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Research Article
Agronomic Benefits of Shubhodaya-Mycorrhizal Bio-Fertilizer on Banana Production in Embu County, Kenya

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Abstract

Background and Objective: Banana (*Musa* spp.) fruit yields in Kenya ranges from 4.5-10 tons per hectare per annum compared to the international levels of 40-50 t. This low production is attributed majorly to poor soil fertility management. This study was carried out to evaluate the effect of shubhodaya-mycorrhizal bio-fertilizer on banana productivity in Embu County. **Materials and Methods:** The experiment was set up in 5 sites distributed in different agro-ecological zones within Embu County. Application of treatments was preceded by soil chemical analysis to determine the soil fertility status. There were 6 treatments designated as T_1: 5 g of NPK (13:2:44) fertilizer (control), T_2: 5 g NPK+20 g bio-fertilizer, T_3: 5 g NPK+30 g bio-fertilizer, T_4: 5 g NPK+40 g bio-fertilizer, T_5: 5 g NPK+50 g bio-fertilizer and T_6: 50 g bio-fertilizer alone. The experiment was laid out in a randomized complete block design with 4 replications. A tissue culture banana cv. Gal was used as the test crop. **Results:** Soil analysis results indicated low soil fertility status characterized by acidic pH and low levels of macro and micronutrients. Treatment T_5 produced the highest growth rate and weight of first bunch. Sole application of the bio-fertilizer at a rate of 50 g produced better results than when integrated at lower rates with the inorganic fertilizer. **Conclusion:** Shubhodaya mycorrhizal bio-fertilizer can serve as alternative eco-friendly source of plant nutrients in banana production.

Key words: Shubhodaya mycorrhizal, bio-fertilizer, soil fertility, banana yields, macronutrients, micronutrients, plant nutrients

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Banana (*Musa* spp.) is a highly nutritious medicinal fruit that is ranked as the third most cultivated crop in the world[1]. Its consumption is vital in maintaining good health due to its high supply of vitamin A, potassium, carbohydrates[2]. Over 70 million people in the world rely on banana consumption for approximately 25% of their carbohydrate requirements[3]. As a major food and cash crop, banana contributes significantly to the Gross Domestic Product (GDP) of Kenyan economy and plays a major role in the diets of the people[4,5]. It is a principal source of food, employment and income in many developing countries where it is ranked fourth most important food crop after rice, wheat and maize[6]. However, banana productivity in Kenya has been declining and is estimated to average between 4.5 and 10 t ha^{-1} per year against the international production[3] of 40-50 t ha^{-1}. Mfilinge *et al.*[7] cited low crop productivity as a general problem facing most smallholder farming systems in Sub-Saharan Africa (SSA).

Meru is the leading banana producing County in Kenya followed by Kirinyaga County. In the third place, Embu County produces 12% of all bananas produced in Kenya hence has a very high production potential[2]. However, the County has recorded declined banana yields in the past years. It is reported by Ouma and Jagwe[8] that biotic and abiotic constraints coupled with inappropriate husbandry practices have contributed to the decline in banana productivity. Husbandry practices include soil fertility management practices and plant nutrition approaches[9]. Bananas perform best in deep, loamy and silty clay loam soil[10] with pH of 5.8-7.5. The soil should be rich in organic matter and with adequate nitrogen, phosphorus and potassium[11]. Most tropical soils are reportedly acidic and have declined in fertility thus leading to declining crop yield. Liming is recommended in acidic soils in order to make them suitable for banana production[12,13]. However, the best fertilization regime should also be based on soil analysis which provides a guide on appropriate fertility management system from year to year[10,14].

The recommended average rates of nutrients applications for bananas in tropical areas comprise of 400-600 kg of nitrogen, 200-300 kg of phosphorous (P_2O_5), 850-1100 kg of potassium and 2 tons of lime per hectare per year[10]. These relatively high fertilizer rates are necessary because high yielding banana crops extract large quantities of nutrients from the soil[14]. Previous experiments showed that a crop producing 40-60 t of yield per hectare removes 250-300 kg nitrogen, 25-40 kg phosphorous, 800-1200 kg of potassium, 150-180 kg calcium, 40-50 kg magnesium and 14-20 kg sulphur per hectare[10]. Many fertilizers have been used for banana production but a composite with an NPK formulation is suitable for most soils[10]. In addition, 20-40 kg of well decomposed organic manure is recommended on yearly basis per stool[10].

There are some emerging eco-friendly technologies which are alternative to chemical fertilizers in banana production[15]. Bio-fertilizers and organic manures are eco-friendly and effective in reducing the use of inorganic fertilizers thus promoting soil health and agricultural productivity[16]. Bio-fertilizers have immense benefits in crop production including increased crop productivity, improvement of soil structure and environmental safety[15,17]. According to Sanginga and Woomer[9], inoculation of tissue culture bananas with arbuscular mycorrhizal fungi (AMF) enhances their early growth through substantially enhanced root network. Itelima *et al.*[18] reported that bio-fertilizers keep the soil environment rich in all kinds of macro and micro nutrients via nitrogen fixation, phosphate and potassium mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter.

Shubhodaya-mycorrhizal bio-fertilizer is an organic fertilizer consisting of a carrier medium rich in live microorganisms (different types of fungi) which forms a mutually beneficial or symbiotic relationship with host plants as they grow in the soil[19]. It is a consortium of three different highly adoptable species of *Glomus* mycorrhizal fungus[20]. It improves plant mineral nutrients acquisition in exchange for carbon compounds or excess sugars from plants, resulting in host plant growth responses[21]. It offers up to 50% reduction in chemical fertilizer use as it mobilizes and transfers phosphorus, nitrogen, sulphur and micronutrients like copper, zinc, manganese, iron, cobalt, molybdenum and boron[17]. It is also very effective in water scarcity areas and increases yield between 25-50%. In addition, it stimulates and promotes plant growth hormones resulting in better plant growth and increased plant disease resistance especially soil borne diseases. The bio-fertilizer is also non-toxic, non-hazardous and eco-friendly and improves soil structure, texture and restores natural soil fertility[17]. Other significant roles include, plant protection from biotic and abiotic stresses by altering host environmental tolerance to water deficit or pollutants or reducing susceptibility to soil borne pathogens[22,23].

Combining shubhodaya mycorrhizal bio-fertilizer with recommended levels of inorganic compound fertilizers (NPK) tremendously increased plant height and number of fruits per plant of papaya over treatments which received recommended rate of inorganic fertilizer alone[24]. Other studies

with the bio-fertilizer have indicated increase in yields of paddy rice by 15-23%, papaya by 42%, potatoes by 31%, onions by 25%, carrots by 23%, coriander by 30% and fenugreek by 27%[20]. However, there is scanty data on its use in bananas production thus not yet adopted by banana farmers as an alternative source of plant nutrients. There is need to evaluate and document its agronomic benefits in banana production and it's potential in mitigating low banana productivity.

MATERIALS AND METHODS

Description of the study sites: Embu County lies between 700-1780 masl on the Eastern slopes of Mt. Kenya. The average annual rainfall is 1252 mm and is received in two distinct rainy seasons. The long rains occur from mid-March to September with an average rainfall of 650 mm and the short rains occur from mid-October to February with an average of 450 mm[25]. The mean annual temperature for the area is 19.5°C with an average minimum and maximum of 14.10 and 250°C, respectively. The mean annual evapo-transpiration is 950 mm while the mean annual potential evaporation is 1422 mm[26]. The soils are mainly humic Nitisols which are deep, of highly weathered friable clay texture[27]. These soils had originally moderate to high inherent fertility which has since declined due to continuous cultivation without adequate replenishment of nutrients. Most farmers rely on production of maize, pulses and horticultural crops alongside livestock keeping.

The study was carried out in selected farmers' fields in 5 selected study sites from April, 2018 to March, 2019. The five sites were Nthambo representing Embu West Sub-County, Njukiri representing Embu North Sub-County, Gichemwe and Ugweri representing Runyenjes Sub-County and Riandu representing Mbeere North Sub-County. Nthambo and Njukiri are found in upper midland (UM) 2 agro-ecological zone at an elevation of 1510 and 1498 masl, respectively. Ugweri is found in UM 3 agro-ecological zone at an elevation of 1223 m above sea level while Riandu is found in lower midland 3 agro-ecological zone at an elevation of 1213 m above sea level. The five sites dominate the banana production areas of Embu County and were representative of about 70% of smallholder farmers and almost 90% of households engaged in agricultural activities.

Soil chemical analysis: Soil samples were collected from the 5 experimental sites to determine the inherent soil chemical properties limiting banana productivity in Embu County. Fifteen samples were taken from different spots at equal distance per site at a depth of 0-20 cm observing a zigzag movement pattern. The soil was bulked and mixed to obtain a representative composite sample for analysis per site. The soil was analysed for pH, exchangeable acidity, cation exchange capacity (CEC) and standard wet chemical analysis for macro and micronutrients. The soil testing and analysis was conducted at crop nutrition soil Laboratories in Nairobi and verified at International Centre for Tropical Agriculture (CIAT).

Experimental design and layout: The experiment was laid out in a randomized complete block design (RCBD) with 4 replications. Six banana plants were planted per treatment per block. The planting hole was measuring 90 cm by 90 cm square and 60 cm deep. The plants were spaced at 4 m between the rows and 3 m between plants in all the 5 experimental sites. The hole was dug separating the top soil (up to 20 cm deep) with the sub soil. Twenty kg of well decomposed farm yard manure and 200 g of TSP fertilizer were mixed with top soil and the hole re-filled to two thirds. The test crop was tissue culture banana cv. Gal (an essential derivative of William Hybrids) and the plantlets were planted in a depth of 20-30 cm. The plantlets were sourced from Mimea International Ltd in Nairobi and hardened at Safalmond Ltd., at Iveche in Embu County. Uniform seedlings of the same age and size were selected.

Six treatments were allotted randomly in each of the replicates 2 months after planting as follows: T_1: Control (5 g multi-K NPK (13:2:44), T_2: 5 g multi-K NPK (13:2:44)+20 g bio-fertilizer, T_3: 5 g multi-K NPK (13:2:44)+30 g bio-fertilizer, T_4: 5 g multi-K NPK (13:2:44)+40 g bio-fertilizer, T_5: 5 g multi-K NPK (13:2:44)+50 g bio-fertilizer and T_6: 50 g bio-fertilizer. The 5 g Multi-K NPK (13:2:44) fertilizer was applied as basal dressing 2 weeks after Shubhodaya bio-fertilizer application. Regular watering was carried out twice per week during the dry months. All other crop management practices were carried out as recommended and uniformly to all the plants in all the sites.

Data collection: The growth data was taken every month from the second month after planting up to first flowering. However, the data reported in this paper was taken at the ninth month just before flowering. Three suckers were maintained per stool and data was taken from the first sucker only. The plant growth parameters included: plant height measured from the base to terminal bud apex; leaf length and girth of the pseudo-stem taken at 20 cm from the base of the plant. The yield parameters were measured from the ninth month onwards and they included the number of days to flowering, number of hands per bunch and bunch weight of first crop.

Statistical analysis: The data was subjected to analysis of variance (ANOVA) and the means were separated using least significant difference (LSD) at 5% level of significance. Pearson correlation was carried out to determine the relationship between growth and yield variables. Coefficient of variation (CV) was also calculated to demonstrate the accuracy of the experiment.

RESULTS

Inherent soil chemical properties: Soil sampling and analysis was conducted in the 5 experimental sites located in farmer's fields to determine fertility components and the pH in banana production areas. The soil analysis results of all the 5 experimental sites indicated slightly acidic to acidic pH with low levels of most essential macro and micronutrients except manganese and percent hydrogen. The soils also indicated low CEC, low C/N ratio and low levels of organic matter, Calcium: Magnesium (Ca: Mg ratio) imbalance (Table 1).

Plant height: Significant ($p<0.05$) differences in plant height were observed between treatments in all the sites. The treatment means for all the 5 experimental sites were also significantly ($p<0.05$) different from each other. The highest plant height (221.75 cm) was recorded in treatment T5 (5 g NPK+50 g bio-fertilizer). Significant differences in mean plant height were also observed between different experimental sites. The highest mean plant height was observed at Njukiri (207.08 cm), Nthambo (206.92 cm) and Riandu (206.88 cm) sites which were not significantly different from each other but were significantly ($p<0.05$) higher than Gichemwe (195.4 cm) and Ugweri (198.83 cm) as shown in Table 2. Site and treatment interactions were also significant ($p<0.05$) indicating that the test crop responded differently to different treatments at different sites (data not shown).

Leaf length: Mean leaf length recorded significant ($p<0.05$) variations between treatments in all the 5 study sites. The treatment means for all the 5 experimental sites combined were also significantly ($p<0.05$) different from each other. The highest mean leaf length (185.70 cm) was recorded in treatment T5 (5 g NPK+50 g bio-fertilizer) while the smallest (169.35 cm) was recorded in the control treatment. Significant differences in mean leaf length were also observed between different experimental sites. The longest mean leaf length was recorded at Njukiri (181.46 cm) which was significantly ($p<0.05$) different from all the other sites (Table 3). Site and treatment interactions were also significant ($p<0.05$) indicating that the test crop responded differently to different treatments at different sites.

Table 1: Soil analysis results from the 5 experimental sites

Parameters	Units	Guide low	Guide high	Nthambo	Njukiri	Gichemwe	Ugweri	Riandu
pH (H_2O)		5.80	7.00	5.60 (L)	6.15 (O)	4.93 (L)	5.99 (O)	6.12 (O)
EC (salts)	µS cm^{-1}		<800.00	740.00 (H)	53.00 (O)	72.00(O)	59.00 (O)	87.00 (O)
Phosphorus (P)	ppm	40.00	100.00	6.72 (L)	22.90 (L)	23.40 (L)	9.53 (L)	1.20 (L)
Potassium (K)	ppm	290.00	464.00	430.00 (O)	503.00 (H)	268.00 (L)	349.00 (O)	320.00 (O)
Calcium (Ca)	ppm	1490.00	2080.00	1270.00 (L)	1810.00 (O)	631.00 (L)	1120.00 (L)	1150.00 (L)
Magnesium (Mg)	ppm	178.00	321.00	289.00 (O)	308.00 (O)	182.00 (L)	227.00 (O)	270.00 (O)
Sulphur (S)	ppm	10.00	200.00	12.10 (L)	2.30 (L)	39.10 (L)	3.58 (L)	8.26 (L)
Sodium (Na)	ppm		<171.00	16.80 (O)	49.30 (O)	13.40 (O)	12.00 (O)	17.90 (O)
Iron (Fe)	ppm	30.00	300.00	81.40 (L)	72.50 (L)	92.50 (L)	62.60 (L)	60.40 (L)
Manganese (Mn)	ppm	30.00	250.00	483.00 (H)	345.00 (H)	416.00 (H)	364.00 (H)	320.00 (H)
Boron (B)	ppm	0.80	2.00	0.70 (L)	0.78 (L)	0.53 (L)	0.47 (L)	0.51 (L)
Copper (Cu)	ppm	2.00	10.00	2.10 (L)	1.11 (L)	1.05 (L)	0.82 (L)	0.96 (L)
Zinc (Zn)	ppm	2.00	20.00	24.50 (H)	12.10 (O)	5.80 (L)	3.34 (L)	4.69 (L)
CEC	meq/100 g	15.00	30.00	14.90 (L)	16.00 (L)	11.80 (L)	10.60 (L)	14.60 (L)
Nitrogen (N)	%	0.20	0.50	0.26 (L)	0.24 (L)	0.30 (L)	0.25 (L)	0.28 (L)
Organic matter	%	3.00	8.00	6.05 (O)	5.64 (O)	6.05 (O)	5.02 (O)	5.23 (O)
C/N ratio	Ratio	10.00	25.00	13.50 (L)	13.70 (L)	11.70 (L)	11.70 (L)	10.90 (L)
Calcium (Ca)	%	50.00	70.00	42.70 (L)	56.60 (L)	26.80 (L)	52.60 (L)	49.00 (L)
Magnesium (Mg)	%	10.00	18.00	16.20 (O)	16.00 (O)	12.90 (O)	17.80 (O)	19.20 (H)
Potassium (K)	%	5.00	8.00	7.41 (O)	8.06 (H)	5.84 (O)	8.41 (H)	6.99 (O)
Sodium (ESP)	%	0.00	5.00	0.49 (O)	1.34 (O)	0.50 (O)	0.49 (O)	0.66 (O)
Other bases	%	3.00	10.00	6.20 (O)	5.25 (O)	7.54 (O)	5.42 (O)	5.64 (O)
Hydrogen (H)	%	10.00	15.00	27.00 (H)	12.80 (O)	46.40 (H)	15.30 (H)	15.60 (H)
Ca:Mg ratio	Ratio	4.00	7.00	2.64 (L)	3.53 (L)	2.08 (L)	2.96 (L)	2.56 (L)

L: Low, O: Optimum, H: High

Table 2: Effect of mycorrhizal bio-fertilizer on plant height

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment means
T1	194.00^{a}	196.00^{a}	189.75^{a}	179.75^{a}	182.25^{a}	188.35^{a}
T2	195.50^{a}	197.00^{a}	194.75^{b}	181.00^{a}	188.00^{b}	191.25^{b}
T3	198.50^{a}	198.75^{a}	201.50^{c}	184.50^{a}	189.00^{b}	194.45^{c}
T4	212.75^{b}	213.50^{b}	212.25^{d}	196.25^{b}	206.25^{c}	208.20^{d}
T5	225.00^{c}	221.75^{c}	224.50^{e}	218.25^{d}	219.25^{d}	221.75^{f}
T6	216.75^{b}	214.50^{b}	218.50^{e}	210.50^{c}	208.25^{c}	213.70^{e}
Site means	207.08^{c}	206.92^{c}	206.88^{c}	195.04^{a}	198.83^{b}	-
CV	1.5	1.70	1.50	1.90	1.30	1.50
p-value	0.0001	0.0001	0.0001	0.0001	0.0001	<0.0001
LSD 5%	4.74	5.43	4.75	5.46	3.77	2.54

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05

Table 3: Effect of mycorrhizal bio-fertilizer on leaf length

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment means
T1	171.00^{a}	169.50^{a}	169.25^{a}	170.25^{a}	166.75^{a}	169.35^{a}
T2	174.00^{a}	170.00^{ab}	170.25^{ab}	171.75^{a}	169.75^{a}	171.15^{b}
T3	174.00^{a}	172.75^{b}	173.50^{bc}	170.25^{a}	173.50^{b}	172.80^{c}
T4	185.25^{b}	180.25^{c}	172.75^{bc}	172.25^{a}	178.50^{c}	177.80^{d}
T5	193.25^{c}	187.00^{d}	188.50^{e}	175.25^{b}	185.00^{d}	185.70^{f}
T6	191.25^{c}	182.25^{c}	180.50^{d}	172.50^{a}	177.25^{c}	180.75^{e}
Site means	181.46^{d}	176.96^{c}	175.71^{bc}	172.04^{a}	175.13^{b}	-
CV	1.60	1.10	1.10	1.00	1.40	0.80
p-value	0.0001	0.0001	0.0001	0.0073	0.0001	<0.0001
LSD 5%	4.51	3.00	3.03	2.51	3.64	1.52

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05

Table 4: Effect of mycorrhizal bio-fertilizer on pseudo-stem girth (cm)

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment Means
T1	65.75^{a}	63.00^{a}	68.50^{ab}	65.25^{a}	64.75^{a}	65.45^{a}
T2	68.75^{b}	65.00^{b}	67.50^{a}	66.75^{b}	70.25^{b}	67.65^{b}
T3	69.50^{b}	64.00^{ab}	68.75^{b}	67.75^{b}	71.50^{b}	68.30^{b}
T4	69.25^{b}	66.25^{cd}	69.00^{b}	68.00^{bc}	74.00^{c}	69.30^{c}
T5	74.50^{c}	69.00^{e}	70.00^{c}	69.25^{c}	80.25^{d}	72.60^{e}
T6	73.75^{c}	66.75^{d}	68.00^{ab}	67.25^{b}	75.50^{c}	70.25^{d}
Site means	70.25^{d}	65.67^{a}	68.63^{c}	67.38^{b}	72.71^{e}	-
CV	2.3	1.3	1.0	1.2	2.0	0.8
p-value	0.0001	0.0001	0.0034	0.0002	0.0001	<0.0001
LSD 5%	2.40	1.30	1.07	1.27	2.21	0.89

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05

Pseudo-stem girth (cm): Significant (p<0.05) differences in mean pseudo-stem girth were observed between treatments in all the 5 sites. The treatment means for all the experimental sites combined were also significantly (p<0.05) different from each other. The biggest mean pseudo-stem girth (72.60 cm) was recorded in treatment T5 (5 g NPK+50 g bio-fertilizer) while the smallest was recorded in the control treatment T1 (5 g NPK fertilizer alone). Significant differences in mean pseudo-stem girth were also observed between different experimental sites. The biggest mean pseudo-stem girth was recorded at Ugweri (72.71 cm) and the smallest was recorded at Nthambo at 65.67 cm (Table 4). Site and treatment interactions were also significant (p<0.05) indicating that the test crop responded differently to different treatments at different sites.

Days to flowering: Different fertilizer treatments did not show significant effects (p>0.05) on days to flowering at Riandu, Gichemwe and Ugweri but significant (p<0.05) effects were observed at Nthambo and Njukiri sites. The average days to flowering for all the experimental sites were also not significantly different (p>0.05) from each other. However, significant (p<0.05) differences in average days to flowering were observed between different experimental sites. The shortest time to flowering was recorded at Ugweri (290 days) followed by Riandu (292 days). Njukiri, Gichemwe and Nthambo were not significantly different in the average days to flowering, recording an average of 316, 317 and 318 days respectively (Table 5). Site and treatment interactions were significant (p<0.05) indicating that different treatments had different effects on flowering time at different experimental sites (data not shown).

Table 5: Effect of mycorrhizal bio-fertilizer on number of days to flowering

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment means
T1	315.50^{ab}	319.50^{c}	290.00^{a}	316.75^{a}	289.75^{a}	306.30^{a}
T2	314.00^{a}	315.00^{a}	294.00^{a}	317.00^{a}	290.50^{a}	306.10^{a}
T3	318.00^{bc}	316.25^{ab}	289.25^{a}	316.25^{a}	290.25^{a}	306.00^{a}
T4	315.50^{ab}	317.75^{bc}	294.25^{a}	317.00^{a}	290.50^{a}	307.00^{a}
T5	318.75^{c}	319.00^{c}	294.50^{a}	317.00^{a}	290.00^{a}	307.85^{a}
T6	317.00^{bc}	318.50^{bc}	289.25^{a}	316.75^{a}	290.25^{a}	306.35^{a}
Site means	316.46^{c}	317.67^{c}	291.88^{b}	316.79^{c}	290.21^{a}	-
CV	0.6	0.5	1.3	0.3	0.4	0.8
p-value	0.0227	0.0062	0.1486	0.8087	0.9427	0.072
LSD 5%	2.8	2.31	NS	NS	NS	NS

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05, NS: Not significant

Table 6: Effect of mycorrhizal bio-fertilizer on number of hands per bunch

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment means
T1	8.75^{a}	8.75^{a}	9.00^{a}	9.00^{a}	9.00^{a}	8.90^{a}
T2	8.75^{a}	8.50^{a}	9.00^{a}	9.00^{a}	9.00^{a}	8.85^{a}
T3	9.00^{a}	9.00^{a}	8.75^{a}	8.75^{a}	9.00^{a}	8.90^{a}
T4	9.00^{a}	8.75^{a}	9.00^{a}	8.75^{a}	9.00^{a}	8.90^{a}
T5	8.75^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	8.95^{a}
T6	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}	9.00^{a}
Site means	8.88^{ab}	8.83^{a}	8.96^{ab}	8.92^{ab}	9.00^{b}	-
CV	3.9	4.3	0.2	3.3	0.0	4.1
p-value	0.6813	0.3759	0.4510	0.5988	-	0.630
LSD 5%	NS	NS	NS	NS	NS	NS

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05, NS: Not significant

Table 7: Effect of mycorrhizal bio-fertilizer on bunch weight (kg)

Treatments	Njukiri	Nthambo	Riandu	Gichemwe	Ugweri	Treatment means
T1	20.75^{a}	21.00^{a}	22.75^{a}	22.50^{a}	20.00^{a}	21.40^{a}
T2	21.50^{ab}	24.00^{b}	25.25^{ab}	23.75^{a}	24.75^{b}	23.85^{b}
T3	24.50^{bc}	25.55^{b}	24.75^{abc}	28.75^{b}	24.50^{b}	25.60^{c}
T4	26.25^{cd}	29.25^{c}	29.00^{bcd}	30.00^{b}	28.25^{c}	28.55^{d}
T5	31.75^{e}	34.00^{d}	31.25^{d}	34.50^{c}	31.00^{c}	32.50^{f}
T6	29.50^{de}	33.50^{d}	29.75^{cd}	33.50^{c}	28.25^{c}	30.90^{e}
Site means	25.71^{a}	27.88^{cd}	27.13^{bc}	28.83^{d}	26.13^{ab}	-
CV	8.90	4.60	11.60	7.20	7.8	4.30
p-value	0.0001	0.0001	0.0105	0.0001	0.0001	<0.0001
LSD 5%	3.43	1.93	4.74	3.13	3.06	1.45

Treatment and site means followed by the same letter within the column and within the row respectively, are not significantly different at p = 0.05

Number of hands per bunch: Different fertilizer treatments did not show significant (p>0.05) effects on number of hands per bunch in all the experimental sites. Similarly, there were no significant (p>0.05) differences in number of hands per bunch between different experimental sites (Table 6). Site and treatment interactions were also not significant (p>0.05) indicating that different treatments produced similar effects on number of hands per bunch in different experimental sites.

Bunch weight (kg): The bunch weight responded significantly to different fertilizer treatment in all the 5 experimental sites. The treatment means of bunch weight for all the experimental sites combined were also significantly (p<0.05) different from each other. The highest bunch weight (32.50 kg) was obtained under treatment T5 (5 g NPK+50 g bio-fertilizer) while the lowest (21.40 kg) was obtained under the control treatment T1 (5 g NPK fertilizer alone). Significant differences in mean bunch weight were also observed between different experimental sites. Gichemwe produced the heaviest bunches averaging 28.83 kg followed by Nthambo and Riandu at 27.88 and 27.13 kg, respectively. Ugweri and Njukiri produced significantly lighter bunches averaging 26.13 and 25.71 kg respectively (Table 7). Site and treatment interactions were not significant (p>0.05) indicating that different fertilizer treatments produced similar effects on bunch weight at different sites.

Pearson correlation between growth and yield variables: Correlation between the growth variables and days to flowering as well as number of hands per bunch was not

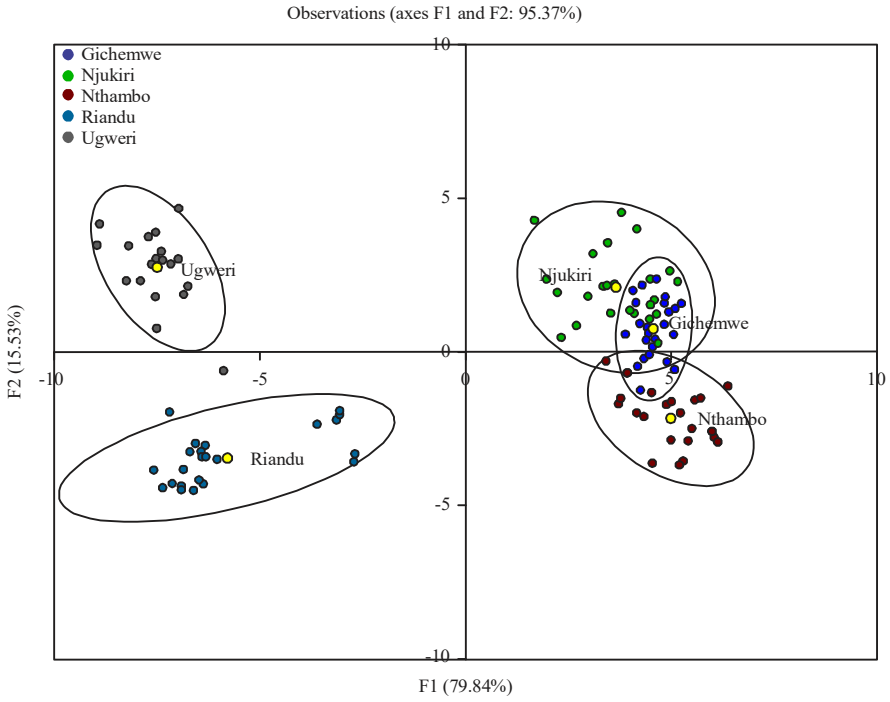


Fig. 1: Discriminant analysis depicting location differences

Table 8: Correlation matrix (Pearson) between growth and yield parameters

Variables	Days to flowering	Number of hands/bunch	Weight (kg) of 1st bunch
Plant height	0.056	0.064	0.711*
Leaf length	0.125	0.064	0.554*
Pseudo stem girth	-0.371*	0.129	0.379*

*Values are different from 0 with a significance level $\alpha = 0.05$

significant except for pseudo-stem girth which was negatively correlated to days to flowering (Table 8). However, all the growth variables recorded significant positive correlation with weight of first bunch (Table 8).

Site variations: Discriminant analysis grouped the five sites based on their similarities as determined by the growth and yield responses in Fig. 1. Factor 1 explained 79.84% of the total variation while Factor 2 explained 15.53% variation. Based on the variable verses factor correlations, Njukiri, Gichemwe and Nthambo were plotted closely together at F1 coordinates of 3.674, 4.590 and 4.993, respectively and F2 coordinates of 2.105, 0.757 and -2.148, respectively (Fig. 1). Ugweri was plotted separately on the left upper segment at F1 and F2 coordinates of -7.473 and 2.732 respectively. Riandu was also plotted separately on the left lower segment at F1 and F2 coordinates of -5.784 and -3.445, respectively. This separation shows that most growth and yield variables were similar at Njukiri and Gichemwe. The other three sites were distinctly variable but also conferred to some variables similar effects as the other sites. For example, although Nthambo was significantly different from Njukiri and Gichemwe, it had more similarities with the two sites than with Riandu and Ugweri. There was also closer proximity between Ugweri and Riandu as compared to the proximity between each of them with the other 3 sites.

DISCUSSION

Soil analysis results indicated low inherent fertility in the soil as characterized by low pH levels, Ca:Mg imbalance, low levels of NPK nutrients and essential secondary macro and micro nutrients, low CEC and low levels of organic matter. According to Itelima *et al.*[18], a good quality soil is one that is 45% minerals (sand, silt and clay), 25% water, 25% air and 5% organic and living matter. Soil fertility has been cited as the most important constraint limiting crop yield in Sub Saharan Africa[28-32] and especially among resource-poor farmers[33]. Maintaining soil quality can reportedly reduce the problems of land degradation, decreasing soil fertility and rapidly

declining production levels in many parts of the world[18]. In a study conducted by Wairegi[30] in Uganda, declining soil fertility was noted in soil organic matter, total N and K/(Ca+Mg).

Extractable N, P, K, Ca, Mg and vital micro-nutrients were below critical levels. Their levels in the top soil were 20-70% less than the levels found in the 1960s indicating a 30-80% decline in inherent fertility. The soil pH was also tending to acidic levels. According to Van Asten *et al.*[28], deficiencies in K, N and Mg are commonly detected in fertilizer trials and banana foliar samples. Banana demands greater quantities of N, P and K in addition to smaller quantities of micronutrients. This coupled with acidic nature of soils, inappropriate use of inorganic fertilizers without testing the soils and little or no use of organic manures may have contributed to depletion of soil fertility thus causing a major drawback for higher banana productivity in Embu County. It is estimated that nutrient depletion countries in Sub-Saharan is high with losses of 130 kg N, 5 kg P and 25 kg K ha^{-1}/year being reported in the East African highlands[32]. This is attributed to soil erosion and high outputs of nutrients in harvested products.

Application of mycorrhizal bio-fertilizer was found to have significant effects on all the banana growth parameters that were evaluated namely, plant height, leaf length and pseudostem girth. A significantly higher growth was observed in the treatments with bio-fertilizer (treatments 2-6) as compared to the control treatment T1. Similar results were obtained in a study by Hazarika *et al.*[34] where a combination of inorganic fertilizers with organic manures, bio-fertilizers and bioagents significantly increased growth parameters, leaf characteristics and leaf nutrient status of banana. A combination of 5 g multi-K NPK (13:2:44) with the highest rate of bio-fertilizer (50 g) was found to produce the highest growth. However, a cost benefit analysis is also recommended to determine the optimum application rates that would guarantee highest returns to the farmers. Bora *et al.*[35] also reported that Vesicular Arbuscular Mycorrhizae (VAM) significantly increase growth components of plants compared to non-mycorrhizal. Singh *et al.*[36] also produced better growth in mycorrhizal treatments than in non-mycorrhizal treatment in pomegranate.

A straight application of 50 g bio-fertilizer alone performed dismally as compared to when the same rate of bio-fertilizer was combined with 5 g multi-K NPK (13:2:44). This was an indication that integrating bio-fertilizer with inorganic fertilizers may have a significant influence in banana production than use of bio-fertilizer alone. This can be attributed to improved uptake of multi-K NPK by banana roots when treated with the mycorrhizal bio-fertilizer. Bora *et al.*[35] reported that VAM is significantly effective in increasing nutrient uptake by the plants. Combining inorganic fertilizers with VAM can therefore reduce plant requirement of the inorganic fertilizers. According to Bora *et al.*[35] and Singh *et al.*[37], organic and natural rocks fertilizers in combination with NPK bio-fertilizers can reduce the need for NPK mineral fertilizers by about 50%. Singh *et al.*[36] achieved about 50% saving of phosphorus through the use of VAM in pomegranate production. Bio-fertilizers can therefore be important components of integrated nutrient management systems for sustaining agricultural productivity and a healthy environment. It's also worth noting that when 50g bio-fertilizer was used alone, it performed significantly better than when it was used at lower rates (20, 30 and 40 g) but in combination with 5g NPK. Singh *et al.*[37] reported that VAM have the ability to supplement requirement of inorganic fertilizers and improve crop productivity.

Bananas in Njukiri, Gichemwe and Nthambo sites took significantly longer to flower compared to the ones in Riandu and Ugweri. This was attributed to varying environmental conditions at different sites including weather and soil properties. The former sites are found at a relatively higher and cooler elevations at the foot of the highlands in the UM2 agro-ecological zone. The other two sites are found in lower and warmer elevations in the UM3 and LM3 respectively[38]. Faster flowering is expected in warmer areas due to faster accumulation of degree days to crop maturity. Treatment T5 (5 g NPK+50 g bio-fertilizer) produced the heaviest banana fruit bunch while the control treatment (5 g NPK fertilizer alone) produced the lightest bunch. Bora *et al.*[35] reported that VAM significantly increase yield components of plants compared to non-mycorrhizal control. According to Singh *et al.*[37], when integrating bio-fertilizer and NPK, recommended dose of NPK is needed for yield maximization but optimum yield can be obtained with 50% saving of NPK fertilizer. All the growth variables recorded significant positive correlation with weight of first bunch indicating that growth components can be used as good indicators of yield.

Discriminant analysis was able to separate the five sites based on the growth and yield characteristics where close proximity was noted between Gichemwe and Njukiri sites both of which also shared some similarities with Nthambo site. The other two sites namely Ugweri and Riandu were distinctly separated from the former three sites in the discriminant analysis. This separation occurred as expected because Gichemwe, Njukiri and Nthambo lies in UM2 agro-ecological zone at an elevation of 1510, 1507 and 1498 masl,

respectively. Ugweri is located in UM3 agro-ecological zone at an elevation of 1223 m above sea level while Riandu is located in LM3 agro-ecological zone at an elevation of 1213 m above sea level[38]. The UM2 and UM3 occur below the highlands and are warmer than the highlands and suitable for banana production. In the contrary, LM3 is hot and dry and suitable for growing drought-tolerant crops such as millet, sorghum, cowpeas and green grams or irrigated agriculture[38]. This study therefore corroborates the report of Abdel Latef *et al.*[39] that VAM to improve plant growth and production under abiotic stress conditions. This is achieved through improvement of root length, leaf area, plant biomass and nutrient uptake under drought condition[40]. Plant growth is further improved by the formation of extensive hyphal networks and secretion of glomalin, which in turn enhance water and nutrient uptake and improve soil structure[40-42]. This study recommends integration of mycorrhizal bio-fertilizer with inorganic fertilizers for banana production in Embu County and other banana producing areas in Kenya to boost banana yields. A cost benefit analysis is also recommended to determine the optimum application rates that would guarantee highest returns to the farmers.

CONCLUSION

The soil analysis established that there was low inherent soil fertility in all the study sites and identified this as one of the major banana production constraints in Embu County. Application Shubhodaya Mycorrhizal bio-fertilizer at the highest rate of 50 g in combination with 5 g multi-K NPK (13:2:44) produced the highest growth and yields of bananas than the lower rates or when the inorganic fertilizer was used alone. However, sole application of the bio-fertilizer at a rate of 50 g produced better results than when integrated at lower rates with the inorganic fertilizer.

SIGNIFICANCE STATEMENT

This study discovered the potential of Shubhodaya Mycorrhizal bio-fertilizer as alternative eco-friendly source of plant nutrients in banana production. This can be utilized by researchers and growers to improve the declining yields of bananas and restore the health of tropical soils which are highly degraded by inorganic fertilizers. This study further helps the researchers to contribute to reduced emission of greenhouse gases from inorganic fertilizers without adversely affecting productivity. Consequently, agronomic sustainability is ensured.

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