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EFFECT OF MOISTURE REGIMES AND INOCULATION ON GROWTH AND YIELD OF BAMBARA GROUNDNUT IN NORTHERN GUINEA SAVANNAH OF NIGERIA

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ABSTRACT

The experiment was conducted to evaluate the effect of Moisture regimes and inoculation on growth and yield of Bambara groundnut in dry season of 2021/2022 at irrigation farm of College of Agriculture and Animal Science, Mando Kaduna and Institute for Agricultural Research IAR, A.B.U., Samaru-Zaria, both located in the Northern Guinea Savannah Ecological Zone of Nigeria respectively. Treatments consisted of four levels of moisture regimes (25%, 50%, 75%, and 100%) and two levels of inoculation; no inoculation and inoculation. Treatment were factorially combined in a randomized complete block design (RCBD) and replicated three times. Data on growth parameter were collected on number of leaves, number of branches, net assimilation rate, days to 50% flowering and kernel yield kg/ha were collected. Results showed that 100% moisture regime significantly resulted in highest growth indices like number of leaves, number of branches, net assimilation rate, days to 50% flowering and kernel yield kg/ha of Bambara groundnut over other regimes evaluated. While inoculation of Bambara groundnut significantly resulted in higher performance in both growth and yield parameters evaluated over non-inoculated Bambara groundnut plants. From the results obtained, the combination of 100% moisture regimes produced better performance on growth and yield of inoculated Bambara groundnut at both locations.

Keywords: Moisture regimes, Bambara groundnut, Inoculation, Growth, Yield, Nigerian Savannah

INTRODUCTION

A hardy leguminous crop, Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an important food crop of secondary nature in Africa particularly in West Africa, mainly grown by smallholders in semi-arid drier regions (Adeyeye *et al*., 2019).. Bambara groundnut is an important source of protein in the diets of a large percentage of the population, particularly the resource poor rural people who cannot afford expensive animal protein (Emilia and Agbachi, 2018). Bambara groundnut is an indeterminate annual herb, with creeping stems carrying trifoliate leaves with erect petioles (Toungos *et al.*,2010).. Flowers are formed at the base of the petioles, usually in pairs. After pollination, the peduncle grows out and pods form on or under the ground. The pods usually contain one seed. Unripe and ripe seeds are used for human consumption (Linnemann and Azam-Ali 1993).

Bambara groundnut is used for food, feed and for industrial as well as for medicinal use (Obidiebube *et al*., 2019). As a legume, it fixes atmospheric nitrogen through root nodules which contributes to improving soil fertility (Sprent *et al*., 2010), in addition to being an agronomically and nutritionally good complement to cereal crops (Halimi *et al.*, 2019). It is one of the underutilized (orphaned) leguminous crops that could be an important future crop to cushion global food demand and ensure food security especially in Africa and the Asian continent (Khan *et al*., 2020).Production is primarily at subsistence level, and only the surplus is sold. For Africa, the crop offers various benefits, being an ideal subsistence crop, a good rotation crop, a good backstop for hungry times, and a promising commercial resource (Gerrano *et al*., 2021). Bambara ground nut is also a drought resistant, neglected underutilized species, third after groundnut in importance. According to Tanimu (1996), its food security potential is highly undermined.

Bambara plant makes little demand on soil nutrients, thus is useful for climate change adaptable agriculture. Bamabara groundnut increases photosynthetic capacity, through Rhizobium or Bradyrhizobium mediated biochemical sequences in the host plants roots causing nodulation and the fixing of nitrogen required by the plant. Access to the nitrogen allows the plants to produce leaves fortified with nitrogen that can be recycled throughout the plant which in turn yields nitrogen-rich seeds. Through these symbiotic relationships, it fixes atmospheric nitrogen to the soil, thereby benefitting crop rotations and intercropping systems (Alhassan *et al*., 2012). Although Bambara groundnut's growth and yield potential have been documented reduction in water availability during vegetative and reproductive growth stages may be a constraint to the growth and yield of Bambara groundnut (Agyeman *et al*.,2021). Most importantly, the response and sensitivity to the time of drought stress vary significantly among different species and varieties and are linked to the intensity and length of the stress Mabhaudhi. (2012).

Drought stress negatively influences crop growth and development and has been described as the most damaging climate hazard affecting two-thirds of the global population and threatening food security according to Mabhaudhi and Modi ,(2013). The frequency and severity of drought are projected to increase due to decreased precipitation and increased evaporation due to global climate change. Based on its negative implication on crop growth and development, plants have advanced various molecular strategies to reduce their use of resources and adjust their growth to adapt to hostile environmental conditions (Vurayai *et al* 2011b). Crop responses to drought stress vary significantly and are dependent on the severity and duration of the drought stress (Mabhaudhi *et al*., 2013).

Rhizobium spp is a group of bacteria which has ability of providing nutrients for soybean crops. When symbiotic with legume crops, this group of bacteria is able to infect plant roots and form root nodules. Root nodule serves to take nitrogen in the atmosphere and move it as nutrients needed by host plants. Rhizobium spp can donate nitrogen in the form of amino acids to soybean plants (Ahmed *et al*., 2001). Rhizobium spp fixing nitrogen occurs when atmospheric nitrogen is converted to ammonia by enzyme nitrogenase, and microbial genes are required to fixate nitrogen to be widely distributed in to the environment. Rhizobia can live in plant residues (saprophytes) or in plants (endophytes) or saprophyte related to plant roots (rhizobacteria) as reported by Haqrderson and atkins, (2003). The study of (Ahmed *et al.*, 2001) showed that the number of nodules formed was high if the soil was inoculated with Rhizobium. Rhizobium spp can be symbiotic with soybean plants, and capable to fixate air nitrogen to meet the nutrient needs of host plants. The interactions between root nodules and symbiotic bacteria have been studied through proteomics genumes during the signal exchange and symbiotic growth (Mualle *et al*., 2007)

The present low yield of Bambara groundnut in Nigeria is between 0.5 - 0.85 ton/ha despite having a potential yield of up to 3 ton/ha (Majola *et al.,* 2021). The current low yield obtained from Bambara groundnut in Nigeria as reported by farmers has been attributed to a number of factors, among which are non-adherence to proper agronomic practices in its cultivation by farmers like; the use of local unimproved accessions with low productive potential in place of improved cultivars, coupled with poor soil fertility and biotic /abiotic (stress) factors among others. Because of its ability to fix atmospheric nitrogen, Bambara ground nut contributes to improving soil fertility status through nodulation. In most savannah soils, the nodule bacteria (indigenous rhizobia) are not adequate for aiding proper nodulation, it is necessary to inoculate the seed or the soil with highly effective strain rhizobia (Sprent *et al*., 2010).

Water is the source of life, all living things depends on it. Water is essential in the cultivation of Bambara ground nut. The shortage of rainfall in terms of amount, intensity duration leading to drought and sometimes short dry spells as a result of climate change led to poor crop performance (during rainy season) resulting in low or no yield at all. Water shortage at any vegetative / reproductive growth stages in dry season cultivation of Bambara groundnut can have a negative impact on survival and can result in poor germination, poor vegetative growth resulting in poor yield and yield components of Bambara nut. Most times farmers do not use water judiciously but are wasteful, but what happens during water scarcity or not enough water during Bambara ground nut cultivation? In this trial therefore, varied water regimes will be applied and their attendant consequences examined in Bambara nut cultivation. Therefore, this study was undertaken to investigate the effect of different soil moisture regimes and inoculation on growth and yield of Bambara groundnut in the Nigerian savannah.

MATERIALS AND METHODS

Two field trials were conducted during the dry season of 2021/2022 at the research farm of the Institute for Agricultural Research (I.A.R), Ahmadu Bello University, Samaru, Zaria (Latitude 11^0 11' N Longitude 7^0 38' E and 686m above sea level) and Research Farm of the College of Animal Sciences (Division of Agricultural Colleges, Ahmadu Bello University Zaria) Mando, Mando (11^0 07' N, Longitude. 07^0 13' E, 698m above sea level) both in Northern Guinea Savanna Agro ecological zone of Nigeria. Soil samples were randomly collected from various points at the two experimental sites at a depth of 0-30cm prior to land preparation and a composite sample taken for physico-chemical analysis in the Soil analytical laboratory of Department of Agronomy, A.B,U Zaria as described by (Black, 1965) and are presented AS Table 1. Meteorological data were obtained from Institute for Agricultural Research (I.A.R) Zaria weather station, and the weather station, Mando Airport, Mando. Data collected are Relative Humidity, Temperature, Sunshine hours, Rainfall (Appendix1). The treatments consisted of four moisture regimes (25%, 50%, 75% and 100%) and two levels of inoculation (No inoculation and inoculation). The treatments were factorially combined and arranged in a Randomized Complete Block Design (RCBD) and replicated three times. The gross plot size was 4mx4.5m ($18m^2$) and net plot of 3mx4m ($12m^2$). Cow dung as a source of nutrients was applied at rate of 2 t ha^{-1}two weeks prior to land preparation to facilitate release of required plant nutrients early to the growing crop. The Bambara groundnut Landrace used was a local variety called Giwa-white as described by Tanimu,(1996) obtained from Samaru seeds dealers. It's of medium duration with profuse branching/ spreading habit, which matures between 100-110 days and has a potential seed yield of $3tha^{-1}$ (Majola *et al.,* 2020).

The land was ploughed, harrowed twice and their ridges made of 75m apart then plots and border areas were laid out which were separated by 1m and 0.5m paths respectively. Two seeds were manually sown 15cm apart along the ridges on 29^{th} Feb 2022 at Samaru and 8^{th} Mar 2022 at Mando respectively. Thinning was carried out at 2 WAS to 2 plants par stand. Inoculation was carried out at planting with a commercial inoculant (Nodumax) according to the manufactures specification as described by Famawanga *et al*. 2022. The experimental field was irrigated (immediately after sowing) at 10 days interval for a month to supply moisture to the crop up to 4WAS, then moisture treatments commenced. This was made possible with the use of reference evapotranspiration of Samaru and Mando to get the water requirement of the crop at both Samaru and Mando. Thereafter, an orifice was used to irrigate the various plots to give 100%, 75%, 50% or 25% levels of actual water requirement of the crop. The aim here was to reduce water wastage in cultivation of Bambara nut, as it's a hardy crop mostly grown in the dry lands of Northern Nigeria, with little available moisture. This variation in moisture applied was used to determine if there is any resultant significant difference in growth and yield of the crop as a result of reduced or varied moisture availability.

Weed control was conducted prior to land preparation with glyphosate sprayed at the rate of 1.4 a.i kg/ha to keep the land weed free and this was followed by manual hoe weeding at 3 and 6 WAS. The ridges were molded up at 12 WAS. Karate (Lambdacyhalothrin) at the rate of 0.8 litre $ha-^1$ along with Benlate (benomyl) at the rate of 11kga.i ha^{-1} were applied 3 times using CP-15 knapsack starting from 8WAS, 10 WAS and 12 WAS as a routine preventive measure against pest and disease incidence. The matured Bambara groundnut plants were harvested at physiological maturely (on 29^{th} May, 2022 at Samaru and 9^{th} June 2022 at Mando respectively (while plant parts are still green and pods are easily remove from soft moist ground). The plants in net plot were harvested by carefully digging up whole plant along with the pods with a hoe and picking up the remaining pods from the soil. Thereafter, kernels were separated from the plants and haulms were weighed and allowed to dry for seven days under the sun. The dried pods and haulm from each net plot were then re-weighed using mettle's balance (model E200D) and the value recorded on per plot basis and later computed on per hectare basis..

Data were collected at 4, 8, and 12 WAS on growth parameters like Number of leaves, Number of Branches, Net assimilation rate (NAR), Days to 50% flowering and Kernel yield kg/ha at harvest from both locations. The data collected were analyzed using analysis of variance (ANOVA) technique, the treatment means were separated using Duncan's Multiple Range Test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Details of the soil physical and chemical properties of the experimental sites were presented as table 1. The soil at Samaru was found to be of sandy loam textural class while that of Mando is of loam textural class. The soil at Samaru had a moderate N content, low level of available phosphorus (P), potassium (K) and Cathion exchange capacity (CEC). The Samaru soil had a moderate level of Organic carbon, calcium, magnesium and sodium with a slightly acidic pH in water and moderately acidic in calcium chloride solution ($Cacl_2$). The soil at Mando has a moderate N and P content with moderate calcium, magnesium and sodium content, also low level of organic carbon, potassium and CEC were observed. PH was slightly acidic in both water and cacl2 solution.

Table 1: Physical and Chemical Properties of the Soil at both Mando and Samaru during 2022 Dry Season

	Mando	Samaru
Physical Properties (%)		
Clay	41.0	10.0
Silt	27.0	30.0
Sand	32.0	60.0
Textural Class	Loam	Sandy Loam
Chemical Properties		
PH (H_2O) 1:2,5	6.24	6.12
PH 0.01m $CaCl_2$	5.86	5.63
Total Nitrogen (gkg^{-1})	3.2	4.4
Available Pmg Kg^{-1}	1.65	5.24
Organic Carbon	1.67	1.01
Exchangeable Bases (Cmol Kg^{-1})		
Calcium Meq/100g	2.59	2.12
Magnesium Meq/100g	0.71	0.80
Potassium Meq/100g	0.01	0.13
Sodium Meq/100g	0.17	0.61
CEC Meq/100g	3.38	3.54

Source: Analytical Lab of department of Agronomy, ABU Zaria

Number of Leaves Plant^{-1}

The effect of moisture regime and inoculation on number of leaves of Bambara groundnut at 4, 8 and 12 WAS at Samaru and Mando during 2022 dry season is presented as Table 2. The effect of moisture regimes on number of leaves per Bambara nut plant was significant ($p \leq 0.05$) in both locations in 2022. The control 25% produced least number of leaves while 100% moisture availability produces highest number of leaves as well. In 2022 (Samaru), 100 percent moisture regime produce the highest number of leaves at 8WAS which is statistically similar to 75percent and 50 percent moisture availability at 10 and 12 WAS (Samaru) as well as 8WAS (Mando).

There was a significant ($p \leq 0.05$) response to inoculation by number of leaves of Bambara ground nut plants in both locations across all sampling periods in 2022 where inoculated plants produced more leaves than non-inoculated Bambara nut plants.

The interaction between moisture regime and inoculation on number of leaves at Mando at 4WAS during 2022 dry season was presented as Table 3. While inoculation remains constant, increased application of moisture regime produced higher number of leaves which progresses up to 100%. The highest number of leaves was produced by the combination of 100% moisture regime with inoculated Bambara groundnut.

Table 2: Effect of Moisture regime and inoculation on Number of Leaves Plant^{-1} of Bambara groundnut at Samaru and Mando during 2022 Dry Season

Treatment	Number of Leaves Plant^{-1}					
	Samaru			Mando		
	Weeks after Sowing (WAS)			Weeks after Sowing (WAS)		
	4	8	12	4	8	12
Moisture regimes (%)						
0.0	26.49c	5485c	92.02c	23.76d	50.53d	73.47d
2.0	27.24b	55.25c	92.80c	24.22c	51.87c	76.26c
4.0	27.55b	56.31ab	93.08ab	25.57b	53.53b	80.29b
6.0	27.82a	57.24a	93.48a	26.53a	54.16a	81.87a
SE±	0.088	0.377	0.227	0.156	0.146	0.204
Inoculation						
Non-inoculated	26.96b	55.33b	92.38b	24.17b	51.75b	76.15b
Inoculated	27.54a	56.49a	93.32a	25.63a	53.29a	79.80a
SE±	0.062	0.265	0.161	0.109	0.105	0.144
Interaction						
L x S	NS	NS	NS	*	NS	NS

Means followed by the same letter(s) within a column and treatment are significant at 1% and 5% level of probability (DMRT). NS – Not Significant. * Significant at 5% level of probability, ** highly significant at 1% level of probability.

Table 3: Interaction effect between moisture regime and inoculation on Number of Leaves Plant^{-1} at 4 WAS at Mando during 2022 dry Season

	Number of Leaves Plant^{-1}			
	Moisture regime (%)			
Inoculation	25	50	75	100
No-Inoculation	22.83f	23.75	24.68d	25.43c
Inoculation	23.73e	24.69	26.47b	27.63a
SE		0.211		

Means followed by the same letter(s) within a column of treatments means are significant at 5% level of probability and 1% level of probability. NS: not significant.

Number of Branches plant^{-1}

Table 4 showed the effect of moisture regime and inoculation on number of branches of Bambara groundnut at 4, 8 and 12 WAS at Samaru and Mando during 2022 dry seasons. The effect of moisture regimes on number of branches of Bambara groundnut number of branches in both years and locations was also significant ($p \leq 0.05$) across all sampling periods except at 4WAS (2022) at Samaru and 4WAS (2022) at Mando where they are statistically similar. 25 percent (25%) moisture regime produces fewer branches while 100% moisture regime produces more number of branches relative to other moisture regimes evaluated in both locations.

Similarly, at both locations in 2022, number of branches of inoculated Bambara nut differs significantly ($p \leq 0.05$) to non-inoculated plants, the inoculated plants produce a greater number of branches than non-inoculated Bambara ground nut plants. The interaction between moisture regime and inoculation on number of leaves at Mando at 4WAS during 2022 dry season was presented as Table 5. While inoculation remains constant, increased application of moisture regime produced higher number of leaves which progresses up to 100%. The highest number of leaves was produced by the combination of 100% moisture regime with inoculated Bambara groundnut.

Table 4: Effect of Moisture regime and inoculation on Number of Branches Plant^{-1} of Bambara groundnut at Samaru and Mando during 2022 Dry Season

Treatment	Number of Branches Plant^{-1}					
	Samaru			Mando		
	Weeks after Sowing (WAS)			Weeks after Sowing (WAS)		
	4	8	12	4	8	12
Moisture regimes (%)						
0.0	7.08b	8.40d	11.40d	7.05b	8.41d	11.44d
2.0	7.23ab	8.65c	12.17c	7.41ab	8.87c	12.25c
4.0	7.38a	8.93b	12.84b	7.69a	9.37b	13.03b
6.0	7.73a	9.17a	13.67a	7.78a	9.79a	13.65a
SE±	0.055	0.067	0.074	0.108	0.127	0.126
Significance	NS	NS	NS	NS	NS	NS
Inoculation						
Non-inoculated	7.17b	8.62b	11.83b	7.09b	8.52b	11.83b
Inoculated	7.36a	8.95a	13.21a	7.87a	9.71a	13.36a
SE±	0.039	0.047	0.053	0.077	0.090	0.089
Interaction						
L x S	NS	NS	*	NS	NS	NS

Means followed by the same letter(s) within a column and treatment are significant at 1% and 5% level of probability (DMRT). NS – Not Significant. * Significant at 5% level of probability, ** highly significant at 1% level of probability.

Table 5: Interaction effect between moisture regime and inoculation on Number of Branches Plant^{-1} of Bambara groundnut at 12 WAS at Samaru during 2022 dry Season

Inoculation	Number of Branches Plant^{-1}			
	Moisture regime (%)			
	25	50	75	100
No-Inoculation	11.21f	11.60e	11.98d	12.52c
Inoculation	11.58e	12.73c	13.70b	14.82a
SE		0.105		

Means followed by the same letter(s) within a column of treatments means are significant at 5% level of probability and 1% level of probability. NS: not significant.

Net Assimilation Rate (NAR) (g m^2 wk^{-1})

Table 6 shows the effect of moisture regimes and inoculation on net assimilation rate (NAR) of Bambara groundnut at Samaru and Mando during 2022 dry seasons. The effect of moisture regimes on net assimilation rates of Bambara nut in both locations in 2022 was found to be significant ($P \leq 0.05$) except at 8 – 10 WAS at Samaru in 2022. Application of 100% moisture regime produced plants with highest NAR values while 25% moisture availability produced plant with least NAR values. Application of 100% moisture availability was found to be statistically similar to 75% moisture regime at 8 – 10 WAS at Mando 2022.

Similarly, net assimilation rate's response to inoculation of Bambara nut was not significant at all sampling periods at both locations and years except at 10 – 12 WAS at Mando (2022) where inoculated plant had a highest value of NAR over those not inoculated in both locations and years. There was no interaction effect between the variables.

Table 6: Effect of Moisture regime and inoculation on Net Assimilation Rate (NAR) ($g.m^2.wk^{-1}$) of Bambara groundnut at Samaru and Mando during 2022 Dry Season

Treatment	Net Assimilation Rate (NAR) ($G.M^2.WK^{-1}$)					
	Samaru			Mando		
	Weeks after sowing (WAS)			Weeks after sowing (WAS)		
	4	8	12	4	8	12
Moisture regimes (%)						
0.0	72.36b	30.19	15.83b	66.49c	25.09c	17.18d
2.0	58.06c	31.24	17.03b	70.06b	33.35b	31.11b
4.0	65.66c	32.94	19.20b	67.27b	31.92b	27.07c
6.0	88.35a	32.93	23.58a	100.13a	36.58a	36.42a
SE±	4.214	1.237	1.195	3.156	0.578	0.584
Significance	NS	NS	NS	NS	NS	NS
Inoculation						
Non-inoculated	67.97	32.42	18.13	73.37	31.43	26.03b
Inoculated	72.23	33.73	19.68	78.58	32.05	29.27a
SE±	2.980	0.875	0.845	2.231	0.408	0.413
Interaction						
L x S	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a column and treatment are significant at 1% and 5% level of probability (DMRT). NS – Not Significant. * Significant at 5% level of probability, ** highly significant at 1% level of probability.

Days to 50% Flowering

Table 7 shows the effect of poultry manure rate, moisture regimes and inoculation on days to 50% flowering of Bambara groundnut at Samaru and Mando during 2022 dry seasons and the combined.

The response of days to 50% flowering of Bambara groundnut to inoculation was significant ($P \leq 0.05$) at all sampling periods, locations, years and the combined. the non-inoculated plant attains days to 50% flowering earlier than those inoculated plant that came late so also is the combined effect in which the non-inoculated plant attain earlier flowering.

The effect of poultry manure rates on days to 50% flowering was also significant ($P \leq 0.05$) at all sampling period in all location and years and the combined. The control (0 tons/ha) flowering earlier than 2, 4 and 6 tons/ha and the combined which flowered later.

The effect of moisture regime was also significant ($P \leq 0.05$) at all sampling periods location and years as well as the combined where treatment with 25% moisture regime attained flowering earlier than other moisture treatments and the combined which flowered later.

Table 7: Effect of Moisture regime and inoculation on Days to 50% flowering of Bambara groundnut at Samaru and Mando during 2022 Dry Season

Treatment	Days to 50% Flowering	
	Samaru	Mando
	Weeks after Sowing (WAS)	Weeks after Sowing (WAS)
	2022 Combined	2022 Combined
Moisture regimes (%)		
0.0	43.42a	42.97a
2.0	43.37a	41.86a
4.0	42.59b	41.87b
6.0	42.37c	41.35b
SE±	0.055	0.051
Inoculation		
Non-inoculated	43.58a	43.78a
Inoculated	42.25b	42.89b
SE±	0.039	0.036
Interaction		
L x S	*	NS

Means followed by the same letter(s) within a column and treatment are significant at 1% and 5% level of probability (DMRT). NS – Not Significant. * Significant at 5% level of probability, ** highly significant at 1% level of probability.

Table 8: Interaction between poultry manure rate and inoculation on days to 50% flowering of Bambara groundnut at Samaru during 2022 warm dry season

Treatment	Days to 50% Flowering			
	Moisture regime (%)			
Inoculants (I)	**0**	**2**	**4**	**6**
Non inoculated (1_1)	44.00a	44.00a	44.00a	43.00b
Inoculated (1_2)	42.25c	42.75c	43.00b	43.08b
SE±	0.079			

Means followed by same letter in the column and row are not different statistically at P=0.05 level of probability using DMRT

Kernel Yield kg ha^{-1}

Table 9 showed the effect of poultry manure rate and inoculation on kernel yield kg ha^{-1}of Bambara groundnut at Samaru, Mando and combined during 2022 dry seasons. The effect of poultry manure rates on kernel yield kg ha^{-1}was also significant (<0.05) in both years, locations and combined where the control (0 tons ha^{-1}) produces lower kernel yield and 6 t ha^{-1} produces highest kernel yield relative to other rates evaluated. The response of kernel yield of Bambara groundnut to inoculation during 2022 dry season at both locations and combined in 2021 was significant ($P \leq 0.05$). Inoculated Bambara nut plants had a higher kernel yield kg ha^{-1} than non- inoculated plants.

There was a significant interaction between poultry manure and Inoculation on Bambara ground nut kernel yield kg ha^{-1}at Samaru during 2022 dry season as presented in Table 10. The highest kernel yield kg ha^{-1} was obtained at the combination of 6 tons ha^{-1} poultry manure which was statistically similar with 4, and 2 tons ha^{-1} with inoculated plants.

Table 9: Effect of Moisture regime and inoculation on Kernel yield kg/ha of Bambara groundnut at Samaru and Mando during 2022 Dry Season

Treatment	Kernel yield kg/ha at Harvest	
	Samaru	**Mando**
Moisture regime		
0.0	388.92d	379.85c
2.0	404.96c	413.21b
4.0	43785b	435.85a
6.0	447.76a	445.97a
SE±	1.722	5.792
Inoculation		
Non-inoculated	400.31b	404.43b
Inoculated	442.91a	432.45a
SE±	1.218	4.095
Interaction		
L x S	NS	*

Means followed by the same letter(s) within a column and treatment are significant at 1% and 5% level of probability (DMRT). NS – Not Significant. * Significant at 5% level of probability, ** highly significant at 1% level of probability.

Table 10: Interaction effect between Moisture regime and inoculation on Kernel yield kg/ha at Mando during 2022 dry Season

	Kernel yield kg/ha			
	Moisture regime (%)			
Inoculation	**0**	**2**	**4**	**6**
Non-inoculated	268.11^{c}	287.45^{bc}	297.91^{bc}	327.37^{ab}
Inoculated	278.51^{c}	302.69^{bc}	314.41^{abc}	347.57^{a}
SE		21.994		

Means followed by the same letter(s) within a column of treatments means are significant at 5% level of probability and 1% level of probability. NS: not significant.

Discussion

Generally, the performance of Bambara Groundnut depends largely on environmental factors which comprises of soil type and fertility, climate (favorable temperature, sunshine hours and relative humidity). These factors influence the crops growth and development which effectively improve the yield potentials of the crop. Sandy loam soil (at Samaru) encourages better growth performance in Bambara groundnut than clayed-loamy soil (at Mando) and as was seen in the performance of the crop in Samaru was better than at Mando. This could possibly be due to better enhancement of and encouraging growth avenues like providing better drainage capability for better soil aeration enhancing soil microbial activities than clay soil. This is in line with the report of Brink. (1999) and Olayinka *et al.* (2016) which states that growth and yield attribute of Bambara groundnut were found to be highest in sandy loamy soil than in loam soil. This is further corroborated by Nyau *et al. (*2017) who reported that Bambara groundnut grows well on well drained sandy-loam soil and sandy soil development of pod in the soil easy as well as easy harvesting than other soil.

There was significant increase in growth parameters, such as number of leaves, number of branches, net assimilation rate and kernel yield of Bambara groundnut where moisture levels were applied at either 50%, 75% or 100% moisture availability of the crop water requirement over the control (25% moisture availability) across the years and locations. Shorter plants with least number of leaves with fewer branches and lower net assimilation rate values were recorded in plots with least amount of available water (25%) due to water stress/deficit in such plots when compare to other plots with higher moisture levels where 50%, 75% moisture regimes were applied. The higher moisture regimes recorded the highest number of leaves on tallest plants with most branches as well as with widest canopies.

Water sufficiency (100% moisture regime) to the growing crops aids the performance of almost all physiological, metabiologocial and other processes that take place in plants to ensure proper growth, development for higher yield performance as stated by Hsiao, (1973). The growth responses of Bambara groundnut to water sufficiency would most certainly encourage the utilization of resource needed for growth and development to the maximum. Bambara groundnut would utilize such resource maximizing in all growth indices like plant length, number of leaves, number of branches, canopy spread, LAI, CGR, RGR and NAR and higher amount of dry matter would be recorded. As a drought tolerant crop, Bambara groundnut responds to water deficit by a decrease and or alteration of various physiological and biochemical processes that are essential for plant growth, development and productivity (Madueke *et al*, 2011). Water deficit depending on its severity, influences physiological and other metabolic processes like stomatal opening and closing, photosynthesis, water transport and assimilate translocation, enzymatic processes among others are severely restricted in a water stressed environment. Nitrogen fixation abilities of legumes and reduction in root nodule flux has been associated with the inhibition of nitrogen fixation under drought (Madueke *et al*, 2011).

Ngwako *et al*, (2013) reported that water sufficiency (100% water regime) increased Bambara groundnut growth parameters like number of leaves, plant height, number of branches, canopy spread, LAI, CGR, RGR and NAR and higher amount of dry matter, as well as yield and yield component like number of pod plant^{-1}, pod yield ha^{-1} and kernel yield ha^{-1}. Even though Bambara groundnut has been reported to be drought tolerant, water stress was still able to affect the yield and yield components in this trial. Due to water deficit in plots with 25% available moisture, in this trial the least values of growth attributes like number of leaves, number of branches, plant height, canopy spread and LAI were recorded. Lower values of yield and yield components like number of pod/plant number of kernels/pod, pod yield/plot, pod yield/ha, kernel yield/plot and kernel yield/ha harvest index, haulm yield/ha and shelling percentage among others was recorded also in plots with least amount of moisture, these results are similar to the findings of Berchie *et al*, (2012) who reported reduced number of leaves, canopy spread, LAI and kernel yield/plot and ha in Bambara groundnut land races in response to limited water availability under field condition as reported by Mabhaudhi *et al*, (2013). Early flowering due to water stress which reduce vegetable growth (leaf number and LAI) is a major mechanism for moderating water loss under drought stress (Blom, 2005). According to Araus *et al,* 2002. Early flowering in reference to limited water availability, is a drought escape mechanism. This is equally true for reduced flowering duration with the objective being to reproduce before water stress become terminal.

In this study, it was observed that induced water deficit reduced kernel yield through reduced pod number and mass may be related to a shorter flowering duration, which limited pod number, while low pod mass may be linked to earlier senescence which affect pod filling. This was also observed in the number of empty pods, reduced shelling percentage, the observed reduced harvest index and haulm yield/ha due to water stress could be due to reduction in plant height, number of leaves and canopy spread as a result of water stress. However, what is noteworthy is Bambara groundnuts ability to still produce yield even under server water stress (25% moisture availability) according to Berchie *et al*, (2012), this confirms Bambara groundnut resilience under drought stress and further justifies the need for more research on the crop, with a view to promoting it as a food security crop. The results of water use efficiency (WUE) of Bambara groundnut nut showed no significant difference (P>0.05) between water regimes in this trial at both location and season, water use efficiency was highest at 60 days followed by 30 days and 90 days has least water use efficiency. This suggest that water use efficiency increased in response to limited water availability as the plant grows. High water use efficiency under limited water condition is linked to reduced canopy size (plant height, leaf number and LAI) reduced transpirational losses (Low stomatal conductance) as well as shorten growth duration (Blom, 2009). While reduced canopy size and stomatal closure directly moderate water losses by the crop, reduced crop duration effectively reduces the amount of water applied to the crop. As such, in line with observed reduction in canopy size, Stomatal conductance and crop duration.

Application of microbial inoculant significantly improved the growth, yield and yield parameters of Bambara groundnut, thus improving the crops productivity. The increase in growth attributes such as plant height, number of leaves, number of branches, canopy spread, leaf area index, days to 50% flowering, crop growth rate, relative growth rate, net assimilation rate and total dray matter produced could be as a result of microbial inoculation of the crop which possibly enhanced and boost the crops vigor that probably improved the crops nutrients uptake from the soil as well as encouraged an improved the microbial activities in the soil. Microbial inoculation helps in increasing nodulation, thus increased atmospheric N fixation. This is in line with the report of (Fasasi and Babalola 2021), who reported that addition to applying poultry manure which supplies adequate nutrients to the inoculated growing plants hence boosting and improving plant growth, reducing heavy metal contamination, and controlling phytopathogens which enhances sustainable agriculture. Kyei-Boahen *et al,* (2017) reported that the successful field rhizobia inoculation serves as a vigor boost to the growing plant which possibly contributed to better plant growth, development and kernel yield when compared with non-inoculation plants. Oburger and Schmidt, (2016) corroborated that the microbes in the soil helps in decomposition of organic matter, transformation of nutrients and regulation of soil productivity for an improved plant growth and development The significant effect of inoculation on Bambara groundnut plant height, number of leaves, number of branches, canopy spread, total dry matter produced and flowering could probably be due to inoculation rhizobia which may complement the little or no indigenous rhizobia available in the soil. The differences in the impact of inoculation recorded on the growth parameters like plant height number of leaves, canopy spread and number of branches and others of inoculated Bambara groundnut plants was significant over non-inoculated plants. The increase in plant height and other growth attributes of Bambara nut could lead to increase in shoot dry matter due to inoculations positive effect on stem girth, width and ability of the inoculation to significantly influence modulation. This agrees with the result of Glick (2020); Babalola *et al,* (2022) who states that positive response to inoculation is likely to occur when indigenous rhizobia population is less than 5 or 10 rhizobia cells g^{-1} soil with high degree adaptability to the environment than non-inoculated plants, furthermore, significant difference observed in the biomass yield in this trial shows that microbial inoculation enhances biomass yield over non-inoculated plant. Similar findings was observed by Solomon *et al,* (2012)who reported that the effect of inoculation of rhizobia strains significantly influence dry matter production at mid flowering. Caliskan (2007) and Amani (2007) also reported that plant height of soya bean increased with application of inoculations, number of leaves, number of branches as well as wideness of the canopy also increased in the inoculated plants over non inoculated plants. This agrees with the report of Mohammed *et al*, (2011) who stated that maximum leaves and branches in inoculated plants may be attributed to symbiotic relationship of rhizobium (bacteria) with the root of leguminous crops, which fixes atmospheric nitrogen into the roots of groundnut and thus the number of leaves per plant was increased. Maximum number of branches and canopy spread of inoculated over non inoculated may be due to effect of inoculation as reported by Mohammed *et al,* (2011) who further postulated that the significant difference observed due to inoculation may be due to efficient nitrogen fixation by the crop by the nitrogen fixing bacteria in the plants root nodules.

Increase in crop physiological indices like crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR) i9u8 of inoculated Bambara groundnut plants over non inoculated plant may possibly be as a result of good symbiosis between the rhizobium inoculation, good environmental conditions (adequate temperature, humidity and sunshine hours) and proper crop management. This is in line with the work of Woomer *et al,* (2014) who stated that the success of rhizobium inoculation primarily depends on the rhizobium strain, the legume genotype, the environmental condition and the crop management. There was a significant and positive response on application of inoculants on Bambara ground nut's number of pods/plant, pod yield ha^{-1} and kernel yield ha^{-1}.

CONCLUSION

From the result of this study, Application of 100% moisture regime also gave the highest values in terms of growth and yield characters of Bambara ground nut over other moisture regimes evaluated. Inoculation of Bambara groundnut could be considered as it produced a better performance in terms of both growth, and yield of the crop which is beneficial for food, feed and for income generation in this trial. Therefore, 100% moisture regime on inoculated Bambara groundnut could be considered for better performance of growth and yield of Bambara groundnut at Samaru and Mando both in Kaduna State of Nigeria.

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APPENDIX

Appendix I: Meteorological data showing monthly mean minimum and maximum temperatures, relative humidity and sunshine hours during 2021/2022 warm dry season at Samaru

Month	Air temperature (ºC)		Relative humidly (%)	Sunshine hours (from 6am-6pm)
	Min	Max		
Jan	16.31	30.62	19.11	6.4
Feb	18.68	32.14	26.78	7.2
Mar	22.13	35.49	24.34	6.8
Apr	24.53	38.43	25.44	6.7
May	27.44	34.31	26.48	6.6
June	21.31	30.63	40.44	5.8
July	19.45	28.71	43.56	5.6
Aug	18.36	27.44	58.44	5.4

Source: Meteorological unit of institute for Agricultural research (IAR), Ahmadu Bello University Samaru-Zaria

Appendix II: Meteorological Data Showing mean minimum and maximum temperature, relative humidity and sunshine hours during 2021/2022 warm dry season at Mando

Month	Air Temperature (ºC)		Relative humidity (%)	Sunshine hours from (6am-6pm)
	Min	Max		
Jan	14.63	28.26	19.31	6.2
Feb	17.86	31.41	25.41	6.8
Mar	20.31	33.92	23.31	6.4
Apr	22.54	37.62	24.45	6.6
May	25.43	34.81	25.48	6.3
June	20.44	30.12	36.44	5.4
July	19.41	27.41	39.43	5.5
Aug	18.43	26.43	54.51	5.4

Source: Meteorology Unit of Kaduna International airport. Kaduna airodrome, Kaduna