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Vegetative Growth and Nutrient Use Efficiency of Tissue-Cultured 'Saba' Banana (*Musa*) Plantlets in Response to Fertigroe® N, P, and K Nanofertilizers

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The study determined the effect of using FertiGroe® Nano N (18-0-0), Nano P (0-18-0), and Nano K (0-0-38) nanofertilizers on the growth and nutrient use efficiency of tissue-cultured 'Saba' banana (Musa ABB) plantlets. For 7 wk, conventional fertilizers (CF) and FertiGroe® nanofertilizers (NF) were applied to the plantlets at graduated level of the recommended rate (RR). Vegetative growth was monitored weekly. At the end of the experiment, samples were collected for dry matter partitioning and leaf tissue analysis. Fertilizer treatment significantly improved pseudostem growth and dry matter production of 'Saba' banana plantlets. Plantlets applied with neither conventional fertilizer (CF) nor nanofertilizer NF (control) produced significantly shorter and thinner pseudostem, and less dry matter compared to plantlets that were applied with NF or CF, regardless of the recommended rate (RR) used. Despite having significantly shorter and thinner pseudostem, plantlets applied with NF at 50% RR and 75% RR produced dry matter comparable to plantlets applied with CF at 75% RR and 100% RR by allocating more dry matter to the leaves. Foliar P concentration was not limiting to the plants and its nutrient concentration in the leaves did not vary significantly across the treatments. N uptake was highest in plantlets applied with NF at 75% RR (0.187 g) and CF at 75% RR (0.158 g), 100% RR (0.167 g) and 125% RR (0.173 g). K uptake was highest in plantlets that received NF at 50% RR (0.355 g) and 75% RR (0.358 g) and CF at 75% RR (0.353 g). Nutrient use efficiency of the plantlets was measured using apparent nutrient recovery. Apparent potassium recovery of the plantlets applied with NF was higher compared to that of plantlets applied with CF. The computed optimum RR for FertiGroe® N nanofertilizer was 23.5% lower than the computed optimum RR for CF. FertiGroe® N nanofertilizer can also increase apparent nitrogen recovery by 36.87% compared to CF.

Key Words: banana, nutrient use efficiency, nanotechnology, nanofertilizer, controlled-release fertilizer

Abbreviations: ANR – apparent nutrient recovery, CF – conventional fertilizer, CNC – critical nutrient concentration, CRF – controlled release fertilizer, NF – FertiGroe® nanofertilizer, RR – recommended rate

INTRODUCTION

Bananas are highly efficient in producing biomass over a short period of time (Melo et al. 2010 as cited by Nomura et al. 2016). They are substantial feeders of nutrients and require a large quantity of nutrients to grow rapidly and to have high fruit yield (Memon et al. 2005). Consequently, high fertilizer utilization significantly affects banana yield (Bathan and Lantican 2009). In the Philippines, the recommended rate (RR) of fertilization for banana depends on the variety and location. For 'Lakatan' and 'Latundan' banana, the RR is 254 kg ha^{-1} of N, 30 kg ha^{-1} of P_2O_5, and 350 kg ha^{-1} of K_2O, while for 'Saba' banana, the RR is 220 kg ha^{-1} of N, 20 kg ha^{-1} of P_2O_5, and 260 kg ha^{-1} of K_2O (Aguilar et al. 2010).

In commercial fertilizers, about 40%–70% of nitrogen content is lost in the environment through leaching, volatilization, and microbial utilization (Trenkel 1997 as cited by Solanki et al. 2015). Losses in phosphorus and potassium content of commercial fertilizers are higher and can reach up to 90% (Ombȯdi and Saigusa 2000 as cited by Solanki et al. 2015). Losses occur because most commercial fertilizers are water-soluble. They are considered as quick-release fertilizers, which when properly placed in moistened soil, will release available nutrient in a short period for plant use. The release patterns of quick-release fertilizers peak immediately and at times do not synchronize with the growth of the plants (Liu et al. 2014). The excess nutrients from the fertilizer are usually converted into insoluble salts and become losses (Cui et al. 2010 as cited by Solanki et al. 2015).

In the case of banana, these losses increase the production cost and also contaminate soil and water resources. Excessive and inappropriate chemical fertilizer in the soil causes land degradation and eventually lead to soil infertility (Tirado and Bedoya 2008). To address this problem, more precise and smarter nutrient management in banana production is necessary. Fertilizer application should be adequate, timely, and proper to ensure higher nutrient use efficiency. One effective option of ensuring higher nutrient use efficiency is the use of controlled release fertilizer (CRF).

Nutrients in CRF are in forms that delay their availability for plant use (Liu et al. 2014) and are coated or encapsulated with inorganic or organic materials (Du et al. 2006 as cited by Liu et al. 2014). CRF extends nutrient availability significantly longer compared to quick-release fertilizers (Liu et al. 2014). In soils with temperature below 25°C, at least 25% of the total nutrient in CFR is still available after 28 d (Trenkel 2010 as cited by Liu et al. 2014).

Through nanotechnology, CRFs are becoming more promising and efficient in managing plant nutrition. Nanotechnology deals with the study of materials (nanomaterials) and particles (nanoparticles) that have at least one dimension of single unit between 1 and 100 nm (Liu and Lal 2015). At this scale, the physical, chemical, and biological properties of materials differ from those of larger scale materials (Khan and Rizvi 2017). Nanomaterials that deliver nutrients to the plant are referred to as nanofertilizers. They are usually prepared in two ways: thru encapsulation of the nutrients in a nanomaterial and coating with a thin protective film or thru conversion of nutrients into particles or emulsions of nanoscale proportion (de Rosa et al. 2010 as cited by Khan and Rizvi 2015).

Nanofertilizers can deliver the nutrients directly to plant cells if the particle size (5–20 nm) is smaller than the cell wall pores (Liu and Lal 2015). At the nanoscopic level, particles carrying essential nutrients can penetrate the nano openings of root tissues, thus further increasing absorption and uptake. These fertilizers can exhibit initial burst and, subsequently, controlled release of nutrients. They also have the capability to supply nutrients in desirable proportions while preventing fixation and other forms of losses (Manikandan and Subramanian 2015). These characteristics enable the high sorption capacity and controlled-release kinetics of nanofertilizers (Solanki et al. 2015).

Nanofertilizers have the potential to further increase nutrient uptake efficiency (Khan and Rizvi 2017). Compared to conventional fertilizers, the use of nanofertilizers may lead to significantly improved crop growth and increased yield, as well as reduced nutrient losses and enhanced fertilizer use efficiency (Liu and Lal 2015).

FertiGroe® nanofertilizer (NF) is an example of controlled release nanofertilizers produced by encapsulating nutrients inside a nanomaterial, specifically zeolite. It is a single-nutrient nanofertilizer formulated by the National Institute of Molecular Biology and Biotechnology (Biotech) of the University of the Philippines Los Baños (UPLB) through the fund support from the Department of Science and Technology (DOST). Nanofertilizers produced from nutrient-augmented-zeolite have been proven effective through several laboratory and field experiments (Liu and Lal 2015).

The particle size of zeolites usually does not occur at nanoscales, but the arrangement of its SiO_4 and AlO_4 tetrahedra creates channels and voids that are within nanoscales. The nano-porous characteristic of zeolite enables it to have high specific surface area, high cation capacity, and high selectivity with plant macronutrients, such as K^+ and NH_4^+. When activated, the voids within the zeolite can be sites of nutrient exchange and encapsulate such nutrients. At the zeolite exchange sites, nutrients are slowly released for plant uptake (Liu and Lal 2015). Nutrient loading in zeolites has been intensively studied since the l970s (Ming and Allen 2001 as cited by Liu and Lal 2015).

Applying FertiGroe®Nano N, Nano P, and Nano K nanofertilizer to banana production can be economically viable because it can decrease production cost while maintaining the integrity of the environment. Using fertilizers that can follow the dynamic nutrient requirement of the crops can lead to a more competitive banana industry and might enhance the country's comparative advantage. Thus, this study was conducted to determine the effect of FertiGroe® nanofertilizers on the growth and nutrient uptake of 'Saba' banana plantlets.

MATERIALS AND METHODS

Experimental Design

The fertilization program (Table 1) employed in Lapanday Foods Corp. was used as reference for the 12 fertilizer treatments (Table 2). These treatments were graduated levels of the recommended rate of fertilizers (1.00–0.4–0.4 g N-P_2O_5-K_2O per plant) using either urea (46-0-0) and complete fertilizer (14-14-14) as conventional fertilizer (CF), and FertiGroe® N (18-0-0), P (0-18-0), and K (0-0-38) nanofertilizers.

Table 1. Reference fertilization program used for 'Saba' banana plantlets[a,b].

Weeks After Transplanting	Nutrient Source	Basal Application (g per Plant)	Drenching (g/L of Distilled Water)
0	Complete	2.00	-
1	Urea	-	2.30
2	Complete	-	5.00
3	Urea	-	5.00
4	Urea	-	2.30
5	Complete	-	5.00
6	Urea	-	5.00
7	Urea	-	2.30
8	Urea	-	2.30

[a]The amount of fertilizer is based on the recommended rate (RR) of 1.00–0.4–0.4 g N-P_2O_5-K_2O per plant.
[b]At 0 wk, 2 g of complete fertilizers was basally applied. For the succeeding week, fertilizers were drenched to the plantlets twice a week at 30 mL per drenching. Foliar fertilizer was applied once a week.

Two sets of controls (C1 and C2) were used in the study. Plantlets at C1 were applied with neither solid nor foliar fertilizer while plantlets at C2 were applied with foliar fertilizers only. This procedure was done to examine whether or not the vegetative and nutrient-use efficiency response of the plantlets was brought about by the solid fertilizer used. The experiment was laid out in Randomized Complete Block Design (RCBD). Treatments were replicated five times, with four plantlets per replicate. The experiment was conducted in an existing clonal nursery, with 50% shading, at the Southern Philippines Agribusiness and Marine and Aquatic School of Technology in Digos City from February 21, 2018, to April 20, 2018.

Potting Out and Preparation of 'Saba' Banana Plantlets

Four- to six-week-old 'Saba' banana tissue-cultured plantlets from JV Mejos Agri-Ventures in Davao City were used for the experiment. Plant height and pseudostem girth were measured before transplanting to establish the baseline profile of the plants. Each plantlet was potted in polyethylene plastic bags filled with 450 g of the potting medium (150 g garden soil and 300 g coconut coir dust). Halfway in filling up the bags, varying amounts of FertiGroe® nanofertilizers or conventional fertilizers were separately applied to the potting media. The amount and type of fertilizers applied were based on the RR for basal application and according to the designated treatment. No fertilizers were applied on bags that were used for C1 and C2. Potting media samples were gathered for analysis.

Fertilizer Application

From week 1 to week 7, fertilizers were prepared based on an existing fertilizer program for 'Saba' banana plantlets. Urea and complete fertilizers were dissolved in distilled water, while NF was suspended in distilled water. Both fertilizers, solution (CF) and suspension (NF), were applied at 30 mL per plantlet. Fertilizer was applied twice a week. NF suspension was thoroughly shaken before every application to ensure uniform dispersion.

Foliar fertilizers were applied twice a week in all the treatments except C1. Throughout the experiment, the plantlets were maintained by regular irrigation and weeding.

Parameters Gathered

Plant height and pseudostem girth of the plantlets were monitored every week. Plant height was measured from the base of the plant up to the "V" point or the meeting point of the two youngest leaves.

The pseudostem girth of the plantlets was measured at 1/3 of the height of the plant. Growth curves were generated from the weekly increase in plant height and pseudostem girth. Chlorophyll intensity and foliar nitrogen concentration was estimated, 4 wk after transplanting, using a chlorophyll meter (Konica Minolta chlorophyll meter SPAD 502Plus). The increments in plant height and pseudostem girth from week 0 to week 7 were also computed. At the end of the experiment, three samples from each treatment were collected for dry matter partitioning. Leaf samples were then used for tissue analysis. Nutrient uptake (NU) and apparent nutrient recovery (ANR) efficiency were computed to determine the plantlet's nutrient use efficiency based on the equation

NU,N,P or K, (g)= Nutrient Concentration,N,P,or K, (%) x Dry Matter (g)

ANR,N,P or K,% = [[NU of Fertilized Plantlets,(g) - NU of

Control Plantets,(g)]/Nutrient Applied,(g)] x 100

Statistical Analysis

Growth parameters and SPAD readings were subjected to one-way ANOVA in RCBD, while nutrient concentration and nutrient uptake in the leaves were subjected to one-way ANOVA in CRD. Means were compared using Tukey's HSD. Regression analysis was used to generate the equations that defined the apparent nutrient recovery of the plantlets. The optimum RR for NF and CF were determined using mathematical analysis.

RESULTS AND DISCUSSION

Pseudostem Height and Girth

Both the pseudostem height and girth of the plantlets, regardless of fertilizer treatment, exhibited steady growth (Fig. 1 and 2). The pseudostem of 'Saba' banana plantlets under C1 and C2 grew poorly compared to plantlets under other fertilizer treatments.

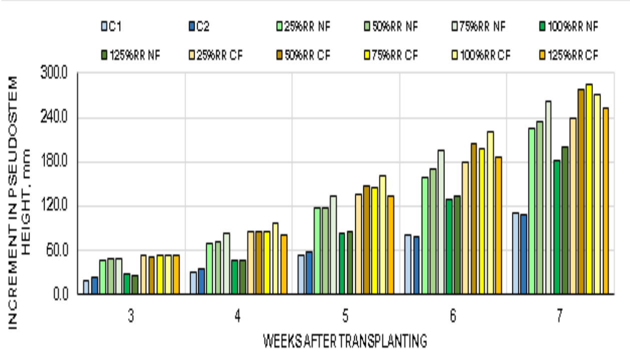

Fig. 1. Weekly increment, in mm, in pseudosetem height of 'Saba' banana plantlets at different fertilizer treatments.

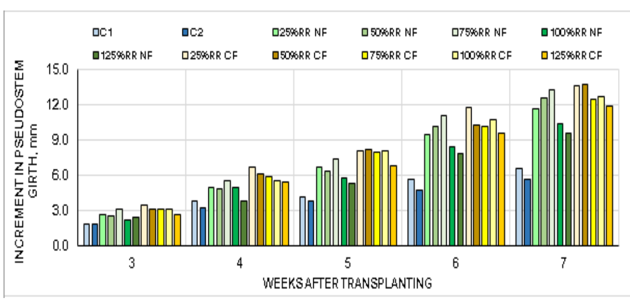

Fig. 2. Weekly increment, in mm, in pseudostem girth of 'Saba' banana plantlets at different fertilizer treatments.

Fertilizer treatment showed a significant effect on pseudostem growth 7 wk after transplanting (Table 3). The control plantlets were significantly shorter and had less increment in pseudostem height and girth than those applied with either fertilizer type. Plantlets applied with NF at 75% RR and with CF at 100% RR were the tallest in each fertilizer type; however, no significant difference was noted between the pseudostem height of plantlets applied with conventional fertilizers at 25% RR and those at 50% RR.

Table 2. Fertilizer treatments used for the experiment[a].

Treatment No.	Treatment Code	Solid Fertilizer Source	Recommended Rate (%)
1	C1	-	-
2	C2	-	-
3	25% RR NF	FertiGroe®	25
4	50% RR NF	FertiGroe®	50
5	75% RR NF	FertiGroe®	75
6	100% RR NF	FertiGroe®	100
7	125% RR NF	FertiGroe®	125
8	25% RR CF	Conventional	25
9	50% RR CF	Conventional	50
10	75% RR CF	Conventional	75
11	100% RR CF	Conventional	100
12	125% RR CF	Conventional	125

[a]The recommended rate was 1.00–0.4–0.4 g N-P_2O_5-K_2O per plant. All plantlets received foliar fertilizer as source of micronutrients except those assigned in C1 (Control 1).
CF – conventional fertilizer, FertiGroe® Nanofertilizer,
RR – recommended rate

The final pseudostem height of the plantlets and their corresponding increment increased as the amount of NF applied increased from 0% RR to 75% RR; beyond this range, additional NF application resulted in negative effect on the final pseudostem height. Plantlets applied with CF did not differ significantly in terms of final pseudostem height and the corresponding increment. This result shows that limiting the RR for CF at 25% will still produce plantlets with pseudostem height comparable to those plantlets applied with CF at higher RR.

The same trend was also observed on the effect of fertilizer treatment on the plantlet's pseudostem girth. The girth produced by plantlets applied with NF at 75% RR and CF at 50% RR was thick and comparable with those applied with CF at lower RR. The final pseudostem girth and its corresponding increment increased as the amount of NF applied increased from 0% RR to 75% RR and then decreased as the amount of NF applied went beyond 75% RR.

The increment in pseudostem height and girth were used as an indicator of dry matter accumulation in response to different fertilizer treatments. In general, the final increment on both pseudostem height and pseudostem girth of plantlets applied with NF at 75% RR and applied with CF at 25% RR were comparable.

Notwithstanding the significant effect of the fertilizer treatment on the plantlets' pseudostem height and girth, the optimum rate of NF and CF that can be used for 'Saba' banana plantlets cannot be established. On one hand,

Table 3. Pseudostem growth of 'Saba' banana plantlets at different fertilizer treatments 7 wk after transplanting[a].

Treatment Code	Pseudostem Height (mm)			Pseudostem Girth (mm)		
	Initial	Final[b]	Increment[c]	Initial	Final[d]	Increment[e]
C1	28.75	137.75^{ef}	109.00^{d}	3.54	10.18^{d}	6.64^{cd}
C2	24.10	132.00^{f}	107.90^{d}	3.58	9.32^{d}	5.74^{d}
25% RR NF	26.85	251.75^{bcd}	224.90^{abc}	4.28	15.97^{abc}	11.70^{ab}
50% RR NF	26.20	267.25^{abc}	241.05^{ab}	4.22	16.77^{ab}	12.55^{ab}
75% RR NF	25.25	286.25^{ab}	261.00^{a}	4.03	17.30^{a}	13.28^{ab}
100% RR NF	21.00	200.00^{de}	179.00^{c}	2.46	12.80^{bcd}	10.35^{ab}
125% RR NF	21.95	216.00^{cd}	194.00^{bc}	2.75	12.40^{cd}	9.65^{bc}
25% RR CF	32.50	270.60^{abc}	238.10^{abc}	4.29	17.88^{a}	13.59^{a}
50% RR CF	27.80	304.85^{ab}	277.05^{a}	4.50	18.20^{a}	13.70^{a}
75% RR CF	31.95	315.25^{a}	283.30^{a}	4.55	17.05^{a}	12.50^{a}
100% RR CF	28.30	300.50^{ab}	272.20^{a}	4.70	17.45^{a}	12.75^{ab}
125% RR CF	28.00	281.75^{ab}	253.75^{ab}	4.65	16.55^{abc}	11.90^{ab}

[a]Treatment means within columns having the same letter are not significantly different at HSD (α=0.05)
[b]cv=24.17%, [c]cv=26.14%, [d]cv=26.40%, [e]cv=31.63%
CF – conventional fertilizer, FertiGroe® nanofertilizer,
RR – recommended rate

increasing the amount of conventional fertilizers beyond 25% RR had no significant effect on pseudostem development. The pseudostem development of the plantlets indicated that the optimum rate for FertiGroe® nanofertilizer for 'Saba' banana plantlets is between 50% RR and 75% RR. In addition, increasing fertilizer application up to the optimum range promotes growth of pseudostem in terms of height and girth increment; beyond the optimum range, the fertilizer applied had no significant effect on plantlet development. This was evident in the sudden drop in weekly increments of plantlets that received fertilizers at 100% RR and 125% RR. When excessive nutrients were applied to the plants, the nutrient concentration may exceed the critical nutrient level, which often results in decreased yield due to toxicity or reduced concentrations of other nutrients (Brady and Weil 2004, as cited by Memon et al. 2005).

Dry Matter Partitioning

Regardless of fertilizer treatment, dry matter produced by the plantlets (Fig. 3) favored leaf production; however, applying NF or CF, at any RR, significantly increased the amount of dry matter produced by the plantlets.

Plantlets at C1 and C2 produced the least biomass at 3.69 and 3.4 g, respectively, while those applied with NF and CF at 75% RR produced the highest biomass at 11.66 g and 12.34 g, respectively. No significant difference was noted between biomass produced by plantlets under C1 and C2, thus indicating that when N, P, and K were limited, the micronutrients chelated in the foliar fertilizers had no significant effect on the growth and development of the plantlets. The biomass produced by plantlets applied with NF at 50% RR (10.70 g) was not significantly different from that produced by plantlets applied with either fertilizer type at 75% RR, thus showing that plantlets may require lesser amounts of fertilizer than 100% RR. Increasing the amount of fertilizer applied from 0% RR to 75% RR increased biomass production of the plantlets. Beyond 75% RR, the increase would lead to insignificant effects on the plantlets, which means that 75% RR for 'Saba' banana plantlets is optimum.

Plantlets applied with NF at 50% RR and 75% RR, despite having shorter and thinner pseudostem, were able to produce dry matter that was comparable to those plantlets applied with CF fertilizer at the same or higher RR. Dry matter partitioning (Fig. 4) showed the ability of plantlets to convert the nutrient applied into biomass.

Sixty-three percent to 75% of the total dry matter produced by plantlets was allocated to the leaves. The sink strength of leaves peaks during the first 4 mo of banana (Eckstein et al. 1995, as cited by Robinson and Sauco 2010), which shows that during the early vegetative stage, 'Saba' banana tends to allocate most of its biomass to the leaves if nutrients are available. Thus, even though the plantlets applied with NF at 50% RR were shorter,

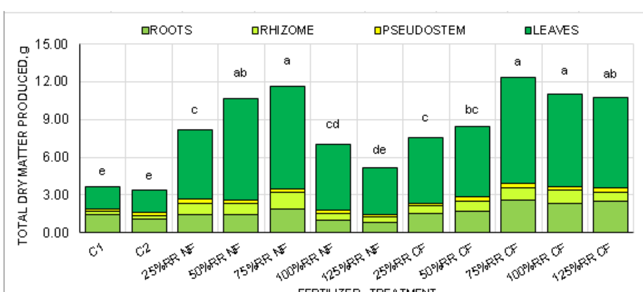

Fig. 3. Total dry matter produced by 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv=9.19%.

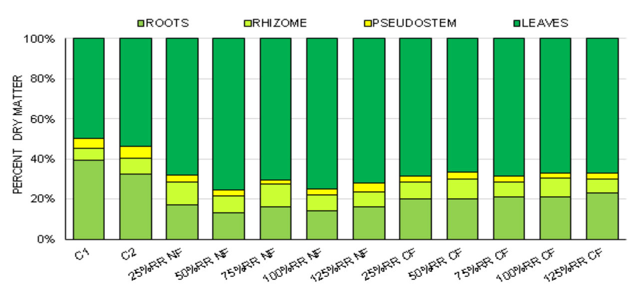

Fig. 4. Dry matter partitioning (%) of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting.

they were able to produce dry matter comparable with those applied with CF at 75% RR, 100% RR and 125% RR.

The proportion of dry matter accumulated in the roots was higher for plantlets that did not receive any amount of NF or CF. This observation was similar to the dry matter partitioning of 'Lakatan' banana plantlets that were under water stress. In conditions where either nutrient or water is deficient, the allocation of the dry matter in the root increases to enhance nutrient absorption (Elleva et al. 2018); at low nutrient concentration, the root becomes a nutrient sink.

The results observed are consistent with the optimal partitioning theory, which states that plants allocate most of their assimilates to the organ that has the most limited resources (Zhang et al. 2015, as cited by Elleva et al. 2018). If deficiency is below ground, dry matter will accumulate at the roots, and if the deficiency is above ground, it will accumulate at the leaves (Poorter et al. 2015, as cited by Elleva et al. 2018).

Nutrient Uptake

Because the sink strength of the leaves was higher in 'Saba' banana plantlets, N, P, and K concentrations (Fig. 5, 6 and 7) of the leaves were used to determine the nutritional status of the plantlets 7 wk after transplanting.

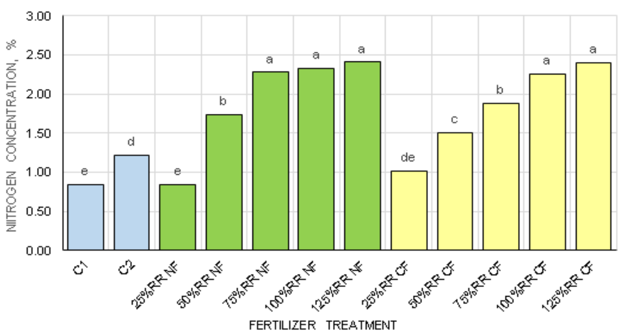

Fig. 5. Nitrogen concentration (%) in the leaves of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv=3.13%.

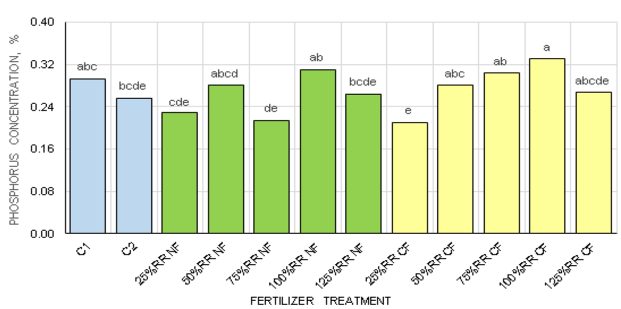

Fig. 6. Phosphorus concentration (%), in the leaves of 'Saba'banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv=8.49%.

The nutrient concentrations were then compared and verified with the standard values (Table 4) for diagnosing the nutritional status of banana. These standard values were established from the third youngest fully expanded leaf of fully developed banana plant (Memon et al. 2005).

Table 4. Standard critical nutrient concentration (CNC) range (%) in banana leaves (Martin-Prevel 1987, as cited by Halliday and Trenkel 1992).

Nutritional Status	N	P	K
Deficit	1.60	-	1.30
	-		-
	2.10		2.60
Low	2.00	0.10	2.70
	-	-	-
	2.50	0.20	3.20
Optimum	2.70	0.20	3.20
	-	-	-
	3.60	0.30	5.40

Like most monocots, 'Saba' banana plantlets have high affinity with K as shown in the high K concentration of the leaves in all treatments, followed by the concentration of N and then P. Of all the macronutrients, N and K are demanded the most by bananas as they influence various plant functions, including root growth and fruit development (Kumar and Kumar 2008, as cited by Nomura et al. 2016).

Applying CF and NF at any RR significantly increased foliar nutrient concentration. P concentration on the leaves of the 'Saba' banana plantlets ranged from 0.21% to 0.33%, which is within the optimum P leaf concentration in banana. This result shows that P was not limiting in all treatments. Bananas can accumulate P requirement for a long period of time (Robinson and Sauco 2010) and decrease when the optimum level is reached.

Similarly, NF and CF at any RR also significantly increased N and K concentrations in the leaves of 'Saba' banana plantlets. The highest N concentration was noted

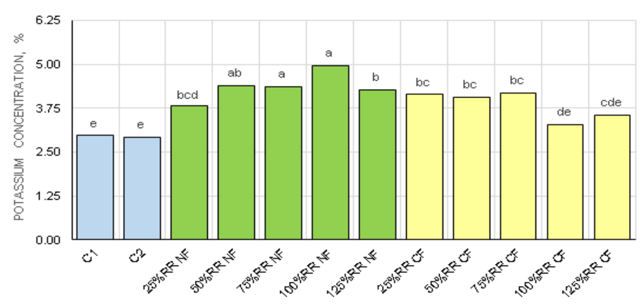

Fig. 7. Potassium concentration (%) in the leaves of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv=4.84%.

in plantlets that received FertiGroe® at 75% RR (2.28%), 100% RR (2.33%), and 125% RR (2.41%) and conventional fertilizers at 100% RR (2.26%) and 75% RR (2.40%). The N concentrations in these five treatments were comparable to one another. Similarly, K concentration was highest in plantlets applied with NF at 50% RR (4.39%), 75% RR (4.37%), and 100% RR (4.96%). Plantlets applied with CF at similar rates had significantly lower K concentration in the leaves.

Both N and K concentration in the leaves of banana plantlets are expected to be lower than the critical nutrient concentration (CNC) because of the difference in sampling stage. The CNC range was established using leaf samples of fully developed banana plants. The reliability and soundness of the obtained nutrient concentration from the plantlets can still be verified using the CNC range. Based on the nutrient concentration in the leaves, the optimum RR (ORR) for FertiGroe® N lies between 50% RR and 75% RR while the ORR for FertiGroe® K lies between 25% RR and 50% RR. The nutrient concentration in the leaves indicated that NF could reduce the fertilizer requirement of 'Saba' banana plantlets.

Nutrient Use Efficiency

SPAD readings of 'Saba' banana plantlets were also used to gauge their nutrient efficiency response to both NF and CF. Chlorophyll meter (SPAD) was used to determine the degree of 'greenness' of the leaves, which can be used as an indicator of the plants' N use efficiency; a higher SPAD measurement indicates a more efficient use of N fertilizers. Applying NF or CF significantly increased the SPAD readings of 'Saba' banana plantlets, 4 wk after transplanting (Fig. 8).

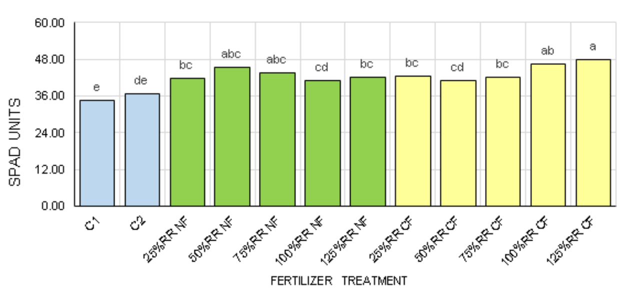

Fig. 8. SPAD readings of 'Saba' banana plantlets at different fertilizer treatments, 4 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv = 11.18.

SPAD readings were measured during the 4th week of the experiment. Results showed that fertilizer treatment had a significant effect on SPAD readings or chlorophyll content. The least SPAD readings were observed in the control plantlets (34.54 SPAD units for C1 and 36.74 SPAD units for C2). The highest SPAD readings were observed in plantlets applied with NF at 50% RR (45.52 SPAD units) and 75% RR (43.66 SPAD units) and in plantlets applied with conventional fertilizers at 100% RR (46.42 SPAD units) and 125% RR (47.97 SPAD units). SPAD readings of the plantlets from these treatments did not differ significantly. Consequently, the highest SPAD reading was observed at the established optimum RR for FertiGroe® Nano N. This result shows that N uptake of plantlets treated with FertiGroe® NanoN nanofertilizers was more efficient compared to the conventional fertilizers. The N and K uptake of the leaves are presented Figures 9 and 10.

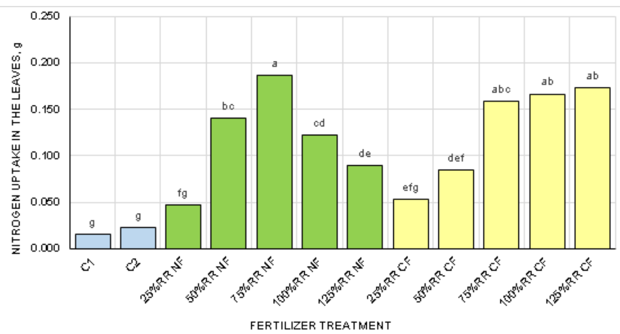

Fig. 9. Nitrogen uptake (g) of the leaves of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv = 12.70%.

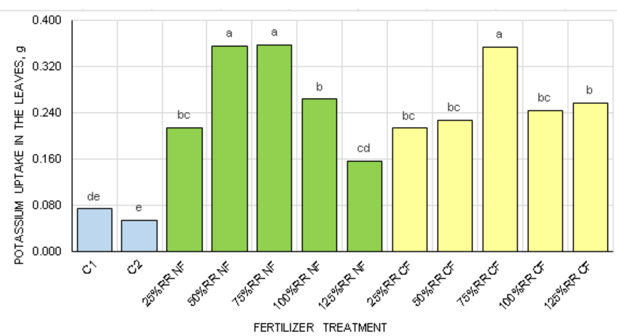

Fig. 10. Potassium uptake of the leaves of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting. Treatment means having the same letter are not significantly different at HSD (α = 0.05), cv = 12.81%).

Plantlets at C1 and C2 had the lowest N (0.016 g and 0.022 g) and K (0.073 g and 0.053 g) uptake. N uptake was highest in plantlets that received NF at 75% RR (0.187 g). This result is consistent with the SPAD reading obtained at 4 wk after transplanting. N uptake of plantlets applied with NF at 75% RR were not significantly different from the N uptake of plantlets applied with conventional fertilizer at 75% RR (0.158 g), 100% RR (0.167 g) and 125% RR (0.172 g). K uptake was highest and comparable in plantlets that received NF at 50% RR (0.355 g) and 75% RR (0.358 g) and CF at 75% RR (0.355 g). K uptake values of the plantlets at these fertilizer treatments were not significantly different from one another.

No significant effect on N and K uptake was observed beyond the 75% RR. Plantlets that received N and K beyond the 75% RR even exhibited a decrease in nutrient uptake as a result of the decrease in leaf biomass.

Nutrient use efficiency of the plantlets was measured using the apparent nutrient recovery for both N (Fig. 11) and K (Fig. 12), which is commonly used as a gauge of

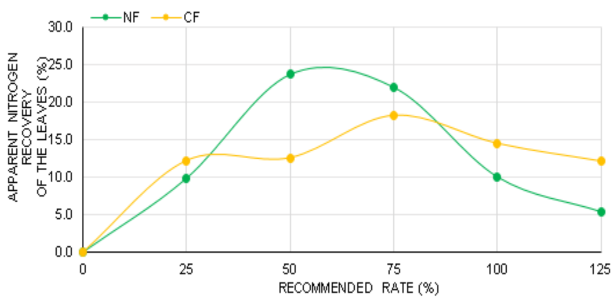

Fig. 11. Apparent nitrogen recovery (%) of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting.

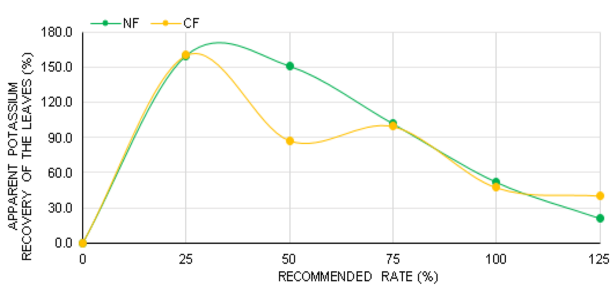

Fig. 12. Apparent potassium recovery (%) of 'Saba' banana plantlets at different fertilizer treatments, 7 wk after transplanting.

plant ability to acquire the nutrient applied to the soil (Baligar et al. 2001). The proportion of nutrient absorbed by the plant from fertilizers cannot be precisely quantified without the use of radioactive tracers, hence, apparent nutrient recovery for routine analysis is used as an alternative method in determining the plant's nutrient use efficiency (Karklins and Ruza 2015). It is the difference between the nutrient uptake of the above-ground part of the fertilized and the unfertilized crop relative to the quantity to the nutrient applied (Fixen et al. 2015).

The apparent N recovery of the plantlets showed that using CF at 0% RR to 30% RR resulted in higher N efficiency compared to using NF. NF at 30% RR to 85% RR had higher N efficiency compared to using CF. Beyond 85% RR, using CF had higher nitrogen efficiency compared to NF. The apparent N recovery of the plantlets peaked between 50% RR and 75% RR, regardless of the type of fertilizer used. Beyond the 75% RR, apparent N recovery of the plantlets decreased. Therefore, optimum RR for both fertilizers is between 50% RR and 75% RR. At this range, it was established that plantlets applied with NF were more nutrient use efficient compared to those applied with CF. Further, the apparent N recovery of 'Saba' banana plantlets at these RRs was also consistent with the SPAD reading, thus showing that FertiGroe® Nano N, when applied between 50% RR and 75% RR were used more efficiently by the plantlets despite the drenching of N fertilizers. This observation can be attributed to the manner by which N was released.

On the other hand, apparent K recovery decreased from 25% RR to 125% RR, regardless of type of fertilizer applied. It was also observed that the apparent K recovery at 25% RR reached more than 100%. This result can be attributed to the high organic matter present in the potting media and the high affinity of banana to K.

K concentration in the potting media increased through the application of fertilizer and the mineralization of organic matter. Through time, mineralization of the organic matter specifically coconut coir dust released nutrients in their available forms. The increase in available K in the soil stimulated luxury consumption in 'Saba' banana plantlets.

Most plants can accumulate more nutrients than what is needed at a given time and then remobilize the nutrients in the future (Reetz et al. 2015). If K is readily available, plants tend to absorb it beyond their requirement. High accumulation of K during optimal growing condition is an insurance strategy by plants to cope with sudden environmental stress (Zorb et al. 2014). K uptake tends to become constant once a concentration that may be toxic to the plant has been reached.

The amount of K from the fertilizer absorbed by the 'Saba' banana plantlets became constant despite the increase in RR. However, with the apparent K recovery from 25% RR to 75% RR, NF was still higher compared to CF, which shows that K use efficiency of plantlets increased when applied with FertiGroe® Nano K. With the same potting media, the amount of K applied may be gradually decreased as the plantlets grow to maximize the K from the mineralization of organic matter in the soil media. However, it is still recommended to apply potassium to the plantlets at RR between 25% RR to 50% RR. Potassium uptake of banana during the early vegetative stage is significantly higher compared to potassium uptake during fruit development stage. The K needed for fruit development is derived from the K reserved from other organs. As a result, there was a sudden drop in the dry matter allocation in the pseudostem, rhizome and leaves during fruit development (Robinson and Sauco 2010). Supplying K fertilizers between 25% RR and 50% RR can ensure that the plantlets can store enough K in preparation for crop establishment and eventually for fruit development.

Through polynomial regression (Fig. 13), an equation

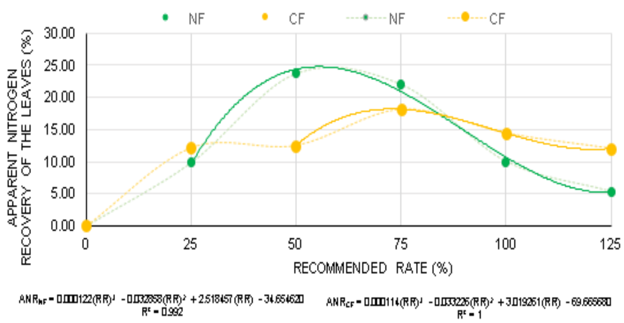

Fig. 13. Polynomial regression (n=3) of the apparent nitrogen recovery of 'Saba' banana at different fertilizer treatments, 7 wk after transplanting.

and a fitted curve was generated for the N uptake recovery of both fertilizers. To increase the equation's coefficient of determination (r2), N uptake wherein the apparent nitrogen recovery started to peak was determined. It was also established that the optimum RR lies between 50% RR and 75% RR. Mathematical analysis was then used to determine the optimum RR for nitrogen-based fertilizer (Table 5).

Table 5. Optimum apparent nitrogen uptake recovery in 'Saba' banana plantlets using FertiGroe® nanofertilizers and conventional fertilizers.

Type of Commercial Fertilizers	Computed Optimum RR for Nitrogen (%)	Computed Apparent Nitrogen Uptake Recovery (%)
FertiGroe®	55.44	24.77
Conventional	72.45	18.09

RR – recommended rate

Polynomial equation (n=3) with high correlation defined the apparent nitrogen recovery of the plantlets when applied with NF from 25% RR to 125% RR and with CF from 50% RR to 100% RR. The computed optimum RR for FertiGroe® Nano N was 23.5% lower than the computed optimum RR for CF. At ORR FertiGroe® N nanofertilizer may increase apparent nitrogen recovery by 36.87% compared to CF. This result shows that NF can reduce the recommended rate 23.5% for nitrogen-based fertilizer and at the same time increase N use efficiency of 'Saba' banana plantlets.

CONCLUSION

Fertilizer treatment showed a significant effect on both the growth and the fertilizer use of 'Saba' banana plantlets. The response of the plantlets to NF was almost similar to its response to conventional fertilizers. Fertilizer application improved vegetative growth, increased biomass production, and increased N and K concentration in the leaves. P was not limiting to the 'Saba' banana plantlets. Beyond the optimum RR of nutrient application, a negative effect on the growth of the plantlets was noted. FertiGroe® Nano N and Nano K nanofertilizers increased nutrient use efficiency. The optimum RR for FertiGroe® Nano N and nitrogen-based CF were at 55.44% RR and 72.45% RR, respectively. The computed apparent N recovery at the optimum RR for NF was 36.87% higher than that at the optimum RR for urea. Plantlets absorbed higher K of because of its higher amount in the soil. As the result of this study, FertiGroe® nanofertilizer can be an economical alternative as fertilizer and can be further investigated under farmer's field conditions.

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