necessarily be taken into account.

Conclusion

The application of 4 t ha and 5 t ha^{-1} of organic manure had a significant effect on plant height, width, and haulm yields compared to the control. Pod and seed yields were not significantly affected by organic manure fertilization. The supply of 2 t ha^{-1} of organic manure was the most successful in terms of gains in nodule numbers and weights. The correlations between the growth and yield parameters of Bambara groundnut show that its good growth would positively influence its production. In prospects, it would be interesting to determine the beneficial effect of combined organic manure and mineral fertilizers, and agronomic and economic optima of organic manure on the improvement of Bambara groundnut productivity and soil fertility.

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Table 1: Physical and chemical properties of the soil of the experimental site

Property	Value obtained	
Soil layer (cm)	0-10	10-36
Sand (%)	86	50
Silt (%)	5	10
Clay (%)	10	40
Soil textural class	Sand	Sandy-clay
Total Organic Matter (%)	0.38	0.42
Total Carbon (%)	0.22	0.24
Total Nitrogen (%)	0.02	0.02
C/N	11	14
Total Phosphorus (mg Kg^{-1})	218.40	273,00
Total potassium (mg Kg^{-1})	544.11	1165,96
pH (H_20) (W/V: 1/2.5)	5.81	5.53
pH (KCl) (W/V: 1/2.5)	5.39	5.30

Table 2: Chemical properties of the cow dung

Chemical properties	Value obtained (%)
Total Organic Matter	53.64
Total Carbon	31.11
Total Nitrogen	2.03
C/N	15.33
Total Phosphorus	1.30
Total potassium	1.78

Table 3: Effect of treatments on vegetative growth of Bambara groundnut

Traitements	PlH	PlS	PLen	PWid	SLen	SWid
	cm		mm			
M-5000	19.65±0,64a	42.05±1.43ab	15.17±0.22a	12.35± 0.16a	10.45±0.17a	8.77±0.13a
M-4000	20.00±0.65a	43.65±1.39a	15.38±0.16a	12.34±0.17a	10.84± 0.13a	9.14±0.15a
M-3000	17.80±0.69ab	38.90±1.28abc	14.88±0.16a	12.06±0,16a	10.38±0.14a	8.98±0.13a
M-2000	16.55±0.55b	37.50±1.45bc	14.88±0.18a	12.00±0.18a	10.34±0.13a	8.73±0.10a
M-0	16.00±0.45b	35.50±1.02c	15.30±0.20a	12.33±0.14a	10.50±0.14a	9.09±0.12a
P	< 0.0001	0.000	0.22	0.38	0.11	0.09
Significance	HS	HS	NS	NS	NS	NS

***M-0**: control (0 kg ha^{-1} of manure**); M-2000**: 2 kg ha^{-1} of manure; **M-3000**: 3 kg ha^{-1} of manure; **M-4000**: 4 kg ha^{-1} of manure; **M-5000**: 5 kg ha^{-1} of manure; **PlH**: plant heights; **PlS**: plant widths; PLen: pod lengths; **PWid**: pod widths; **SLen**: seed lengths; **SWid**: seed widths; The values in the table are the means ± standard errors of each parameter according to the treatments. **P** = Probability according to ANOVA at 5% level of significance. Means in the same column with the same letter do not differ significantly according to the TukeyHSD test at the 5% significance level. **P < 0.05**: significant (S); **P ≤ 0.01**: very significant (VS); **P ≤ 0.001** (HS): highly significant; **P ≥0.05**: Not significant (NS)*

Table 4: Effect of organic fertilizer on yields of Bambara groundnut

Traitements	NN	NDW	PDWf	HY	PY	SY
		mg	g	t ha^{-1}		
M-5000	32.25±2.29a	160.35±15.92ab	34.75±1.19a	3.73± 0.29a	3.92±0.34a	3.07±0.28a
M-4000	35.75±2.85a	252.85±25.16ab	33.00±4.08a	3.35±0.30bc	3.65±0.26a	2.82±0.20a
M-3000	30.33±5.93a	208.30±22.63ab	32.00±1.85a	2.97±0.15abc	3.59±0.12a	2.82±0.24a
M-2000	54.25±6.35a	287.63±32.42a	26.75±2.83a	2.68±0.12ab	3.21±0.25a	2.53±0.20a
M-0	31.75±3.98a	216.10±22.63b	27.75±2.99a	2.34±0.23b	3.37±0.26a	2.53±0.22a
P	0.31	0.04	0.46	0.02	0.56	0.55
Significance	NS	S	NS	S	NS	NS

***M-0**: control (0 kg ha^{-1} of manure); **M-2000**: 2 kg ha^{-1} of manure; **M-3000**: 3 kg ha^{-1} of manure; **M-4000**: 4 kg ha^{-1} of manure; **M-5000**: 5 kg ha^{-1} of manure; **NDN**: nodule number; **NDW**: nodule dry weight; **PDWf**: plant total biomass at flowering stage; **HY**: Haulm yields at harvest; **PY**: pod yields; **SY**: seed yields; The values in the table are the means ± standard errors of each parameter according to the treatments. **P** = Probability according to ANOVA at 5% level of significance. Means in the same column with the same letter do not differ significantly according to the TukeyHSD test at the 5% significance level**.** **P < 0.05**: significant (S); **P ≤ 0.01**: very significant (VS); **P ≤ 0.001**: highly significant (HS); P **≥ 0.05**: No significant (NS)*

Table 5: Pearson correlation among nodulation, growth and yield parameters of Bambara groundnut

Parameters		PlH	PWid	SWid	PlS	PLen	SLen	NDW	NN	PY	PDWf	HY	SY
		cm	**mm**	**mm**	**cm**	**mm**	**mm**	**mg**		**t ha^{-1}**	**g**	**t ha^{-1}**	**t ha^{-1}**
PlH	cm	**1**											
PWid	mm	0.25	**1**										
SWid	mm	0.22	**0.54***	**1**									
PlS	cm	**0.77*****	0.42	0.17	**1**								
PLen	mm	0.38	**0.81*****	0.35	**0.52*****	**1**							
SLen	mm	0.43	**0.77*****	**0.73*****	**0.52*****	**0.79*****	**1**						
NDW	mg	0.05	-0.32	0.11	-0.30	-0.34	-0.11	**1**					
NN	NN	-0.07	-0.30	-0.06	-0.37	-0.39	-0.19	**0.89*****	**1**				
PY	t ha^{-1}	0.35	0.30	-0.11	0.40	0.43	0.15	-0.26	-0.41	**1**			
PDWf	g	**0.52***	-0.04	0.04	0.21	-0.02	0.04	0.34	0.21	**0.47***	**1**		
HY	t ha^{-1}	**0.51***	0.19	0.03	**0.48*****	0.23	0.27	-0.12	-0.15	**0.58****	0.34	**1**	
SY	t ha^{-1}	0.35	0.31	-0.14	0.40	0.42	0.15	-0.26	-0.35	**0.98*****	**0.48***	**0.56****	**1**

***PlH**: plant heights; **PlS**: plant widths; **PLen**: pod lengths; **PWid**: pod widths; **SLen**: seed lengths; **SWid**: seed widths; **NDN**: nodule number; **NDW**: nodule dry weight; **PDWf**: plant total biomass at flowering stage; **HY**: Plant yields at harvest; **PY**: pod yields; **SY**: seed yields; **P < 0.05**= significant difference at 5% (*), **P ≤ 0.01** = very significant difference at 5% (**), **P ≤ 0.001**= Hight significant difference at 5% (***)*