Journal of Plant Nutrition

ISSN: 0190-4167 (Print) 1532-4087 (Online) Journal homepage: https://www.tandfonline.com/loi/lpla20

Evaluation of White yam (*Dioscorea rotundata*) genotypes for arbuscular mycorrhizal colonization, leaf nutrient concentrations and tuber yield under NPK fertilizer application

Michael Olajire Dare, Olajire Fagbola, Robert C. Abaidoo & Robert Asiedu

To cite this article: Michael Olajire Dare, Olajire Fagbola, Robert C. Abaidoo & Robert Asiedu (2014) Evaluation of White yam (*Dioscorea rotundata*) genotypes for arbuscular mycorrhizal colonization, leaf nutrient concentrations and tuber yield under NPK fertilizer application, Journal of Plant Nutrition, 37:5, 658-673, DOI: 10.1080/01904167.2013.867988

To link to this article: https://doi.org/10.1080/01904167.2013.867988

Journal of Plant Nutrition, 37:658–673, 2014

ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904167.2013.867988

Taylor & Francis
Taylor & Francis Group

EVALUATION OF WHITE YAM (*DIOSCOREA ROTUNDATA*) GENOTYPES FOR ARBUSCULAR MYCORRHIZAL COLONIZATION, LEAF NUTRIENT CONCENTRATIONS AND TUBER YIELD UNDER NPK FERTILIZER APPLICATION

Michael Olajire Dare,[1,2] Olajire Fagbola,[3] Robert C. Abaidoo,[2] and Robert Asiedu[2]

[1]*Department of Soil Science and Land Management, University of Agriculture, Abeokuta, Nigeria*
[2]*International Institute of Tropical Agriculture, Ibadan, Nigeria*
[3]*Department of Agronomy, University of Ibadan, Ibadan, Nigeria*

□ *Yield decline in yam may not only be due to soil nutrient depletion but also to the activity of soil microflora. Arbuscular mycorrhizal (AM) symbiosis helps in plant nutrition but may be affected by the application of fertilizer. The effects of nitrogen (N), phosphorus (P), and potassium (K) fertilizer rates on the AM colonization, leaf nutrient concentrations, and tuber yields of eleven genotypes of* Dioscorea rotundata *were investigated at Ibadan, Nigeria. The soil was ferric luvisol. Eleven genotypes were selected from the previously conducted screening of 75 genotypes of* D. rotundata *for fertilizer response. Four application rates: 0, 200, 400, and 600 kg ha^{-1} of NPK 15-15-15 were applied in a split plot design with four replications. Fertilizer rate was the main plot and variety was the sub plot. Percentage AM colonization was significantly reduced at 600 kg ha^{-1} but not at lower rates when compared to zero rate and it was negatively correlated with leaf N, P, and zinc (Zn) concentrations. Leaf N concentrations were significantly increased at 200 kg ha^{-1} in five genotypes and at 600 kg ha^{-1} in two genotypes compared to zero application. Leaf P and K concentrations were decreased with the application of fertilizer in most of the genotypes. The NPK fertilizer of 15-15-15 at the rate of 200–400 kg ha^{-1} gave yield response in eight genotypes of* D. rotundata*, with minimal or no effect on their AM colonization when compared to zero application. Long term study on the effect of fertilizer application on AM symbiosis in yam is recommended.*

Keywords: arbuscular mycorrhiza, fertilizer, leaf nutrient concentrations, tuber yield, yam

Received 4 June 2011; accepted 2 August 2012.
Address correspondence to M.O. Dare, Department of Soil Science and Land Management, University of Agriculture, Abeokuta, PMB 2240, Abeokuta, Nigeria. E-mail: lajiire@yahoo.co.uk

INTRODUCTION

Yam (*Dioscorea* species) is a tuber crop widely cultivated in West Africa and many parts of the world with humid and sub-humid climates (Onwueme and Charles, 1994; Suja et al., 2003; Egesi et al., 2007). In Nigeria, it is a staple food and the most important tuber crop cultivated in terms of land area. Of nearly 4 million hectares of land planted with yam in 2000, more than 69% of the areas were located in Nigeria (FAOSTAT, 2000; Ekanayake and Asiedu, 2003). Additionally, yam has socio-cultural significances in the traditions of many West Africans (Orkwor and Asadu, 1998).

Soil nutrient depletion and the consequent yield decline have become serious threats to yam productivity in West Africa. Yam requires large quantities of nutrients and good soil condition to maintain its optimal yield (Degras, 1993; Ekanayake and Asiedu, 2003). The removal of nutrient reserves in soil by yam is usually not replenished after cultivation because the bulk of the nutrients removed are in the edible tuber. Continuous cropping in the yam-based cropping systems therefore leads to serious soil nutrient depletion. A major component of soil fertility management in yam production is the use of fertilizers (Degras, 1993; Orkwor and Asadu, 1998). However, variable fertilizer recommendations, which are sometimes conflicting, are common for yam. Recommendation of 300 kg ha^{-1} nitrogen (N) phosphorus (P) potassium (K) of 12-12-17 for acid soils and 50 kg N ha^{-1} + 60 kg potassium oxide (K_2O) for other soils in Southwestern Nigeria were made by Obigbesan (1981). Recently, Agbaje et al. (2005) recommended 200 kg ha^{-1} and 400 kg ha^{-1} of NPK 20-10-10 for new hybrid yam varieties in separate locations within Southwest Nigeria. Recommending fertilizers for yam requires research that will incorporate factors such as environmental conditions, soil characteristics, field history, crop genotypes, and fertilizer factors such as quantity, type, time, and methods of application (Orkwor and Asadu, 1998).

In soil fertility management, the biological component of the soil has always played a significant role. It is evident that plant nutrition in depleted soils can be enhanced by the colonization of plant root by arbuscular mycorrhizal fungi (AMF) (Smith and Read, 2008). Yam has been reported to be highly colonized by AMF with benefit of increased P and N uptake (Zaag et al., 1980, Dare et al., 2010). Studies on the selection of yam genotypes for efficient arbuscular micorrhizal (AM) colonization have also been conducted (Dare et al., 2008). Since AM colonization enhances nutrient uptake in plants, knowledge of the relationship between AM colonization and nutrients concentration in yam can have significant implication for increased productivity of the crop. Sobulo (1972) suggested that yield of yam would be adversely affected when the content of nitrate nitrogen in the leaf falls below 0.1 percent.

Breeding and selection of *Dioscorea rotundata* genotypes for quality and sustainable high tuber yield require information on nutrient acquisition and

fertilizer management. Quite a number of new genotypes are now available from international and national breeding programs but there is no information on their responses to fertilizer application. Since application of fertilizer can influence the AM symbiosis in crops (Sieverding, 1991; Treseder and Allen, 2002), there is need to evaluate the effect of fertilizer application on the AM colonization of some varieties and hybrids of yam. Hence, this study was conducted to determine the effect of N-P-K 15-15-15 fertilizer application on the AM colonization, leaf nutrient concentrations and tuber yield of eleven genotypes of *D. rotundata*.

MATERIALS AND METHODS

Screening of *D. rotundata* Genotypes in 2005 for Response to NPK Fertilizer

A preliminary investigation was carried out to screen 75 genotypes of *D. rotundata* for response to NPK fertilizer. These genotypes consisted mainly of International Institute of Tropical Agriculture (IITA) hybrids and eight landrace cultivars collected in Nigeria. The experiment was conducted in the 2005 yam growing season at the International Institute of Tropical Agriculture, Ibadan (3° 45′E, 7° 30′N) in the derived savanna region of Nigeria. The soil was a ferric luvisol. Soil characteristics for the experimental area were pH, 5.5; organic matter (%), 1.79; Total N (g kg^{-1}), 0.09; Mehlich-3 extractable P (mg kg^{-1}) 20.72; calcium (Ca) (cmol kg^{-1}), 2.94; K (cmol kg^{-1}), 0.62; and magnesium (Mg) (cmol kg^{-1}), 0.62. Two rates of NPK 15:15:15 were applied as nil (0 kg ha^{-1}) and high (600 kg ha^{-1}). The experiment was set up as a randomized complete block design with four replications. Yam setts weighing 50 g (± 5 g) were planted at a spacing of 0.5 m × 1 m along and between ridges, respectively, on experimental plots of size 5 m × 2 m in April 2005. Fertilizer was applied to relevant plots as single dose at 12 weeks after planting using side band method. Stakes and mulches were not applied in the experiment. Data were collected on tuber yields for each genotype.

Evaluation of Selected Genotypes for AM Colonization, Leaf Nutrient Concentration, and Yield in 2006

A field trial was conducted in the 2006 yam growing season at IITA, Ibadan, in another plot of land different from the one used for screening experiment. The soil had a pH (H_2O), 5.1; organic matter (%), 0.99; total N, 0.06 g kg^{-1}; Mehlich-3 extractable P, 2.97 mg kg^{-1}; K, 0.32 cmol kg^{-1}; Ca, 1.30 cmol kg^{-1}; Mg, 0.044 cmol/kg; zinc (Zn), 5.88 mg kg^{-1}; and 752, 132, and 116 g kg^{-1} of sand, silt, and clay, respectively. The plot used for the experiment had been previously cultivated with yam in 2001, 2003, and

2005 without fertilizer application. Eleven genotypes of *D. rotundata* were selected from screening experiment in 2005 based on their performance and fertilizer response. TDrs '97/00793', '97/00777', '01/00504' '91/00609' and '93-32' (landrace cultivar) were selected for their significant response to fertilizer, TDrs '96/01818', '97/00205', '97/00632', '96/00629', and '93-31' (landrace cultivar) were selected as genotypes with no response to fertilizer while TDr '97/00903' was selected as genotype with negative response to fertilizer application. Other factor that affected selection of these genotypes was the availability of planting materials.

The experiment was laid out as a split plot in a randomized complete block design with four replicates. The main plot treatment was fertilizer NPK 15:15:15 application rates at 4 levels: 0, 200, 400, and 600 kg ha^{-1}. The sub-plots were assigned to yam genotypes. Experimental plot size was 5 m × 4 m with plant spacing of 1 m × 1 m. The spacing between each main plot was 2 m apart. Yam setts, each weighing between 100–150 g were planted on ridges with no stakes and mulches. The plots were kept weed free as weeding was done every three weeks. Fertilizer treatments were applied in a single dose at 10 weeks after planting (about 6 weeks after sprouting) using the side band method.

Data Collection and Statistical Analysis

Prior to planting, soil samples were collected and analyzed for soil physical and chemical properties. Root sampling was done four weeks after fertilizer application to determine the AM colonization of the yam roots. The percentage AM colonization of the root was determined by the grid line-intersect method of Giovanetti and Mosse (1980), after clearing the roots with potassium hydroxide (KOH) and staining with Chlorazol Black E (Brundrett et al., 1984). Roots were randomly sampled in a non-destructive manner from five plants per plot.

Leaf sampling for the determination of leaf nutrient concentration was done four months after planting. First fully matured leaves (blade and petiole intact) were collected in the morning between the hours of 0900 and 1030 from five plants that were randomly selected for root sampling. These leaves were air-dried, ground and analyzed for N, P, K, Ca, Mg, and Zn. Leaves were analyzed for N using Kjeldahl digestion, P was determined colorimetrically using an acidified solution containing vanadate and molybdate and K, Ca, Mg, and Zn were determined using atomic absorption spectroscopy according to procedures of IITA (1982). Tuber yield of each genotype at different fertilizer rates was measured at harvesting.

Analysis of variance was conducted using PROC GLM of Statistical Analytical System (SAS Institute, Cary, NC, USA). Standard error of means (SE) was provided to draw inferences on the means. Measured variables were correlated using PROC CORR of SAS.

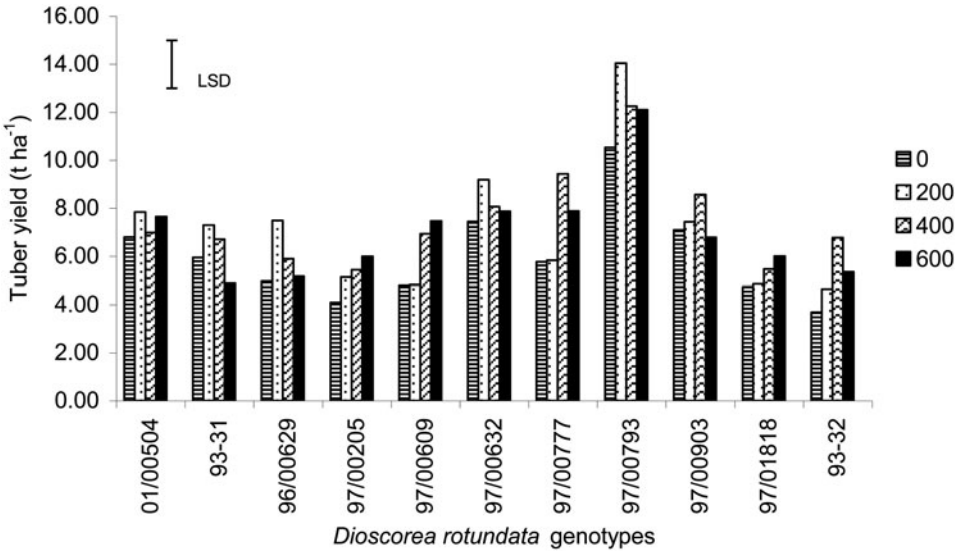

FIGURE 1 Tuber yields of eleven genotypes of *Dioscorea rotundata* (TDr) at different application rates of NPK fertilizer. 0: 0 kg ha^{-1} of NPK 15-15-15; 200: 200 kg ha^{-1} of NPK 15-15-15; 400: 400 kg ha^{-1} of NPK 15-15-15; 600: 600 kg ha^{-1} of NPK 15-15-15.

RESULTS

Screening of 75 Genotypes for Fertilizer Response

The tuber yields of the 75 genotypes in the screening experiment ranged from 1.46.1 t ha^{-1} (Table 1). Significant differences were observed based on genotype and fertilizer application rate. The tuber yields of TDrs '93-32', '01/00504', '02/00354', '96/00155', '91/00609', '96/01576', '96/02025', '97/00777', '97/00793', and TDr '97/01217' were significantly increased by fertilizer application while the tuber yields of TDrs '96/00274', '96/01817', '97/00903' and 'Kpagoki' were significantly reduced at the 600 kg ha^{-1} fertilizer application (Table 1). All other genotypes did not show significant response to fertilizer application. Highest tuber yields were observed in TDr '97/00793' when fertilizer was applied and in TDr '97/00632' when fertilizer was not applied.

Effect of Fertilizer Application on Tuber Yields, AM Colonization, and Leaf Nutrient Concentrations of the Selected 11 Yam Genotypes

Application of NPK 15-15-15 fertilizer significantly ($P < 0.05$) increased the tuber yields of TDrs '93-31', '96/00629', '97/00609', '97/00777', '97/00793' and '93-32' (Figure 1). Although the tuber yield of TDrs '01/00540', '97/00205', '97/00632', and '97/00903' at different fertilizer

TABLE 1 Tuber yields of 75 TDr genotypes screened in 2005 under 0 and 600 kg ha^{-1} NPK fertilizer

	Tuber yield (t ha^{-1})				Tuber yield (t ha^{-1})		
Genotype	NPK 600[a]	NPK 0[b]	Yield difference[c]	Genotypes	NPK 600[a]	NPK 0[b]	Yield difference[c]
TDr 93-32	3.5	1.6	1.9	TDr 96/01818	3.5	3.9	(0.4)
TDr 99-13	2.6	2.0	0.7	TDr 96/01876	3.3	2.6	0.6
TDr 00/00376	3.8	3.8	0	TDr 96/01879	2.5	3.3	(0.8)
TDr 00/01738	1.6	1.4	0.1	TDr 96/01998	1.7	2.6	(0.9)
TDr 01/00418	2.7	3.3	(0.6)	TDr 96/02025	3.0	1.6	1.4
TDr 01/00540	4.6	3.5	1.2	TDr 96/02033	2.2	2.6	(0.4)
TDr 01/00601	3.6	3.4	0.2	TDr 96/02433	2.7	3.0	(0.3)
TDr 01/00657	2.6	1.8	0.8	TDr 96/02671	2.0	2.0	0
TDr 01/00691	4.6	4.5	0.2	TDr 97/00205	3.5	2.7	0.8
TDr 02/00354	2.9	1.5	1.4	TDr 97/00585	3.4	2.9	0.5
TDr 131	1.7	1.8	(0.1)	TDr 97/00587	2.2	2.6	(0.4)
TDr 335	2.6	2.6	0	TDr 97/00588	3.4	3.9	(0.5)
TDr 89/02665	2.9	3.2	(0.3)	TDr 97/00632	5.3	4.7	0.6
TDr 93-2	3.4	3.7	(0.4)	TDr 97/00777	3.5	1.4	2.1
TDr 93-31	1.7	2.4	(0.7)	TDr 97/00793	6.1	3.4	2.7
TDr 93-49	1.3	1.9	(0.6)	TDr 97/00840	3.6	2.7	0.8
TDr 95/01932	2.0	2.2	(0.2)	TDr 97/00893	2.9	2.8	0.2
TDr 95/19127	2.1	2.2	(0.1)	TDr 97/00903	3.1	4.5	(1.4)
TDr 95/19156	2.2	1.4	0.8	TDr 97/00917	3.0	3.6	(0.6)
TDr 96/00155	4.3	3.1	1.2	TDr 97/01178	2.3	3.1	(0.8)
TDr 96/00274	2.6	3.8	(1.2)	TDr 97/01217	3.6	2.2	1.4
TDr 96/00528	2.3	2.8	(0.5)	TDr 97/01221	2.5	2.4	0
TDr 96/00604	3.2	4.2	(1.0)	TDr 97/01302	3.2	3.3	(0.1)
TDr 96/00609	5.1	2.4	2.7	TDr 97/01655	2.3	1.9	0.4
TDr 96/00614	4.0	3.2	0.8	TDr 97/01715	3.4	3.8	(0.4)
TDr 96/00629	2.7	2.7	0	TDr 97/02456	2.4	3.0	(0.6)
TDr 96/00960	3.5	3.2	0.3	TDr 97/05570	2.4	2.0	0.3
TDr 96/00970	2.6	2.1	0.5	TDr 98/00258	3.3	2.9	0.3
TDr 96/01335	3.2	2.8	0.4	TDr 98/00515	1.7	2.6	(0.9)
TDr 96/01395	1.9	2.6	(0.7)	TDr 98/00933	3.0	2.4	0.6
TDr 96/01524	2.7	3.1	(0.4)	TDr 98/01946	2.9	2.2	0.7
TDr 96/01576	3.3	2.0	1.3	TDr 98/03015	3.1	2.3	0.8
TDr 96/01712	2.2	2.4	(0.2)	TDr 99/00274	3.0	2.6	0.4
TDr 96/01717	1.8	2.6	(0.8)	TDr 99/02281	2.9	2.7	0.2
TDr 96/01724	3.4	2.3	1.0	TDr 99/02310	2.7	2.6	0.1
TDr 96/01799	2.8	2.9	(0.1)	TDr 99/02780	2.6	2.2	0.4
TDr 96/01815	3.0	3.0	0	Kpagoki	1.6	2.8	(1.2)
TDr 96/01817	1.8	3.3	(1.5)				
ANOVA				SE			
Genotype (G)	***			0.324			
Fertilizer Rate (F)	*			0.053			
G*F	***			0.458			

[a]NPK 15-15-15 at 600 kg ha^{-1} rate of application; [b] NPK 15-15-15 at 0 kg ha^{-1} rate of application; [c]values in parenthesis indicate yield decline due to application of fertilizer.

TABLE 2 Percentage AM colonization of *D. rotundata* genotypes under different NPK fertilizer rates

Genotype	AM colonization (%) under specified fertilizer rate				
	0[a]	200	400	600	Mean
TDr 01/00504	50.46	62.41	65.79	52.63	57.82
TDr 93-31	66.99	68.54	69.65	49.99	63.79
TDr 96/00629	63.18	58.52	52.15	40.85	53.67
TDr 97/00205	39.85	40.14	43.46	28.42	37.97
TDr 97/00609	52.18	44.33	53.12	32.11	45.43
TDr 97/00632	38.79	62.85	50.20	40.81	48.16
TDr 97/00777	40.84	58.12	44.96	20.21	41.03
TDr 97/00793	60.54	60.76	54.47	34.53	52.57
TDr 97/00903	55.45	49.75	56.55	37.98	49.93
TDr 97/01818	40.56	52.70	45.49	31.45	42.55
TDr 93-32	53.05	61.40	56.15	33.39	51.00
Mean	51.08	56.32	53.82	36.58	
SE					
Fertilizer rate (F)	1.965				
Genotype (G)	3.259				
G×F	6.517				
F test					
Fertilizer rate (F)	0.0034				
Genotype (G)	0.0001				
G×F	0.7721				

[a]NPK 15-15-15 rates in kg ha^{-1}.

rates were not significantly affected, more than one t ha^{-1} tuber yield increase were observed between the control rate and 200 kg ha^{-1} or 400 kg ha^{-1} fertilizer rate of these genotypes. TDr '97/00793' had higher tuber yield than any other genotype even at the control rate. Highest yields were obtained in TDrs '01/00504', '93-31', '96/00629', '97/00632', and '97/00793' at 200 kg ha^{-1}; '97/00777', '97/00903', and '93-32' at 400 kg ha^{-1}; and TDr '97/00205', '97/00609', and '97/01818' at 600 kg ha^{-1} (Figure 1).

The percentage AM colonization was significantly affected by the fertilizer rate and genotypes, but not with the interaction of the two factors. The highest AM colonization (70%) was observed in TDr '93-31' at 400 kg ha^{-1} NPK application rate while the lowest (20%) was observed in TDr '97/00777' at 600 kg ha^{-1} NPK application rate (Table 2). Reduction of more than 15% in AM colonization was observed when 0 kg ha^{-1} was compared with 600 kg ha^{-1} fertilizer in all genotypes except TDrs '01/00504', '97/00632', '97/00205', and '97/01818' (Table 2). Percentage AM colonization of TDr '97/00205' was consistently lower at all rates when compared with other genotypes. The mean AM colonization of TDr '93-31' was significantly higher than other genotypes (Table 2). Lowest mean AM colonization was observed in TDr '97/00205', and it was significantly lower than AM colonization of other genotypes except that of TDRs '97/00777' and '97/01818'.

The leaf N concentrations ranged from 2.44–4.16% dry matter and significant ($P < 0.05$) effect of genotype and fertilizer rates were observed in the 11 genotypes (Table 3). The leaf N concentrations were significantly lower at 0 kg ha^{-1} rate compared to other rates in TDrs '01/00504', '96/00629', '97/00609' and '93-32'. There was no significant difference in the leaf N concentrations of TDr '97/00205', '97/00632', '97/00777', '97/00903', and '97/01818' when treatment without fertilizer application and treatment with fertilizer application were compared. In TDr '93-31' and '97/00793', leaf N concentrations at 0 kg ha^{-1} was significantly lower to that of 200 and 400 kg ha^{-1}, respectively. The leaf N concentrations at 200 and 400 kg ha^{-1} in TDr '01/00504' were also significantly lower when compared to 600 kg ha^{-1}. Comparing the varieties at each level of fertilizer application, TDr '93-32' had significantly lower leaf N concentration than the other varieties when fertilizer was not applied while TDr '97/00632' had significantly higher leaf N concentrations than others. At 200 kg ha^{-1}, TDr '01/00504' had lower leaf N concentration compared to TDRs '93-31', '97/00609', '97/00632', and '97/01818'.

Leaf P concentration ranged from 0.17–0.32% dry matter. Incidentally, the two extremes were observed at 0 kg ha^{-1} rate in TDr '93-32' and TDr '91/00609', respectively (Table 3). While fertilizer application significantly lower leaf P concentration in TDr '91/00609', leaf P concentration was increased by fertilizer application in TDr '93-31'. The leaf P concentration of plants under the control fertilizer rate was significantly higher than 200 kg ha^{-1} fertilizer rates in TDr '97/00205', TDr '97/00609', TDr '97/00632', TDr '97/00777', and TDr '97/00793'. Significantly higher leaf P concentration at 600 kg ha^{-1} compared to 0 kg ha^{-1} was observed only in one variety, TDr '96/00629' (Table 3).

Significant differences in leaf K concentration of the 11 genotypes were due only to genotype effect. The leaf K concentration ranged from 1.61–3.25% for the 11 genotypes (Table 3). The mean leaf K concentration was significantly higher in TDr '97/00609' and '97/00793' relative to other genotypes. TDr '93-31' and TDr '93-32' had the lowest mean leaf K concentration of 1.78 and 1.94 percent, respectively. It was observed that leaf P and K concentrations of TDr '97/00609' at 0 kg ha^{-1} were higher than other fertilizer application rates.

The leaf Ca, Mg, and Zn concentrations of yam plants were significantly affected by genotype and fertilizer rate effect. The leaf concentration range of 1.22–2.92% dry matter was observed for Ca, 0.23–0.39% dry matter for Mg, and 35.82–75.80 mg kg^{-1} for Zn (Table 4). TDr '93-31' and TDr '93-32' had the highest mean leaf Ca concentration while Tdr '97/00609' had the lowest (Table 4). Higher leaf Ca concentration was obtained at either 200 or 400 kg ha^{-1} in TDrs '01/00504', TDr '93-31', TDr '97/01818' and TDr '93-32'. TDr '97/00632' and TDr '97/00903' had their highest leaf Ca concentration at the control fertilizer which was significantly higher than that at 600 kg ha^{-1}.

TABLE 3 Leaf N, P and K concentrations (% dry matter) of *D. rotundata* genotypes grown under different rates of NPK fertilizer (kg ha^{-1})

	Leaf N concentration					Leaf P concentration					Leaf K concentration				
Genotype	0[a]	200	400	600	Mean	0[a]	200	400	600	Mean	0[a]	200	400	600	Mean
TDr 01/00504	2.88	3.44	3.58	4.01	3.48	0.21	0.20	0.23	0.23	0.22	2.18	2.16	2.21	2.20	2.18
TDr 93-31	3.33	4.01	3.74	3.60	3.55	0.22	0.20	0.19	0.21	0.20	2.14	1.91	1.64	2.09	1.94
TDr 96/00629	3.03	3.62	3.63	3.91	3.55	0.20	0.21	0.21	0.24	0.21	2.21	2.70	2.26	2.47	2.41
TDr 97/00205	3.39	3.69	3.66	3.52	3.57	0.24	0.21	0.22	0.21	0.22	2.12	2.39	2.07	2.15	2.18
TDr 97/00609	3.43	4.01	3.97	4.08	3.87	0.32	0.24	0.25	0.25	0.27	3.25	2.87	2.78	2.52	2.86
TDr 97/00632	3.86	3.88	3.94	4.15	3.96	0.26	0.23	0.24	0.25	0.24	1.75	2.07	2.00	2.31	2.03
TDr 97/00777	3.67	3.73	3.69	4.16	3.81	0.26	0.21	0.23	0.26	0.24	2.42	2.20	1.93	2.07	2.16
TDr 97/00793	3.29	3.66	3.84	3.57	3.59	0.27	0.24	0.29	0.24	0.26	2.63	2.75	2.63	2.59	2.65
TDr 97/00903	3.62	3.82	3.93	3.96	3.83	0.26	0.24	0.25	0.24	0.25	2.50	2.45	2.41	2.39	2.44
TDr 97/01818	3.61	3.95	3.79	3.95	3.82	0.22	0.21	0.20	0.23	0.21	2.22	1.92	2.01	1.86	2.00
TDr 93-32	2.44	3.62	3.11	3.73	3.23	0.17	0.21	0.22	0.22	0.21	1.71	1.85	1.61	1.93	1.78
Means	3.33	3.77	3.67	3.88	3.66	0.24	0.22	0.23	0.23	0.23	2.28	2.30	2.14	2.24	2.24
S.E.															
Rate	0.046					0.0034					0.048				
Genotype	0.076					0.0056					0.080				
Rate*Genotype	0.153					0.0113					0.160				
F value															
Rate	0.0031					0.30					0.3300				
Genotype	0.0001					0.0001					0.0001				
Rate*genotype	0.0027					0.0001					0.2410				

[a]NPK 15-15-15 rates in kg ha^{-1}.

TABLE 4 Leaf Ca, Mg and Zn concentrations (% dry matter) of *D. rotundata* genotypes grown under different rates of NPK fertilizer (kg ha^{-1})

	Leaf Ca concentration					Leaf Mg concentration					Leaf Zn concentration				
Genotype	0[a]	200	400	600	Mean	0[a]	200	400	600	Mean	0[a]	200	400	600	Mean
TDr 01/00504	1.46	2.50	2.80	1.92	2.17	0.27	0.33	0.34	0.32	0.31	38.56	42.25	47.23	57.08	46.28
TDr 93-31	1.94	2.88	2.80	1.76	2.34	0.27	0.38	0.35	0.25	0.31	35.82	36.49	36.70	46.34	38.84
TDr 96/00629	1.76	2.09	2.01	1.24	1.77	0.29	0.31	0.28	0.22	0.27	49.24	49.56	44.60	45.74	47.28
TDr 97/00205	1.93	1.63	2.08	1.86	1.88	0.30	0.30	0.31	0.31	0.30	48.92	44.01	37.07	41.68	42.92
TDr 97/00609	1.22	1.32	1.73	1.34	1.40	0.28	0.25	0.27	0.26	0.27	46.38	43.44	60.43	55.75	51.50
TDr 97/00632	2.47	2.11	2.09	1.43	2.02	0.35	0.30	0.30	0.23	0.29	59.99	42.14	49.12	43.60	48.71
TDr 97/00777	1.89	1.85	2.22	2.14	2.02	0.35	0.34	0.38	0.31	0.35	55.81	45.61	50.96	75.80	57.04
TDr 97/00793	2.04	1.86	2.28	1.83	2.00	0.32	0.31	0.34	0.30	0.32	46.09	50.45	56.42	47.61	50.14
TDr 97/00903	2.16	1.95	1.90	1.37	1.84	0.30	0.31	0.28	0.25	0.29	59.78	46.48	56.27	55.02	54.39
TDr 97/01818	1.83	2.92	1.94	2.44	2.28	0.28	0.36	0.27	0.30	0.30	54.61	52.97	53.63	62.90	56.03
TDr 93-32	1.83	2.80	2.48	2.15	2.32	0.24	0.39	0.36	0.33	0.33	36.20	45.67	34.40	58.76	43.76
Means	1.87	2.17	2.21	1.77	2.01	0.29	0.33	0.32	0.28	0.30	48.31	45.37	47.89	53.66	48.81
S.E.															
Rate	0.058					0.007					1.147				
Genotype	0.096					0.009					1.902				
Rate*Genotype	0.192					0.019					3.805				
F value															
Rate	0.0009					0.01					0.033				
Genotype	0.0001					0.0001					0.0001				
Rate*genotype	0.0001					0.0001					0.0001				

[a]NPK 15-15-15 rates in kg ha^{-1}.

The leaf Mg concentration was significantly higher at 200 and 400 kg ha^{-1} than at 0 kg ha^{-1} in TDrs '01/00504', '93-31' and '93-32'. At 600 kg ha^{-1}, leaf Mg concentration was significantly reduced when compared to 0 or 200 kg ha^{-1} fertilizer rates in TDrs '96/00629', '97/00632', and '97/00903'. Leaf Zn concentration was significantly higher at 0 kg ha^{-1} fertilizer rate than other rates in TDr '97/00632' (Table 4). At 0 kg ha^{-1}, TDrs '93-31' and '93-32' were significantly lower in Leaf Zn concentration compared to other varieties except TDr '01/00504'. The two landrace cultivars also had significantly higher leaf Zn concentration at 600 kg ha^{-1} fertilizer rate compared to 0 kg ha^{-1} rate. TDr '97/00632' had its highest leaf Ca, Mg, and Zn concentrations at 0 kg ha^{-1} and as the rate of fertilizer application increased, leaf Ca and Mg decreased in this genotype.

Correlation analysis of AM colonization and leaf nutrient concentrations showed that AM colonization was weakly and negatively correlated ($P < 0.05$) with leaf N ($r = 23$), P ($r = 20$) and Zn ($r = 26$) concentrations while it was positively correlated with leaf Ca ($r = 20$) concentration of the 11 genotypes (Table 5). Positive correlation was also observed between the tuber yield and leaf N, P, K, and Mg concentrations. Nitrogen was positively correlated with P, K, and Zn while the correlation between Ca and P or K was negative. There was also a strong positive correlation ($r = 63$) between Ca and Mg.

DISCUSSION

Soil characteristics have been identified as one of the major factors contributing to yam response to fertilizer application (Onwueme and Charles, 1994; Agbaje et al., 2005). Although the soils used for the study in 2005 and 2006 had adequate K for yam production, they were deficient in N, P, and soil organic matter (SOM) as required for good growth in yam. Yam will likely respond to fertilizer application on soil with less 0.1% N, less than 10 mg kg^{-1} available P, less than 0.15 cmol kg^{-1} K, and less than 1.7% SOM (Obigbesan, 1981; Kayode, 1985). The response of yam genotypes to fertilizer application in 2006 was clear evidence that the initial soils status could not supply adequate nutrient needed for good performance. The initial nutrient status of the soil was probably due to the agricultural intensification, considering the fact that the fields have been cultivated previously for five years with one-year fallow in between.

The reduction of AM colonization at 600 kg ha^{-1} NPK 15-15-15 application rate in most genotypes was in line with reports that AM root colonization is reduced when soil P is increased (Miller and Jackson, 1998, Kahiluoto et al., 2001; Smith and Read, 2008). Meanwhile, the percentage AM colonization above 40% observed at 600 kg ha^{-1} rate in some genotypes can be considered significant, which probably was a result of promiscuity of some yam genotypes for AM colonization irrespective of soil P level (Dare et al., 2008). The

TABLE 5 Correlation coefficients for tuber yield, AM colonization and leaf nutrient concentrations in eleven *D. rotundata* genotypes.

	AM Colonization	Tuber yield	N	P	Ca	Mg	K	Zn
AM Colonization	—							
Tuber yield	0.13	—						
	0.08							
N	−0.23	0.23	—					
	0.002	*0.0024*						
P	−0.20	0.31	0.51	—				
	0.009	*<.0001*	*<.0001*					
Ca	0.20	0.01	−0.06	−0.20	—			
	0.0066	*0.832*	*0.429*	*0.0085*				
Mg	0.03	0.17	0.19	0.18	0.63	—		
	0.7205	*0.0250*	*0.0116*	*0.016*	*<.0001*			
K	−0.03	0.26	0.28	0.54	−0.49	−0.25	—	
	0.7244	*0.0006*	*0.0002*	*<.0001*	*<.0001*	*0.0008*		
Zn	−0.26	0.13	0.47	0.43	0.03	0.13	0.11	—
	0.0005	*0.0781*	*<.0001*	*<.0001*	*0.7211*	*0.0956*	*0.1429*	

Numbers in italics represent probability value.

AM colonization percentages at 200 and 400 kg ha^{-1} rate were comparable with that of 0 kg ha^{-1} rate despite the addition of P from the application of these two rates. The level of soil available P at these two rates may still be low to allowed considerable AM development and activity because the initial soil available P before fertilizer application was very low. The weak inverse correlation of arbuscular mycorrhizal colonization with leaf N, P, and Zn concentration suggests that their high concentration in the yam may affect AM colonization negatively. However, the long-term implications of fertilizer application at these rates on AM root colonization of yam needs investigation. The observed varietal differences in AM colonization can be exploited especially in low input agriculture. The genetic improvement of yam seemed not to reduce its ability to form AM symbiosis as reported in wheat (Hetrick et al., 1996) because the AM root colonization of hybrids and landrace cultivars was comparable in this study.

The influence of genetic factor was observed in this study. TDr '97/00793' had higher yield potential than other genotypes because its tuber yield at 0 kg ha^{-1} was higher than tuber yield of other genotypes irrespective of fertilizer rate. The higher tuber yields obtained in most of the IITA hybrids over the landrace cultivars is indicative of crop improvement on these hybrids. Orkwor and Ekanayake (1998) stated that improved genetic and cultural management practices are required to increase yield of cultivated yams.

The ranges of leaf N, P, and K concentrations observed in this study were in agreement with those of Obigbesan (1981) and Sobulo (1972). However, the results for leaf P, Ca, and Zn were lower than those of Kang and Wilson (1981). Reports on critical nutrient level are rare for yam, however, Plank (1989) suggested 2.75% N and between 0.1 and 0.2% P as critical levels for most crops. Also, Howeler (1990) reported critical leaf P concentration of less than 0.44% for cassava, 0.22% for sweet potato, and 0.40% for taro. TDr '93-32' at 0 kg ha^{-1} probably had leaf N and P concentrations below the critical level as the tuber yield of this genotype was significantly increased with higher leaf N and P concentrations. It was observed in this study that some genotypes of yam were more efficient than others irrespective of fertilizer application in the accumulation of K in the leaves. While leaf K concentration ranged from 2.52–3.25% in TDr '97/00609', it was 1.61–1.85% in TDr '93-32' even at 600 kg ha^{-1} NPK application. The range of leaf Zn concentration observed in the present study was within the range reported by Shiwachi et al. (2004) when yam varieties were grown in nutrient solution. However, lower ranges were observed for Ca and Mg in our study. Information is limited on the critical leaf Mg, Ca, and Zn concentrations in yam. However, the range of these nutrients in the leaves of yam fell within the sufficiency range suggested generally for crops (Jones and Case, 1990). It is probably an indication of the inadequate supply of these nutrients (Ca, Mg, and Zn) by the soil.

A complexity of interactions and relationships between nutrients concentrations in genotypes and fertilizer application was observed in the present study. Negative interaction was observed between leaf N and K concentrations of some of the genotypes. While NPK fertilizer application increased leaf N concentrations of TDr '93-31', TDr '97/00609', TDr '97/01818', TDr '97/00777', and TDr '97/00903', it caused a decrease in leaf K and P concentration of these genotypes. This was not the case in TDr '01/00540', TDr '96/00629', TDr '97/00632', and TDr '97/00793', where application of fertilizer led to increase in leaf N and K concentrations. In TDr '97/00632', application of fertilizer increased leaf N and K concentrations and reduced other leaf nutrient concentrations. Changing of one level of nutrient in the soil will often affect the uptake or transport of another nutrient within a plant and it usually depends on the nutrient involved and varies among plant species and genotypes (Rosen and Bierman, 2005). Since K is not deficient in the soil used for the study, the supply of NPK 15-15-15 could have resulted in soil K imbalance to which the genotypes responded differently. Plank (1989) stated that as a result of balance phenomena, heavy application of N or K fertilizer could cause K deficiency in plants. In the present study, leaf K concentration reduction but not deficiency occurred in some genotypes. Positive correlation was observed between tuber yield and leaf concentrations of N, P, K, and Mg. This reaffirmed the importance of these nutrients in yam as stated in other studies (Obigbesan, 1981; Shiwachi et al., 2004).

One of the major interests of this research is to establish the fertilizer rates for optimum tuber yield for each of the genotypes in this study. This rate will serve as a benchmark for these genotypes as this was the first fertilizer response trial on them. Optimum yields using NPK 15-15-15 were obtained at 200 kg ha^{-1} for TDr '01/00504', TDr '93-31', TDr '96/00629', TDr '97/00632', and TDr '97/00793' and at 400 kg ha^{-1} for TDr '97/00777', TDr '97/00903', and TDr '93-32'. Close to our results is the rate of 200 kg ha^{-1} of NPK 20-10-10 that was reported as optimum for late season planting of three newly released hybrid yams at Ibadan (Agbaje et al., 2005). Trials conducted on yield response to fertilizers have revealed different optimum elemental rates of N, P, and K for tuber yield and good growth of yam. Kpeglo et al. (1981) recommended 90 kg N, 25 kg P, and 30 kg K $hectare^{-1}$ for optimum yield of yam at Ibadan. The 200 kg ha-1 rate of NPK 15-15-15 in the present study represented 30 kg ha-1 each of N, phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) while 400 kg ha^{-1} represented 60 kg ha-1 each of N, P_2O_5, and K_2O. Buri et al. (2005) stated that elemental rate of 15-15-20 or 30-30-40 kg ha^{-1} of N-P_2O_5-K_2O can be recommended for *D. rotundata* in all agroecological zones of central Ghana, which included derived savanna.

In summary, NPK 15-15-15 fertilizer application at 200 and 400 kg ha^{-1} significantly increased the tuber yields of eight of the eleven *D. rotundata*

genotypes and at these two rates, AM colonization was not reduced when compared to zero fertilizer application. Also, leaf N concentrations were increased at these two rates in all the genotypes. Extensive study on the long term effect of fertilizer application on AM is recommended.

FUNDING

The authors thank IITA for funding the project.

REFERENCES

Agbaje, G. O., A. A. Adegbite, G. A. Oluwatosin, and T. A. Akinlosotu. 2005. Influence of NPK fertilizer on tuber yield and yield components of new hybrid yam varieties in south western Nigeria. *African Journal Root Tuber Crops* 6: 48–53.

Brundrett, M., Y. Piche, and R. L. Peterson. 1984. A new method for observing the morphology of vesicular arbuscular mycorrhiza. *Canadian Journal Botany* 62: 2118–2134.

Buri, M. M., Issaka, R. N., and R. J. Carsky. 2005. Developing fertilizer recommendation for white yam (*Dioscorea rotundata*) in Central Ghana. *African Journal Root Tuber Crops* 6: 20–27.

Dare, M. O., R. C. Abaidoo, O. Fagbola, and R. Asiedu. 2008. Genetic variation and genotype × environment interaction in yams (*Dioscorea* spp.) for root colonization by arbuscular mycorrhiza. *Journal Food Agriculture Environment* 6: 227–233.

Dare, M. O., R. C. Abaidoo, O. Fagbola, and R. Asiedu. 2010. Effects of arbuscular mycorrhizal inoculation and phosphorus application on yield and nutrient uptake of yam. *Communications in Soil Science and Plant Analysis* 41: 2729–2743.

Degras, L. 1993. *The Yam. A Tropical Root Crop.* London: Macmillan.

Egesi, C. N., B. O. Odu, S. Ogunyemi, R. Asiedu, and J. Hughes. 2007. Evaluation of water yam (*Dioscorea alata* L.) germplasm for reaction to yam anthracnose and virus disease and their effect on yield. *Journal Phytopathologia* 155: 536–543.

Ekanayake, I. J., and R. Asiedu. 2003. Problems and perspectives of yam-based cropping systems in Africa. *Journal Crop Production* 9: 531–558.

FAOSTAT. 2000. *FAOSTAT*. Rome: Food and Agriculture Organization of the United Nation.

Giovanetti, M., and B. Mosse. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytologist* 84: 489–500.

Hetrick, B. A .D., G. W. T. Wilson, and T. C. Todd. 1996. Mycorrhizal response in wheat cultivars: relationship to phosphorus. *Canadian Journal Botany* 74: 19–25.

Howeler, R. H. 1990. Phosphorus requirements and management of tropical root and tuber crops. Phosphorus requirements for sustainable agriculture in Asia and Oceania. *International Rice Research Institute Report* 427–444. Manila: International Rice Research Institute.

International Institute of Tropical Agriculture (IITA). 1982. *Automated and semi-automated methods of soil and plant analysis. International Institute of Tropical Agriculture (IITA) Manual Series No. 7.* Ibadan, Nigeria: IITA.

Jones, J. B., and V. W. Case. 1990. Sampling, handling, and analyzing plant tissue samples. In: *Soil Testing and Plant Analysis,* ed. R.L. Westerman, 389–427. Madison, WI: Soil Science Society of America.

Kahiluoto, H., E. Ketoja, M. Vestberg, and I. Saarela. 2001. Promotion of AM utilization through reduced P fertilization. 2. Field studies. *Plant and Soil* 231: 65–79.

Kang, B. T., and J. E. Wilson. 1981. Effect of mound size and fertilizer on white guinea yam (*Dioscorea rotundata*) in southern Nigeria. *Plant and Soil* 61: 319–327.

Kayode, G. O. 1985. Effects of NPK fertilizers on tuber yield, starch content and dry matter accumulation of white guinea yam (*Dioscorea rotundata*) in a forest alfisol of south western Nigeria. *Experimental Agriculture* 21: 389–393.

Kpeglo, K. D., G. O. Obigbesan, and J. E. Wilson. 1981. Yield and shelf life of white yam as influenced by fertilizer. In *Tropical Root Crops: Research Strategies for the 1980s*, eds. E. RTerry, K. A. Oduro, F. Caveness, pp. 198–202. Proceedings of the first Triennial Root Crops Symposium of the

International Society for Tropical Root Crops–Africa Branch. Ottawa: International Development Research Centre.

Miller, R. L., and L. E. Jackson. 1998. Survey of vesicular-arbuscular mycorrhizae in lettuce production in relation to management and soil factors. *Journal Agricultural Science* 130: 173–182.

Obigbesan, G. O. 1981. Nutrient requirements of yams (*Dioscorea* species). *Agricultural Research Bulletin* 2(1): 20.

Onwueme, I. C., and W. B. Charles. 1994. Tropical root and tuber crops production. Perspectives and Future Prospects. *FAO Plant Production and Protection Paper* 126: 50–112.

Orkwor, G. C., and C. L. A. Asadu. 1998. Agronomy. In: *Food Yams. Advances in Research*, eds. G. C. Orkwor, R. Asiedu, and I. J. Ekanayake, pp. 105–141. Ibadan, Nigeria: IITA and NRCRI.

Orkwor, G. C., and I. J. Ekanayake. 1998. Growth and development. In: *Food Yams. Advances in Research*, eds. G.C. Orkwor, R. Asiedu, and I.J. Ekanayake, 39–62. Ibadan, Nigeria: IITA and NRCRI.

Plank, C. O. 1989. *Plant Analysis Handbook for Georgia.* Athens, GA: University of Georgia Cooperative Extension Service.

Rosen, C. J., and P. M. Bierman. 2005. Nutrient management for fruit and vegetable crop production. Available at: www.extension.umn.edu/distribution/horticulture/components/M1190.pdf (Accessed 24 Dec 2007).

Shiwachi, H., C. C. Okonkwo, and R. Asiedu. 2004. Nutrient deficiency symptoms in yams (*Dioscorea* spp.). *Tropical Science* 44: 155–162.

Sieverding, E. 1991. *Vesicular-Arbuscular Mycorrhiza Management in Tropical Agrosystems.* Eschborn, Germany: Technical Cooperation, Federal Republic of Germany, Germany. 372 pp.

Smith, S. E., and D. J. Read, 2008. *Mycorrhiza Symbiosis.* San Deigo, CA: Academic Press.

Sobulo, R. A. 1972. Studies on white yam (*Dioscorea rotundata*). II. Changes in nutrient content with age. *Experimental Agriculture* 8: 107–115.

Suja G., V. M. Nair, P. Sarawathy, and R. Pushpakumari. 2003. Plant population and sett size effects on white yam (*Dioscorea rotundata* Poir.) intercropped in coconut gardens. *Tropical Agriculture (Trinidad)* 80: 157–162

Treseder, K .K., and M. F. Allen. 2002. Direct nitrogen and phosphorus limitation of arbuscular mycorrhizal fungi, a model and field test. *New Phytologist* 155: 507–515.

Zaag Vander, P., R. L. Fox, P. K. Kwakye, and G. O. Obigbesan. 1980. The phosphorus requirements of yam (*Dioscorea* spp.). *Tropical Agriculture (Trinidad)* 57: 97–10.