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Nitrogen and potassium fertilizer influenced nutrient use efficiency and biomass yield of two plantain (*Musa* spp. AAB) genotypes

Simon Chinekenwa Aba[1]* and Kayode Paul Baiyeri[1,2]

[1]Department of Crop Science, University of Nigeria, Nsukka, Nigeria.
[2]Visiting Scientist at the International Institute of Tropical Agriculture, P. M. B. 5320, Ibadan, Oyo State, Nigeria.

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Nitrogen and potassium are key nutrients for optimum productivity in *Musa* species. In this study, optimum doses of N and K were determined for two plantain genotypes. The growth and dry matter yield (DMY) of 'PITA 24' (a hybrid plantain of the International Institute of Tropical Agriculture) and a landrace, 'Agbagba' were evaluated on factorial doses of N (0, 200, 400 and 600 kg.ha^{-1}) and K_2O (0, 300, 600 and 900 kg.ha^{-1}). The nutrient use efficiencies of the applied nutrients were also studied. Analysis of variance showed that fertilizer combination significantly ($p<0.05$) influenced the genotype performance and genotype-by-fertilizer interaction effects. Growth and DMY in both genotypes were superior where both nutrients were applied together. 'PITA 24' maintained a better growth, higher DMY, and greater efficiency of nutrient use than 'Agbagba'. Both genotypes had the best growth where N was applied at 200 or 400 kg.ha^{-1} in combination with 300, 600 or 900 kg.ha^{-1} of K_2O. The control plants were the poorest. Agronomic efficiency (*AE*) of applied K^+ was high at $N_{200}K_{300}$, $N_{400}K_{300}$, and $N_{600}K_{300}$; similarly, *AE* of applied N was superior at $N_{200}K_{600}$, $N_{200}K_{300}$, and $N_{200}K_{900}$. The partial factor productivity from the applied nutrients was highest at $N_{200}K_{300}$, suggesting that it was most economical to grow plantain with 200 kg N and 300 kg K_2O ha^{-1}. For optimum performance of plantains in the humid tropics of southeastern Nigeria, results from the study suggest the combined application of 200 to 400 kg N and 300 to 600 kg K_2O per hectare, per annum.

Key words: Plantains, dry matter yield, nutrient use efficiency.

INTRODUCTION

The edible bananas (*Musa* AAA) and plantains (*Musa* spp. AAB) belong to the genus *Musa* and family *Musaceae* (Stover and Simmonds, 1987). As principal staple food with rice, cassava and yam, plantains are rich sources of dietary energy, vitamins (A, B6 and C) and minerals such as calcium, potassium, phosphorus, iron and zinc (Tenkouano et al., 2002). Plantain and banana crops are traditionally grown in heavily manured compound farms where the productivity could be sustained for many years. These crops are now being

*Corresponding author. E-mail: simon.aba@unn.edu.ng.

cultivated on large-scale commercial farms under sole cropping where yield decline sets-in after few production cycles (Wilson et al., 1987). The rapid yield decline observed in most plantations has been a major limitation to large scale cultivation of plantain and banana crops in West and Central Africa. Yield decline in *Musa* crops is particularly severe in the landrace genotypes, and has been blamed on poor soil fertility and the associated biotic stresses (Braide and Wilson, 1980) including black Sigatoka (*Mycosphaeralla fijiensis* Morelet) disease, and attack by root-knot nematodes (*Meloidogyne incognita*) and corm weevils (*Cosmopolites sordidus*).

In this regard, the International Institute of Tropical Agriculture (IITA), Nigeria, has advanced the use of improved hybrids which are resistant/tolerant to diseases and pests, and are high yielding with good postharvest qualities. However, sustaining the yields of new cultivars in the farmers' fields requires appropriate crop management practices, especially soil fertility management. In the tropics, rapid population growth and continuing land degradation pose a great challenge to soil fertility management (Sanchez et al., 1997). Therefore, external nutrient inputs are needed to sustain crop yields on most tropical soils.

The productivity of determinate fruit species like *Musa* is largely dependent on the prevailing crop environment prior the reproductive growth stage, of which soil fertility is major determinant. Under declining soil fertility, the damage caused by banana weevil and soil nematodes tends to increase (Obiefuna, 1990). Besides, *Musa* plants easily lodge under poor fertility and stressed conditions due to the plant's morphology (Robinson, 1996), which includes superficial rooting, heavy canopy, succulent trunk, and the 'high mat' syndrome (that is, when the plant base grows out of the soil). For optimal yield, bananas require large doses of plant nutrients which cannot be supplied solely by the soil reserve (Lahav, 1995). For instance, Irizarry et al.(1981) calculated that an acceptable harvest of 35 tonnes fruits/ha leaves the soil depleted by 250 kg N, 45 kg P_2O_5 , 702 kg K_2O, 100 kg MgO, 252 kg CaO, and 24 kg sulphur. Sound fertilizer recommendations are based on crop requirements for a particular expected yield, corrected for the ability of the soil to meet those requirements (FADINAP, 2000). Fertilizer best practices require that fertilizer nutrients should be applied at the right dose, right time and at the right place (Fixen and Reetz, 2006).

Significant progress has been made in overcoming soil fertility deficit in *Musa* fields. In Nigeria, Obiefuna et al. (1981) recommended 200 g N in 3-4 split applications (at 3 monthly intervals) with a basal dressing of 200 g each of potassium and phosphorus per plant for optimum yield. This recommendation is equivalent to 320 $kg.ha^{-1}$ of N, P and K each, at a plant population of 1600 per ha. Empirical data have shown that delayed fertilizer application beyond 3 months after planting (MAP) hinders the growth and yield of plantains (Obiefuna, 1984a); thus, fertilizer application should start not later than 2 MAP to ensure efficient nutrient utilization and optimal performance.

Nitrogen and potassium are the key nutrient elements for optimum growth and yield in *Musa* species (Twyford and Walmsley, 1974; Lahav and Turner 1989; Lahav, 1995). Nitrogen is essentially required in the synthesis of amino acids, proteins and enzymes for metabolic pathways. Among the essential plant nutrients, potassium assumes the greatest significance since it is required in relatively large quantities by plants. The K^+ requirement for *Musa* crops is often a double-fold that of N, and the high yield of plantains is associated with heavy potassium application (Bekunda and Manzi, 2003). An optimal dose of 300g K per plant (≈ 500 kg $K.ha^{-1}$ at 3 × 2 m spacing) applied to plantains at about 19/20th leaf stage (4-5 MAP, when it is most needed for floral initiation) had significant improvements on bunch yield and fruit metric traits compared to the control plants (Obiefuna, 1984b). The efficiency of fruit set is also increased by over 10%, while the maturity period is shortened for three months. K^+ is connected with the assimilation of CO_2 and the subsequent formation and translocation of sugars within the plant, and also with the utilization efficiency of available water (Ng Kee kwong et al., 1994).

Application of N-fertilizer could sometimes reduce the economic crop yield (Baiyeri, 2002), since nitrogen supports vegetative growth in crops. Baiyeri (2002) evaluated the effect of four rates (0, 224, 448, and 672 kg N/ha) of urea-N with basal application of 200 kg P_2O_5 and 350 kg K_2O per hectare on the growth, yield and harvest index of falsehorn plantain. Harvest index significantly increased up to 448 kg N/ha and then declined; meaning that the application of N-fertilizer beyond 448 kg N/ha had no added advantage in the study area.

Basically, the fertilizer requirements for *Musa* crops range from 200 to 400 kg/ha N, 45 to 60 kg/ha P, and 240 to 480 kg/ha K per year (FAO, 2000). However, Awodoyin (2003) recommended 320 kg N, 160 kg P_20_5 and 320 kg K_20 per hectare for optimal performance of plantains in the Nigerian rainforest belt. Wilson et al. (1987) suggested split application of mineral fertilizers in combination with organic mulching (3-5 $t.ha^{-1}$); thus 300 kg N and 550 kg K_2O per hectare annually in six split doses, P_2O_5 at 250 kg/ha (applied at planting) and $CaMg(SO_4)_2$ at 60 kg/ha biannually.

Despite the inorganic fertilizer nutrient combinations recommended to optimize yield of plantain crops, reports from the major producing countries of West and Central Africa identified that very few farmers use inorganic fertilizers due to poor access predicated on cost and poor distribution (Dauda, 1996; Katungi et al., 2006). Bekunda and Woomer (1996), however, identified a paucity of information on the optimal fertilizer recommendations and rates for plantains in most parts of West and Central Africa.

Agriculture in most part of Africa is characterized by poor yields owing to the severely depleted soils and low use of agricultural inputs including mineral fertilizers and improved seeds (Bationo et al., 2006). Organic sources of plant nutrients are certainly not available in sufficient quantities to optimize yield and feed the sub-Saharan Africa's current population of over 750 million (Vanlauwe, 2004). The use of mineral fertilizers is a swift approach to restore lost nutrients and bring life to the severely depleted soils (Van Keulen and Breman, 1990).

In this study, the growth and dry matter yield of a hybrid plantain, 'PITA 24' (Plantain of the International Institute of Tropical Agriculture) and a landrace, 'Agbagba', and the efficiency of the applied nutrients were evaluated across factorial doses of nitrogen and potassium fertilizers for a growth period of six months. Information obtained thereof would guide in future field trials. Studies (Baiyeri and Mbah, 1994; Ndukwe et al., 2012) have shown that pre-flowering growth parameters in plantains have significant and positive relationship with the final fruit yield.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the screen-house of the high rainfall station of the International Institute of Tropical Agriculture (IITA), Onne (04° 43' N, 07° 01' E, 10m above sea level), Rivers State, southeast Nigeria between March and September, 2007. The station is characterized by an average daily temperature of about 27°C, an annual unimodal rainfall of 2400 mm, solar radiation averaging 14 MJm^{-2}, and high relative humidity with average values ranging from 78% in February to 89% in July and September (Ortiz et al., 1997). The topsoil used for this study was characterized as a sandy loam (77 sand, 3% silt and 20% clay), and slightly acidic (pH 5.3) with moderate fertility. Organic matter content of 1.53%, total nitrogen of 0.09% and total phosphorus of 0.02% were recorded. The Zn, Fe, Cu and Mn contents of the soil were 8.63, 274, 1.24, and 28 mg/kg of soil, respectively; whereas the exchangeable cations including K^+, Ca^{2+}, Mg^{2+}, Na^+ and H^+ were 0.07, 1.40, 0.21, 0.38, and 0.84 $cmol^+.kg^{-1}$ of soil, respectively. The effective cation exchange capacity (ECEC) of 2.89 $cmol^+.kg^{-1}$ was recorded.

Design of experiment

In a screen-house study, a 4 × 4 factorial experiment involving four rates of N (0, 200, 400 and 600 $kg.ha^{-1}.yr^{-1}$) and K (0, 300, 600 and 900 kg K_2O $ha^{-1}.yr^{-1}$) were evaluated with a blanket dose of 100 kg P_2O_5 per hectare on growth, dry matter yield and nutrient use efficiency of 'PITA 24' and 'Agbagba' plantains. The sixteen fertilizer nutrient combinations were replicated eight times in split-plots (representing the two plantain genotypes under study) in completely randomized design.

Treatment application

Macro-propagated plants (Baiyeri and Aba, 2005) were grown with topsoil in polypots where fertilizer N, P and K were supplied using urea (46% N), single superphosphate (18% P_2O_5) and Muriate of Potash (60% K_2O), respectively. The varying calculated fertilizer doses were applied top-dressed in 2-split doses at 4 weeks after planting (WAP), and thereafter at 8 weeks. A systemic insecticide/nematicide Furadan 3G (3% a.i., carbofuran) was applied at 5 g per plant, and watering was regulated to minimize leaching losses.

Data collection

At 3 and 6 months after planting (MAP), data were collected on plant height (from soil level to the V-junction of the topmost opposite petioles), plant base girth (cm), number of live leaves and total leaf area (cm^2) per plant following Obiefuna and Ndubizu (1979). Four plants each across the fertilizer treatments were subjected to destructive sampling at 3 and 6 MAP to assess the dry matter accumulation and partitioning to the above-ground and below-ground components. Data were also collected on the number of roots per plant, length of the 5 longest roots and the corm cross-sectional diameter.

Nutrient use efficiencies *viz.*, agronomic efficiency (response ratio) and the partial factor productivity (*Pfp*) from applied nutrients were calculated as weight ratios following Jagadeeswaran et al. (2005); thus:

$$Agronomic\ Efficiency\ (AE) = \frac{(DMYield\ in\ fertilized\ plots) - (DMYield\ in\ control\ plot)}{Quantity\ of\ fertilizer\ nutrient\ applied\ (\mathrm{N\ or\ K_2O})}$$

Where, DMYield = whole plant dry matter yield.

$$Partial\ Factor\ Productivity\ (Pfp) = \frac{Total\ dry\ matter\ yield\ per\ plant}{Quantity\ of\ fertilizer\ nutrients\ received\ (\mathrm{N + P_2O_5 + K_2O})}$$

Partial factor productivity from the applied nutrients is a useful measure of nutrient use efficiency since it provides an integrative index that quantifies total yield relative to utilization of all nutrient resources in the system; thus, the decimal fraction of the plant yield to total applied nutrients (Cassman et al., 1996; Jagadeeswaran et al. (2005).

Statistical analysis

Analysis of variance (ANOVA) was performed on the generated data following the procedures outlined for factorial experiments in completely randomized design (CRD) using GenStat Discovery Edition 4 2011. Where the F-test was significant, treatment means were separated using Fisher's Least Significant Difference (F-LSD) at 5% probability level. Principal components analysis was also done to identify the most influenced or responsive parameters following the fertilizer treatment application. The data were further subjected to correlation analysis using the Pearson's multiple correlation analysis of SPSS 17.0 software (SPSS, 2008) to assess the interrelationships among the studied parameters.

RESULTS

Data presented in Table 1 are the plant growth parameters, dry matter yield and the nutrient use efficiencies of 'PITA 24' and 'Agbagba' plantains as influenced by varying combinations of N and K fertilizer doses after a 3-month growth period. Fertilizer application significantly ($p<0.05$) influenced the clonal performance and clone-by-fertilizer interaction effects in most of the studied parameters. In both clones, the shoot growth (height, pseudostem girth, number of leaves and total leaf

Table 1. Effects of N and K fertilizer doses on plant growth indices, dry matter yield and nutrient use efficiency in Agbagba and PITA 24 plantains measured at 3 months after planting (MAP).

Clone	Fertilizer dose [kg.ha^{-1}]	Ht [cm]	Gt [cm]	NL [#]	LA [m^2]	NR [#]	ARL [cm]	Dry matter yield per plant [g]			Nutrient use efficiencies		
								Above ground	Below ground	Whole plant	*AE*K$^+$	*AE*N	*PFP* [NPK]
Agbagba	Control	46.0	8.7	5	0.32	32	71.1	25.4	27.0	52.4	0.0	0.0	18.52
	N_0K_{300}	49.0	9.7	4	0.32	28	67.6	24.3	36.2	60.5	1.03	0.0	5.67
	N_0K_{600}	58.3	10.8	4	0.43	31	61.9	29.1	31.1	60.2	0.47	0.0	3.09
	N_0K_{900}	48.0	9.8	4	0.35	25	63.0	22.5	28.3	50.8	-0.07	0.0	1.86
	$N_{200}K_0$	67.0	11.3	5	0.68	24	52.2	32.1	21.9	54.0	0.0	0.29	6.47
	$N_{400}K_0$	73.3	12.0	4	0.60	28	60.0	39.9	25.5	65.4	0.0	1.18	4.72
	$N_{600}K_0$	61.0	11.3	6	0.73	29	46.4	47.4	22.9	70.3	0.0	1.08	3.63
	$N_{200}K_{300}$	78.3	14.0	8	1.05	39	44.3	65.8	35.7	101.5	6.26	8.89	6.26
	$N_{200}K_{600}$	91.7	14.7	7	1.22	39	50.4	78.0	51.4	129.4	4.62	13.95	5.17
	$N_{200}K_{900}$	95.0	15.2	7	1.34	33	48.6	82.5	45.5	128.0	3.09	13.70	3.89
	$N_{400}K_{300}$	83.3	13.6	7	1.15	33	57.3	81.4	37.1	118.5	8.43	5.99	5.46
	$N_{400}K_{600}$	90.0	16.0	9	1.26	36	42.1	73.0	39.8	112.8	3.63	5.47	3.69
	$N_{400}K_{900}$	88.3	15.4	9	1.43	35	48.8	81.4	48.6	130.0	3.17	7.03	3.39
	$N_{600}K_{300}$	76.7	14.4	8	1.08	33	48.5	62.3	31.5	93.8	5.28	2.50	3.44
	$N_{600}K_{600}$	80.0	14.4	7	1.05	26	45.2	66.0	37.1	103.1	3.04	3.06	2.86
	$N_{600}K_{900}$	85.0	15.4	7	0.98	21	35.5	60.0	28.8	88.8	1.49	2.20	2.02
	Mean	73.2	12.9	6	0.87	31	52.7	54.4	34.3	88.7	2.53	4.08	5.01
PITA 24	Control	53.3	8.5	5	0.38	38	78.6	28.7	37.1	65.8	0.0	0.0	23.25
	N_0K_{300}	61.0	10.3	6	0.68	39	69.8	48.4	49.2	97.6	4.06	0.0	9.15
	N_0K_{600}	65.0	11.3	5	0.59	31	62.4	35.8	30.6	66.4	0.04	0.0	3.41
	N_0K_{900}	65.0	11.8	6	0.58	31	51.7	29.1	27.1	56.2	-0.39	0.0	2.06
	$N_{200}K_0$	66.7	9.8	4	0.36	36	72.1	25.6	29.6	55.2	0.0	-1.92	6.61
	$N_{400}K_0$	63.3	11.3	5	0.42	33	73.9	29.5	30.6	60.1	0.0	-0.52	4.33
	$N_{600}K_0$	66.7	11.6	6	0.56	31	67.6	37.3	32.8	70.1	0.0	0.26	3.62
	$N_{200}K_{300}$	71.7	12.7	9	1.14	50	71.5	46.2	74.5	120.7	7.00	9.95	7.46
	$N_{200}K_{600}$	75.0	11.5	8	0.88	41	64.1	46.2	45.0	91.2	1.52	4.60	3.66
	$N_{200}K_{900}$	78.3	13.0	8	1.09	40	63.1	60.8	39.1	99.9	1.39	6.18	3.04
	$N_{400}K_{300}$	73.3	13.3	10	1.04	29	73.5	65.3	60.8	126.1	7.69	5.46	5.81
	$N_{400}K_{600}$	71.7	12.5	9	0.98	36	47.9	56.6	39.9	96.5	1.84	2.78	3.16
	$N_{400}K_{900}$	70.0	12.8	8	1.89	35	48.6	53.3	31.1	84.4	0.76	1.68	2.20
	$N_{600}K_{300}$	63.3	11.5	9	0.90	30	59.7	51.3	28.0	79.3	1.72	0.82	2.91
	$N_{600}K_{600}$	75.0	12.7	10	1.03	28	67.5	63.0	39.4	102.4	2.19	2.21	2.84
	$N_{600}K_{900}$	70.0	12.1	9	1.03	23	52.9	52.6	28.3	80.9	0.62	0.91	1.84

Table 1. Contd.

	Mean	68.1	11.7	7	0.85	32	64.4	45.6	38.9	84.6	1.78	2.03	5.33
$LSD_{0.05}$	Clones	3.0	0.4	0.5	ns	ns	6.4	4.9	Ns	Ns	0.59	0.75	ns
Clone × Fertilizer		12.1	1.8	ns	0.3	ns	ns	19.7	Ns	10.3	2.39	3.00	3.59

Ht = plant height; Gt = plant girth; NL = number of live leaves; LA = photosynthetically active leaf area; NR = number of roots; ARL = average length of the 5 longest roots; *AE* = agronomic efficiency of applied nutrient; PFP = partial factor productivity from applied nutrients; $LSD_{0.05}$ = Least significant difference at 5% probability level.

area per plant) improved significantly ($p<0.05$) with increasing doses of N and K, and plant growth was superior in all cases where both nutrients were applied together. Both clones maintained the best growth where N was applied at 200 or 400 $kg.ha^{-1}$ in combination with 300 to 900 $kg.ha^{-1}$ of K_2O. At these rates, the plants had the tallest height, largest stem girth and the broadest leaf area, and sustained greater number of leaves. Growth in 'PITA 24' was also fairly good at 600 kg N combined with 600-900 kg of K_2O per hectare.

The number of roots per plant was neither influenced by clone nor clone × fertilizer interaction. The average root length per plant seemingly declined with incremental doses of the fertilizer nutrients. In both clones, the shortest roots were observed at 400 kg N combined with 600 kg K_2O per hectare ($N_{400}K_{600}$). At 3 MAP, shoot growth was apparently better in 'Agbagba', but 'PITA 24' had longer roots.

The above-ground dry matter (AGDM) yield was significantly ($p<0.05$) influenced by clone, and clone × fertilizer interaction effects. In 'Agbagba', the AGDM yield was highest at $N_{200}K_{900}$ followed closely by $N_{400}K_{900}$. The AGDM yield in 'PITA 24' was highest at $N_{400}K_{300}$, but statistically similar in all cases where N and K were applied together. Below-ground dry matter (BGDM) yield at 3 MAP was neither influenced by clone nor clone × fertilizer interaction; rather there was a significant ($p<0.05$) clone-by-fertilizer interaction effect in the whole-plant dry matter (WPDM) yield. In 'Agbagba', WPDM yield was highest (130 g) where 400 kg N was combined with 900 kg K_2O ($N_{400}K_{900}$) per hectare. This was however not statistically different from the dry matter yield obtained at $N_{200}K_{600}$ (129.4 g) and $N_{200}K_{900}$ (128 g). At these rates ($N_{400}K_{900}$, $N_{200}K_{600}$ and $N_{200}K_{900}$), there was a somewhat synergistic improvement in WPDM yield (positive nutrient interaction), since the combined doses of both nutrients produced greater dry matter yields than observed from the sole nutrients summed together. In 'PITA 24', dry matter yield was highest at $N_{400}K_{300}$ (126.1 g). Dry matter yield in both clones was correspondingly low in all cases where the fertilizer nutrients were applied singly, especially when a high dose of K_2O (900 kg per hectare) was applied. The WPDM yield in both clones increased sequentially with incremental doses of N, where N was applied singly (i.e., $N_{600}K_0$ > $N4_{00}K_0$ > $N_{200}K_0$). Dry matter yield was a little higher in 'Agbagba' after the 3-month growth period.

Significant ($p<0.05$) clone and clone × fertilizer interaction effects were observed in the calculated efficiencies of the applied nutrients. The agronomic efficiency (*AE*) of applied K^+ (that is, dry matter yield per unit of K_2O applied) in both clones was highest at $N_{400}K_{300}$, followed closely by $N_{200}K_{300}$. Nitrogen use efficiency (agronomic efficiency of applied nitrogen, *AE*-N; that is, the dry matter yield per unit dose of applied N) in 'Agbagba' was highest at $N_{200}K_{600}$ (13.95) followed closely by $N_{200}K_{900}$ (13.70). In 'PITA 24', the *AE*-N was highest at $N_{200}K_{300}$ (9.95) followed by $N_{200}K_{900}$ (6.18). At 3 MAP, N and K use efficiency values were higher in 'Agbagba'. The partial factor productivity (*Pfp*) from the applied nutrients (calculated as the plant dry matter yield per unit dose of N + P_2O_5 + K_2O) was not influenced by clone, but by clone × fertilizer interaction. The *Pfp* value was exceedingly high in the control plants where K and N fertilizers were not applied. Among the plants that received ample doses of N, P and K, the *Pfp* value from the three fertilizer nutrients was significantly ($p<0.05$) superior at $N_{200}K_{300}$ in both clones.

At 6 MAP (Table 2), plant growth indices (height, stem girth, number of live leaves, leaf area) and dry matter yield in both clones were statistically ($p<0.05$) superior in plants that received the two fertilizer nutrients (N and K) together. In 'Agbagba', the tallest plants were observed at $N_{400}K_{600}$ and $N_{600}K_{900}$. In this clone, the pseudostem girth was largest where N was applied at 200 or 400 $kg.ha^{-1}$ in combination with 300 to 900 kg K_2O per hectare. Plants that received 400 or 600 kg of N in combination with 300 to 900 kg of K_2O produced the highest number of leaves and the broadest leaf area. The tallest and widest girth plants in 'PITA 24' were observed where 400 or 600 kg N was combined with 600 to 900 kg K_2O per hectare. In this clone, the number of leaves was high and similar in all the plants that received 400 or 600 kg N

Table 2. Effects of N & K fertilizer doses on plant growth indices, dry matter yield and nutrient use efficiency in Agbagba and PITA 24 plantains measured at 6 months after planting (MAP).

Clone	Fertilizer dose [kg.ha^{-1}]	Ht [cm]	Gt [cm]	NL [#]	LA [m^2]	NR [#]	ARL [cm]	Dry matter yield per plant [g]			Nutrient use efficiencies		
								Above ground	Below ground	Whole plant	*AEK*$^+$	*AE*N	*PFP* [NPK]
Agbagba	Control	53.3	11.1	4	0.24	38	104.7	37.1	28.7	65.8	0.0	0.0	23.25
	N_0K_{300}	56.7	12.9	4	0.31	32	71.7	43.7	55.0	98.7	4.19	0.0	9.25
	N_0K_{600}	59.0	14.8	4	0.31	36	79.1	34.7	36.9	71.6	0.35	0.0	3.67
	N_0K_{900}	55.0	14.4	4	0.24	30	73.7	32.1	52.6	84.7	0.77	0.0	3.10
	$N_{200}K_0$	71.7	13.8	3	0.32	40	73.5	44.7	29.4	74.1	0.0	1.50	8.87
	$N_{400}K_0$	74.0	14.3	3	0.49	36	69.3	49.2	37.8	87.0	0.0	1.92	6.27
	$N_{600}K_0$	72.5	13.0	5	0.52	32	59.3	55.2	28.5	83.7	0.0	1.08	4.32
	$N_{200}K_{300}$	83.0	17.6	6	1.14	43	71.1	88.6	60.5	149.1	10.63	15.09	9.21
	$N_{200}K_{600}$	95.0	17.6	6	1.21	42	67.7	83.3	77.5	160.8	5.70	17.21	6.43
	$N_{200}K_{900}$	97.0	17.5	6	1.37	45	54.8	106.3	62.1	168.4	4.19	18.58	5.13
	$N_{400}K_{300}$	88.0	15.9	6	1.23	45	77.5	86.3	45.4	131.7	8.41	5.97	6.07
	$N_{400}K_{600}$	101.0	17.6	7	1.59	37	60.3	116.7	51.3	168.0	6.13	9.26	5.50
	$N_{400}K_{900}$	88.0	17.6	7	1.48	37	54.3	109.8	52.4	162.2	3.93	8.73	4.22
	$N_{600}K_{300}$	90.0	16.1	8	1.49	36	51.9	100.4	46.4	146.8	10.33	4.89	5.39
	$N_{600}K_{600}$	91.0	15.4	7	1.44	33	52.1	104.2	38.3	142.5	4.60	4.63	3.95
	$N_{600}K_{900}$	101.0	16.4	8	1.65	27	40.1	122.9	31.6	154.5	3.62	5.35	3.52
	Mean	79.8	15.4	5	0.94	37	66.3	75.9	45.9	121.9	3.93	5.89	6.76
PITA 24	Control	58.0	10.3	4	0.31	44	83.6	29.9	55.8	85.7	0.0	0.0	30.28
	N_0K_{300}	66.0	11.4	4	0.55	41	81.5	61.0	112.8	173.8	11.23	0.0	16.28
	N_0K_{600}	71.0	12.6	4	0.57	34	66.2	59.4	93.9	153.3	4.05	0.0	7.86
	N_0K_{900}	72.0	13.0	4	0.64	38	73.4	63.0	107.8	170.8	3.47	0.0	6.25
	$N_{200}K_0$	80.0	10.9	3	0.48	42	94.0	41.2	73.3	114.5	0.0	5.22	13.71
	$N_{400}K_0$	88.8	12.8	4	0.69	37	75.3	59.2	91.0	150.2	0.0	5.84	10.83
	$N_{600}K_0$	89.0	13.1	4	1.00	53	87.7	65.5	86.2	151.7	0.0	3.98	7.82
	$N_{200}K_{300}$	98.0	15.9	6	1.56	62	76.5	111.4	157.9	269.3	23.42	33.26	16.63
	$N_{200}K_{600}$	105.0	16.9	8	1.99	61	74.8	110.1	159.7	269.8	11.05	33.35	10.79
	$N_{200}K_{900}$	104.0	16.3	7	1.87	53	63.5	110.1	110.3	220.4	5.50	24.40	6.71
	$N_{400}K_{300}$	101.0	15.3	10	2.01	37	74.7	112.0	107.0	219.0	17.00	12.07	10.09
	$N_{400}K_{600}$	112.0	17.6	11	2.45	54	67.3	129.5	125.3	254.8	10.15	15.31	8.34
	$N_{400}K_{900}$	113.0	17.8	11	2.40	59	61.0	151.0	120.7	271.7	7.59	16.85	7.08
	$N_{600}K_{300}$	102.0	16.0	11	1.16	52	69.1	115.8	146.5	262.3	22.52	10.66	9.63
	$N_{600}K_{600}$	103.0	17.2	11	2.26	56	67.9	131.1	129.5	260.6	10.50	10.56	7.23
	$N_{600}K_{900}$	113.0	17.6	11	2.34	51	55.9	140.1	130.7	270.8	7.55	11.18	6.17

Table 2. Contd.

	Mean	92.2	14.7	7	1.46	48	73.3	93.1	111.1	206.1	8.38	11.41	10.98
$LSD_{0.05}$	Clones	2.9	0.4	1.0	0.08	3.0	ns	5.8	11.5	15.7	1.05	1.50	1.56
Clone × Fertilizer		11.7	1.7	2.0	0.32	11.0	ns	16.7	27.7	Ns	4.20	6.10	ns

Ht = plant height; Gt = plant girth; NL = number of live leaves; LA = photosynthetically active leaf area; NR = number of roots; ARL = average length of the 5 longest roots; *AE* = agronomic efficiency of applied nutrient; PFP = partial factor productivity from applied nutrients; $LSD_{0.05}$ = Least significant difference at 5% probability level.

in combination with 300 to 900 kg K_2O per hectare. The total leaf area per plant in 'PITA 24' was statistically (p<0.05) superior at $N_{400}K_{600}$ (2.45 m^2), $N_{400}K_{900}$ (2.40 m^2), $N_{600}K_{600}$ (2.26 m^2) and $N_{600}K_{900}$ (2.34 m^2).

In both clones, the number of roots per plant was superior when 200 kg N was applied with 300 to 900 kg K_2O per hectare, but root number and root length seemingly declined at higher doses of N and K combinations.

In 'Agbagba', the longest roots were observed in the control plants (104.7 cm), whereas $N_{200}K_0$ produced the longest roots (94.0 cm) in 'PITA 24'. The AGDM yield in 'Agbagba' was superior and statistically similar at $N_{400}K_{600}$ (116.7 g) and $N_{600}K_{900}$ (122.9 g), whereas $N_{400}K_{900}$ produced the highest AGDM yield (151.0 g) in 'PITA 24' followed closely by $N_{600}K_{900}$ (140.1 g), $N_{600}K_{600}$ (131.1 g) and $N_{400}K_{600}$ (129.5 g), respectively. Combinations $N_{200}K_{600}$ and $N_{200}K_{300}$ produced the highest BGDM yield in both clones. In 'Agbagba' the highest WPDM yield was recorded at $N_{200}K_{900}$ (168.4 g). A similar whole-plant dry matter (WPDM) yield was produced at $N_{400}K_{600}$ (168.0 g), $N_{400}K_{900}$ (162.2 g) and $N_{200}K_{600}$ (160.8 g). The WPDM yield in 'PITA 24' was highest at $N_{400}K_{900}$ (271.7 g), followed by $N_{600}K_{900}$ (270.8 g), $N_{200}K_{600}$ (269.8 g) and $N_{200}K_{300}$ (269.3 g), respectively; and was equally high in all combinations where N and K were applied together.

In both clones, the agronomic efficiency of applied potassium (*AE*-K^+) was highest at $N_{200}K_{300}$, followed by $N_{600}K_{300}$ and $N_{400}K_{300}$, respectively. In 'Agbagba' the agronomic efficiency of applied nitrogen (*AE*-N) at 6 MAP was highest at $N_{200}K_{900}$ (18.58) followed closely by $N_{200}K_{600}$ (17.21) and $N_{200}K_{300}$ (15.09). The *AE*-N value in 'PITA 24' was highest and similar for $N_{200}K_{600}$ (33.35) and $N_{200}K_{300}$ (33.26), followed by $N_{200}K_{900}$ (24.40 g).

In all cases where ample doses of N and K were applied together, the partial factor productivity (*Pfp*) from the applied nutrients (N, P and K) in both clones was highest at $N_{200}K_{300}$ followed by $N_{200}K_{600}$ and $N_{400}K_{300}$, respectively. The *Pfp* value was exceedingly high in the control plants where N and K were not applied. For each nutrient element, the *Pfp* value declined progressively as the nutrient dose increased. At 6 MAP, plant height, number of leaves per plant, total leaf area, number of roots and average root length per plant were statistically (p<0.05) superior in 'PITA 24', but pseudostem girth was larger in 'Agbagba'. Dry matter yield and the nutrient use efficiency values were almost double-fold higher in 'PITA 24'.

The main effect of the fertilizer nutrient doses on plantain growth, dry matter yield and nutrient use efficiency (at 3 and 6 MAP) presented in Table 3 were in most cases significant (p<0.05). At 3 MAP, plant height, stem girth and number of leaves were similar and superior in all cases where N and K were applied together, whereas the poorest growth was observed in the control plants. The largest leaf area was recorded at $N_{400}K_{900}$ (1.66 m^2), followed by $N_{200}K_{900}$ (1.21 m^2) and $N_{400}K_{600}$ (1.12 m^2), respectively. Leaf area was relatively large in all cases where N and K were applied together, whereas root length seemingly declined with incremental doses of applied nutrients. The number of roots per plant was highest at $N_{200}K_{300}$ (44), followed by $N_{200}K_{900}$ (43) and $N_{200}K_{600}$ (40), respectively. Also at 3 MAP, the above-ground and whole-plant dry matter yield values were highest at $N_{400}K_{300}$, followed by $N_{200}K_{900}$, and significantly (p<0.05) high in all cases where N and K were applied together. The *AE*-K^+ was highest at $N_{400}K_{300}$ (8.06), followed by $N_{200}K_{300}$ (6.63), whereas the efficiency of applied nitrogen (*AE*-N) was high and statistically similar in $N_{200}K_{900}$ (9.93), $N_{200}K_{300}$ (9.42) and $N_{200}K_{600}$ (9.27). The partial factor productivity (*Pfp*) value (for the plants that received N, P and K) was highest at $N_{200}K_{300}$ (6.86), followed by $N_{400}K_{300}$ (5.63), whereas $N_{600}K_{900}$ recorded the least value (1.93).

At 6 MAP (Table 3), plant height was tallest at $N_{600}K_{900}$ (107.0 cm), followed by $N_{400}K_{600}$ (106.5 cm); and correspondingly high in all cases where ample doses of N and K were applied together. Similarly, pseudostem girth, number of leaves per plant, and leaf area values were statistically superior where N and K were applied together, and were highest at $N_{400}K_{900}$, $N_{600}K_{900}$ and

Table 3. Main effect of combined doses of N and K on growth, dry matter yield and nutrient use efficiency in plantains (*Musa* AAB) measured at 3 and 6 months after planting.

Fertilizer dose [kg.ha^{-1}]	Ht [cm]	Gt [cm]	NL [#]	LA [m^2]	NR [#]	ARL [cm]	Dry matter yield per plant [g]			Nutrient use efficiencies		
							Above ground	Below ground	Whole Plant	*AE*K$^+$	*AE*N	*PFP* [NPK]
						3 months after planting						
Control	49.7	8.6	5	0.35	38	77.4	27.0	32.1	59.1	0.0	0.0	20.88
N_0K_{300}	55.0	10.0	5	0.50	34	76.6	36.3	42.7	79.0	2.54	0.0	7.41
N_0K_{600}	61.7	11.1	5	0.51	33	62.2	32.5	30.8	63.3	0.25	0.0	3.25
N_0K_{900}	56.5	10.8	5	0.46	30	62.7	25.8	27.7	53.5	-0.28	0.0	1.96
$N_{200}K_0$	66.9	10.6	4	0.52	38	73.1	28.8	25.8	54.6	0.0	-0.82	6.54
$N_{400}K_0$	68.3	11.7	5	0.51	35	67.7	34.6	28.1	62.7	0.0	0.33	4.52
$N_{600}K_0$	63.9	11.5	6	0.65	30	67.0	42.3	27.9	70.2	0.0	0.67	3.62
$N_{200}K_{300}$	75.0	13.4	8	1.09	44	57.9	56.0	55.1	111.1	6.63	9.42	6.86
$N_{200}K_{600}$	83.3	13.1	8	1.05	40	57.3	62.1	48.2	110.3	3.07	9.27	4.41
$N_{200}K_{900}$	86.7	14.1	8	1.21	43	56.1	71.6	42.3	113.9	2.24	9.93	3.47
$N_{400}K_{300}$	78.3	13.5	9	1.10	37	65.4	73.4	49.0	122.4	8.06	5.72	5.63
$N_{400}K_{600}$	80.8	14.2	9	1.12	36	45.0	64.8	39.8	104.6	2.73	4.13	3.43
$N_{400}K_{900}$	79.2	14.1	9	1.66	36	48.7	67.4	39.9	107.2	1.96	4.36	2.79
$N_{600}K_{300}$	70.0	12.9	9	0.99	31	54.1	56.8	29.8	86.6	3.50	1.66	3.18
$N_{600}K_{600}$	77.5	13.6	8	1.04	31	56.5	64.5	38.2	102.7	2.62	2.63	2.85
$N_{600}K_{900}$	77.5	13.8	8	1.00	22	48.0	56.3	28.5	84.8	1.05	1.55	1.93
$LSD_{(0.05)}$	8.6	1.3	1.0	0.4	12	18.2	14.0	ns	29.0	1.69	2.12	2.54
						6 months after planting						
Control	55.6	10.7	4	0.27	38	91.6	33.5	42.2	75.7	0.0	0.0	26.77
N_0K_{300}	61.0	12.2	4	0.43	36	68.7	52.4	83.9	136.3	7.71	0.0	12.77
N_0K_{600}	65.0	13.7	4	0.44	32	72.7	47.0	65.4	112.4	2.20	0.0	5.77
N_0K_{900}	63.5	13.7	4	0.44	31	68.2	47.6	80.2	127.8	2.12	0.0	4.67
$N_{200}K_0$	75.9	12.4	3	0.40	33	72.8	43.0	51.3	94.3	0.0	3.36	11.29
$N_{400}K_0$	81.4	13.6	3	0.59	33	71.6	54.2	64.4	118.6	0.0	3.88	8.55
$N_{600}K_0$	80.8	13.1	4	0.76	43	63.5	60.4	57.3	117.7	0.0	2.53	6.07
$N_{200}K_{300}$	90.5	16.8	6	1.35	52	73.8	100.0	109.2	209.2	17.02	24.17	12.92
$N_{200}K_{600}$	100.0	17.3	7	1.60	51	71.2	96.7	118.6	215.3	8.38	25.28	8.61

Table 3. Contd.

$N_{200}K_{900}$	100.5	16.9	7	1.62	43	59.0	108.2	86.2	194.4	4.84	21.49	5.92
$N_{400}K_{300}$	94.5	15.6	8	1.62	35	76.1	99.2	76.2	175.4	12.70	9.02	8.08
$N_{400}K_{600}$	106.5	17.6	9	2.02	46	63.8	123.1	88.3	211.4	8.14	12.29	6.92
$N_{400}K_{900}$	100.5	17.7	9	1.94	47	57.7	130.4	86.5	216.9	5.76	12.79	5.65
$N_{600}K_{300}$	96.0	16.1	9	1.83	44	60.5	108.1	96.5	204.6	16.43	7.77	7.51
$N_{600}K_{600}$	97.0	16.3	9	1.85	41	59.8	117.7	83.9	201.6	7.55	7.60	5.59
$N_{600}K_{900}$	107.0	17.0	10	1.99	40	44.2	131.5	81.2	212.7	5.59	8.27	4.84
$LSD_{(0.05)}$	8.3	1.2	1.0	0.22	7	12.3	16.3	32.6	44.4	2.96	4.31	4.40

Ht = plant height; Gt = plant girth; NL = number of live leaves; LA = photosynthetically active leaf area; NR = number of roots; ARL = average length of the 5 longest roots; *AE* = agronomic efficiency of applied nutrient; PFP = partial factor productivity from applied nutrients; $LSD_{(0.05)}$ = Least significant difference at 5% probability level.

$N_{400}K_{600}$. Also at 6 MAP, the highest number of roots were produced at $N_{200}K_{300}$ (52) and $N_{200}K_{600}$ (51), whereas the control plants produced the longest roots. Thus, root length declined with incremental doses of the applied nutrients.

The dry matter yield at 6 MAP was poorest in the control plants, and was generally poor in all cases where the nutrient elements were applied singly. The AGDM yield was high, and statistically similar at $N_{600}K_{900}$ (131.5 g), $N_{400}K_{900}$ (130.4 g), $N_{400}K_{600}$ (123.1 g) and $N_{600}K_{600}$ (117.7 g). Below-ground dry matter yield (BGDM) was highest at $N_{200}K_{600}$ (118.6 g), followed by $N_{200}K_{300}$ (109.2 g). The WPDM yield at 6 MAP was significantly ($p<0.05$) higher in all cases where N and K were applied together. Whole-plant dry matter yield was highest at $N_{400}K_{900}$ (216.9 g), followed by $N_{200}K_{600}$ (215.3 g), $N_{600}K_{900}$ (212.7 g), $N_{400}K_{600}$ (211.4 g), and $N_{200}K_{300}$ (209.2 g), respectively. The control plants produced the least dry matter yield (75.7 g) after $N_{200}K_0$ (94.3 g). Potassium use efficiency was significantly ($p<0.05$) high at $N_{200}K_{300}$ (17.02) and $N_{600}K_{300}$ (16.43), followed by $N_{400}K_{300}$ (12.70), $N_{200}K_{600}$ (8.38) and $N_{400}K_{600}$ (8.14), respectively. The *AE*-N value was high and statistically similar in $N_{200}K_{600}$ (25.28), $N_{200}K_{300}$ (24.17) and $N_{200}K_{900}$ (21.49), followed by $N_{400}K_{900}$ (12.79) and $N_{400}K_{600}$ (12.29). Among the plants that received the three nutrient elements (NPK), the *Pfp* value was highest at $N_{200}K_{300}$ (12.92), followed by $N_{200}K_{600}$ (8.61), $N_{400}K_{300}$ (8.08), $N_{600}K_{300}$ (7.51) and $N_{400}K_{600}$ (6.92), respectively. The poorest value (among the plants that received N, P and K) was recorded in $N_{600}K_{900}$ (4.84).

The principal component analysis (PCA) results (Table 4) captured more than 80% of the total variation that existed among the studied parameters following the fertilizer treatments after the 3 and 6 months growth periods. Plant stature (height, stem girth, leaf area, number of live leaves), the above-ground and whole-plant dry matter yield, and the agronomic efficiency of applied nitrogen (*AE*-N) accounted for more than half (51.44 to 60.70%) of the total variation observed at the end of the 3 and 6 months growth periods. The partial factor productivity (*Pfp*) from the applied nutrients (a ratio of dry matter yield to the total applied nutrients) and the length of the plant roots, and the below-ground dry matter yield explained merely 15 to 18% of the total variation, whereas the number of roots per plant explained about 8.34 and 5.48% of the observed variations at 3 and 6 MAP, respectively.

The correlative responses among the studied parameters for the 3 and 6 months growth periods are shown in Table 5. Pseudostem girth had a very strong positive relationship with plant height at both growth periods. Throughout the study period, the number of leaves per plant maintained a moderate positive significant ($p<0.05$) relationship with plant height, stem girth, whole-plant and below-ground dry matter yield, as well as, the agronomic efficiency of applied nitrogen and potassium.

At 3 MAP, the number of roots per plant had very low positive relationship with plant height ($r=0.261^*$), girth ($r=0.270^*$), number of live leaves ($r=0.029$) and total leaf area ($r=0.201^*$). The magnitude of these coefficients greatly increased at 6 MAP. The

Table 4. Principal Component Analysis† showing the relative contributions of growth traits, dry matter yield and nutrient use efficiencies to the total variation observed following the fertilizer treatment applications after a 3 and 5 months growth periods

Traits	3 months after planting				6 months after planting			
	Prin1 (51.44%)	**Prin2 (18.56%)**	**Prin3 (8.34%)**	**Prin4 (5.24%)**	**Prin1 (60.70%)**	**Prin2 (15.34%)**	**Prin3 (5.48%)**	**Prin4 (4.83%)**
AE-K^+	-0.26165	-0.29142	0.34909	0.02662	-0.26083	-0.19989	0.06656	0.06644
AE-N_2	**-0.27881**	-0.24057	0.23557	-0.21356	**-0.27840**	-0.17868	-0.14090	0.36261
PFP [NPK]	0.04618	**-0.44108**	-0.36316	0.69081	0.00566	**-0.56777**	0.03868	**-0.65799**
AgDM (g)	**-0.35876**	0.06509	-0.11315	0.08713	**-0.33196**	0.13409	0.09943	-0.16919
AvRL (cm)	0.12476	**-0.40335**	0.45728	-0.22433	0.06430	**-0.49490**	0.67057	0.43211
BgDM (g)	-0.23367	**-0.44529**	-0.02050	-0.07528	-0.27476	-0.35724	-0.16083	0.03459
CD (cm)	**-0.34381**	0.11848	-0.07431	-0.13863	**-0.31852**	0.06985	-0.13442	0.18455
PGt (cm)	**-0.34523**	0.21320	-0.07205	-0.01662	**-0.33032**	0.17513	0.09402	0.08264
PHt (cm)	**-0.31464**	0.21026	-0.16626	-0.17436	**-0.31121**	0.16485	0.11309	0.09609
LA (m^2)	**-0.30247**	0.20608	0.10158	0.20501	**-0.33353**	0.14681	0.21939	-0.12973
NLvs (#)	-0.26222	0.13688	0.43159	**0.49987**	**-0.27830**	0.19580	0.40072	-0.37845
Rts (#)	-0.17506	-0.30056	**-0.47614**	-0.26631	-0.23402	-0.25938	**-0.48749**	0.02504
WPDM (g)	**-0.35428**	-0.20542	-0.08232	0.01303	**-0.33723**	-0.15916	-0.05237	-0.06171
Latent Roots	6.687	2.413	1.084	0.681	7.892	1.994	0.712	0.628

PHt = plant height; PGt = plant girth; NLvs = number of live leaves; LA = photosynthetically active leaf area; CD = corm cross-sectional diameter; Rts = number of roots; AvRL = average length of the 5 longest roots; *AE* = agronomic efficiency of applied nutrient; PFP [NPK] = partial factor productivity from applied nutrients, AgDM = above-ground dry matter yield, BgDM = below-ground dry matter yield, WPDM = whole-plant dry matter yield (†PCA based on correlation matrix).

number of roots per plant also maintained moderate positive significant ($p<0.05$) relationships with the nutrient use efficiency values (*Pfp*, *AE*-N and *AE*-K^+), as well as, the below-ground and whole-plant dry matter yield at both growth periods.

The average root length had very weak relationship with most of the parameters studied at 3 months. At 6 MAP, moderate to high positive significant ($p<0.01$) relationships were maintained between the root length and most of the other parameters. For instance, the correlation coefficients between the root length (AvRL) and *AE*-N, *AE*-K^+, WPDM, BgDM yield and number of roots per plant were 0.696**, 0.672**, 0.678**, 0.678** and 0.915**, respectively. Similarly, corm size (diameter) increased significantly ($p<0.05$) with plant size (height, girth, number of leaves, leaf area and root number), the agronomic efficiencies of applied nitrogen and potassium, as well as, the dry matter yield at both growth periods.

The partial factor productivity (*Pfp*) from applied nutrients had very poor relationship with most of the studied parameters at both growth periods. However at 6 MAP, a weak but significant ($p<0.01$) positive relationship existed between *Pfp* and root length (r=0.329**), the above-ground dry matter (r=0.394**) and below-ground dry matter yield (r=0.203*). The agronomic efficiency of applied nutrients (N and K) had moderate positive significant ($p<0.01$) relationships with the plant growth parameters (including plant height, pseudostem girth, number of leaves, leaf area, number of roots and corm diameter) and dry matter yield at both growth stages. The whole-

Table 5. Linear correlation matrix between the plant growth parameters, dry matter yield and nutrient use efficiency in plantains measured at 3 and 6 MAP as influenced by factorial combinations of N and K fertilizer.

Traits[†]	3 months after planting												
	PFP$_{[NPK]}$	AE-N_2	AE-K^+	WPDM	BgDM	AgDM	AvRL	CD	#Rts	LA	NLvs	PGt	PHt
PHt	-0.286**	0.416**	0.330**	0.669**	0.260*	0.836**	-0.434**	0.778**	0.261*	0.674**	0.454**	0.827**	1
PGt	-0.305**	0.473**	0.396**	0.726**	0.339**	0.859**	-0.487**	0.865**	0.270**	0.791**	0.626**	1	
NLvs	-0.207*	0.453**	0.521**	0.495**	0.209*	0.606**	-0.239*	0.522**	0.029ns	0.676**	1		
LA	-0.249*	0.429**	0.393**	0.562**	0.229*	0.694**	-0.361**	0.704**	0.201*	1			
#Rts	0.266**	0.410**	0.387**	0.520**	0.517**	0.374**	-0.059ns	0.296**	1				
CD	-0.236*	0.542**	0.450**	0.778**	0.443**	0.849**	-0.375**	1					
AvRL	0.238*	0.028ns	0.138ns	-0.119ns	0.201*	-0.366**	1						
AgDM	-0.077ns	0.553**	0.545**	0.867**	0.433**	1							
BgDM	0.354**	0.666**	0.654**	0.825**	1								
WPDM	0.148ns	0.715**	0.704**	1									
AE-K^+	0.074ns	0.691**	1										
AE-N_2	-.001ns	1											
PFP$_{[NPK]}$	1												
	6 months after planting												
PHt	-0.165ns	0.641**	0.511**	0.799**	0.489**	-0.211*	0.518**	0.836**	0.739**	0.879**	0.685**	0.900**	1
PGt	-0.198*	0.697**	0.554**	0.863**	0.500**	-0.259**	0.568**	0.919**	0.812**	0.912**	0.744**	1	
NLvs	-0.134ns	0.407**	0.492**	0.614**	0.388**	-0.243**	0.423**	0.810**	0.667**	0.905**	1		
LA	-0.131ns	0.642**	0.599**	0.802**	0.539**	-0.222*	0.584**	0.921**	0.823**	1			
#Rts	0.168ns	0.758**	0.741**	0.837**	0.666**	-0.064ns	0.915**	0.857**	1				
CD	-0.080ns	0.646**	0.644**	0.830**	0.482**	-0.300**	0.575**	1					
AvRL	0.329**	0.696**	0.672**	0.678**	0.678**	0.134ns	1						
AgDM	0.394**	0.020ns	0.044ns	-0.210*	0.002ns	1							
BgDM	0.203*	0.585**	0.502**	0.572**	1								
WPDM	-0.145ns	0.649**	0.588**	1									
AE-K^+	0.129ns	0.608**	1										
AE-N_2	.104ns	1											
PFP$_{[NPK]}$	1												

** Correlation is significant at 1% probability level (2-tailed); *Significant at 5% probability level; ns = not significant, [†]Description of studied traits is same as in Table 4.

plant dry matter yield maintained a high positive relationship with plant height, pseudostem girth, leaf area, root number, corm diameter and the efficiency of applied nutrients (N and K), particularly at 6 MAP.

DISCUSSION

The significant variability observed in the growth indices and plant stature (height, stem girth, leaf number, leaf area, etc.), dry matter yield, and the efficiency of nutrient use in this study corroborates the assertion that plant nutrition is the most singular factor controlling growth behavior and crop yields (Akinrinde, 2006). In this study, plants that received ample doses of nitrogen and potassium maintained superior growth and higher dry matter yield than those grown with single doses of the either nutrients (N or K), and the non-fertilized control plants. This observation is in line with the Liebig's law of minimum, that 'the most limiting factor of crop production determines the extent of crop performance'. Thus, an addition of the most limiting element would often cause more efficient utilization of a less limiting element. In addition to nutrient amounts, the balance between different nutrients plays a vital role in the improvement of crop yields (Krauss, 2000). Changing the level of one nutrient element in the soil will often affect the uptake or transport within the plant of another nutrient. In a complete nutrient management program, balanced nutrient supply is very important since 'optimum nutrient ratios' in the soil or plant tissues could be obtained even when nutrient amounts are not in the sufficient range. Two nutrients could both be in the deficiency range or at toxicity levels, yet maintain an optimum balance (Jones, 2002).

The potassium requirement for *Musa* crops is often a double-fold that of nitrogen (Lahav, 1995; Bekunda and Manzi, 2003). Conversely, potassium deficiency diminishes growth and yield potentials in bananas and plantains because of the decreased uptake of other essential elements, particularly N and P (Twyford and Walmsley, 1973; Akinyemi et al., 2004). Although high concentrations of K^+ may be tolerated in plants, a significant yield reduction has been reported in plantain due to the inhibitory action of excessive doses of potassium on the absorption of other plant nutrients (Obiefuna, 1984b). In the present study, the two plantain genotypes maintained their best growth where N was applied at 200 or 400 kg.ha^{-1} in combination with 300, 600 or 900 kg K_2O per hectare. Thus, fertilizer combinations $N_{200}K_{900}$ (that is, 200 kg N + 900 kg K_2O.ha^{-1}), $N_{400}K_{600}$, $N_{400}K_{900}$, $N_{200}K_{600}$, $N_{600}K_{900}$ and $N_{200}K_{300}$ produced the highest dry matter yield suggesting that besides the essentiality of N and K in the nutrition of plantain crops, higher doses of potassium are required than nitrogen. The whole-plant dry matter yield was expectedly poorest in the control plants, and was generally poor in all cases where the nutrient elements were applied singly.

It was also observed from this study that the efficiency of nutrients use varied significantly with factorial doses of the applied nutrients. At the end of the 6-month growth period, potassium use efficiency values were high where K_2O was applied at 300 or 600 kg.ha^{-1} in combination with 200, 400 or 600 kg of nitrogen per hectare. Similarly, the efficiency of applied N was high and statistically similar where nitrogen was applied at 200 or 400 kg in combination with 300 to 900 kg K_2O per hectare. The partial factor productivity value from the applied nutrients (dry matter yield per unit dose of N + P_2O_5 + K_2O) was highest in plants that received a combination of 200 kg N and 300 kg K_2O with the blanket application of 100 kg P_2O_5 per hectare. This suggests that within the limits of the present study, it would be most economical to grow plantain with 200 kg N and 300 kg K_2O per hectare. In soils of poor native fertility, yield potential is expected to be higher at 400 kg N plus 600 kg K_2O.ha^{-1}. As earlier stated, the fertilizer requirements for *Musa* crops range from 200 to 400 kg/ha N, 45 to 60 kg/ha P, and 240 to 480 kg/ha K per year (FAO, 2000). Wilson et al. (1987) suggested split applications of 300 kg N and 550 kg K_2O per hectare annually in combination with organic mulching (at 3-5 t.ha^{-1}) and P_2O_5 at 250 kg/ha (applied at planting) for optimal performance of plantains in the rainforest belt of West and Central Africa. Stover and Simmonds (1987) also recommended 300 to 600 kg nitrogen and 400 to 800 kg potassium per hectare for the dessert bananas.

The principal component analysis results revealed that plant stature (height, stem girth, corm size diameter, number of leaves per plant, and total leaf area), the whole-plant dry matter yield and the agronomic efficiency of applied nitrogen were the most influenced parameters following the fertilizer treatment applications. The correlative responses between these variables were found to be highly positive, meaning that they would increase or decrease correspondingly with each other in response to applied fertilizer treatment. At the end of the 6-month growth period, 'PITA 24', a hybrid genotype, maintained a better growth, produced higher dry matter yield, and had a greater efficiency of nutrient use than the landrace plantain, 'Agbagba'. Variability in the efficiency of resource conversion and biomass yield has been observed in *Musa* species, and could be attributed to differences in genomes (Robinson, 1996; Stover and Simmonds, 1987). In an earlier study (Aba et al., 2009), bunch and fruit yield in 'PITA 24' was found to be higher than that of a landrace plantain, 'Mbi-Egome'. The whole-plant biomass accumulation, just like the size of the source organs (essentially photosynthetic leaf area) has a direct relationship with the quality and quantity of photo-assimilates partitioned to the harvestable portion (Baiyeri et al., 2005). Results from Ndukwe et al. (2012) showed significant positive relationship between the pre-flowering growth variables of plantains and the final bunch harvest. The higher biomass yield found in 'PITA 24' plantain would eventually translate to higher bunch yield.

Conclusions

(1) At the end of the 6-months growth period, 'PITA 24' hybrid maintained a better growth, produced higher dry matter yield, and had a greater efficiency of nutrient use than the landrace, 'Agbagba'.
(2) Plants that received combined doses of nitrogen and potassium fertilizer maintained superior growth and higher dry matter yield than those grown with single doses of either nutrients (N or K), while the non-fertilized control plants produced the poorest biomass.
(3) The two plantain genotypes maintained the best growth where N was applied at 200 or 400 $kg.ha^{-1}$ in combination with 300, 600 or 900 kg K_2O per hectare; thus fertilizer combinations $N_{200}K_{900}$ (that is, 200 kg N + 900 kg $K_2O.ha^{-1}$), $N_{400}K_{600}$, $N_{400}K_{900}$, $N_{200}K_{600}$, $N_{600}K_{900}$ and $N_{200}K_{300}$ produced similar growth and dry matter yield.
(4) The agronomic efficiency (*AE*) of the applied K^+ (that is, dry matter yield per unit of K_2O applied) was high and similar at $N_{200}K_{300}$, $N_{400}K_{300}$ and $N_{600}K_{300}$; whereas the agronomic efficiency of applied N (the dry matter yield per unit dose of applied N) was superior at $N_{200}K_{600}$, $N_{200}K_{300}$ and $N_{200}K_{900}$.
(5) For both genotypes, the partial factor productivity (*Pfp*) values from the applied nutrients (that is, the whole plant dry matter yield per unit dose of N + P_2O_5 + K_2O applied) were highest at $N_{200}K_{300}$, suggesting that it was most economical to grow plantains with 200 kg N and 300 kg $K_2O.ha^{-1}.yr^{-1}$. Absolute yield could be higher at 400 kg N and 600 kg $K_2O.ha^{-1}.yr^{-1}$ in very poor soils.
(6) For optimum growth of plantains in the humid tropical region of southeastern Nigeria, results from the present study suggest the combined application of 200 to 400 kg N, 300 to 600 kg K_2O and 100 kg P_2O_5 per hectare per annum. This translates to an annual application rate of 261 to 522 g urea, 300 to 600 g MOP and 333 g SSP per plant at the recommended spacing of 3 × 2 m. The exact application rates depend largely on the soil native fertility.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Aba SC, Baiyeri KP, Tenkouano A (2009). Factorial combination of manure rates and bunch pruning intensities influenced bunch physical traits of two plantain (*Musa* spp. AAB) genotypes. Int. Agrophys. 23:207-213. http://www.old.international-agrophysics.org/artykuly
Akinrinde EA (2006). Issues of optimum nutrient supply for sustainable crop production in tropical developing countries. Pak. J. Nutr. 5:387-397. http://www.pjbs.org/pjnonline/fin508.pdf
Akinyemi SOS, Olaleye AO, Tijani-Eniola H, Akinyemi JO (2004). Effect of potassium fertilizer on the yield of plantain-melon intercropped on an Oxic Paleustalf in south Western Nigeria. Proceedings of the 4th International Crop Science held on September 26 to October 1, 2004 in Brisbane, Australia. Available online at: www.cropscience.org.au
Awodoyin R (2003). Plantain production as a business. Hortic. Magaz. 1:11-13.
Baiyeri KP, Aba SC (2005). Response of Musa species to macro-propagation. I: Genetic and initiation media effects on number, quality and survival of plantlets at prenursery and early nursery stages. Afr. J. Biotechnol. 4:223-228 http://www.academicjournals.org/AJB
Baiyeri KP (2002). Nitrogen fertilizer influenced harvest index of plantain (*Musa* AAB, cv. Agbagba) in a sub-humid zone of southeastern Nigeria. J. Sustainable Agric. 20:95-102. DOI: 10.1300/J064v20n01_09
Baiyeri KP, Mbah BN (1994). Growth and yield correlation in false horn plantain *Musa* AAB cv. Agbagba in a sub-humid zone of Nigeria. MusAfrica 5:3-4.
Baiyeri KP, Mbah BN, Mbagwu JSC, Tenkouano A (2005). Comparative morphophysiological and yield characteristics of *Musa* genomes in Nigeria. Bio-Research 3:45-55.
Bationo A, Hartemink A, Lungu O, Naimi M, Okoth P, Smaling E, Thiombiano L (2006). Africa soils: Their productivity and profitability of fertilizer use. A background paper presented at the African fertilizer Summit of June 9-13, 2006, Abuja, Nigeria. http://www.alfredhartemink.nl/PDF/2006%20-%20Fertilizer%20Summit%20Paper.pdf
Bekunda M, Manzi G (2003). Use of the partial nutrient budget as an indicator of nutrient depletion in the highlands of Southwestern Uganda. Nutr. Cycling Ecosyst. 67:187-195. DOI: 10.1023/A:1025509400226.
Bekunda MA, Woomer PL (1996). Organic resource management in banana-based cropping systems of the lake Victoria Basin, Uganda. Agric. Ecosyst. Environ. 59:171-180. http://data2.xjlas.ac.cn
Braide JO, Wilson GF (1980). Plantain decline: A look at possible causes. Paradisiaca 4:3-7.
Cassman KG, Gines GC, Dizon MA, Samson MI, Alcantara JM (1996). Nitrogen-use efficiency in tropical lowland rice systems: Contributions from indigenous and applied nitrogen. Field Crops Res. 47:1-12. DOI: http://dx.doi.org/10.1016/0378-4290(95)00101-8
Dauda OJ (1996). Plantain and banana production in the Gambia" Proceedings of the Regional Workshop held on September 23-27, 1995 at the IITA High Rainfall Station, Onne, Rivers state, Nigeria. pp. 96-97.
FADINAP (2000). Integrated plant nutrient system: A training manual" Fertilizer Advisory, Development and Information Network for Asia

and the Pacific. pp. 70-82. http://www.fadinap.org/ipns/srilanka/ipnsmanual/toc.htm

FAO (2000). Fertilizer Requirements in 2015 and 2030" Food and Agricultural Organization of the United Nations, Rome, Italy. pp. 25-26. ftp://ftp.fao.org/agl/agll/docs/barfinal.pdf

Fixen PE, Reetz HF (2006). Fertilizer best management practices-making the best better. Better Crops 90(2):3. Available at http://www.ipni.net/ppiweb/bcrops.nsf

GenStat (2011). GenStat Discovery Edition 4, Release 10.3DE (PC/Windows 7). VSN International Ltd., Rothamsted Experimental Station, Hemel, Hempstead, UK. http://www.vsni.co.uk

Irizarry H, Abruna F, Rodriguez J, Diaz N (1981). Nutrient uptake by intensively managed plantains as related to stage of growth at two locations. J. Agric. Univ. Puerto Rico 65:331-345. http://www.nal.usda.gov

Jagadeeswaran R, Murugappan V, Govindaswamy M (2005). Effect of slow release NPK fertilizer sources on the nutrient use efficiency in Turmeric (*Curcuma longa* L.). World J. Agric. Sci. 1:65-69. http://www.idosi.org/wjas/wjas1(1)/14.pdf

Jones Jr JB (2002). Agronomic Handbook: Management of Crops, Soils and Their Fertility" Taylor and Francis, London, UK. ISBN-13: 9780849308970.

Katungi E, Smale M, Tushemerierwe W (2006). "Management of Banana Plantations" In: Tushemereirwe W, Bagamba F, Katungi E, Kikulwe E, Karamura D, Edmeades S, Smale M (eds). Uganda Country Report: A Baseline Assessment of Banana Production and Management Practices in Uganda. NARO/IFPRI/INIBAP, Kampala. pp. 50-60.

Krauss A (2000). Balanced Fertilization: Integral Part of Sustainable Soil Management" In: Virchow D, Braun JV (eds).Villages in the Future. International Potash Institute (IPI) Press, Hanover, Germany. Pp. 157-168. DOI: 10.1007/978-3-642-56575-5_28

Lahav E, Turner DW (1989). Banana Nutrition". International Potash Institute, Bulletin N°·12, Worblaufen-Bern,Switzerland. http://www.ipipotash.org/udocs/ipi_bulletin_7_fertilising_for_high_yield_banana.pdf

Lahav E (1995). Banana Nutrition" In: Gowen S (ed). Banana and Plantains. Chapman and Hall, London. ISBN-9780412368707. pp. 258-316.

Ndukwe OO, Baiyeri KP, Muoneke CO, Tenkouano A (2012). Studies on intra and inter correlative responses of phenological, yield and postharvest traits in some plantain (Musa spp.) genotypes in Nigeria. Agro-Science 10:69-77. http://www.ajol.info/index.php

Ng Kee kwong KF, Bholah MA, Cavalot PC, Gauthier J, Deville PJ (1994). Influence of broadcast and split applications of potassium on sugar cane yield in Mauritius. Revue Agricole et Sucriere de l'ile Maurice 73(3):29-35. http://www.africabib.org

Obiefuna JC (1990). Effect of manures and composts on nematodes, borer weevils and yield of plantain. J. Biol. Agricul. Horticul. 6:277-283.DOI: 10.1080/01448765.1990.9754527

Obiefuna JC (1984a). Effect of delayed fertilizer application on the growth and yield of plantains in south Western Nigeria. Fertilizer Res. 5:309-313. DOI: 10.1007/BF01051630

Obiefuna JC (1984b). Effect of potassium application during the floral initiation stage of plantains (*Musa* AAB). Fertil. Res. 5:315-319. DOI: 10.1007/BF01051631

Obiefuna JC, Ndubizu TOC (1979). Estimating leaf area of plantain. Scientia Horticulturae 11:31-36. DOI: 10.1016/0304-4238(79)90051-7

Obiefuna JC, Majumder PK, Ucheagwu AC (1981). The effect of the various nitrogen levels on the growth and yield of false-horn plantains cv. Agbagba. Proceedings of the 2nd International Conference on Plantains and Cooking Bananas held on July 29 to August 3, 1981, IITA, Ibadan, Nigeria.

Ortiz R, Austin PD, Vuylsteke D (1997). IITA high rainfall station: Twenty years of research for sustainable agriculture in the West African humid forest. HortScience 32:969-972. http://hortsci.ashspublications.org/content/32/6/969.full.pdf

Robinson JC (1996). Bananas and Plantains" CAB Press, London, UK. ISBN-13: 9780851989853.

Sanchez P, Shepherd KD, Soule M, Place FM, Buresh RJ (1997). Soil Fertility Replenishment in Africa an Investment in Natural Resource Capital" In: Buresh RJ, Sanchez PA, Calhoun F (eds). *Replenishing Soil Fertility in Africa.* Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin, USA. pp. 1-46 http://www.worldagroforestry.org

SPSS (2008). SPSS Statistics for Windows, Release 17.0.0" Statistical Package for Social Sciences (SPSS) Inc., USA.

Stover RH, Simmonds NW (1987). Banana. 3rd Edn., John Wiley and Sons Inc., New York, ISBN-13:978-0470206843.

Tenkouano A, Faturoti B, Adeniji T, Akele S (2002). Promotion of micronutritional quality of musa hybrids" Project E-Enhancing Livelihoods, Improving the Resource Base and Protecting the Environment Through Starchy Stable, Peri-Urban and Tree Crop Systems of the Humid and Sub-Humid Zones of West and Central Africa. pp. 18-20. http://www.iita.org/research/projann2002/IITAProjE.2002.pdf

Twyford IT, Walmsley D (1973). The mineral composition of the Robusta banana plant. Plant Soil 39:227-243.

Twyford IT, Walmsley D (1974). The mineral composition of the Robusta banana plant II. The concentration of mineral constituents. Plant Soil. 41:459-470. DOI: 10.1007/BF02185809

Van Keulen H, Breman H (1990). Agricultural development in the West African Sahelian region: A cure against land hunger, Agric. Ecosyst. Environ. 32:177-197. http://dx.doi.org/10.1016/0167-8809(90)90159-B

Vanlauwe B (2004). Integrated Soil Fertiliy Management Research at TSBF: The Framework, the Principles and their Application" In: Bationo A (ed). Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan African. Academy Science Publishers, Nairobi, Kenya. pp. 50-69. ISBN: 9966-24-075-6.

Wilson GF, Swennen R, de Langhe E (1987). Effects of mulch and fertilizer on yield and longevity of a medium and giant plantain and a banana cultivar. Proceedings of the 3rd Meeting on International Cooperation for Effective Plantain and Banana Research held on May 27-31, 1985, Abidjan, Cote d'Ivoire. pp. 109-111. http://www.musalit.org/pdf/FA885289.pdf