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Research Article
Growth and Yield Responses of Groundnut (*Arachis hypogaea* L.) to Arbuscular Mycorrhizal Fungi Inoculation in Calabar, Nigeria

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Abstract

Background and Objective: The search for more affordable, environmentally friendly and sustainable approaches in managing our rapidly declining soils for increased crop yield is inevitable. This study evaluated the growth and yield responses of two groundnut varieties to inoculation with two species of arbuscular mycorrhizal fungi (AMF). **Materials and Methods:** Field experiments were carried out at the University of Calabar Teaching and Research Farm. These experiments were dispersed in a 2×3 factorial disposition and arranged in a randomized complete blocked design (RCBD) with three replications. Two groundnut varieties (SAMNUT 21 and SAMNUT 22) were combined with two arbuscular mycorrhizal fungi species; *Glomus clarum* and *Gigaspora gigantea* and an un-inoculated control. Data collected were subjected to statistical analysis using a two way analysis of variance and significant means were compared using Fisher's least significant difference (FLSD) at 5% probability level. **Results:** Data analysis showed that inoculation of the groundnut varieties with AMF significantly ($p \leq 0$) increased number of pods/plant, pod yield, seed yield and 100-seed weight. The highest enhancements in yield attributes were obtained when variety SAMNUT 21 was inoculated with *Glomus clarum* while *G. gigantea* inoculation enhanced the growth attributes of SAMNUT 22. **Conclusion:** Thus *G. clarum* was more effective in yield enhancement in SAMNUT 21 variety compared to *G. gigantea* which enhanced growth in SAMNUT 22. This technology could be incorporated into groundnut cropping systems by resource poor farmers in Calabar for yield improvement.

Key words: Arbuscular mycorrhizal fungi, SAMNUT 21 and SAMNUT 22, *Glomus clarum*, groundnut, *Gigaspora gigantea*, inoculation

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) also known as peanut is one of the most popularly consumed grain legumes in tropical Africa. Nigeria tops as the largest producer of groundnut in West Africa with 51% contribution to its production in the region[1]. It is a member of the sub-family Papilionaceae which is the largest and most important member of the family Fabaceae[2]. Groundnut is grown principally for its edible oil, protein and carbohydrate although it is rich in essential minerals and vitamins[3]. Groundnut is also able to fix atmospheric nitrogen in the soil through symbiotic association with soil bacteria found in the soil. It is therefore a crop of choice for resource poor farmers particularly for those that do not have the means to enrich the soil through fertilizer amendment.

An Arbuscular mycorrhizal fungus (AMF) association is considered to be a symbiosis between specific soil fungi and the plant root[4]. It is fast becoming an important constituent of our modern day agricultural systems. The extra radical hyphae of AMF have been found to function as root extensions that effectively draw phosphate from the soil for use by the plants[5]. This conceivable role of AMF in terms of their involvement in phosphate nutrition has gained much importance in recent times[6]. Van der Heijden *et al.*[7] enumerated the roles of mycorrhizal fungus on crop productivity to include; increased acquisition of nutrient, enhanced seedling establishment, resistance drought and heavy metals. It also mediates N- fixation, improve soil structure by stimulation of soil aggregation, stimulate activities of micro-organism as well as suppresses weeds and some soil pathogens. It is generally reported that all legumes can potentially form beneficial mutual relationship with AMF and more over rhizobium and AMF are synergistic in their mode of action[8]. Studies by Jackson and Masson[9] reported a positive relationship between P availability, mycorrhizal infection and pod yield in groundnut. Most legumes form symbiotic pairs with mycorrhizal fungi and nitrogen fixing bacteria, thereby establishing threefold association implicated in the supply of N and P to plants[10]. It has been shown that both the arbuscular mycorrhizal fungus and rhizobium functions as bio-fertilizers and possess the ability to make available some soil nutrients present in the soil in unavailable form through biological processes[11]. When legumes are symbiotic with both *Rhizobium* spp. and AM fungi, plant growth is generally much more enhanced than with either alone[12]. Inoculation of groundnut with AMF significantly increased leaf number, shoot length, pod number, nodule number of groundnut plant as compared with non-mycorrhizal plants[13]. Copetta *et al.*[14] showed increase in some morphological parameters in *Ocimum* spp. due to inoculation with AM fungi. Trotta *et al.*[15] and Torelli *et al.*[16] reported an enhancement in shoot and root dry weights of plants when inoculated with *G. fasciculatum*. Al-Khaliel[17] reported significant differences in the growth indices of peanut inoculated with two AM fungi species grown in various substrate soils. The increase in shoot and root dry weight in mycorrhizal plants was attributed to an increase in the supply of nutrients[18,19]. Fritz *et al.*[20] reported that tomatoes treated with AMF showed better growth response in terms of shoot and root length, number of leaves fruits as well as fresh and dry weights. Highest pod yields were observed in plants inoculated with AMF. Mooney *et al.*[21] reported that plant inoculated with AMF produced dry pod yield which was 7.3 times higher than the un-inoculated plants which is attributable to the ability of AMF to extend and explore the soil volume beyond the rhizosphere. Ozgonen *et al.*[22] reported that AMF inoculation improved yield and reduced disease infection in peanuts. Also phyto-hormones (Indole Acetic acid (IAA) and cytokinins) released by AMF contribute to the plant growth enhancement[23]. Cowpea plants grown on acidic soils inherently low in P were reported to have benefited from AMF inoculation which has the ability of increasing the P availability to the host plant[24].

The AMF is therefore considered to be beneficial for use in sustainable farming systems due to their efficiency even in areas with inherently low soil nutrient availability and can help in mobilizing nutrients bound to organic matter and soil particles for plant growth. Arbuscular mycorrhizae also act as bio-protectants against pathogens and toxic substances[25]. Calabar is located in the humid tropical rainforest ecology. According to Eshett[26], soils in this region are said to be marginal, fertility-wise. Poor soil fertility is aggravated by torrential rains, high acidity and immobilization and leaching of soil nutrients. Attempts to ameliorate these problems with the use of inorganic and organic fertilizers are still fraught with numerous problems. Therefore, cheaper, accessible alternatives to their use should be sought, developed and exploited for more ecofriendly and sustainable crop production. Arbuscular mycorrhizal fungi (AMF), known to form symbiotic association with most agricultural crops and helps in mobilizing less mobile nutrient elements for plants' use becomes an inevitable and a readily available eco-friendly alternative. Little or no work has been done in Calabar evaluating the efficiency of AMF species on groundnut production; therefore, this work was conceptualized to assess the efficiency of two species of AMF in enhancing the productivity of two groundnut varieties in Calabar, Nigeria.

MATERIALS AND METHODS

Study site information: The field trials were carried out in the University of Calabar Teaching and Research Farm, Calabar in the 2012 as well as 2013 cropping seasons. Calabar was situated in the south eastern rainforest zone of Nigeria between Latitudes 4°45' and 4°58' N of equator and longitudes 8°19' and 8°37' E of the Greenwich Meridian with an annual rainfall in the range of 2200-3700 mm, a mean annual temperature range of 27-28°C and relative humidity of between[27] 75-85%.

Experimental design and treatment: The studies were 2x3 factorial experiments arranged in the field in randomized complete block design (RCBD). Two varieties of groundnut (SAMNUT 22 and SAMNUT 21) and two mycorrhizal fungi species (*G. clarum* and *G. gigantea*) plus an un-inoculated control were factorially combined and randomly assigned to experimental plots. There were a total of 6 treatment combinations. Each of these treatment combinations was replicated three (3) times. Each experimental plot measured 2×2 m with 0.5 m^2 between treatment plots while 1 m^2 alley separated each block from the other.

Physical and chemical properties of the soil at the study site: Collection of soil samples at random spots (0-30 cm) of the soil were done prior to seed bed preparation. These soil samples were bulked, air dried and prepared for routine laboratory analysis using procedures outlined by IITA[28].

Preparation of experimental materials: The inoculums were prepared from the starter cultures of arbuscular mycorrhizal fungi (*Gigaspora gigantea* and *Glomus clarum*) obtained from the Soil Microbiology Unit of the Department of Agronomy, University of Ibadan, Nigeria. Seeds of two groundnut varieties namely; SAMNUT 22 and SAMNUT 21 were obtained from the Institute for Agricultural Research (IAR), Zaria Nigeria. Preparation of inoculums involved the multiplication of the starter cultures of the AMF species in a sterilized soil, planted with maize and watered with Hogland's solution for 3 months. The spore density of AMF inoculums prepared in this way as estimated by the method of Gerdemann and Nicolson[29] was 48 and 50 spores/10 g of soil for *G. clarum* and *G. gigantea*, respectively

Agronomic practices: Before sowing, 20 g of each AMF species inoculum was placed in the planting hole before placing the seeds following the treatment allocation following a method adopted by Okon[30]. Two seeds of groundnut were sown at distance of 20×30 cm and later thinned to one plant per stand two weeks after planting (WAP) to give a total of 67 plants/plot (166,666.67 ha^{-1}). The plots were weeded by hand-pulling within the crop rows and hand -hoeing between rows at 2 and 4 WAP. During weeding, the bases of the groundnut plants were earthed up to protect developing pegs and provide loose medium for easy penetration and enlargement of pods.

Data collection on growth and yield parameters: Data were collected from two inner rows of each plot on plant height, number of leaves/plant, number of branches/plant at 3, 5 and 7 WAP. Other data collected included, length of pod, number of pods/plant, pod yield (t ha^{-1}), number of seeds/pod, whole dry weight/plant, harvest index, threshing 100 seed weight and seed yield (t ha^{-1}).

Data analysis: Data obtained from the experiment were subjected to a two way analysis of variance using a 2×3 factorial in randomized complete block design (RCBD) and computed using Microsoft excel. Significant treatment means were compared using Fisher's Least Significant difference (F-LSD) ($p \leq 0.05$) as described by Gomez and Gomez[31].

RESULTS

Physical and chemical properties of soil at the experimental site: The result of physicochemical properties of the soil at the experimental site shown in Table 1. The soil at the site where the experiments were conducted was classified as sandy loam in texture, moderately acidic (5.10 and 5.34), low in nitrogen

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

Soil properties	2010	2011
Physical properties		
Sand (%)	87.60%	85.94%
Silt(%)	8.00%	8.00%
Clay(%)	4.40%	6.06%
Textural classification	Loamy sand	Loamy sand
Chemical properties		
Soil pH	5.10	5.34
Organic matter	1.95%	2.19%
Total nitrogen	0.09%	0.08%
Available phosphorus	28.25 mg kg^{-1}	30.19 mg kg^{-1}
Calcium	4.02 cmol kg^{-1}	4.08 cmol kg^{-1}
Magnesium	1.06 cmol kg^{-1}	1.02 cmol kg^{-1}
Potassium	0.10 cmol kg^{-1}	0.19 cmol kg^{-1}
Sodium	0.15 cmol kg^{-1}	0.09 cmol kg^{-1}
Exchangeable soil acidity	1.71 cmol kg^{-1}	1.86 cmol kg^{-1}
ECEC	7.04 cmol kg^{-1}	7.24 cmol kg^{-1}
Base saturation	80.0%	75.0%
E.C	0.012 d Sm^{-1}	0.015 d Sm^{-1}

(0.09 and 0.08%), organic N (1.95 and 2.19%), exchangeable potassium (0.10 and 0.19 cmol kg^{-1}), Calcium (4.02 and 4.08 cmol kg^{-1}) and magnesium (1.06 and 1.02 cmol kg^{-1}) for 2010 and 2011, respectively. However, available phosphorus was moderate (28.25 and 30.19 mg kg^{-1}).

Effects of AMF inoculation on the height of two varieties of groundnut: The results of effects of AMF inoculation on the height of two varieties of groundnut at different sampling periods were presented in Table 2. Groundnut inoculated with *G. clarum* produced the tallest plants (9.34 and 18.59 cm at 3 and 5 weeks after planting (WAP), respectively and these were not significantly taller compared to those inoculated with *G. gigantea* with heights of 8.42 and 17.06 cm, respectively within the same sampling periods in 2012. All mycorrhizal plants had significant (p<0.05) enhancement in groundnut growth relative to the non-mycorrhizal plants However, at 7 WAP, inoculation with *G. clarum* produced significant taller plants (32.04 cm) compared to those inoculated with *G. gigantea* with plant height of 25.86 cm. This in turn was significantly taller when compared to the non-mycorrhizal plants (21.86 cm). In 2013, plants inoculated with *G. clarum* produced significantly (p<0.05) taller groundnut plants (20.60 and 34.90 cm) relative to *G. gigantea* (17.57 and 27.53 cm) and the un-inoculated plants 15.35 and 32.05 cm tall, respectively at 5 and 7 WAP. Also, at 7 WAP, in 2012 planting season, variety SAMNUT 22 was significantly (p<0.05) taller plant (27.83 cm) compared (23.33cm) in SAMNUT 21. In 2013, SAMNUT 22 had plant heights of 11.02, 19.00 and 29.81 cm at 3, 5, 7 WAP, respectively which were significantly higher when compared to those in SAMNUT 21 (10.75, 16.68 and 27.65 cm), respectively. There were significant interaction effects between variety of groundnut planted and the species of AMF on plant height in both years except at 3 and 5 WAP in 2013. Inoculation of SAMNUT 22 plants with *G. clarum* produced significantly (p<0.05) taller plants compared to those inoculated with *G. gigantea*. Generally, *G. clarum* was more efficient in growth enhancement of both groundnut varieties than *G. gigantea*. Effects of AMF inoculation on the number of leaves of two varieties of groundnut: In both seasons, inoculation of groundnut plants with AMF had significant effect on the number leaves per plant at 7 WAP in 2012 and at 5 and 7 WAP in 2013. Plant inoculated with *G. clarum* had the highest number of leaves (56.46 and 37.59) at 7 and 5 WAP in 2012 which were significantly higher compared to those borne by plants inoculated with *G. gigantea* (52.05 and 29.21) in the same sampling periods. At 7 WAP in 2013 plants inoculated with *G. gigantea* had 52.28 leaves and this did not differ significantly from 51.77 leaves produced by plant inoculated with *G. clarum*. However, non-mycorrhizal plants had significantly the least number of leaves compared to the mycorrhizal plants. Groundnut varieties SAMNUT 21 and SAMNUT 22 did not differ significantly (p>0.05) in their number of leaves at 3 WAP in 2012 as well as 3, 5 and 7 WAP in 2013 (Table 3). At 5 and 7 WAP, SAMNUT 21 plants significantly (p<0.05) produced more leaves 30.50 and 50.92 respectively compared to SAMNUT 22 plants which had 27.52, and 44.93 leaves within same periods. There was significant interaction effect between variety of groundnut planted and the species of AMF used on the number of leaves produced with in both years except at 3 WAP in 2013. At 3WAP, in 2012,

Table 2: Effect of Arbuscular mycorrhizal fungi inoculation on height (cm) of groundnut at 3, 5 and 7 weeks after planting (WAP) in 2012 and 2013

	2012 planting season			2013 planting season		
Mycorrhizal fungi	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
Control	6.42	15.67	21.86	7.52	15.35	32.05
G. gigantea	8.42	17.06	25.86	10.52	17.57	27.53
G. clarum	9.34	18.59	32.04	13.10	20.60	34.90
LSD(0.05)	1.23	2.23	2.14	NS	0.24	0.23
Groundnut varieties						
SAMNUT 22	9.52	18.63	27.83	11.02	19.00	29.81
SAMNUT 21	6.17	15.58	23.33	10.75	16.68	27.65
LSD (0.05)	NS	NS	2.62	0.84	0.14	0.35
Interactions						
Control×SAMNUT 22	7.11	16.21	20.50	8.54	16.50	23.63
Control×SAMNUT 21	4.42	15.13	23.21	6.49	14.20	23.73
G. gigantea×SAMNUT 22	9.85	17.96	26.17	9.71	18.50	28.67
G. gigantea×SAMNUT 21	6.99	16.16	25.54	11.33	16.63	26.39
G. clarum×SAMNUT 22	11.59	21.71	36.83	11.76	22.00	37.11
G. clarum×SAMNUT 21	7.09	13.46	27.25	14.43	19.20	32.68
LSD (0.05)	2.13	3.91	3.70	NS	NS	0.70

NS: Not significant at 5% level of probability

Table 3: Effect of arbuscular mycorrhizal fungi inoculation on number of leaves of groundnut at 3, 5 and 7 weeks after planting (WAP) in 2012 and 2013

	2012 planting season			2013 planting season		
Mycorrhizal fungi	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
Control	13.38	25.25	35.35	25.81	25.25	37.43
G. gigantea	16.92	29.21	52.05	33.81	29.21	52.28
G. clarum	18.17	37.59	56.46	40.53	37.59	51.77
LSD(0.05)	NS	NS	4.29	NS	0.82	0.59
Groundnut varieties						
SAMNUT 22	15.58	27.52	44.93	17.13	27.52	44.84
SAMNUT 21	16.61	30.50	50.92	17.75	30.50	49.48
LSD (0.05)	NS	NS	NS	NS	1.23	0.89
Interactions						
Control×SAMNUT 22	12.83	21.33	35.92	13.26	21.33	35.20
Control×SAMNUT 21	13.92	29.17	34.75	16.32	29.17	39.67
G. gigantea×SAMNUT 22	13.04	25.33	44.42	17.49	25.33	44.85
G. gigantea×SAMNUT 21	20.75	33.08	59.67	17.20	33.08	59.71
G. clarum×SAMNUT 22	21.17	35.92	54.58	20.62	35.92	54.47
G. clarum×SAMNUT 21	15.17	39.25	58.33	19.23	39.25	49.06
LSD (0.05)	5.59	8.42	7.40	NS	2.46	1.78

NS: Not significant at 5% level of probability inoculation of SAMNUT 22 plants with *G. clarum* produced the highest number of leaves (21.17) compared to SAMNUT 21 inoculated with *G. gigantea* (20.75). At 5 WAP, in both 2012 and 2013, SAMNUT 21 plants with *G. clarum*, SAMNUT 22 inoculated with *G. clarum* as well as SAMNUT 21 inoculated with *G. gigantea* produced 39.25, 35.92 and 33.08 leaves, respectively and were not significantly different. At 7 WAP, SAMNUT 21 plants with *G. gigantea*, SAMNUT 21 inoculated with *G. clarum* as well as SAMNUT 22 inoculated with *G. clarum* had 59.67, 58.33 and 54.58 leaves, respectively which were not significantly different from each other but were significantly different from other treatment combinations in terms number of leaves produced. At 7 WAP in 2013, SAMNUT 21 plants inoculated with *G. gigantea* produced significantly ($p<0.05$) higher number of leaves (59.71) followed by SAMNUT 22 plants inoculated with *G. clarum* (54.47).

Effects of AMF inoculation and groundnut variety on pod length, number of pods/plant, pod yield and number of seeds/pod: The results of the effects of AMF inoculation of groundnut on pod length, number of pods/plant, pod yield and number of seeds/pod are presented in Table 4. In both years, the increase in pod length due to AMF inoculation and groundnut variety were not significant ($p>0.05$). Also, there were no significant interaction between the AMF species used and the groundnut variety cultivated on the pod length. Groundnut inoculated with *G. clarum* significantly ($p<0.05$) produced more pods (20.35 and 20.55) than those inoculated with *G. gigantea* (16.59 and 16.74) in 2012 and 2013 respectively. On the other hand, the number of pods produced per plant by SAMNUT 21 (17.45 and 17.61 was significantly ($p<0.05$) more than that produced by SAMNUT 22 (13.63 and 13.82) in 2012 and 2013, respectively. In 2012, number of pod produced by SAMNUT 22 plants inoculated with *G. clarum*, SAMNUT 21 plants inoculated with *G. gigantea* and SAMNUT 21 inoculated with *G. clarum* were 21.41, 21.07 and 19.28 respectively. These were statistically similar ($p>0.05$) but significantly higher when compared to all other treatment combinations and the control. However, in 2013, SAMNUT 22 plants inoculated with *G. clarum* significantly produced the highest number of pods (21.60) when compared to all other treatment combinations and the control. Inoculation with AMF significantly ($p<0.05$) enhanced pod yield of groundnut relative un-inoculated plants. However, inoculation of groundnut plants with *G. clarum* produced significantly ($p<0.05$) higher pod yield of 4.70 and 4.77 t ha^{-1} in 2012 and 2013, respectively. Variety SAMNUT 21 significantly ($p<0.05$) had higher pod yield (4.07 and 4.14 t ha^{-1}) compared to SAMNUT 22 that produced 2.88 and 2.29 t ha^{-1} in 2012 and 2013 respectively. In both years, inoculation of SAMNUT 21 plants with *G. clarum* significantly produced the highest pod yield of 4.94 and 4.98 t ha^{-1}, respectively compared to other treatment combinations. Also in both years, AMF inoculation and variety of groundnut did not significantly influence the number of seeds pod in both years nor was there any significant interaction effect between them in determining the number of seeds pod.

Effect of arbuscular mycorrhizal fungi on biomass, haulms weight, harvest index, threshing percentage, 100 seed weight and seed yield of groundnut: The dry matter accumulation was significantly ($p<0.05$) enhanced by AMF

Table 4: Effect of arbuscular mycorrhizal fungi inoculation on pod length (cm)/plant, number of pods/plant, pod yield (t/ha) and number of seeds/plant of groundnut

	Pod length (cm)/plant		No. of pod/plant		Pod yield (t ha^{-1})		No. of seeds/pod	
Mycorrhizal fungi	2012	2013	2012	2013	2012	2013	2012	2013
Control	2.63	2.58	9.69	9.85	2.27	2.30	0.42	1.79
G. gigantea	2.82	2.78	16.59	16.74	3.47	3.63	0.45	1.91
G. clarum	2.71	2.81	20.35	20.55	4.70	4.77	0.49	1.95
LSD (0.05)	NS	NS	2.85	0.03	0.21	0.04	NS	NS
Groundnut varieties								
SAMNUT 22	2.92	2.81	13.63	13.82	2.88	2.99	1.98	1.88
SAMNUT 21	2.51	2.64	17.45	17.61	4.07	4.14	1.84	1.89
LSD (0.05)	NS	NS	3.59	0.04	0.03	0.06	NS	NS
Interactions								
Control×SAMNUT 22	2.71	2.66	7.37	7.54	1.74	1.78	1.83	1.77
Control×SAMNUT 21	2.55	2.49	12.00	12.15	2.80	2.82	1.70	1.81
G. gigantea×SAMNUT 22	3.05	2.89	12.10	21.31	2.46	2.63	2.17	1.91
G. gigantea×SAMNUT 21	2.59	2.66	21.07	21.17	4.48	4.63	1.93	1.91
G. clarum×SAMNUT 22	3.02	2.87	21.41	21.60	4.45	4.55	1.90	1.95
G. clarum×SAMNUT 21	2.39	2.76	19.28	19.50	4.94	4.98	1.90	1.95
LSD (0.05)	NS	NS	4.94	0.08	0.06	0.11	NS	NS

NS: Not significant at 5% level of probability

Table 5: Effect of arbuscular mychorrhizal fungi on biomass, haulms weight, harvest index, threshing percentage, 100-seed weight and see yield of groundnut, Haulms weight should be expunged and biomass should be rendered as whole plant dry weight to synchronize with the table and write-up

Mycorrhizal fungi	Whole plant dry weight (g plant^{-1})		Harvest index		Threshing (%)		100 seed weight (g)		Seed yield (t ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Control	41.51	13.80	0.42	0.41	21.99	20.20	34.05	34.22	1.76	1.86
G. gigantea	56.71	20.80	0.45	0.40	22.84	26.60	39.90	40.04	2.84	2.94
G. clarum	56.39	27.30	0.49	0.49	24.41	27.34	40.12	40.34	3.19	3.27
LSD (0.05)	8.30	1.46	NS	0.02	NS	0.54	3.60	0.08	0.63	0.04
Groundnut varieties										
SAMNUT 22	50.36	17.42	0.42	0.43	23.75	24.45	37.23	37.43	2.09	2.19
SAMNUT 21	52.71	23.84	0.48	0.47	22.40	24.07	38.81	38.97	3.10	3.19
LSD (0.05)	NS	NS	0.06	0.01	NS	NS	NS	0.05	0.51	0.02
Interactions										
Control×SAMNUT 22	38.50	10.72	0.36	0.37	19.20	19.34	33.77	33.86	1.42	1.51
Control×SAMNUT 21	44.52	16.88	0.48	0.45	24.77	21.07	34.33	34.59	2.10	2.22
G. gigantea×SAMNUT 22	56.40	14.81	0.42	0.43	23.433	25.30	38.60	38.71	2.16	2.32
G. gigantea×SAMNUT 21	57.01	26.80	0.47	0.46	22.24	27.90	41.20	41.37	3.52	3.56
G. clarum×SAMNUT 22	56.19	26.75	0.48	0.49	28.63	28.72	39.33	39.71	2.69	2.76
G. clarum×SAMNUT 21	56.60	27.84	0.49	0.49	20.19	25.95	40.90	40.96	3.68	3.79
LSD(0.05)	NS	NS	NS	NS	NS	1.08	NS	0.15	NS	0.07

NS: Not significant at 5% level of probability

inoculation (Table 5) in 2012, there was no significant (p>0.05) difference between *G. gigantea* and *G. clarum* which dry matter of 56.71 and 56.39 g/plant but both had significantly higher dry matter relative to the non-mycorrhizal plants. However, in 2013 *G. clarum* inoculated plant had s significantly (p<0.05) higher dry matter (27.30 g/plant) compared to *G. gigantea* with dry matter of 20.80 g/plant. The two varieties of groundnut did not significantly (p>0.05) differ in their whole plant dry matter accumulation for both years of trial (Table 5). There was no significant interaction effect between AMF and groundnut variety in determining the whole plant dry matter accumulation for both years of trial. The increase in harvest index due to AMF inoculation was not significant (p>0.05) in 2012 but in 2013 *G. clarum* inoculated plants significantly had the highest harvest index (0.49) compared to those inoculated with *G. gigantea* with harvest index of 0.40 which was statistically similar to the control plants (0.41). Variety SAMNUT 21 had a significantly (p<0.05) higher harvest index (0.48 and 0.47) compared to SAMNUT 22 with harvest index of 0.42 and 0.43 in 2012 and 2013, respectively (Table 5). There was no significant interaction effect between AMF and groundnut variety in determining the harvest index for both years of trial. The effect on threshing percentage due to AMF inoculation was not significant difference (p>0.05) in 2012 but in 2013, AMF inoculation significantly increased threshing percentage relative to the un-inoculated plants (Table 5). The *G. clarum* had a threshing percentage of 27.34 % which was not significantly higher than that of *G. gigantea* (26.6%). There was no significant interaction effect between AMF and groundnut variety in determining the harvest index in 2012 but in 2013, variety SAMNUT 22 inoculated with *G. clarum* and SAMNUT 21 inoculated with *G. gigantea* had threshing percentages of 28.72 and 27.90%, respectively and did differ significantly (p>0.05) from each other but were significantly higher when compared to other treatment combinations. Inoculation of groundnut with AMF significantly (p<0.05) increased 100-seed weight compared with the non-mycorrhizal plants in 2012 and 2013 (Table 5). Plants inoculated with *G. clarum* had higher 100 seed weights (40.12 and 40.34 g which were not significantly different from those of *G. gigantea* which were 39.90 and 40.04 g in 2012 and 2013, respectively but both AMF species produced significantly higher seed weights compared to the control. The 100-seed weight of SAMNUT 21 (38.97 g) was significantly (p<0.05) higher when compared to that of SAMNUT 22 (37.43 g) in 2013 only (Table 5). SAMNUT 21 plants inoculated with *G. gigantea* produced significantly (p<0.05) the highest 100-seed weight (41.37 g) in 2013.

AMF inoculation significantly (p<0.05) increased seed yield compared with the non-mycorrhizal plants. Plants inoculated with *G. clarum* had higher seed yields (3.19 and 3.27 t ha^{-1}) which were significantly higher when compared to those inoculated with *G. gigantea* which produced seed yields of 2.84 and 2.94 t ha^{-1} in 2012 and 2013, respectively groundnut variety, SAMNUT 21 had significantly (p<0.05) higher seed yield (3.10 and 3.19 t ha^{-1} compared to SAMNUT 22 with seed yield of 2.09 and 2.19 t ha^{-1} in 2012 and 2013, respectively. Also, AMF and groundnut variety had significant interaction effect on seed yield in 2013 only. In 2013, *G. clarum* inoculated SAMNUT 21 plants significantly ($p<0.05$) produced the highest seed yield (3.79 t ha^{-1}).

DISCUSSION

The results of the soil analysis indicate a soil of low fertility status, typical of tropical humid rainforest agro-ecology. Tropical soils are very fragile and nutrient loss by leaching is a common occurrence. Replenishment of these nutrients through fallow is constrained by short period of fallow as a result of intense pressure on the available land[32]. The site used for the trial was low in total nitrogen, organic carbon, cation exchange capacity and moderate in available phosphorus. These are optimum conditions for the establishment of AM fungi association with plant roots[33]. *Arbuscular mycorrhizal* fungus has the ability of enhancing the uptake of less mobile nutrient elements like P, Zn, Cu and Fe as a result of their interactions with soil cations[34] like Ca^{2+}, Fe^{3+} and Al^{3+}. This is made possible as the fungus can develop a vast network of extra-radical hyphae with a very large surface area (about 40 times) and with a great potential to explore greater volume of soil for nutrient mining[33,35]. AMF inoculation significantly enhanced the growth, dry matter, yield and its attributes of both groundnut varieties compared to plants not inoculated with AMF. This corroborates findings of earlier researchers who worked on different leguminous plants[13,22,36-40] and reported enhanced growth, biomass yield and seed yield in AMF treated groundnut plants relative to untreated plants. Enhanced performance of groundnut by AMF in this trial could be attributed to better nutrient uptake especially the less mobile elements, improved N-nutrition due to synergistic interaction among AMF, nitrogen-fixing rhizobia and other beneficial micro-organisms increased photosynthetic rates, better adaptation to both biotic and abiotic stress as observed by earlier investigators[34,41-47]. In this study, it was observed that *G. clarum* was more efficient in the enhancement of yield and yield components of groundnut than *G. gigantea*. Up-till date, there is no convincing evidence demonstrating host-specificity of AM fungi, however, host preferences and selectivity have been widely reported[7,48]. There has been an observation that agricultural soils are AMF impoverished relative to natural ecosystems[49]. The differences in AMF species effectiveness could partly be attributed to their adaptability to variation in edaphic and climatic factors. For instance in Nigeria, it has been reported recently that *G. clarum* and *G. deserticola* are more abundant in the savanna agro-ecology, *G. etunicatum* and *G. gigantea* adapt better to the humid forest zone, while *Glomus mosseae* occurred in large population in all the agro-ecological zones[50]. It could be that, *G. clarum* was more adaptable to the soil type and climatic factors in the study area than *G. gigantea*. Studies have shown that cowpea and other legumes responded better to *Glomus* spp. inoculation than *Gigaspora* spp. on surface and sub-surface soils[39]. It was observed that variety SAMNUT 21 had greater plant biomass and seed yield than SAMNUT 22 while the later produced longer pods and were taller than the former variety. This could be attributed to variations in their genetic make-up. Garba *et al.*[51] had earlier reported that SAMNUT 21 was a high yielding variety with good yield components like flower production. From the results of this work, *G. clarum* was more efficient in yield enhancement in SAMNUT 21 while *G. gigantea* was more effective in growth enhancement. This could be attributed to the relative efficiency of the respective AMF species to facilitate the uptake of certain nutrient elements needed for different physiological functions in the plant.

CONCLUSION AND RECOMMENDATIONS

It could be concluded that the production of groundnut in the marginal soils of Calabar by resource poor farmers may be enhanced through inoculation with an efficient species of arbuscular mycorrhizal fungi such as *G. clarum* and *G. gigantea*. The technology is cheap, eco-friendly and does not require special equipment or intensive training for adoption. However, subsequent trials should consider a consortium of different AMF species with different varieties of groundnut.

SIGNIFICANCE STATEMENT

The study shows that the highest enhancements in yield attributes were obtained when variety SAMNUT 21 was inoculated with Glomus *clarum* while *G. gigantea* inoculation generally enhanced the growth attributes of SAMNUT 22. Thus, *G. clarum* and *G. gigantea* may provide the small scale resource poor farmers, suitable alternatives to mineral and organic fertilizers to boost groundnut yields in Calabar in an environmentally friendly and sustainable manner.

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