RESEARCH ARTICLE

European Journal of Agriculture and Food Sciences
www.ejfood.org

Effect of Biofertilizers and Farmyard Manure on Growth and Tuber Yield of Potatoes (*Solanum tuberosum* L.) in Highlands of Kenya

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ABSTRACT

Poor soil fertility is among the significant constraints to potato production in Kenya. Increased potato production currently depends on the use of chemical fertilizers for nutrients. The prices of chemical fertilizers continuously increase, becoming unaffordable for small-scale farmers who mostly grow potatoes. Therefore, the continuous use of chemical fertilizers such as NPK may cause complete depletion of other macro and micro-nutrients in potato production areas of Kenya. In addition, it increases the cost of inputs and triggers environmental pollution. The objective of this study was to evaluate alternative soil amendments using different bio-fertilizers in potato production. Two field experiments were conducted during the 2019 and 2020 seasons using two potato varieties (*Shangi* and *Kenya mpya*). The treatments were 30 t ha^{-1} of farmyard manure (FYM), two different biofertilizers (*Trichoderma asperellum*, T.R., and *Bacillus subtilis,* B.A.) applied at a rate of (150 mL/10 kg) and NPK (0 and 100 kg ha^{-1}) as negative and positive controls respectively. Field experiments were carried out in randomized complete block design in a split-plot arrangement. The results indicated that FYM+TR increased potato yield and plant height by 19.81% and 18.99%, respectively, compared to the control. FYM+TR also increased tuber dry matter, marketable tuber weight, and potato grade by 25.15% 18.99%, respectively, compared to the positive control. The study recommends using FYM+TR and FYM+ BA for potato production in Kenya as they were found to increase crop performance and subsequent yield, which is beneficial to the environment and safe for farmers.

Keywords: Biofertilizers, Farmyard Manure, *Kenya Mpya,* Potato Performance, *Shang.*

Submitted: March 13, 2022

Published: October 13, 2022

ISSN: 2684-1827

DOI: 10.24018/ejfood.2022.4.5.479

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I. INTRODUCTION

Potato (*Solanum tuberosum*) is an essential nutrient-dense crop globally and helps ensure food security especially in developing countries. The tuber crop is a good source of carbohydrates, proteins, vitamins and minerals. It has gained industrial use in production of starch, crisps and chips due to increased urbanization worldwide [1]. The crop yield per unit area and nutritional value are relatively higher compared to cereal grains [2]. The global and Africa annual potato production is estimated to be 377 and 25 metric tonnes respectively. China is the world's largest potato producer accounting for half of the global production, followed by Europe. On the other hand, Africa grows about 7% of the world's potatoes [3]. Kenya is ranked fifth in Africa with production of 1.35 metric tonnes annually [4]. In Kenya potato average yield is 8 t ha^{-1} compared to the potential of 40 t ha^{-1} [5].

Potato is an important food crop in Kenya after maize and wheat. Most small-scale farmers depend on it as a source of income. About 800 000 farmers grow potatoes, with an estimated 2.5 million people working in the potato sub-sector as transporters, market agents, processors, exporters, etc. [2]. Despite its importance, the potato sector suffers from many problems, including poor seed quality, poor agronomic practices, pests and diseases, and poor soil fertility [6]. Soil fertility management in Kenya involves addition of substantial amounts of nutrients to the soil, therefore farmers consider high fertilizer prices as a huge constraint in potato production [7]. Most Kenyan farmers use recommended fertilizer rates in potato production while others use less than the recommended or no fertilizer. Less-than-recommended rates are attributed to the high cost of fertilizers and lack of soil testing facilities [8]. subsequently, this has led to potato yields falling below the true potential per hectare.

In Sub-Saharan Africa, Kenya ranks 78th in fertilizer use, and the standard national fertilizer rate is about 31.3 kg/ha. However, this is still less than 50 kg/ha, an international standard recommendation [3]. Commercial fertilizers such as DAP and NPK (20:20:0, 23:23:0) are the most widely used. In Kenya, less than 30% of smallholder farmers in high-potential areas use fertilizers, while less than 20% use fertilizers in low-potential areas. Small-scale farmers' low fertilizer usage can be attributed to a lack of knowledge and inability to afford their costs [9]. Significant constraints of potato production in highland areas that reduce the yield of potatoes include a rapid decline in soil fertility caused by unceasing cultivation without satisfactory replenishment of mined nutrients [10]. Besides, most farmers use chemical fertilizers in potato production, which cause changes in the soil's physicochemical properties. In addition, there are concerns about pollution to the environment, associated with reduced yields, soil degradation, nutrient imbalances, and acidification [11]. Biofertilizers, also called microbial inoculants, are organic products containing specific microorganisms derived from plant roots and the rhizosphere. They have been shown to improve growth and subsequent yield; colonize the rhizosphere and the interior of the plant, promoting plant growth when applied to the seed, plant surface or the soil [12]. They not only improve soil fertility and crop productivity by adding nutrients to the soil but also protect the plant from pests and diseases. They have been shown to enhance the growth of the root system, extend its life, degrade harmful microorganisms, increase the survival of seedlings, and reduce the time to flowering [13]. Farmyard manure (FYM) releases nutrients slowly, and steadily and activates soil microbial biomass. FYM can also sustain cropping systems through better nutrient recycling and improvement of soil physical attributes [14]. Consequently, farmers need a combined application of biofertilizers and organic fertilizers in potato production. This may reduce the application rate of inorganic fertilizers and reduce environmental pollution risk. Ultimately, the nutrient supply of organic and biofertilizers is economically viable, environmentally friendly, and socially acceptable without affecting the gross plant production. Therefore, the present study was carried out to determine the response of potatoes to different combinations of organic manure and biofertilizers in Kenya.

II. Materials and Methods

A. Site Description

The field experiments were conducted at Egerton University, main campus Njoro and KALRO Tigoni, Kiambu County in Kenya. Egerton University lies between longitude 35° 35' E, latitude 0° 23' S, and at an altitude of 2000 meters above sea level (m asl). The temperature range is between 17-22 °C, with an average annual rainfall of 1000 mm. KALRO, Tigoni is located in Kiambu County, on latitude 1'080 S and longitude 36' 400 E. The area receives 1800 mm of rainfall annually, and temperatures range from 10 °C to 25 °C. It has an altitude of 2100 m asl [15].

B. Germplasm

Shangi and *Kenya Mypa* varieties were used in this study. *Shangi* variety is common and the most grown variety in Nakuru. It is a semi-erect medium-tall variety with moderately strong stems.

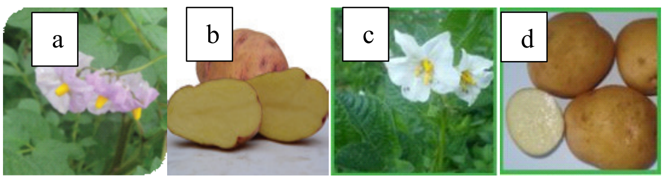

Fig. 1. Shangi and Kenya Mpya Varieties. a) flowers and b) tubers for Shangi, c) flowers, and d) tubers for Kenya Mpya.

The leaves are broad with light green and pink flowers (Fig. 1a). It grows well at an altitude above 1500 m asl, such as Nakuru, Kericho, Bomet, and Narok. It is an early maturing variety with an average yield of 30-40 t ha-1. It has an oval-shaped tuber, smooth cream skin, medium to deep eyes, and white flesh (Fig. 1b). *Kenya Mpya* is one of the newly released varieties used as table variety, especially chips. It grows well in medium to high altitudes of 1400-3000 m asl. It does well in areas such as Nyandarua, Kiambu, Nyeri, Laikipia, Meru, Nakuru, Bomet, Narok, Kwale, Nandi, Kisii, and Cherangani hills. It matures within 3-4 months. The yield of this variety is medium (35-45 t ha-1). The shape of the tubers is Oval, smooth, and cream. It is a tall semi-erect variety (about 1 meter) with solid stems and light green medium-sized leaves. It flowers scarcely, and the flowers are white (Fig. 1c), with yellow flesh with deep eyes (Fig. 1d) [16]. The varieties were selected because they are suitable for experimental sites and grown by most farmers in Nakuru and Kiambu.

C. Experimental Procedure

The experiments were conducted at Egerton University in October 2019 and March 2020 seasons, while at KALRO, Tigoni, it was conducted in October 2019.

Land preparation was done using a mouldboard plough, after which it was harrowed. FYM was applied at the rate of 30 t ha^{-1} and allowed to interact in the soil for two weeks. After incorporation, certified potato seeds *Shangi* and *Kenya Mypa* varieties were sourced from KALRO – Tigoni. Both were planted at a spacing of 75 cm × 30 cm with a planting depth of 10 cm. Biofertilizers (*Trichoderma asperellum* and *Bacillus subtilis*) were applied at 150 mL/10 kg of seed. The recommended dose of fertilizers (NPK 23-23-0) was used as positive control and negative control, at 300 kg ha-1 and 0 kg ha^{-1} respectively.

The field experiments were laid in a randomized complete block design split-plot arrangement. The varieties as the main plot, FYM, and biofertilizer treatments as sub-plots replicated three times. The experiment consisted of 10 treatment combinations comprising FYM with and without biofertilizers (Table I). The rates for fertilizer treatments were calculated according to farmers' practice and recommended nitrogen rate (90 kg ha^{-1}) [17]. The plots were kept weed-free and earthing up done twice while insects and diseases were controlled using Cypertox 250Ec (cyhalothrin 25gl^{-1}) and Ridomil gold (Metalaxyl-M 40 gkg^{-1}, Mancozeb 640 gkg^{-1}), respectively.

Table I: Treatment Combinations For The Experiment

S.N.	Treatment	Treatment details
1	T_0	Negative control (0 NPK)
2	T_1	Positive control (=RDF = NPK 300 kg Ha^{-1}
3	T_2	RDF + *Trichoderma asperellum*
4	T_3	RDF + *Bacillus subtilis*
5	T_4	*Trichoderma asperellum*
6	T_5	*Bacillus subtilis*
7	T_6	FYM
8	T_7	FYM + *Trichoderma asperellum*
9	T_8	FYM + *Bacillus subtilis*
10	T_9	*Trichoderma asperellum* + *Bacillus subtilis*

D. Data Collection

The number of stems per plant and plant height was physically counted at 14, 21, 28, and 35 days after emergence (DAE). After harvesting, 10 plants from the middle rows were uprooted per plot, and number of tubers counted then the average recorded. The average number of marketable tubers was evaluated and counted for those equal or greater to 30 g, and not attacked by disease and insects [18]. The average number of unmarketable tubers were sorted as diseased, insect attack, and small-sized (<30 g). Tubers were then graded into three classes; big size: >60 mm diameter, medium size: 30-60 mm diameter- small size: <30 mm

E. Data Analysis

The data were subjected to SAS software version 9.2. Analysis of variance (ANOVA) and General Linear Model (GLM) procedures of SAS (9.3) at P≤0.05 was done [19].

Statistical model is shown in (1).

$$Y_{ijklm} = \mu + S_I + R_J + V_k + SV_{ik} + B_l + SB_{il} + \varepsilon_{ijklm} \quad (1)$$

where μ= Over all means, S_i= Effect due to $_i{}^{th}$ Season, $R_{j(i)}$ = Effect due to j^{th} block within i^{th} environment, *Vk* = Effect due to k^{th} vareiety *SVi*k = Effect due to interaction of i^{th} season and k^{th} Variety, B_l = Effect due to l^{th} bio-fertilizers, *SBil*= Effect due to interaction i^{th} season and l^{th} biofertilizers *Ɛn (ijklm)*= random error component.

The significantly different treatment means were separated using (2) which shows the least significant difference (lsd) [20].

$$\text{lsd} = \frac{t}{\alpha/2} \times df \times \frac{\sqrt{2MSE}}{r} \quad (2)$$

where t is the *t* value from the *t*- distribution table, α is the level of significance, *df* is the degrees of freedom, *2MSE* is the mean square errors, and *r* is the replicate.

III. Results

A. Effects of Biofertilizers and Farmyard Manure Application on Potato Growth

Analysis of variance (ANOVA) results showed that there were significant differences (P<0.05). Traits responded differently under different growth periods, i.e., fertilizers × time interactions in plant height (Fig. 1a) and the number of stems (Fig. 1b). However, the interaction of Season × Fertilizer × Time was not significantly different. The number of stems was significantly affected by fertilizer treatments where T7 had more stems (3-4), followed by T8, T6, T2, T3, and T1 (Fig 1b). There were no significant differences between varieties; *Kenya mpya* had a higher number of stems (2-7) than *Shangi* (2-6). However, across the seasons showed significant differences, and Egerton season 1 had a higher number of stems (Table III). Plant height was significantly affected by fertilizer treatments, where T7 and T8 had the highest plant height, and the lowest was from T9 and T0. T7 and T8 increased plant height by 19.81% and 14.12%, respectively, compared to a positive control (T1) (Fig 1a).

B. Effects of Biofertilizers and Farmyard Manure Application on Potato Yield

Further ANOVA results showed that there were significant differences (P<0.05) interaction of season and fertilizers. Tuber yield and tuber dry matter were significantly affected by fertilizer treatments. T7 increased tuber yield and dry matter by 25.15% and 13.16 %, followed by T8, which increased by 20.28% and 8.14%, respectively. Varietal differences were observed in tuber yields but not on the dry matter; *Kenya mpya* had a higher tuber yield than *Shangi* (Table II).

On marketability, treatments, T7 and T8 showed an increase of 18.99% and 13.04% in the weight of marketable tubers and 10.86% and 6.65% in the number of marketable tubers compared to the positive control (T1). *Kenya mpya* had the highest weight of marketable tubers (9.40 t ha^{-1}) and many marketable tubers number of tubers (22049) than *Shang*i (9.00 t ha^{-1}) and (19856) respectively. Egerton site had the highest weight of marketable tubers and number of marketable tubers than Tigoni. T7 had the highest weight and number of marketable tubers, followed by T8, and the lowest was from T0 for all varieties (Table IV). However, T0 showed the highest weight of non-marketable tubers and the number of non-marketable tubers for all the variety across all the sites (Table V). Varietal differences were observed in tuber size distribution; *Kenya mpya* variety had higher percentages of big tubers than *Shangi*.

TABLE II: Effect of Farmyard Manure And Bio-Fertilizer Treatments on Potato Tuber Yield (Number of Tubers And Tuber Dry Matter)

Treatment	Total yield (tHa^{-1})		Dry matter (%)	
	Kenya mpya	*Shangi*	*Kenya mpya*	*Shangi*
T5	9.31±0.18	6.56±0.05	20.79±0.83	21.16 ±1.03
T6	7.77±0.19	6.67±0.15	21.18±0.71	22.03 ±0.70
T8	11.86±0.11	9.65±0.97	21.68±1.01	23.91 ±0.5
T7	12.34±0.37	9.77±0.37	24.25±0.42	25.02 ±0.6
T3	9.81±0.33	6.78±0.25	21.46±0.49	23.67 ±0.77
T0	4.01±0.10	5.67±0.21	19.55±0.47	19.01±0.53
T1	9.84±0.48	7.75±0.50	20.69±0.65	22.11 ±0.67
T2	10.22±0.30	7.28±0.18	20.67±0.96	23.67 ±1.33
T4	8.93±0.10	5.91±0.13	20.76±0.44	21.39 ±0.54
T9	6.76±0.11	6.56±0.05	19.84±0.53	[illegible].67 ±0.52

Key: T0: 0 Recommended dose of fertilizer (RDF) T1: RDF T2: RDF + *Trichoderma asperellum* T3: RDF + *Bacillus subtilis* T4: *Trichoderma asperellum* T5: *Bacillus subtilis* T6: FYM T7: FYM + *Trichoderma asperellum* T8: FYM + *Bacillus subtilis* T9: *Trichoderma asperellum* + *Bacillus subtilis*

C. Correlation Between Growth and Yield Parameters (Total Yield And Dry Matter)

Plant height was positively correlated with the dry matter at Egerton season1 (Fig. 3a) and Egerton season 2 (Fig. 3c). However, Tigoni was negatively correlated (Fig. 3b). However, plant height was positively correlated with total yield across the three sites: at Egerton season1 (Fig. 3d), Egerton season 2 (Fig. 3e), and Tigoni (Fig. 3f). Lastly, total yield was positively correlated with dry matter across the three environments: at Egerton season 1 (Fig. 3g) and Egerton (Fig. 3h) and Tigoni season 1 (Fig. 3i).

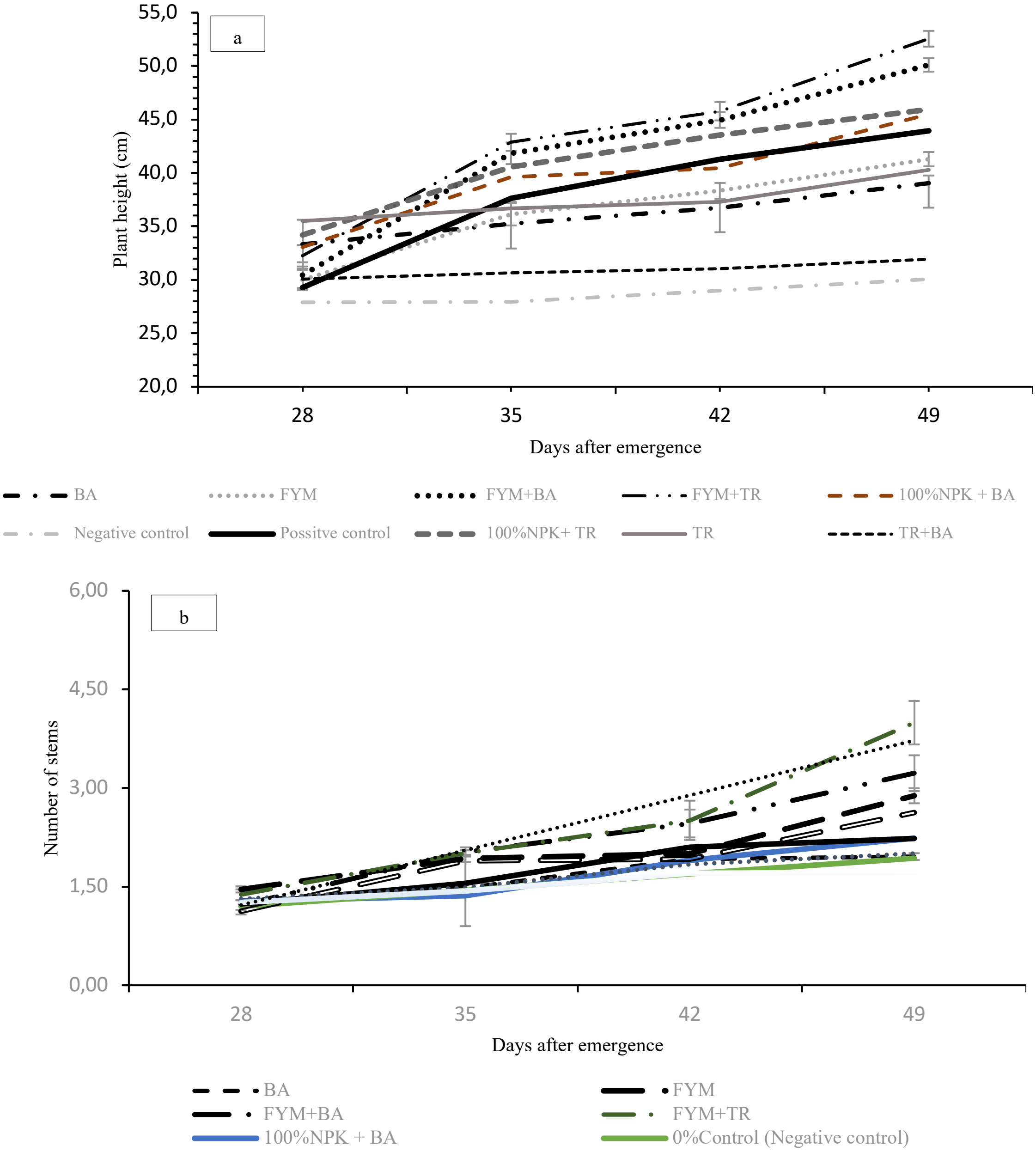

Fig. 2. Biofertilizer treatments effect on potato plant height (cm) for field experiment. Standard error bars. a (Plant height) and b (Number of stems) at Egerton site 1, Egerton site 2 and Tigoni.

Keys: 0NPK = (0% $kgHa^{-1}$ as a Negative control, 100%NPK = NPK $100kgHa^{-1}$ as a positive control, FYM (30t/Ha Farmyard manure), TR = *Trichoderma asperellum,* BA = Bacillus subtilis, FYM+TR = 30t / Ha^{-1} Farmyard manure + *Trichoderma asperellum*, FYM+BA = 3030t/ Ha^{-1} Farmyard manure + *Bacillus subtilis*, 100% NPK + TR = NPK 100 $kgHa^{-1}$ + *Trichoderma asperellum*, 100%NPK+BA = NPK 100kgHa⁻+ *Bacillus subtilis,* TR+BA= *Trichoderma asperellum* + *Bacillus subtilis*.

TABLE III: EFFECT OF FARMYARD MANURE AND BIO-FERTILIZER TREATMENTS ON POTATO PLANT HEIGHT AND NUMBER OF STEMS IN TWO SEASONS (MEANS AND STANDARD ERRORS)

		Environment 1 (Egerton season1)		Environment 2 (Egerton season 2)		Environment 3 (Tigoni season 1)	
Days after emergence (DAE)	Variety	Height (cm)	No. of Stems	Height (cm)	No. of Stems	Plant Height (cm)	No of Stems
28	*Kenyampya*	38.761.28	3.29±0.04	32.44±1.29	2.21±0.06	26.29±1.12	2.30±0.05
	Shangi	30.84 ±2.37	3.28±0.04	33.46±2.66	2.62±0.35	18.75±1.21	2.21±0.04
35	*Kenya mpya*	46.97 ±1.00	4.72±0.08	38.98±1.01	3.60±0.07	38.85±1.02	2.63±0.10
	Shangi	36.87 ±2.87	3.71±0.07	33.51±2.11	3.65±0.07	33.50±0.86	2.49±0.06
42	*Kenya mpya*	53.47 ±1.44	5.37±0.18	40.28±1.45	4.27±0.17	39.67±0.98	3.00±0.18
	Shangi	38.94 ±2.04	4.20±0.12	35.87±3.20	3.39±0.11	36.62±0.96	2.74±0.09
49	*Kenya mpya*	64.32 ±1.46	6.97±0.29	48.72±1.97	4.89±0.30	48.23±1.59	3.54±0.23
	Shangi	41.50 ±2.37	5.98±0.21	39.56±1.39	4.53±0.21	45.05±1.02	3.09±0.15

TABLE IV: EFFECT OF FARMYARD MANURE AND BIO-FERTILIZER TREATMENTS ON THE WEIGHT OF MARKETABLE TUBERS, NUMBER OF MARKETABLE TUBERS AT EGERTON AND TIGONI

	Environment 1 (Egerton season1)				Environment 2 (Egerton season 2)				Environment 3 Tigoni season 1)			
	Weight of -MT (tHa^{-1})		No. of marketable tubers		Weight of MT (tHa^{-1})		No. of marketable tubers		Weight of MT (tHa^{-1})		No. of marketable tubers	
Fertilizers	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*
T5	8.08	4.75	1672.00	1620.00	7.67	4.35	1555.67	1520.00	7.02	3.35	1197.33	1279.33
T6	7.83	7.85	1706.06	1620.67	7.33	7.32	1599.00	1516.33	7.60	5.65	1576.00	1433.00
T8	8.93	8.57	2121.00	1868.67	8.42	8.00	2031.67	1767.00	7.82	8.15	1717.67	1773.67
T7	9.40	9.00	2204.00	1985.67	8.82	8.30	2104.00	1975.00	8.40	8.20	1968.00	1914.67
T3	8.20	8.30	1904.00	1817.00	8.12	7.80	1800.33	1713.67	7.50	7.18	1548.00	1648.67
T0	2.13	4.02	1073.33	912.33	1.60	3.38	934.00	887.00	1.50	1.93	940.00	823.67
T1	7.90	7.95	1988.00	159.33	7.63	7.43	1905.00	1486.67	6.93	6.00	1524.00	1274.33
T2	8.30	9.00	2088.00	1610.00	8.13	8.33	2188.00	1510.33	6.15	7.60	1861.67	1095.67
T4	7.32	7.62	1760.00	1684.67	6.73	7.27	1612.67	1558.00	5.27	6.83	1262.00	1445.00
T9	5.55	5.03	1512.33	1387.33	5.05	4.63	1382.67	1248.33	5.07	3.40	1301.00	1098.33

Weight of M.T- Weight of un-marketable tubers

TABLE V: EFFECT OF FARMYARD MANURE AND BIO-FERTILIZER TREATMENTS ON THE WEIGHT OF UN-MARKETABLE TUBERS, NUMBER OF NON-MARKETABLE TUBERS GROWN AT EGERTON AND TIGONI

	Environment 1 (Egerton season1)				Environment 2 (Egerton season 2)				Environment 3 Tigoni season 1)			
	Weight un-MT (tHa^{-1})		No. of unmarketable tubers		Weight un-MT (tHa^{-1})		No. of unmarketable tubers		Weight un-MT (tHa^{-1})		No. of unmarketable tubers	
Fertilizers	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*	*Kenya mpya*	*Shangi*
T5	4.29	3.39	3069.00	2592.00	2.17	3.25	2934.33	2487.33	4.01	4.06	2736.00	1001.22
T6	2.66	0.45	2026.00	1694.00	2.53	0.40	1970.33	1592.00	1.80	4.98	2133.66	1878.33
T8	0.70	0.55	1180.66	1236.00	0.62	0.46	1047.33	1323.00	0.54	0.48	1133.33	1907.66
T7	0.65	0.51	1071.00	1107.33	0.57	0.40	1037.66	1059.66	0.54	0.46	1058.00	1068.33
T3	2.64	1.44	1286.66	1317.66	1.56	1.33	1251.66	1213.00	1.29	0.65	1278.00	1040.66
T0	4.11	4.49	3555.00	2714.66	3.93	4.04	3439.00	2577.66	2.62	5.28	3046.33	2202.33
T1	2.49	0.41	1865.33	1747.00	2.37	0.40	1763.33	1637.33	1.54	4.96	2040.00	2075.66
T2	0.76	0.59	1378.66	1421.00	0.68	0.50	1278.66	1321.00	0.65	0.56	2104.00	1759.66
T4	4.21	3.25	2114.33	2154.66	2.13	3.17	2045.67	2089.66	3.86	4.01	2259.66	1002.33
T9	2.75	3.4	3395.6	2744.00	2.60	3.33	3226.66	2613.66	2.50	4.13	2964.00	2918.00

Weight of un-M.T- Weight of un-marketable tubers

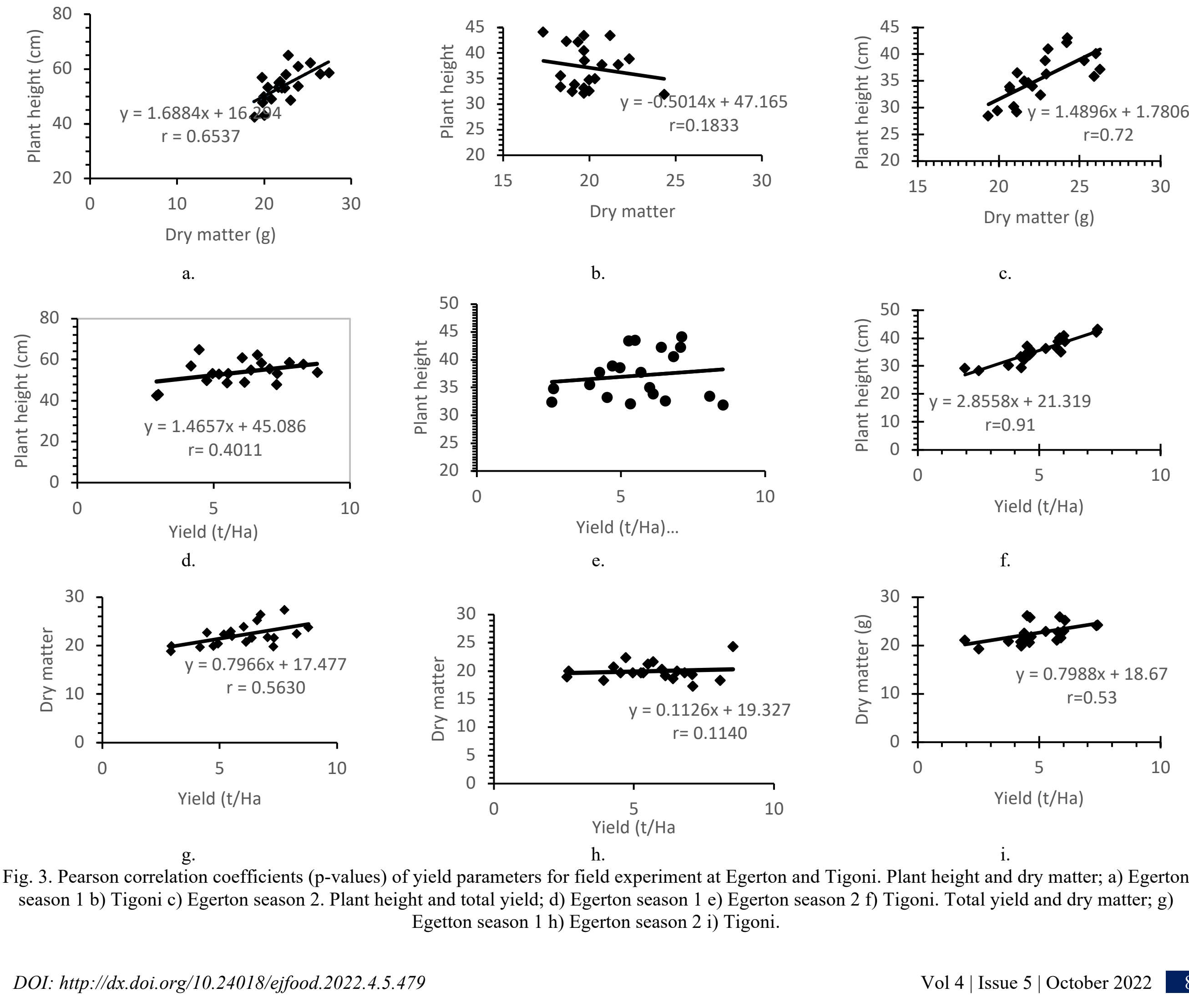

Fig. 3. Pearson correlation coefficients (p-values) of yield parameters for field experiment at Egerton and Tigoni. Plant height and dry matter; a) Egerton season 1 b) Tigoni c) Egerton season 2. Plant height and total yield; d) Egerton season 1 e) Egerton season 2 f) Tigoni. Total yield and dry matter; g) Egetton season 1 h) Egerton season 2 i) Tigoni.

IV. Discussion

The addition of organic matter amendments, such as biofertilizers and farmyard manure, is a common practice for the immobilization of heavy metals and soil enhancement of contaminated soils, increases the availability of phosphorous, and increases the soil pH. Some reports showed that the amendment of contaminated soils with organic matter reduced the bioavailability of heavy metals [21]. Irish potato requires huge nutrients, i.e., a heavy feeder, and is shallow-rooted [22]. This study showed that fertilizer application success depends on crop growth and yield. However, fertilizer treatments did not significantly affect the number of stems. Kumar *et al.* [8] reported that tomato plants used organic sources (100% RDN) of nutrients (FYM, V.C., and PM) recorded much less plant height than those obtained with integrated use of organic sources and tree biofertilizer treatments Azotobactor, phosphate-solubilizing bacteria (PSB) at all the growth stages. FYM at the rate of 30 t/ha plus *Trichoderma asperellum* @150 mL/10kg (T7) and FYM at 30 t/ha plus *Bacillus subtilis* @150 mL/10kg (T8) resulted in the highest plant heights and yield. These results are concurrent with those of Singh *et al.* [23], who reported that farmyard manure and biofertilizers (*Azotobacter)* proved effective in enhancing the growth and yield of tomatoes. Their results showed that the interaction of farmyard manure and Azotobacter was significant. The highest yield was obtained with the application of FYM @ 15 t/ha + *Azotobacter* + 100% recommended dose of nitrogen. This could be attributed to the high phosphorus that enhances root development and improves nutrient uptake, high nitrogen that enhances vegetative growth, good canopy cover, and photosynthesis. According to Zaghloul [24], inoculation of potato tuber with *B. megaterium* var. *phosphaticum* combined with symbiotic Nitrogen fixers, biogas manure, and ammonium sulfate increased nutrient content (N and P) in soil compared to uninoculated treatments. Such results may explain the synergistic effect of phosphate solubilizing bacteria. Therefore, the combination of biofertilizers and farmyard manure increased the availability of soil N and P and improved potato growth and yield.

The results showed that the two treatments (farmyard manure + *Trichoderma asperellum* (FYM+TR) and farmyard manure+ *Bacillus subtilis (*FYM+BA), which applied at the rate of 10 t/ ha^{-1} in FYM and @150 mL/10kg for biofertilizers were showed the best performance in all sites. These two treatments were not significantly different either for total tuber yield dry weight and weight of marketable tubers, the weight of unmarketable tubers, number of marketable tubers, number of unmarketable. Organic and biofertilizers have been shown to have lower unmarketable yields than mineral fertilizers El-sayid *et al.* [25]. There was an increase of 25.15% in total tuber weight and 13.16% dry matter. The weight of marketable tubers from farmyard manure + *Trichoderma asperellum* fertilizer treatment over positive control 100% NPK may be due to additional nutrients in organic fertilizer and biofertilizers over NPK. Congera *et al.* [26] found out that plants supplied with organic fertilizer and biofertilizers (FYM + AZT + PSB) recorded the highest tuber yield per plant (363.33 g $plant^{-1}$) and tuber yield per hectare (34.13 t ha^{-1}). Increasing dry matter content was realized when biofertilizers were combined with organic manures. These results are similar to those reported by Baniuniene and Zekaite [27], Shamorady [7]. Furthermore, Kumar *et al* [8], showed that biofertilizers required organic manuring for its early establishment necessary for exerting a beneficial effect on crop productivity. The increase in the tuber numbers per plant could be attributed to the increased vegetative growth observed due to the balanced nutrient levels, which stimulated the initiation of more stolon, thus increasing the number of tubers per plant. The increased production is attributed to better photosynthetic activity and the accumulation of carbohydrates which helps in better growth of the crop. It is also known that phosphatic fertilizers affect potato tuber yield by influencing the number of tubers produced and the size of tubers. Kumar *et al*. [8] reported that applying sole biofertilizers as seed treatment without inorganic fertilizers, and farmyard manure showed inferior performance productivity. Therefore, biofertilizers need an organic fertilizer for enhanced early establishment, which is necessary to affect the tuber yield positively.

According to the performance of varieties, the two potato varieties under study showed a significant difference in both growth and yield parameters. *Kenya mpya* had the highest plant height, the maximum number of stems, total tuber yield and weight of marketable tubers, the number of marketable tubers, and the highest percentage of grading (i.e., big size tubers). The difference in genetic makeup may have caused the variation between the two varieties. The potato varieties growing in Kenya all differ in morphology, genetics, growth habits, maturity, dormancy period of tubers, yield potential, resistance to biotic and abiotic stresses, and soil and climate requirements [16]. The two varieties also indicated the different dormancy periods; *Kenya mpya* showed a delay of emergence than the *shangi* variety. On genetic and environment interaction (G x E), Tsegaw [6] showed that the genotypes were highly significant for tuber yield and dry matter content, signifying considerable variation among the genotypes. Potato genotypes reported significant variations among potato genotypes concerning tuber yields and dry matter content. Tapiwa [28] noted a significant difference in the yields due to differences in the genetic makeup of the varieties.

V. Conclusion

The findings of this study indicated no significant difference between the two treatment combinations of farmyard manure plus *Trichoderma asperellum* (FYM+TR) and farmyard manure plus *Bacillus subtilis* (FYM+BA). However, FYM+TRI increased potato yield and plant height by 19.81% (52.6 cm) and 18.99% (12.34), respectively, over the standard, recommended dose of fertilizer (RDF). FYM+TRI also increased in weight of marketable tubers and dry matter by 10.86% and 13.16%, respectively. In addition, it showed the highest number of stems and number of tubers. The results also showed that application of biofertilizers or manure singly did not significantly affect potato height and yield. Therefore, Application of bio-fertilizers in combination with organic manures that are locally available, eco-friendly, improve soil fertility and sustain soil health can substantially improve potato yield and good returns under better management practices. Thus, we recommend that organic manures and biofertilizers should be incorporated into agronomic practices for potatoes which should substitute chemical fertilizers to improve potato productivity. Lastly, the study further recommends additional research to assess the combination of other organic fertilizers and biofertilizers on the type performance of potatoes.

Acknowledgment

The authors thank the MasterCard Foundation through RUFORUM for "Transforming African Agricultural Universities to meaningfully contribute to Africa's Growth and Development (TAGDev)" Programme at Egerton University for provision to conduct this research at Egerton University and KALRO - Tigoni

Conflict Of Interest

The authors have declared no conflicts of interest.

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