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RESEARCH ARTICLE

EXPLORATORY STUDY OF FERTILIZER EFFECT ON GROWTH, YIELD ATTRIBUTES AND YIELD RESPONSE OF LOCAL AND IMPROVED BAMBARA GROUNDNUT VARIETIES ON FERRIC LIXISOL, BURKINA FASO

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Abstract

Bambara groundnut is the third most cultivated legume in Burkina Faso. Despite its nutritional and agronomic importance, it remains under studied. Women are the major producers and it often been associated with subsistence farming and small-scale grown on poor soilswith very poor yields.To deal with this, producers are increasingly using chemical fertilizers. Reducing of the amount of chemical fertilizers substituted by organic inputs and using improved varieties could lead to increase yields and ensure sustainability of agricultural productivity. In this study, two Bambara groundnut varieties were assessed under different fertilizer treatments in order to determine the inputs that will improve Bambara groundnut productivity. Experiments were laid out as Split-Plot design during the rainy season with three replications at Tenkodogo University Centre during the rainy season 2022. The experiments consisted of two factors, including the varieties (KVS 235 and Var_Loc) and four levels of fertilization (NPK75 ; Bc3000 ; Bc5000 and NPK37.5 + Bc2500). Growth and yield parameters were recorded according the Bambara groundnut descriptors and subjected to analysis of variance at 95% threshold. The results showed that KVS235 exhibited short cycle for first flowering (32 days) and 50% flowering (35 days) and weight of pods per plant (16.45 g) and best performance of weight of seed per plant (10.32 g). The treatment NKP75 showed maximum weight of pods per plant (18.95 g) and weight of seeds per plant (11.53 g). Yield increased with

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NPK75 (1199.31 kg ha^{-1}), followed by Bc3000 (1095.14 kg ha^{-1}) and Bc5000 (993.75 kg ha^{-1}).

Introduction:-

Bambara groundnut (Vigna subterranea Verdcourt) is one of the most important food legumes grown in Sub-saharan Africa (Toure et al., 2013 ; Khan et al., 2021). It is the third most cultivated legume in Burkina Faso (Ouedraogo et al., 2008) after cowpea (Vigna unguiculata [L.] Walp.) and groundnut (Arachis hypogeae L.). Bambara groundnut is calorie and nutrient dense (387 kcal/100 g)(Minka and Bruneteau, 2000 ; Bonny and Djè, 2011), making it a highly sought after nutritional supplement for many local populations. In addition to the nutritional importance, Bambara groundnut also has important medicinal properties (Atoyebi et al., 2018 ; Brink et al., 2006). The plant is also climate resilient being able to grow under significant water deficit. Further the crop fixes a large amount of nitrogen helping to maintain soil fertility (Mabhaudhi et al., 2013 ; Azam-Ali et al., 2014 ; Ndiang et al., 2022 ; Hillocks et al., 2012).This crop could be used to promote sustainable agriculture for empowering farmers resilience to adverse unfavorable pedoclimatic conditions.

In Burkina Faso, there are very few studies on Bambara groundnut fertilization rates (Nandkangre et al., 2023). Despite the potential, Bambara groundnut remains underutilized and under-researched. Bambara groundnut is mainly cultivated by women on poor soils and has poor yields (Goli et al., 1997 ; Anchirina et al., 2001). In Burkina Faso, agriculture faces insufficient rainfalls and poor soils. Sanchez (2002) reported average annual nutrient depletion rates of 22 kg N ha^{-1}; 2.5 kg P ha^{-1}; 15 kg K ha^{-1} in 37 Africa countries. To cope with these poor soils and improve overall productivity, farmers resort to chemical fertilizers. The inclusion of a large quantity of chemical fertilizers could expose the environment to tremendous pressure. In particular building on the multiple problems that include a shrinking land base (Maitra and Pine, 2020) and showed negative balance of major soil nutrient components (N, P and K) in most Sub-saharan African countries (Stoorvoge et al., 1993 ; Hilhorst et al., 2000). The nutrient inputs in mineral or organic form and many other agricultural practices have demonstrated in enhancing soil fertility and thus increasing crop production (Kaho et al., 2011 ; Useni et al., 2012 ; Khalid et al., 2014 ; Zongo et al., 2021). To tackle gradual soil degradation and environmental pollution it is urgent to look more agroecological practices. Several authors believe that agroecological practices could enable more sustainable production while maintaining an unimpaired environment (Altieri et al., 2012; Altieri et al., 2017). Thereduction of the amount of chemical fertilizers substituted by organic inputs and using improved seed varieties could lead to increase yields and ensure sustainability of agricultural productivity. The objective of this study was to assess two Bambara groundnut varieties under different fertilizers in the Centre-east region, in order to determine the inputs that will improve Bambara groundnut productivity.

Material and Methods:-

Experimental site description and soil characterization

This study was carried out at the experimental site of "Centre Universitaire de Tenkodogo" (11°48’37’’N, 0°22’19’’W) located in Centre-east region of Burkina Faso. Climate of this region is Sudano-sahelian type characterized by two annual seasons, dry (November to May) and humid (June to Octobre). The rainfalls in Tenkodogo between May and October 2022 were 1066.9 mm over 55 days.The characterization of the soil of experimental site was done according to FAO (1994). Soil description showed three different layers. The first layer (0-16 cm) has sandy texture, followed by sandy-clay texture (16-36 cm) and the third layer (> 36 cm) is a ferruginous shell. This soil belongs to the ferric and manganese sesquioxides soils class and specifically to shallow leached ferruginous tropical soil according to the french classification (CPCS, 1967) and matching to endo petroplinthic lixisol according to the World Reference Base for Soil Resources (2015) classification. Physical and chemical properties of the soil are summarized in Table 1 (Zongo et al., 2023).

Table 1:- Physical and chemical properties of the soil of experimental site (Zongo et al., 2023).

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

Plant material

Two varieties (KVS235 and Var_Loc named Bansida in local language) were assessed. KVS235 has been released by the National Institute of Environment and Agricultural Research. This variety has been selected on interesting agronomic characteristics and high commercial value. It has a cream seed coat without eye. Var_Loc (Bansida) is a local variety from the municipality of Zabré in the Centre-east region, where it is widely cultivated. It has a khaki seed coat in color with black spot with an eye.

Agronomic practices and field method

Experiments were carried out during the rainy season 2022-2023 as Split-Plot design. The main plot was comprised of two varieties. The sub-plot treatments were composed of chemical fertilizers (NPK 14-23-14) and Bio-compost (Bc). Four levels of treatments viz. NPK75 (75 kg ha^{-1}) ; Bc3000 (3000 kg ha^{-1}) ; Bc5000 (5000 kg ha^{-1}) and NPK37.5 + Bc2500 (37.5 kg ha^{-1} of NPK mixed with 2500 kg ha^{-1} of Bc) were applied at basal. Compost was produced from substrates composed of cow dung (325.20 kg); ash (64 kg); phosphate rock (50 kg); 2-weeks macerate of crushed Samanea saman leaves (50 kg of leaves for 200 L of water), liquid Trichoderma harzianum spores named solsain (1 L m^{-3}) and grass straw (64 kg). The grass straw comprised Loudetia togoensis (60%), Andropogon pseudapricus (30%) and Andropogon gayanus (10%). Composting lasted 45 days with 4 turnings. When mature, the compost was sieved to 3 mm to obtain a powdery texture. The characteristics of the compost are shown in Table 2.

Table 2:- Chemical characteristics of compost.

Compost characteristics	**Values**
Humidity (%)	28
Dry matter (%)	72
Total organic matter (%)	30.05
Total carbon (%)	17.47
Total nitrogen (%)	1.21
Ration C/N	14
Total phosphorus (%)	0.82
Phosphoric anhydride (P2O5) (%)	1.88
Total potassium (%)	1.10
Potassium oxide (K2O) (%)	1.33
Ammonium (mg/kg)	32.06
Nitrate (mg/kg)	48.00
Inorganic N (mg/kg)	80.07

The experimental design consisted of three blocks.Each block was made up of eight elementary plots measured 2 m x 1.2 m. The spacing between rows were 0.8 m and 1 m between the replication. Sowing was done at one seed per hole on 0.4 x 0.2 m spacings after a flat plowing with a tractor. Forty-four seeds were sowed per plot. Manual weeding operations were carried out on request. Mounding was carried out on the 49^{th} day after sowing (DAS).

Data collection and statistical analysis

Data collection took place during the vegetative phase and after harvesting. The parameters considered in this study are listed in Table 3. The morphological and agronomic parameters were recorded on the basis of Bambara groundnut descriptors (IPGRI et al., 2000). Data recorded were subjected to analysis of variance using Genstat 12 Edition. Each factor effect and their interactions were determined using F-test at $\alpha = 0.05$. Means were separated using Duncan test.

Table 3:- Registered characters, code and notation.

Character	Code	Notation
Vegetative growth and flowering stage		
Rate of emerged plants at 21 days after sowing	RES21	%
Number of days from sowing to first flowering	FFL	Day
Number of days from sowing to 50% flowering	FLO50	Day
Number of nodules	NON	Number
Total biomass at the flowering	TBF	g
Number of leaves per plant	NL/P	Number
Plant height	PlH	cm
Plant spread	PlS	cm
Post-harvest		
Weight of pod per plant	WP/P	g
Weight of seeds per plant	WSP	g
100-seeds weight	W100S	g
Pod filling rate	PFR	%
Yield	YLD	Kg ha^{-1}

Results and Discussion:-

Effect of treatments on emergence rate, flowering and Numbers of nodules

Varieties differed significantly for the date of first flowering ($P< 0.01$), date of 50% flowering ($P< 0.01$) and number of nodules ($P< 0.05$) (Table 4). In contrast, the rate of emergence at 21 DAS was not impacted with values of 83.14±0.33% and 82.20±0.23% for KVS235 and Var_Loc. The seeds used had good qualitywithgermination being higher than 80% for both varieties (MARH, 2022). The rate of emerged plants is greater than most of the varieties characterized by Obidiebube et al. (2000) in Nigeria. But slightly lower than those of Diagara et al. (2022) on Niger varieties. For the flowering attributes (FFL = 32.00±1.06 and FLO50 = 35.00±1.06 days) KVS235 had short flowering cycle of three days, compared to the variety Var_Loc (FFL= 35.00±0.75 and FLO50= 38.00±0.75 days). In general, flowering occur early in the genotypes grown in Burkina Faso (Nandkangré et al., 2023). However, accessions grown in countries with abundant rainfall take a long time to flower (Bonny et Djè, 2011; Massawe et al., 2019). Among breeding objectives in Burkina Faso, there is the reducing of the cycle due to the insufficient of the rainfall, so that plants can complete their ripening cycle. Nandkangre et al. (2022) reported that Bambara groundnut short-cycle varieties get early pods formation. Pods formed in this way will have sufficient time to fill with seeds before the rains shorten.

Table 4:- Values±Standard Errors of emergence rate, flowering traits and number of nodules under the effect of varietal and fertilizer factors.

Source of variation		RES21 (%)	FFL (days)	FLO50 (days)	NON (#)
Varieties	KVS235	83.14±0.33a	32.00±1.06a	35.00±1.06a	22.10±4.24a
	Var_Loc	82.20±0.23a	35.00±0.75b	38.00±0.75b	10.10±3.00b
	Probability	**0.811**	**0.001****	**0.002****	**0.012***
Fertilizers	NPK75	79.92±1.38a	33.00±0.38a	36.00±0.13a	15.30±0.40a
	Bc3000	88.26±2.80a	34.00±0.13a	36.00±0.13a	18.23±1.07a
	Bc5000	82.95±0.14a	34.00±0.13a	36.00±0.13a	14.50±0.80a
	NPK37.5 + Bc2500	79.55±1.56a	34.00±0.13a	37.00±0.38a	16.37±0.14a
	Probability	**0.257**	**0.769**	**0.533**	**0.478**
Var * Fert	**Probability**	**0.427**	**0.901**	**0.819**	**0.035***

Legend : **RES** : Rate of emerged plants at 21 days after sowing ; **FFL:** Number of days from sowing to first flowering**; FLO50 :** Number of days from sowing to 50% flowering**; NON:** Number of nodules ; **Var * Fert :** Interaction variety-fertilizer ; Means within columns with different letters are significantly different; *****: Significant difference at P = 5% treshold ; **** :** Significant difference at P = 1% treshold.

KVS235 has a higher number of nodules (22.10±4.24) than Var_Loc (10.10±3.00) with increase of 118.81%. Nevertheless, the local varieties easily nodule for indigenous native rhizobia. This high number of nodules is an

interesting genotypic characteristic because of the symbiotic association with Rhizobium bacteria for atmospheric nitrogen fixation (Singh et al., 2006), making this major element available for the plant. Redjeki et al. (2013) reported that seed coat compounds play a significant role in nodule development. Moreover, Ibny et al. (2019) that variation in Bambara groundnut seed color influences the choice of microsymbiont partners, through the attraction of native and familiar rhizobia with potential symbiotic efficiency within crop species

In Burkina Faso, Bambara groundnut is grown on marginal soils. It would be advisable to use KVS235 which could trap a large amount of nitrogen as order to improve soil fertility. The different types of fertilizers, their doses and combinations, as well as the interaction variety x fertilizer did not affect significantly the rate of emerged plants and the flowering attributes. However the interaction variety x fertilizer showed significant variation for number of nodules ($P< 0.05$). In-deeph, the interaction KVS235*NPK75 and KVS235*Bc5000 exhibited greatest number of nodules (23.87 and 23.33 nodules respectively).

Effect of treatments on growth parameters

The number of leaves per plant (NL/P) and plant spread (PlS) of KVS235 and Bansida varieties were significantly affected ($P< 0.05$ and $P < 0.01$, respectively) by the overall effect of the different fertilizers (Table 5).Total biomass at flowering (TBF) and plant height (PlH) were not significantly influenced ($P> 0.05$). High number of leaves per plant (NL/P) were recorded with KVS235 (77.68±2.99 leaves) while Var_Loc shown the largest plants (PlS = 34.03±0.93 cm). Local varieties in Burkina Faso have more biomass compared to improved varieties. One of the selection objective for increase productivity being to reduce plant size in favor of grains and fruits production. That supports Var_Loc shown high values of total biomass at flowering (TBF = 4.72±0.30 g), plant height (PlH = 20.22±0.47 cm) and plant spread (PlS = 34.03±0.93 cm) than KVS235 with the respective value of TBF = 3.54±0.42 g, PlH = 18.35±0.66 cm and PlS = 30.32±1.31 cm. However, the high numbers of leaves (NL/P = 77.68±2.99) of KVS235 is very interesting because leaves are the site of photosynthetic activity for migration of the leaves assimilate toward fruits (Mourad et al., 1990). Furthermore, the main carbohydrates in the fruits result from the fixation of CO_2 by photosynthesis (Zombré, 1999) through the leaves. These assimilates are important both for the functioning of the plant and for the final production. The different types of fertilizers, their doses and combinations, as well as the interaction variety x fertilizer did not affect significantly growth attributes. The findings of Hasan et al. (2021) showed significant difference for certain growth parameters such as plant height (PlH), leaves number and branch number under inorganic and organic fertilizers application. This difference could be explained by the initial fertility of the crop soil, the addition of fertilizers, whether organic or chemical, that can have different effects on the soil productivity. Contrary, the NPK fertilization significantly improved growth as measured by the height in shoot, number of leaves and fresh and dry biomass compared to cow dung application in Nigeria (Sotayo and Donli, 2021).

Table 5:- Values±Standard Errors of total biomass, number of leaves and plants dimension under the effect of varietal and fertilizer factors.

Source of variation		**TBF (g)**	**NL/P (#)**	**PlH (cm)**	**PlS (cm)**
Varieties	KVS235	3.54±0.42a	77.68±2.99a	18.35±0.66a	30.32±1.31a
	Var_Loc	4.72±0.30a	69.23±2.11b	20.22±0.47a	34.03±0.93b
	Probability	**0.239**	**0.013***	**0.053**	**0.002****
Fertilizers	NPK75	3.45±0.34a	81.93±4.24a	19.50±0.11a	33.27±0.55a
	Bc3000	4.33±0.10a	69.87±1.79a	19.27±0.01a	30.97±0.60a
	Bc5000	4.04±0.03a	72.13±0.66a	19.23±0.03a	32.07±0.05a
	NPK37.5 + Bc2500	4.66±0.27a	69.90±1.78a	19.13±0.08a	32.40±0.11a
	Probability	**0.103**	**0.408**	**0.93**	**0.599**
Var * Fert	**Probability**	**0.41**	**0.997**	**0.215**	**0.227**

Legend: TBF: Total biomass at the flowering**; NL/P:** Number of leaves per plant**; PlH:** Plant height**; PlS:** Plant spread; **Var * Fert:** Interaction variety-fertilizer; Means within columns with different letters are significantly different; *****: Significant difference at P 5% treshold; ****:** Significant difference at P = 1% treshold.

Effect of treatments on yield and yield components

Comparison of KVS235 and Var_Loc showed significant effect on weight of pods per plant and weight of seeds per plant ($P< 0.05$ – Table 6). Nevertheless, no significant effect was observed for 100-seeds weight and yield ($P> 0.05$ – **Table 6**)). The higher pod and seed weights were recorded with KVS235 (WP/P = 16.45±0.66 g and WS/P =

10.32±0.82 g). The weight of seeds per plant of KVS235 is closed to Ouedraogo et al. (2012) for the same variety for two years in the North-Sahelian phytogeographical domain. This result is different from Obidiebube et al. (2000) with 12 varieties in Anambra State, Nigeria. The weight of pods was ranged from 10.7- 35 g respectively for varieties $IITA_{355}$ and$ENZK_2$ and the weight of seeds ranged to 8.7- 30.5 g for $IITA_{182}$ and $EXMF_4$ respectively. The findings of Nandkangre et al. (2022) exhibited higher seed weight (13.76 g) with eight Bambara groundnut genotypes. Yield was not significantly varied (P> 0.05), but KVS235 showed a trend of higher (1190.62±88.63 kg ha^{-1}) than Var_Loc (939.93±62.67 kg ha^{-1}) with a difference of 250.69 kg ha^{-1}. This difference is not negligible, in so far as yields in the extensive cropping system in Burkina Faso characterized by poor soils are often less than 500 kg ha^{-1}. Majola et al. (2021) reported yields of 500 - 800 kg ha^{-1} under poor soil conditions.

In terms of fertilizations, results showed significant differences in the pod and seed weights (P< 0.05) with respect to the types of fertilizers applied. The lowest values were obtained with Bc3000 (WP/P = 12.79±1.36 g; WS/P = 7.90±0.60 g). The application of chemical fertilizer NPK75 compared to the others fertilizers increase the pod (18.95±1.72 g) and seed (11.53±1.19 g) weights. Although the difference was not significant in yield, maximum yield was recorded with treatment NPK75 (1199.31±67.02 kg ha^{-1}). This is an indication that fertilizers application increases the yield and direct yield parameters of Bambara groundnut and plants responded to different types of fertilizers and rates of compost supplied. Yield and direct yield parameters increase are due to by sufficient quantities of nitrogen, phosphorus and potassium bringing by NPK compared to the compost. As the soil initial fertility was very low, the quantities of major elements provided by NPK increased soil productivity. This positive effect of chemical fertilizers on yield and yield components were also reported by (Ikenganyia et al., 2017; Hasan et al., 2019a; Hasan et al. 2019b; Ko et al., 2022).

Table 6:- Values±Standard Errors of pod weight, seed weight and yield under the effect of varietal and fertilizer factors.

Source of variation		**WP/P (g)**	**WS/P (g)**	**W100S (g)**	**YLD (Kg ha^{-1})**
Varieties	KVS235	16.45±0.66a	10.32±0.82a	42.42±0.47a	1190.62±88.63a
	Var_Loc	14.57±0.47b	8.00±0.58b	43.75±0.33a	939.93±62.67a
	Probability	**0.023***	**0.029***	**0.65**	**0.173**
Fertilizers	NPK75	18.95±1.72a	11.53±1.19a	43.33±0.12a	1199.31±67.02a
	Bc3000	12.79±1.36b	7.90±0.60b	44.33±0.62a	1095.14±14.93a
	Bc5000	14.80±0.35ab	8.87±0.15b	42.00±0.54a	993.75±35.77a
	NPK37.5 + Bc2500	15.49±0.01ab	8.34±0.41b	42.67±0.21a	972.92±46.18a
	Probability	**0.046***	**0.049***	**0.698**	**0.664**
Var * Fert	**Probability**	**0.451**	**0.276**	**0.806**	**0.544**

Legend : **WP/P :** Weight of pod per plant ; **WS/P :** Weight of seed per plant ; **W100S** : 100-seeds weight ; **YLD** : Yield ; **Var * Fert :** Interaction variety-fertilizer ; Means within columns with different letters are significantly different; *****: Significant difference at P 5% treshold.

Conclusion:-

This research was undertaken to compare two varieties of Bambara groundnut, a local (Var_Loc) and an improved (KVS235) variety under different types of fertilizer at varying doses. Data analysis showed that KVS235 exhibited best performances for flowering and yield attributes. In contrast, Bansida (Var_Loc) was better for growth parameters. Maximum weight of pods per plant and weight of seeds per plant were obtained when NPK75 was applied at a significative treshold (P < 0.05). Yield increased with NPK75, followed by Bc3000 and Bc5000 (P > 0.05). However, it will be recommended to determine in long-term impact of different fertilizers on the soil productivity and it would be advisable to carry out an economic analysis to ascertain whether the use of NPK is economically profitable for producers.

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Disclosure of Conflict of Interest

The authors declare that they have no conflicts of interest.

References:-

1. Altieri, M., Nicholls, C. and Montalba, R. (2017). Technological approaches to sustainable agriculture at a crossroads: An agroecological perspective. Sustainability, 9(3):https://doi.org/10.3390/ su9030349.
2. Altieri, M.A., Funes-Monzote, F.R. and Petersen, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. Agronomy for Sustainable Development, 32, 1-13. DOI 10.1007/s13593-011-0065-6.
3. Anchirina, V.M., Yiridoe, E.K. and Bennett-lartey, J.O. (2001). Enhancing sustainable production and genetic resource conservation of Bambara groundnut. A survey of indigenous agricultural knowledge systems: outlo. Agri., 30(4): 281-288.
4. Atoyebi, J.O, Osilesi, O., Abberton, M., Adebawo, O. and Oyatomi, O. (2018). Quantification of selected anti-nutrients and bioactive compounds in African Bambara groundnut [Vigna subterranea (L.) Verdc.]. Am. J. Food Nutr., 6:88-95.
5. Azam-Ali, S., Sesay, A., Karikari, S., Massawe, F., Aguilar-Manjarrez, J.and Bannayan, M. (2014). Assessing the potential of an underutilized crop–a case study using Bambara groundnut. Exp. Agric.,37: 433–472.
6. Benedyeka, Z., Benedijeki, S. and Grzegorezyk, S. (1992). Phosphorous utilization in the dependence on nitrogen fertilization of green sward. Forth International Imphos conference. Phosphorous life and environment, Grand Belgium.
7. Bonny, S. andDjè, Y.(2011). Variabilité morphologique et agronomique des variétés traditionnelles de voandzou (Vigna subterranea L. Verdc,) de Côte d'Ivoire. Journal of Applied Biosciences,41:2820-2835.
8. Brink, M., Grubben, G.J.H. and Belay, G. (2006). Ressources végétales de l'Afrique Tropicale 1: Céréales et légumes secs. Edition M. Brink. Wageningen University, P.O. Box 341, 6700 AH Wageningen, Netherlands, 328.
9. CPCS. (Commision de Pédologie et de cartographie des sols) (1967). Commission de Pédologie et de Cartographie des Sols, Available: https://horizon.documentation.ird.fr/exl- oc/pleins textes/divers16-03/12186.pdf.
10. Diagara, S.M., Issa, A.H., Mamoudou, B.M. and Kiari, B.J.K.K. (2022). Caractérisation agro-morphologique de 30 accessions de voandzou [Vigna subterranea (L.) verdc] cultivées dans la zone soudanienne du Niger. International Journal of Innovation and Applied Studies, 36(2): 553-563.
11. FAO. and ISRIC. (Centre International de Reference et d'Information des Sols). (1994). Directives pour la description des sols. 3ème édition (révisée), Service des sols-ressources, aménagement et conservation, Division de la mise en valeur des terres et des eaux, 78 p.
12. Goli, A.E., Begemann, F. and Ng, N.Q.(1997). Characterization and evaluation of IITA's Bambara groundnut collection. Pp. 101-118. In: Heller, J., Begemann, F. and Mushonga, J., 1997, Bambara groundnut [Vigna subterranea (L.) Verdc.]. Promoting the conservation and use of underutilized and neglected crops .9. Proceeding of the workshops on conservation and Improvement of Bambara groundnut [Vigna subterranea (L.) Verdc.], 14-16 November 1995, Harare, Zimbabwe, 173 p.
13. Hasan, M., Uddin, Md.K., Mohammed, M.T.M., Zuan, A.T.K. and Motmainna, M.(2019a). Impact of chemical and organic fertilizer on the yield and nutritional composition of Bambara groundnut (Vigna subterranea L. Verdc.). Bangladesh J. Bot., 48(4): 919-924
14. Hasan, M., Uddin, Md. K., Mohammed, M.T.M., Zuan, A.T.K. and Motmainna, M. (2019b). Impact of nitrogen and phosphorus fertilizer on growth and yield of Bambara groundnut. Plant Archives, 19(1): 501-504.
15. Hasan, M., Uddin, Md. K., Mohammed, M.T.M., Zuan, A.T.K. and Motmainna, M. (2021). Growth, Yield, Nodulation and Amino Acid Content of Bambara Groundnut (Vigna subterranea) under Inorganic and Organic Fertilizer Application. Legume Research- An International Journal, 44(3): 322-327.
16. Hilhorst, T., Muchena, F.M., Defoer, T., Hassink J, de Jager A, Smaling E, Toulmin C. (2000). Managing Soil Fertility in Africa: Diverse Settings and Changing Practice. In: Nutrients on the Move-Soil Fertility Dynamics in Africa Farming Systems, Hilhorst T. and F.M. Muchena (Eds.). International Institute for Environment Development, USA.
17. Hillocks, R.J., Bennett, C.M., and Mponda, O.M. (2012). Bambara nut: A review of utilisation, market potential and crop improvement. African crop Science Journal, 20(1): 1-16.
18. Ibny, F., Jaiswal, S., Mustapha, M. and Dakora, F.D. (2019). Symbiotic effectiveness and ecologically adaptive traits of native rhizobial symbionts of bambara groundnut (Vigna subterranea l. verdc.) in Africa and their relationship with phylogeny. Sci. Rep., 9: 1-17.
19. Ikenganyia, E.E., Anikwe, M.A.N. and Ngwu, O.E. (2017). Responses of Bambara groundnut [Vigna subterranea (L.) Verdc.] to Phosphate Fertilizer Rates and Plant Spacing and Effects on Soil Nutrient Statues in

a Degraded Tropical Ultisol Agbani Enugu South-east Nigeria. International Journal of Plant & Soil Science, 17(4): 1-17.
20. IPGRI., IITA. and BAMNET. (2000). Descriptors for Bambara groundnut (Vigna subterranea). International Plant Genetic Resources Institute, Rome Italy; International Institute of Tropical Agriculture, Ibadan, Nigeria; The International Bambara Groundnut Network, Germany. ISBN 92-9043-461-9.
21. Kaho, F., Yemefack, M., Feujio-Tegwefouet P.and Tchanthaouang, J.C. (2011). Effet combiné de feuilles de Tithonia diversifolia et des engrais inorganiques sur le rendement du maïs et les propriétés d'un sol ferralitique au centre du Cameroun. Tropicultura, 29(1): 39-45.
22. Khalid, A.A., Tuffour, H.O., Bonsu B.and Mensah, P.Q.(2014). Effects of Poultry Manure and NPK Fertilizer on Physical Properties of a Sandy Soil in Ghana. IJSRAS., 1(1):1-5.
23. Khan, M.M.H., Rafii, M.Y., Ramlee, S.I., Jusoh, M. andAl-Mamun, M. (2021). Bambara Groundnut (Vigna subterranea L. Verdc): A Crop for the New Millennium, Its Genetic Diversity, and Improvements to Mitigate Future Food and Nutritional Challenges. Sustainability, 3, 5530. https://doi.org/10.3390/ su13105530.
24. Ko, O., La, C. and Ogbu, J.O. (2022). Growth and yield responses of groundnut to different rates of NPK fertilizer at Umudike. Int J Agric Sc Food Technol., 8(1): 072-077. DOI: https://dx.doi.org/10.17352/2455-815X.000147
25. Mabhaudhi, T., Modi, A.T. and Beletse, Y.G. (2013). Growth, phenological and yield responses of a Bambara groundnut (Vigna subterranea L. Verdc) landrace to imposed water stress: II. Rain shelter conditions. Afr. Crop Sci. J., 39:191-198.
26. Maitra, S. and Pine, S. (2020). Smart Irrigation for Food Security and Agricultural Sustainability. Ind. J. Nat. Sci., 10: 20435-20439.
27. Majola, N.G.; Gerrano, A.S.and Shimelis, H.(2021). Bambara Groundnut (Vigna subterranea [L.] Verdc.) Production, Utilisation and Genetic Improvement in Sub-Saharan Africa. **Agronomy,11**, 1345. https://doi.org/10.3390/agronomy11071345.
28. MARH. (Ministère de l´Agriculture et des Ressources Halieutiques) (2022). Certification des semences au Burkina Faso: Une opération d'assurance qualité pour une meilleure productivité agricole. https://www.agriculture.bf/jcms/pv10_104105/fr/certification-des-semences-au-burkina-faso-une-operation-d-assurance-qualite-pour-une-meilleure-productivite-agricole. Consulted on July 21, 2023
29. Massawe, F.J., Mwale, S.S., Azam-Ali, S.N. and Roberts, J.A. (2019). Breeding in bambara groundnut (Vigna subterranea (L.) Verdc.): strategic considerations. International Journal of Biochemistry and Biotechnology, 9(2): 001-009.
30. Minka, S.R. and Bruneteau, M. (2000). Partial Chemical Composition of Bambara Pea (Vigna subterranean L. Verde). Food Chemistry, 68:273-276.
31. Mourad, B., Calmes, J., Viala, G. (1990). Répartition du carbone fixé par photosynthèse entre l'amidon et le saccharose dans les feuilles de soja. Influence d'un déficit hydrique. Plant Physiol. Biochem., 28: 113-21.
32. Musa, M., Massawe, F.J., Mayes, S., Alshareef, I., Singh, A. (2016). Nitrogen fixation and N-Balance studies on Bambara groundnut (Vigna subterranea L. Verdc.) Landraces grown on tropical acidic soils of Malaysia. Commun Soil Sci. Plant Anal, 47(4):533-542.
33. Nandkangre, H., Zongo, K.F., Kambou, D.J., Nikiema, B., Ouoba, A., Ouedraogo, H.M., Konaté, M.N., Kima, A.S. and Ouedraogo, M. (2022). Performance of bambara groundnut (Vigna subterranea [L.] Verdcourt) genotypes cropped on plinthite soil in the semi arid-zone, Burkina Faso. International Journal of Plant & Soil Science, 34(23): 1067-1075.
34. Nandkangre, H., Zongo, K.F., Kambou, D.J., Bonkoungou, M., Konate, N.M.., Ouoba, A., Kima, A.S. and Ouedraogo M. (2023). Effect of NPK application dates on agronomic parameters of two Bambara groundnut varieties cultivated on ferric Lixisol in northern Sudanian Sector of Burkina Faso. World Journal of Advanced Research and Reviews, 19(01) : 246-253
35. Ndiang, Z., Semboung, L.F., Ngo, N.L., Wafo, F.D, Tchinda, N.L. and Bell J.M.(2022). Nodulation Potential of Bambara Groundnut (Vigna subterranea L.) in Yaounde (Centre Region of Cameroon). American Journal of Food and Nutrition, 10(1):34-39.
36. Obidiebube, E.A., Eruotor, P.G., Akparobi, S.O., Okolie, H. and Obasi, C.C. (2020). Assessment of Bambara groundnut (Vigna Subterranea (L) Verdc) varieties for adaptation to rainforest agro-ecological zone of Anambra State of Nigeria. Canadian Journal of Agriculture and Crops, 5(1): 1-6.
37. Ouedraogo, M., Ouedraogo, J.T., Tignere, J.B., Balma, D., Dabire, B.C. and Konate, G. (2008) Characterization and evaluation of accessions of bambara groundnut (Vigna subterranean (L.) Verdc.) from Burkina Faso. Sciences & Nature, :191-197.

38. Redjeki, E.S., Maye,s S. and Azam-Ali S. (2013). Evaluating the stability and adaptability of bambara groundnut (Vigna subterranea (L.) verd.) landraces in different agro-ecologies. Acta Hort., 979: 389-400.
39. Sanchez, PA. (2002). Soil fertility and hunger in Africa. Science, 295:2019–2020.
40. Singh, A. andBasu, M. (2006). Bambara Groundnut: Its Physiology and Introduction in India. In Advances in Plant Physiology; I.K. International Publishing House: New Delhi, India, pp. 235-249.
41. Sotayo, F.O. and Donli, P.O. (2021). A Comparative Study of the Effects of Chemical fertilizer (NPK) and Organic Manure (Cow Dung) on the Growth of Bambara Groundnut in Borno State, Nigeria. Dutse Journal of Pure and Applied Sciences, 7 (2): 182-189.
42. Stoorvoge, J.J., Smaling, E.M.A. and Janssen B.H. (1993). Calculating soil nutrient balances in Africa at different scales. I. Supra-national scale. Nutr. Cycl. Agroecosyst., 35:227-235.
43. Toure, Y., Koné, M., Silué, S. and Kouadio, Y.J. (2013). Prospection, collecte et caracterisation agro-morphologique des morphotypes de voandzou (Vigna subterranea (L.) Verdc) de la zone savanicole en côte d'Ivoire. European scientific journal, 9:308-325.
44. Useni, S.Y., Baboy, L.L., Nyembo, K.L. and Mpundu M.M. (2012). Effets des apports combinés de biodéchets et defertilisants inorganiques sur le rendement de trois variétés de Zea mays L. cultivées dans la région de Lubumbashi. Journal of Applied Biosciences, 54: 3935-3943.
45. World Reference base for soil resources (2015). International soil classification system for naming soils and creating legends for soil maps. Classification, correlation and communication, 2nd ed. World Soil Resources Reports No.103, FAO, Rome, 2015. 145 p.
46. Zombré, G. (1999). Synthèse d'amidon et du saccharose dans la feuille du soja, étude de quelques facteurs de régulation. Thèse de doctorat de l'université Paul Sabatier de Toulouse, France.
47. Zongo, K.F., Hien, E., Mare, B.T. and Guebre, D. (2021). Performance de l'association mixte sorgho-niébé sur les productivités du sorgho et des sols en zone Soudano-Sahélienne du Burkina Faso. International Journal of Biological and Chemical Sciences ; 15(3): 987-1005.
48. Zongo, K.F., Nandkangre, H., Guebre, D., Sanon, A., Kambou, D.J., Kabore, P., Ouoba A., Hien, E. and Ouedraogo, M.(2023). Soil characterization and potentiality to improve two Bambara groundnut varieties cropping under rock phosphate fertilization at sudano-sahelian climate of Burkina Faso. International Journal of nnovation and Applied Studies,8(4):829-838.