

ENHANCING BANANA (*Musa* spp.) GROWTH AND PRODUCTIVITY BY BIO-FERTILIZERS IN SANDY SOIL

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Abstract. This investigation was carried out during the two successive seasons of 2016 and 2017 at the private orchard of the modern agriculture company (PICO), El Behera governorate, Egypt, to study the effect of Nitrogen Fixing Bacteria (NFB) and Phosphate Solubilizing Bacteria (PSB) and different rates of N and P as mineral fertilizers (*i.e.* 50% and 75% of recommended dose), compared to the standard recommended mineral fertilization on the growth, yield, fruit quality and leaf mineral contents of Williams banana plants. Results showed that T₈ (50% bio N + 50% bio. P + 50% mineral N and P) and T₇ (100% bio N + 50% bio. P + 50% mineral N and P) enhanced plant growth *i.e.* pseudostem length and perimeter also, it increased bunch weight and yield and improved most physical parameters (*i.e.* finger no./hand, finger length, finger weight, pulp weight, pulp weight and pulp ratio) and chemical characters (T.S.S, total sugar % and reducing sugar %), leaf mineral content (N, P, and K) and chlorophyll a and b were also significantly affected by treatments compared to the control during two season of study. The results suggest that, the utilized biofertilizers can partially substitute the amount of mineral fertilizers, leading to cleaner environment.

Keywords: *P dissolving bacteria, N fixing bacteria, fruit quality, yield, Williams, sustainable agriculture*

Introduction

Banana (*Musa* sp.) is a major crop in tropical and subtropical regions of the world. In Egypt, it represents most important fruit crop after citrus and grapes. It covers an area of 28667 hectares with production of 1228458 tons in 2017 (FAO STAT). Among Crop management practices, plant nutrition in particular represents one of the major factors influencing banana yield. Moreover, all soils are deficient in N, P and K (Akhtar et al., 2003), besides, soil organic matter contents are low (Abbas et al., 2012) and this is true in new reclaimed lands in Egypt. Fertilization is very important not only to meet the crop requirements but also to improve soil fertility.

Soil microorganisms have enormous role in increasing the availability of accumulated phosphates in the soil for plant by solubilization (Goldstien, 1986; Gyaneshwar et al., 2002; Hamim et al., 2019). Moreover, the microorganisms involved P solubilization as well as better scavenging of soluble P can enhance plant growth by increasing the efficiency of biological nitrogen fixation, enhancing the availability of other trace elements and by production of plant growth promoting substances (Goldstien, 1986). This assumes more important for banana, which is a heavy feeder crop requiring large amount of nutrients (Ganapathi and Dharmatti, 2018).

Williams is one of the most widely grown banana varieties in the world (Xu et al., 2005; FAO, 2018). In Egypt, it is cultivated successfully in newly reclaimed soils for its excellent performance, the large bunch with longer fingers, the excellent taste and high tolerance to transportation (Barakat et al., 2011). Very little information is available on the effect of biofertilizers (*Azotobacter chroococcum* and *Bacillus megatherium* var

phosphaticum) on this variety under sandy soil condition. Thus, the present investigation was undertaken to study the effect of biofertilizers as ecofriendly, and low-cost alternative fertilizers on growth and yield attributes of Williams banana.

Materials and methods

The present investigation was conducted during two successive seasons (2016 and 2017) in a private orchard of the modern agriculture company (PICO) located at Badr city (30°36'36.5"N and 30°45'45.5" E), El Behera governorate, Egypt (*Fig. 1*). Monthly average of some metrological data during study period of the experimental site is illustrated in *Figure 2*.



Figure 1. Experimental site location

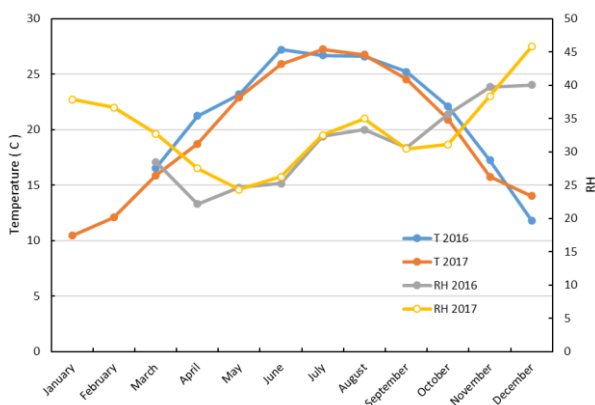


Figure 2. Metrological data during study period of the experimental site

At the beginning of the treatments, three soil samples were collected from different sites at 90 cm depth and analyzed as a composite sample for physical and chemical properties according to (Wilde et al., 1985). The analysis of orchard soil is presented in *Table 1*.

Table 1. Physical and chemical analysis of soil

Chemical properties							
pH	E.C (mmhos/cm)	Organic matter %	Organic carbon %	P(available) Meq/L	SAR	K mg/100g	Ca Meq/L
8.3	0.18	0.68	0.39	24	0.52	0.15	0.8
Physical properties							
Sand (%)		Loam (%)		Clay (%)		Density (g/cm ³)	
75		8.75		16.25		1.21	

The mother plants were planted in mid-March at 3.5*1.5 m apart, received 30 m³ organic matter/Feddan/year. Eight treatments were used; Control treatment fertilized by recommended dose of mineral fertilizers (250, 80 and 480 unite of NPK /4200 m²/year) in forms of ammonium nitrate (33.5% N), phosphoric acid (80% P₂O₅) and potassium sulfate (48% K₂O), respectively. Two levels of each N and P (100% and 50% of recommended dose) were used in combination with two biofertilizers namely;

Azotobacter chroococcum (Az14) as nonsymbiotic nitrogen fixation bacteria (N.F.B) and Bacillus megatherium var phosphaticum (B6) as phosphate dissolving bacteria (P.D.B). The strains were obtained from Bacteriology Lab, Sakha. Agric. Res. Station. Three kg/ 4200 m² from each inoculum was used after mixed with suitable amount of sandy soil and added once at first week of April of each season in crescentic trenches around each plant. The chemical fertilizers were added through drip irrigation system from April to October. The recommended dose of K was applied to all treatments.

The applied treatments were as follows:

- T1- Control (100% mineral N, P fertilizers)
- T2- 100 % Bio P (P.D.B) +100% mineral N
- T3- 100% Bio P + 50% mineral P +100% mineral N
- T4- 100% Bio N (N.F.B) + 100% mineral P
- T5- 100% Bio N + 50% mineral N +100% mineral P
- T6- 100% Bio N +100% Bio P
- T7- 100 % Bio N +100% Bio P + 50% mineral N, P
- T8- 50% Bio P + 50 % Bio N + 50 % mineral N, P

Vegetative growth measurements

At the beginning of the florescence emergence the following parameters were recorded; Pseudostem length (cm) which was measured from the soil surface up to the petiole of the last emerged leaf. Circumference of pseudostem (cm) at 25 cm above soil surface.

Yield and fruit quality

In mid-February of each season, bunches were harvested at the green maturity stage. At harvest, bunch weight (kg), bunch length (cm), and finger number/hand were recorded, three hands were taken randomly/ bunch/ replicate to estimate fruit physical characters including finger weigh (g), length and perimeter (cm), pulp and peel weight / finger (g) and pulp ratio. Fruit chemical characters were estimated in ripe fingers as total soluble solids in pulp juice (TSS) using hand refractometer as Brix, total titratable acidity percentage as malic acid was estimated using phenolphthalein as indicator according to (AOAC, 1985) and total and reducing sugars (Dubois et al., 1956).

Leaf chlorophyll and mineral contents

Leaf samples were taken from the middle part of third upper leaf blade. Chlorophyll (a and b) content expressed as mg/g fresh weight was determined according to Moran and Porath (1980). Leaf samples were washed and oven dried at 70c to a constant weight. Total nitrogen was determined by using micro-kjedehl (AOAC, 1985). Potassium was measured using a flame-photometer and phosphorus was determined colorimetrically (Chapman and Pratt, 1961).

Statistical analysis

The obtained data in both seasons were statistically analyzed using analysis of variance method as simple experiment in randomized complete block design (Snedecor and Cochran, 1980) using CoStat 6.303, CoHort Software, 798 Lighthouse Ave. PMB 320, Monterey, CA, 93940, USA. Duncan' multiple range test were used for means comparison (Duncan, 1955).

Results and discussion

Growth characters

Considering to height and circumference of pseudostem, data presented in *Table 2* indicate that planta treated with T₂ (100% Bio P (P.D.B) +100% N) recorded the lowest significant pseudostem length in the first season and so in the second season but with no significant difference with T₃, T₄ and T₆. Whereas, the highest pseudostem length was recorded at T₈ (50% Bio P + 50% Bio N + 50% mineral NP), especially in the second season.

Table 2. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on vegetative growth characters

Treatments	Pseudostem length (cm)		Pseudostem Circumference (cm)	
	2016	2017	2016	2017
T1	200.0a	194.8b	47.25b	49.5bcd
T2	172.5c	187.5d	40.25c	46.25e
T3	184.5b	189.5cd	49.0b	48.5cde
T4	188.3ab	191.3bcd	45.75b	47.25de
T5	199.3a	193.0 bc	49.5b	49.5 bcd
T6	195.0ab	189.5 cd	49.25b	50.25abcd
T7	197.0ab	193.8 b	53.5 a	50.5 abc
T8	200.5a	198.5 a	55.5a	54.0 a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

Pseudostem circumference showed significant higher values at T₇, T₈ in the first season and T₆, T₇ and T₈ in the second season. These results came in line with Abdel Gawad et al. (2017), who reported that height and circumferences of Grande Naine banana pseudostem increased as consequence of biofertilization and feldspar application.

Data in *Table 3* show that, plants treated with T₈ (50% Bio P + 50% Bio N + 50% mineral N, P) gave the highest bunch weight in both seasons, while T₂ (100% Bio P (P.D.B) +100% N) presented the significant lowest value than all tested treatments. In addition, T₈ recorded the maximum bunch length and the lowest one registered by T₂. These results are in agreement with those reported by Abd El-Naby and Gomaa (2000) and Barakat et al. (2011) who recorded that banana plants supplied with mineral fertilization combined with organic manure improved bunch weight. Also, the results are confirmed by those obtained by Baiea et al. (2015) and Baiea and El-Gioushy (2015) on banana plants.

In both seasons, T₈ (50% Bio P + 50% Bio N + 50% mineral N, P) increased the yield by 2%, 4.1% than the control. Moreover, the rest treatments had intermediate yield among the highest value at T₈ (20, 20.4 T) and the lowest one (14.8, 12.4 T) at T₂ (100% Bio P (P.D.B) +100% N) treatment during 1st and 2nd seasons, respectively. In this concern, Mai et al. (2005) observed that number of hands/bunch increased with 50% or 33% recommended dose of N plus Azospirillum phosphate solubilizing

bacteria. Dave et al. (1991), Zake et al. (2000), and Abd el Moniem et al. (2008) found that biofertilization with algal extract significantly improved yield, bunch and hand weight.

Table 3. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on Bunch weight and length and yield

Treatments	Bunch weight (Kg)		Bunch length (cm)		Yield Ton/ 4200 m ²	
	2016	2017	2016	2017	2016	2017
T1	24.5ab	24.5abc	95.75ab	97.0 a	19.6 ab	19.6 abc
T2	18.5 d	15.5 d	81.75c	74.75c	14.8 d	12.4 d
T3	21.75 c	22.5c	91.5 abc	89.25b	17.4 c	18.0 c
T4	21.5c	22.75 c	91.25abc	87.0b	17.2 c	18.2 c
T5	22.25c	23.25bc	98.0a	89.25b	17.8 c	18.6 bc
T6	21.25c	25.25ab	86.0 bc	96.75a	17.0c	20.2 ab
T7	23.0 bc	25.25 ab	95.75ab	95.5a	18.4 bc	20.2 ab
T8	25.0 a	25.5 a	98.25 a	98.5a	20.0 a	20.4 a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

With respect to fingers No./hand. the differences among the treatments did not reached the limit of significance in the 1st season (Table 4). However, in the 2nd season, T₈ (50% Bio P + 50% Bio N + 50% mineral NP) resulted in increasing the finger No/hand than T₃ and T₂, the latter presented the significant lowest value than all treatments.

Table 4. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on finger characters of Williams Banana fruits

Treatments	Finger No./hand		Finger length(cm)		Finger perimeter(cm)	
	2016	2017	2016	2017	2016	2017
T1	16.75a	15.0ab	21.3 bc	21.0 ab	12.24 a	11.74a
T2	15.25a	12.0 c	20.5 cd	19.25b	11.29 bc	9.5b
T3	16.0a	14.5b	21.0 cd	21.5a	12.24ab	12.24a
T4	15.75a	16.0ab	19.63 d	20.88ab	10.5 c	11.0a
T5	16.5a	16.0ab	22.0abc	21.0ab	12 ab	12.24a
T6	16.0a	15.75ab	21.0 cd	21.5a	12.0 ab	12.24a
T7	16.50a	16.0 ab	23.0 a	22.0a	12.5 a	12.24 a
T8	16.75a	16.5a	23.3 a	22.5a	12.8 a	12.4 a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

The present data revealed that length and perimeter of finger augment as consequence of T₈ (50% Bio P + 50% Bio N + 50% mineral NP) and T₇ (100% Bio N

+100% Bio P + 50% mineral NP) throughout the two growing seasons. on the contrary the lowest value obtained by T4 (100% Bio N (N.F.B) + 100% mineral P) and T2 for each of first and second season.

Data in *Table 5* revealed that, in both seasons, the highest significant finger weight was obtained by T7 followed by T8, while T6 recorded the lowest value. The results are in line with El-Shenawi and Hassouna (2004) who found that supplied Williams banana plants with N at 600 g ammonium nitrate /plant plus 5l HALEX biofertilizer presented the best finger weight. The highest pulp percentage was recorded at T8 treatment in both seasons.

Table 5. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on peel weight, pulp weight and pulp %

Treatments	Finger weight (g)		Peel weight (g)		Pulp weight (g)		Pulp (%)	
	2016	2017	2016	2017	2016	2017	2016	2017
T1	138.3 c	150.0 b	41.8 b	57.25 bc	96.5 c	92.75 bc	69.75 ab	61.83bc
T2	115.0 e	134.5 c	39.25 b	48.10 de	75.25 e	86.4 c	65.43 c	64.23b
T3	135.5 c	144.8 b	42.75 b	53.05 cd	92.75 cd	91.75 c	68.45ab	63.36b
T4	125.3 d	142.8 b	40.55 b	53.55 c	84.75 cd	89.25 c	68.0 ab	62.5bc
T5	146.8 b	148.0 b	44.3 b	59.05 ab	102.50 bc	88.5 c	67.3 bc	59.67c
T6	114.8 e	115.5 d	40.56 b	45.00 e	74.25 e	70.50 d	64.67 c	61.3bc
T7	165.5 a	159.0 a	53.00 a	57.07 ab	112.00 a	101.30 a	67.97ab	63.71b
T8	160.3 a	158.0 a	51.80 a	63.00 a	108.00 ab	95.0 ab	70.32a	70.12a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

Data presented in *Table 6* show that, in the 1st season acidity percentage was similar in the fruit of T5 (100% Bio N + 50% mineral N +100% mineral P), T6 (100% Bio N +100% Bio P) beside the control plants, while the lowest acidity percentage obtained by T2 (100% Bio P (P.D.B) +100% N). Moreover, in the 2nd season the highest and the lowest value recorded when plants treated with T5 (100% Bio N + 50% mineral N +100% mineral P) and T2 (100% Bio P (P.D.B) +100% N), respectively.

In both seasons the highest fruit TSS as Brix was recorded at T6 (100% Bio N +100% Bio P) and the lowest value presented with T2 (100% Bio P (P.D.B) +100% N). Considering total sugars content, in the 1st season, T6 (100% Bio N +100% Bio P), T7 (100% Bio N +100% Bio P + 50% mineral NP) and T8 (50% Bio P + 50% Bio N + 50% mineral NP) gave the highest significant fruit total sugar content, while plants treated with T2 (100% Bio P (P.D.B) +100% N) had the lowest significant value. Moreover, in the second season T7 (100% Bio N +100% Bio P + 50% mineral NP) and T2 (100% Bio P (P.D.B) +100% N) had the highest and lowest values, respectively.

Fruit reducing sugar percent was significantly improved in response to T8 (50% Bio P + 50% Bio N + 50% mineral NP) in the 1st season as well as, T7 (100% Bio N +100% Bio P + 50% mineral NP) and T8 (50% Bio P + 50% Bio N + 50% mineral NP) in the 2nd season led to significant reduction in fruit reducing sugar value.

Attia et al. (2009) on banana observed that biofertilization increased TSS and decreased acidity.

Table 6. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on finger chemical contents of Williams Banana fruits

Treatments	Acidity (%)		TSS (Brix)		Total sugar (%)		Reducing sugar (%)	
	2015	2016	2015	2016	2015	2016	2015	2016
T1	0.25 a	0.21 bc	20.27 bc	22.12 cd	16.49 bc	17.66 a	15.00b	15.39d
T2	0.20 c	0.19 c	19.37 d	19.37d	13.18 e	13.27 c	11.16 d	11.51d
T3	0.21 bc	0.22 ab	24.5 ab	25.17 ab	16.04 cd	15.82b	14.39bc	13.09c
T4	0.23 ab	0.21 bc	22.5 c	21.5 cd	15.29 d	15.52 b	13.86 c	13.65 c
T5	0.25 a	0.24 a	23 bc	23 bc	16.33 bcd	17.94 a	14.34 bc	15.57b
T6	0.25 a	0.20 bc	25.25 a	26.75 a	17.17 a	17.95 a	15.09 b	16.52 ab
T7	0.22 bc	0.22 ab	23.12 bc	26.75a	17.72 a	18.72 a	15.14 b	17.36 a
T8	0.21 bc	0.22 ab	24.12 ab	25.5 ab	17.92 a	18.4 a	16.14 a	17.26 a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

Leaf chemical composition

Data in Table 7 show that leaf N, P and K contents were affected by tested combination of mineral and biofertilizer treatments. In both seasons, T7 (100% Bio N +100% Bio P + 50% mineral NP) and T8 (50% Bio P + 50% Bio N + 50% mineral NP) showed to be most effective for inducing the greatest values of leaf N, P and K. Meanwhile, T2 (100% Bio P (P.D.B) +100% N) for leaf N%, T5 (100% Bio N + 50% mineral N +100% mineral P) for P content and T2 (100% Bio P (P.D.B) +100% N), T3 (100% Bio P + 50% mineral P +100% N) for leaf K% presented the lowest values for N, P and K, respectively in both seasons. Different workers have proposed different critical levels of N, P, K which ranged from 1.8- 4, 0.17- 0.29 and 1.66 - 6.4%, respectively (Angeles et al., 1993; Memon et al., 2010) and their levels were increased by biofertilizer.

Table 7. Effect of Biofertilizers in combination with different levels of N, P mineral fertilizers on chlorophyll a and b content and N, P and K % content

Treatments	Chlorophyll a (mg g ⁻¹)		Chlorophyll b (mg g ⁻¹)		N%		P%		K%	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
T1	2.592 ab	2.310 de	1.207 bc	1.063 c	2.90 b	3.11 b	0.23b	0.24ab	2.6 b	2.66b
T2	2.003 c	2.213 e	1.015 de	0.910 d	2.72 d	2.85 d	0.24ab	0.24ab	2.2 d	2.40 d
T3	2.162 c	2.310 de	0.930 e	0.952 cd	2.84 c	2.92 c	0.23b	0.24ab	2.2 d	2.40d
T4	2.375 b	2.273 e	1.020 de	1.035 cd	2.79c	2.90cd	0.23b	0.23ab	2.46 c	2.50 c
T5	2.750 a	2.615bc	1.300 ab	1.255 b	2.79 c	2.92c	0.20c	0.22b	2.50c	2.60b
T6	2.425 b	2.470 cd	1.072 cde	1.330 ab	2.79 c	2.92c	0.25ab	0.25a	2.60 b	2.62b
T7	2.752 a	2.815 a	1.415a	1.390a	3.25 a	3.35a	0.26 a	0.25a	2.8a	2.80a
T8	2.500b	2.660 ab	1.102 cd	1.450a	3.22a	3.32 a	0.25 ab	0.25a	2.82a	2.80 a

Means within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. T1: Control (100% mineral NP), T2: 100% Bio P (P.D.B) +100% N, T3: 100% Bio P + 50% mineral P +100% N, T4: 100% Bio N (N.F.B) + 100% mineral P, T5: 100% Bio N + 50% mineral N +100% mineral P, T6: 100% Bio N +100% Bio P, T7: 100% Bio N +100% Bio P + 50% mineral NP, T8: 50% Bio P + 50% Bio N + 50% mineral NP

Chlorophyll content showed no clear trend, however, T7 recorded the highest significant content of chlorophyll a and b of in both seasons.

Conclusion

From the obtained results it can be concluded that integrating biofertilizers (Az14 as nitrogen fixation and B6 as phosphate dissolving bacteria) in fertilization program of Williams banana was beneficial in enhancing the most estimated parameters of banana in terms of yield and fruit quality, moreover T7 and T8 treatments are recommended due to their help in minimizing the application of mineral fertilizer to 50%, which is cost-effective and reducing environmental pollution leading to sustainable agriculture production.

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