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Evaluation of Mycorrhizae Potentials in Enhancing the Growth and Yield of *Dioscorea rotundata* Genotypes in Moisture Stressed Soil

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Abstract **-Moisture stress limits the productive capacity of crops; hence drought tolerant genotypes will be required for efficient and sustainable crop production amidst climatic adversities. A pot experiment was conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria to assess the responses of 12 genotypes of white yam (*Dioscorea rotundata)* to moisture stress under mycorrhizal inoculation. The experimental layout was factorial in randomized complete block design of 72 treatment combinations in three replications. Data were collected on vegetative and reproductive traits within 20 weeks of the experiment and processed using SAS. There were significant (P≤0.01) differences on all the measured variables with respect to the effect of the three factors. Abi had the highest significant fresh (56.5 g) and dry (13.1 g) tuber weight while TDr 99/2789 recorded the least (13.4 g and 3.6g) for fresh and dry tuber weight. Mycorrhizal inoculation enhanced the performances of the genotypes. Effect of moisture stress imposition on the studied parameters followed a linear trend; 75% FC at 11WAP < 25% FC at 15 WAP < 25% FC at 11 WAP. The observed significant variation among *D. rotundata* genotypes in this study justifies the basis for screening yam genotypes for moisture stress tolerance.**

***Keywords* – *Dioscorea rotundata,* Genotypes, Mycorrhizal Inoculation, Water Stress.**

I. INTRODUCTION

Yam, a tropical tuber crop in the genus *Dioscorea* with as many as 600 species out of which only six are of economic importance as staple species. Among the six, *Dioscorea rotundata* (white yam) is the most common species in Nigeria. Yam plays an important role in the food security of West African. Nigeria produces about 70 percent of the world production [1]. However, the production of yam in Nigeria is still below the level required for domestic consumption. White yam production in Nigeria is generally under rain fed conditions. As a result of erratic rainfall pattern and limited irrigation systems, tropical tubers are prune to moisture deficit [2]. Soil moisture is critical to the yield of tropical tubers, since it affects root development [3]**.** Responses to moisture stress may differ among genotypes. Selection for good genotype performance under drought conditions (especially at tuber development stage) could enhance higher food production.

Drought stress was reported [4] to influence the development and growth of potato shoots, roots and tubers. Drought stress also induces reduced leaf area and in the long term lowers the ground coverage of sweet potatoes [5]. The effects of moisture stress on a plant are dependent on the timing, duration and severity of the stress. At critical growth stages, drastic yield reduction occurs due moisture stress [6]. Drought stress at the beginning of the tuberization stage induced a longer period of tuber formation but decreased tuber number, growth and yield [6]; [7]; [4]. Jefferies, (1995) observed that water stress application at a later growth stage of plant did not sufficiently aid discrimination among cultivars.

In essence, screening for drought tolerant cultivars should be carried out at critical stage of crop development. Genotypic differences have been observed in tuber yield of potato resulting from the effects of drought stress. Ourneux *et al*. (2003) reported that the timing of water stress within the growing period is a yield determinant and that morphological parameters such as plant height, number of leaves in the main stem and cumulative canopy cover were significantly correlated with tuber yield.

Arbuscular mycorrhizal fungi (AMF) colonization have been identified to stimulate a greater root proliferation and surface area coverage for better utilization of available water by plants [10]. Higher soil water depletion has been observed in plants colonized by mycorrhizae fungi than in non-mycorrhizal plants [11]. This could result from a larger shoots biomass (more evaporative leaf surface area) and finer root systems for increased absorptive surface area in plants with AMF fungi than in non-mycorrhizal plants [12]; [13]. Drought is becoming a serious limitation to global crop production especially in the sub-saharan Africa.

Research on evaluation of available yam germplasm to identify genotypes with good tolerance to drought is novel at this time. There is scarce literature on breeding for drought in yam and there had not been any initial selection of genotypes for drought through a wide screening programme. The present study is a component of the screening protocols for drought tolerance in white yam, Aims therefore includes: identifying some cultivars with good tolerance to drought and understanding their response to AMF for better soil water usage.

II. MATERIALS AND METHODS

A. *Study Location and Soil Preparation*

A pot experiment was conducted in a glass house at the

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International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Bulk soil sample (oxic paleustalf) from 0 to 15 cm soil depth was collected from an IITA experimental plot (7° 26´ N, 3°54´ E) using a soil auger. Physical and chemical properties of the soil were determined. Soil was passed through a 2 mm sieve, sterilized at 110°C for 2 hours and allowed to cool. Sterilized dry soils of 5 kg weight were filled into plastic pots.

B. Experimental Design and Treatments

The experimental layout comprised a factorial combination of twelve genotypes (G), two mycorrhizal (MC) levels and three water levels (WL) in a randomized complete block design with three replicates. The genotypes were TDr 99/02562, TDr Agumaga, TDr Abi, TDr 99/02626, TDr 99/02789 and TDr Didio, TDr Aloshi, TDr Aloshi, TDr 00/00365, TDr 97/00812, TDr Tabene, TDr Saminaka, TDr Amula. Yam tubers of each genotype were cut into minisetts of 50 g weight. The head and tail parts of the tubers were planted to ensure homogeneous sprouting in all treatments.

Soil inoculation method of mycorrhizae application was used at two levels (with and without inoculation). Prior to planting each yam minisett into the prepared plastic pots, 10 g of AMF inoculum was applied into the hole. This inoculum contained soil spores, roots of plants used in propagating the inoculum and hyphae.

Water stress imposition was maintained at three levels namely; 75 % field capacity from 11 weeks after planting (WAP), 25% field capacity from 15 WAP (bulking stage) and 25% field capacity from 11 WAP (tuber initiation stage). These moisture levels were maintained till the end of the experiment. The trial was terminated at 20 weeks after planting.

C. Data Collection

Data were collected on number of leaves, total leaf area at harvest determined using a portable Leaf Area Meter (Model LI-3000, LI-COR, Nebraska, USA), leaf and vine weight, root and tuber weight, AMF spore count and colonization. Below ground and shoot components were weighed fresh, oven-dried to a constant weight at 80°C and weight recorded. Prior to oven drying, tubers were cut into chips for effective drying.

D. Statistical Analysis

Collected data were subjected to analysis of variance and Pearson correlation coefficient analysis. Treatment means were separated using Duncan multiple range test. All statistical analysis was done using SAS 9.2 version

III. RESULTS

Physico-chemical properties shown in Table 1 reveals that the soil was loamy sand, with a basic pH (water) of 8.1, organic carbon (C) 10.5 (gkg^{-1}), total nitrogen (N) 0.13 g kg^{-1}, with a high available phosphorus (P) of 46.16 mg kg^{-1} and calcium (Ca) 7.25 c mol $kg^{-1.}$ Others were as follows; magnesium (Mg) 9 c mol kg^{-1}, potassium 0.15 cmol kg^{-1}, sodium 0.18 cmol kg^{-1} and manganese 88.8 mg kg^{-1}.

Table 1: Pre-planting soil test result of the study area

Properties		Values
Particle size (%)	Sand	790.0
	Silt	90.0
	Clay	120.0
Textural class		loamy sand
pH (1:1H_2O)		8.1
Bulk Density (mg kg^{-1})		1.6
Organic Carbon (g kg^{-1})		10.5
Total Nitrogen (%)		0.1
Available Phosphorous (mg kg-1)		46.2
Exchangeable Cation (cmol kg^{-1})	Mg	1.9
	Ca	7.3
	K	0.2
	Na	0.2
Exchangeable acidity		0.0
Effective Cation Exchange Capacity		9.8

TDr Abi had the highest mean fresh below ground weight of 83.3g, while TDr Saminaka had the highest dry tuber weight of 14.1 g (Table 2). TDr 99/02789 recorded the least fresh (13.4 g) and dry (3.6 g) tuber weight. TDr Agumaga had the least dry root weight of 9.45 g. Generally, the performance of TDr Abi, TDr Aloshi, TDr Saminaka and TDr Didio ranked very high among the twelve genotypes for the below ground biomass (Table 3). Harvest index varied among genotypes with a range of 10.8 (TDr 2789) to 32.0 (TDr Saminaka). TDr Aloshi had the highest total leaf area, but its performance for economic traits such as tuber weight, and harvest index were below the mean value.

Table 3 presents the correlation coefficients of nine parameters for *D. rotundata* genotypes. Fresh root weight had a positive and significant correlation with fresh tuber weight (r =0.91), dry tuber weight (r =0.85), dry leaf weight (r =0.41), harvest index (r =0.67), total leaf area (r =0.31) and number of spores(r =0.55). Fresh tuber weight positively and high significantly correlated to dry root weight (r = 0.90), dry tuber weight (r = 0.91) and harvest index (r = 0.78). It was also significantly and positively related to dry leaf weight (r = 0.31), and total leaf area (r = 0.23).

Fresh leaf weight had a significant but negative correlation with number of tubers (r = -0.19) but was highly significant and positive in agreement with dry leaf weight (r = 0.84) and total leaf area (r = 0.78). Dry root weight was highly significant and positively correlated with dry tuber weight (r = 0.92) and harvest index (r = 0.73) and also significantly and positively related to dry leaf weight (r = 0.36, and total leaf area (r = 0.29).

The main effects of water and mycorrhizal inoculation significantly ($P \leq 0.01$) influenced the performance of the 12 *D. rotundata* genotypes as shown in Table 4. Water applied at 75% FC at 11 WAP produced the best performance for all the parameters. At intermediate stress level (25% FC at 15 WAP), a significant reduction in the

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mean values of the traits was observed while at the highest level of moisture stress level (25% FC at 11 WAP), there was a significant drop in the performances of the genotypes for the nine parameters. Tuber fresh weight of *D. rotundata* genotypes for instance across the water levels, was within the range of 16.8 g to 66.1 g, while the mean value was 38.4 g. Effect of moisture stress imposition on the studied parameters followed a linear trend; 75% FC at 11WAP < 25% FC at 15 WAP < 25% FC at 11 WAP.

Table 2: Variations among parameter of 12 *Dioscorea rotundata* genotypes for some parameters

Genotype (TDr)	Fresh below ground weight	Fresh tuber weight	Dry below ground weight	Dry tuber weight	Fresh vine weight	Fresh leaf weight	Dry leaf weight	Total leaf area	Harvest Index	No. of AMF spores	AMF colonization
				g plant $^{-1}$				cm^2	%		%
99/2562	44.2def	22.3de	9.1d	5.6def	34.3a	26.6cde	5.2cd	1166ef	18.4cd	92.0f	6.6ef
Agumaga	37.9f	23.5de	7.8d	4.8f	30.9ab	21.8e	4.8d	1073f	16.2d	97.0ef	7.1def
Abi	83.3a	56.5a	18.0a	13.2a	26.0bc	46.4a	8.9a	1832b	24.3b	185.0a	13.2abc
99/2626	43.1ef	26.3cd	9.6d	5.8def	31.1ab	31.0bcd	5.8cd	1359cdef	17.7cd	109.0e	2.7f
99/2789	38.9f	13.4e	9.5d	3.6f	31.0ab	35.7b	6.4bc	1583bcde	10.8e	89.0f	8.4cde
Didio	59.5bcd	45.7ab	15.2ab	11.9ab	24.6c	33.4bc	7.5b	1680bcd	24.0b	143.0bc	9.4bcde
Aloshi	61.7bc	37.1bc	13.4bc	8.8bcd	36.6a	43.1a	8.8a	2321a	17.5d	140.0bcd	12.4abcd
00/00365	64.1b	49.1a	15.4ab	10.9abc	30.8ab	23.4e	5.0d	1096f	24.1b	128.0d	13.7ab
97/00812	72.9ab	50.2a	15.5ab	10.4abc	22.2c	35.8b	6.5bc	1770bc	24.6b	149.0bc	13.9ab
Tabene	57.4bcde	48.9a	17.2a	12.3ab	21.8c	25.4de	5.3cd	1207ef	22.5b	150.0bc	7.8def
Saminaka	64.4b	55.6a	16.7ab	14.1a	16.4d	21.0e	4.5d	1275def	32.0a	151.b	15.1a
Amula	47.4cdef	33.0cd	11.0cd	7.9cde	26.0bc	22.8e	5.0d	1089f	22.5bc	135.cd	7.4def

* values represent means across 12 *D. rotundata* genotypes. Means followed by same letter on the column are not significantly diferent at $P = 0.01$

Mycorrhizal inoculation significantly ($P \leq 0.01$) increased root weight, fresh and dry tuber weight, total leaf area, harvest index, AMF spore number and colonization as shown in Table 4. Mycorrhizal inoculation increased the root dry weight by 28.5%, tuber fresh weight by 33.4%, tuber dry weight by 38.2%, total leaf area by 18%, harvest index (19.7), number of spores (100%) and AMF colonization (219%).

Mycorrhizae inoculation significantly increased the total leaf area under varied moisture stress levels (Fig.1). The significant interaction was between mycorrhizae inoculation at 75% FC, 11 WAP and at 25% FC 15 WAP. The interaction of mycorrhizae with 25% FC at 11 WAP was not significant. Under the least stress imposition (75% FC at 11 WAP), addition of mycorrhizae led to significant increase in total leaf area compared to the other moisture stress levels (Fig. 1). Inoculation under moisture stress condition of 25% FC at 15 WAP led to a significant increase in the leaf area compared to mycorrizae inoculation at 25% FC 11 WAP. The later did not result in significant difference in the total leaf area of the twelve genotypes. From Fig. 1, the total leaf area increased with an increase in mycorrhizae and at a decrease in the moisture stress level.

Table 3. Correlation among agronomic traits of 12 *D. rotundata* genotypes

	Fresh root weight	Fresh tuber weight	Fresh vine weight	Fresh leaf weight	Number of tubers	Dry root weight	Dry tuber weight	Dry vine weight	Dry leaf weight	Harvest index	Total leaf area	Number of leaves	Number of spores
Fresh root weight		0.91***	0.14*	0.48***	0.06ns	0.90***	0.85***	0.08ns	0.41***	0.67***	0.31***	0.39***	0.55***
Fresh tuber weight			0.03ns	0.35***	0.11ns	0.90***	0.91***	-0.02ns	0.31***	0.78***	0.23***	0.32***	0.60***
Fresh vine weight				0.60***	-0.15*	0.08ns	0.02ns	0.84***	0.52***	-0.26***	0.46***	0.46***	0.04ns
Fresh leaf weight					-0.19**	0.41***	0.32***	0.49***	0.84***	0.03ns	0.78***	0.62***	0.36***
No. of tubers						0.08ns	0.14*	-0.13ns	-0.17*	0.21**	-0.1ns	-0.00ns	0.09ns
Dry root weight							0.92***	0.04ns	0.36***	0.73***	0.29***	0.35***	0.58***
Dry tuber weight								-0.04ns	0.28***	0.88***	0.23***	0.32***	0.57***
Dry vine weight									0.52***	-0.34***	0.42***	0.33***	0.01ns
Dry leaf weight										-0.03ns	0.70***	0.58***	0.29***
Harvest index											0.00ns	0.14*	0.44***
Total leaf area												0.71***	0.28***
No. of leaves													0.32***

***: significant at P =0.001, **: significant at $P = 0.01$, *: significant at $P \leq 0.05$, ns: not significant at $P < 0.05$, n = 18

The interaction of mycorrhizae inoculation × genotype significantly ($P < 0.01$) influenced the number of AMF spores and AMF colonization (Table 6). With mycorrhizal inoculation, genotypes showed a substantial increase in the number of AMF spores and AMF colonization; the number of AMF spores ranged from 111.3 (TDr 99/2789) to 280.3 (Abi) as against a lower range of 65.8 (TDr 99/2789) to 111.3 (Saminaka) where no mycorrhizal inoculation was absent. Similarly, AMF colonization of the root due to inoculation was in the range of 5.3% (TDr 99/2626) to 23.9% (Abi) while a lower range of 0.0% (TDr 99/2626 and TDr 99/2562) to 12.7% (TDr 97/812) was observed among genotypes when mycorrhizal was inoculated.

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Water level × genotype interaction effect on the dry tuber weight was significant (Fig.2). Under the least moisture stressed treatment (75% FC at 11 WAP), the highest dry tuber weight was recorded in Abi, however, its performance did not differ significantly from *Didio*, TDr 00/365, and *Tabene*. The least genotype in terms of dry tuber weight within the highest water level was TDr 99/2789. At the moisture stress of 25% FC at 15 WAP and 25% FC at 11 WAP, *Saminaka* had the highest tuber dry weight. The tuber dry weight of Saminaka was however not different from that of Abi and Aloshi at the highest moisture stress level of 25% FC at 11 WAP. TDr 99/2789 had the least tuber dry weight under the least moisture.

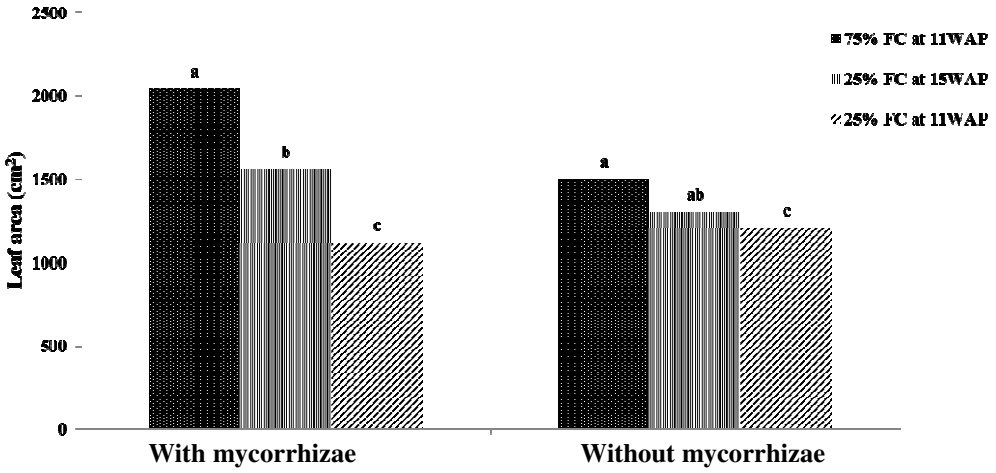

Fig. 1. Influence of mycorrhizal treatment on the leaf area of *D. rotundata* under moisture stress. Bars followed by same letter within mycorrhizal inoculation level are not significantly different at $P = 0.01$

Table 4: Influence of AMF inoculation on the measured parameters of 12 *D. rotundata* genotypes

Treatment	Fresh root weight	Fresh tuber weight	Dry root weight	Dry tuber weight	Fresh vine weight	Fresh leaf weight	Dry leaf weight	Total leaf area	Harvest index	No. of AMF spores	AMF coloniza tion
Mycorrhizal inoculation				g/plant				cm^2	%		%
With mycorrhizae	62.4a	43.9a	14.8a	10.5a	27.9	32.3a	6.3	1576a	23.1a	174.0a	15.0a
Without mycorrhizae	50.0b	32.9b	11.5b	7.6b	27.4	28.9b	6.0	1336b	19.3b	87.0b	4.7b
Water application											
75% FC at 11WAP	92.8a	66.1a	21.8a	15.8a	33.1a	40.2a	7.7a	1771a	27.3a	160.9a	12.9a
25% FC at 15WAP	47.8b	32.0b	11.4b	7.7b	26.6b	28.5b	5.8b	1431b	20.8b	122.2b	8.3b
25% FC at 11WAP	27.7c	16.8c	6.2c	3.7c	23.3c	22.9c	4.9c	1160c	15.5c	109.0c	8.3b

* Values represent means across 12 *D. rotundata* genotypes**.** Means followed by no letter on a column within treatment are not significantly different at $P < 0.01$

Table 5: Influence of mycorrhizal inoculation on fresh vine and leaf weight and root AMF colonization and of *D. rotundata* under moisture stress

Mycorrhizal inoculation	Water level	Fresh vine weight	Fresh leaf weight	AMF colonization
			g/plant	%
With mycorrhizae	75% FC 11 WAP	35.4a	43.7a	17.6a
	25% FC 15 WAP	26.9b	30.7b	12.9b
	25% FC 15 WAP	21.3c	22.2c	14.4c
Without mycorrhizae	75% FC 11 WAP	30.8a	36.7a	8.1a
	25% FC 15 WAP	26.2b	26.3b	3.7b
	25% FC 15 WAP	25.3b	23.5b	2.2b

Means followed by same letter on a column within each mycorrhizal inoculation level are not significantly different at $P = 0.01$.

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Table 6: Influence of mycorrhizal inoculation on number of AMF spores and AMF colonization and of twelve *D. rotundata* genotypes

Genotypes (TDr)	Number of AMF spores		AMF colonization (%)	
	MC1	MC0	MC1	MC0
99/2562	114.2a	70.0b	13.1a	0.0b
Agumaga	114.2a	80.4b	13.3a	0.9b
Abi	280.3a	89.3b	23.9a	2.7b
99/2626	131.1a	87.1b	5.3a	0.0b
99/2789	111.3a	65.8b	12.7a	4.2b
Didio	206.0a	79.6b	11.8a	7.1b
Aloshi	181.3a	99.6b	12.9a	12.0b
00/365	160.9a	94.3b	22.0a	5.3b
97/812	199.0a	98.2b	15.1a	12.7b
Tabene	218.7a	81.8b	13.8a	1.8b
Saminaka	191.5a	111.3b	23.3a	6.9b
Amula	183.5a	111.3b	12.7a	2.2b

MC1- with mycorrhizae, MC0- without mycorrhizae; Means followed by same letters on a row within each parameter for a parameter are not significantly different at P = 0.01

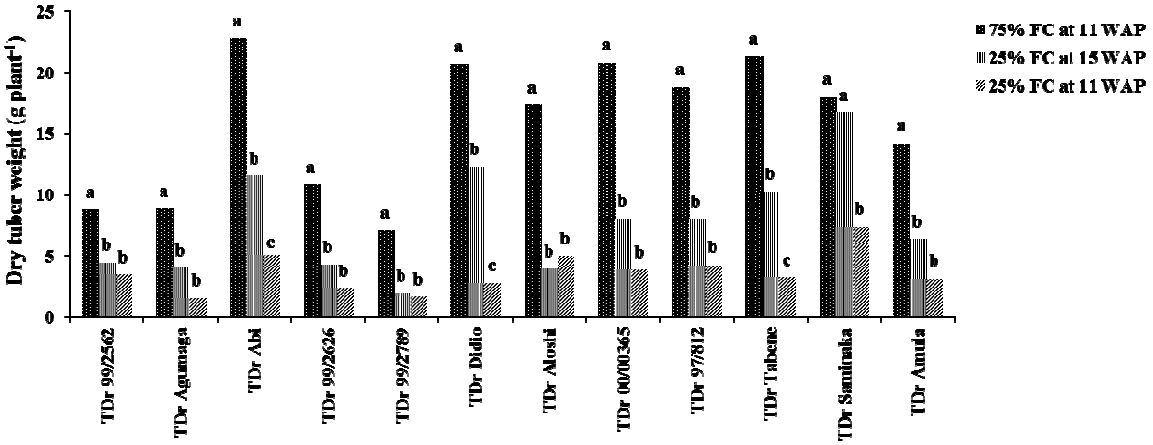

Fig.2. Effect of moisture stress on the dry tuber weight of 12 *D. rotundata* genotypes.
Bars followed by same letter within a genotype are not significantly different at *P* = 0.01

III. DISCUSSION

World poorest households are highly dependent on root and tuber crops such as yam for their sustenance. Thus yam is a food security crop. Information on tolerance of genotypes to moisture stress is necessary for its sustainable productivity [14]. In this study, highly significant positive correlations were observed among some of the measured parameters. Tuber dry weight was highly correlated ($P \leq 0.01$) with root fresh and dry weight, tuber fresh weight, harvest index, leaf area, and yam root colonization by AMF. With this, genotypes could be assessed for their response to drought based on any of these parameters. This could be a good index for the prediction of change occurring in one character at the expense of the proportionate change in the other [15].
Quantitative trait like harvest index are indicators of plant efficiency in photosynthate distribution towards tubers (the economic yield component), hence, selecting genotypes with high harvest index under moisture stress could be important trait for drought tolerant study [16].

Moisture is necessary for crop growth, being a medium for all chemical reactions, solute transport, transpiration and photosynthesis [17]. Highly significant variations ($P \leq 0.01$) occurred among the different stress levels imposed on *D. rotundata* genotypes in the present study. Water is In this study, water application at 75% FC resulted in the best growth and yield performances across studied genotypes, yield was however poorest at the least water application (25% FC at 11WAP) during the tuber initiation stage. Moisture stress imposition at 25% FC at 11WAP caused a decrease of 76.6% on dry tuber weight. The result obtained in this study is in line with the findings of [18], whose work on sweet potato revealed a decrease in plant biomass, leaf area, leaf weight and tuber yield due to water stress. Moreover, lower carbon assimilation resulted in lower assimilate production for the development of vegetative parts. Jefferies (1993) had earlier observed a reduction in both dry matter production and the proportion of dry matter partitioned into tubers due to drought. Agili and Pardales (1997) also noted that the numbers of leaves, fresh and dry weights of the shoot were significantly lower at 30% FC compared to 80% FC soil moisture. *Aloshi*,

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Abi, TDr 97/812, *Saminaka* and TDr 00/00365 were selected as genotypes with promising genetic potential for drought tolerance.

IV. Conclusion

Diversity existed among the studied *D. rotundata* genotypes for drought tolerance. In an effort to meet the demand for yam, the observed variability within these genotypes with respect to drought could provide genetic resource for utilization in breeding for drought tolerance of yam. Tuber initiation stage was the most critical stage for moisture stress in this study. Mycorrhizal inoculation could be used to improve yam production under moisture stress condition.

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