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Effects of compound fertilizer and canola green manure on nutrient use efficiency, growth and yield of potato tuber (*Solanum tuberosum* L.) in Nakuru, Kenya

Norbert Iraboneye*, Nancy W Mungai, Miriam K Charimbu

Egerton University, Department of Crops, Horticulture and Soils, P.O. Box 536-20115, Nakuru, Kenya

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akhasan@bau.edu.bd

**Corresponding Author*
Norbert Iraboneye
iraboneye@gmail.com

Abstract

Unbalanced fertilization is a problem affecting potato production in Kenya, where continuous use of nitrogen-phosphorus fertilizer (diammonium phosphate: DAP) has led to depletion of other macro and micronutrients. Hence, the need to assess alternative soil amendments including use of multi-nutrients compound fertilizer and canola green manure in potato production. Field and pot experiments were conducted in Nakuru during the period from August-December 2019 using two potato varieties (Shangi and Kenya Karibu) in randomized complete block design (RCBD) in split plot arrangement replicated three times (variety as main plot and combination of fertilizer and canola green manure as main plot). Two canola green manure levels (with and without), four levels of fertilizer (NPK + Ca + Mg + micronutrients) at 0 (F1), 250 (F2), 575 (F3), 900 (F4) kg ha^{-1} and recommended fertilizer rate (DAP at 500 kg ha^{-1} + Calcium ammonium nitrate (CAN300 kg ha^{-1}), (F5) as a positive control were used. Pot experiment was carried out at Egerton university farm in a completely randomized design (CRD) with three replicates. Four levels of canola green manure (100, 75, 50 and 0 g kg^{-1} soil) and five levels of fertilizer (NPK + Ca + Mg + micronutrients) as used in the field experiment were used. The results indicated that fertilizer F4 increased potato tuber dry weight and plant height by 5.0 and 5.0%, respectively over the normal recommended F5 under field experiments. F4 also increased nutrients (nitrogen, phosphorus and potassium) uptake by 13, 26 and 3%, respectively under field experiment compared to F5. Generally, canola green manure did not show a significant effect on plant height and yield, though F4 with green manure exhibited an increase of 7 and 38% on plant height and tuber dry weight, respectively. The study recommends the use of F4 (900 kg ha^{-1} of NPK + Ca + Mg + micronutrients) for potato production in Kenya and further recommends additional research to assess compound fertilizers over more seasons with monitoring and evaluation of their effect on soil physical and chemical properties and their economic feasibility.

Keywords: Potato nutrition, diammonium phosphate, multi-nutrients fertilizer

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1 Introduction

Potato (*Solanum tuberosum* L.) is a staple food in Kenya, and approximately 800,000 farmers are involved in the production generating about 500 million USD annually (AGRA, 2019). Kenya is among the top potato producing countries in Eastern Africa community with large production area, though potato production per hectare is declining year by year (Fig. 1) (FAOSTAT, 2020). Despite its importance, the production is far below the potential production. Diseases and poor soil fertility management are the major causes of potato yield reduction in Kenya. Low soil fertility is another production constraint mainly due to continuous cropping without replenishing all mined nutrients. Potato production in Kenya is mostly occupied by smallholder farmers, with a land size below 5 acres (Okello et al., 2016) leading to intensive land use without fallow. Major potato growing areas in Kenya has low soil phosphorus as 2.9 mg kg^{-1} while total nitrogen is lower than 1.5 g kg^{-1} (Muthoni and Nyamongo, 2009). In addition, the available fertilizer recommendations do not consider for potassium (K) yet some studies have indicated the benefit of potassium addition in potato production (Muthoni and Nyamongo, 2009).

In Kenya, potato farmers have been relaying on one source of nutrient diammonium phosphate (DAP). Ammonium based fertilizer such as (DAP) dominate in the production of potatoes, and research has revealed that it has side effect of gradual soil acidification if continuously used over a long time (Muthoni, 2016; Maryanne et al., 2015). Despite acidification issues, DAP does not supply all essential nutrients that are required by potato in large quantities. Potato requires nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca) amongst other nutrients (Haifa, 2020).

Currently there are different types of NPK fertilizers with additional nutrients including micronutrients available in Kenya. However, a lack of information on the benefits of new fertilizer formulations, has limited their utilization. Other factors limiting the use of such fertilizers include access and availability. Apart from nitrogen (N), phosphorus (P), and potassium (K) as major nutrients, potato require other secondary macronutrients such as magnesium (40-60 kg ha^{-1}) and calcium (100-120 kg ha^{-1}) as reported by Haifa (2020). Calcium is a component of cell wall, it helps plants to resist stress condition and plant pathogens attack whereas magnesium, has a crucial role in photosynthesis, and is involved in production sugars and proteins. Annual magnesium application on potato increased the yield by 1- 10% (Yara, 2020). Recent studies focused on the importance of using fertilizers that contains only N, P and K nutrients in potato production (Adrien, 2013; Adhikari, 2014), therefore, there is a need to evaluate the effect of multi-nutrients fertilizers on potato yields.

In addition, this experiment involved use of canola green manure as soil amendment. Green manure, which involves the incorporation of fresh plant material into soil. It has been mostly used for the purpose of adding nutrients into the soil and improvement of soil health through soil physical, chemical and biological properties. However, green manures from certain plants (e.g. Canola and Mustard) has been found to have additional benefit of suppressing growth and development of soil pathogens, weeds and nematodes (McGuire, 2016) including potato soil pathogens. Therefore, the present study was carried out to evaluate the effect of compound fertilizers and canola green manure on nutrient use efficiency, growth and yield of potato.

2 Materials and Methods

2.1 Site description

Two field experiments were conducted at Mau Narok and Elburgon sub counties while pot experiment was conducted at Egerton University farm, all sites are located in Nakuru County, Kenya (Fig. 2). Egerton university site lies between longitude 35°35′ E, latitude 0°23′ S, and at an altitude of 2238 above the sea level (m.a.s.l). Mau-Narok is located in Njoro subcounty at an altitude of 2,900 meters above the sea level (m.a.s.l) and lies between longitude 36°0′ E and latitudes 0°36′ S. The area receives an average annual rainfall of 1,200-1,900 mm (Onwonga et al., 2014). In the last 10 years (2009-2020), the site experienced a minimum and maximum temperature of 8-14 and 19-27 °C, respectively (World Weather Online, 2020). The soil is well drained, deep to very deep, very dark greyish brown, friable and smeary, clay loam, with thick humic topsoil (mollic andosols) (Jaetzold et al., 2007). Elburgon is located in Molo sub-county at an altitude of 2,200 m.a.s.l and lies between longitude 35°41′ E and latitudes 0°12′ S. This area experiences mean annual rainfall of 1000-1400 mm and mean temperatures of 13.7-20 °C (Jaetzold et al., 2007). The soils of Elburgon are acidic, well drained, deep, dark reddish brown with a mollic A horizon, and classified as mollic Andosols (Onwonga et al., 2014). According to MoALF (2016), Elburgon site is in Upper high land zone two (UH2) and Mau-Narok is in Upper high land zone one (UH1). The sites were selected because they are suitable for potato production.

2.2 Varieties used in the study

Shangi and Kenya karibu potato varieties were used in these experiments. Shangi (Fig. 3A and Fig. 3B) is popular and the most grown variety in Nakuru, it grows well in the altitude above 1500 m.a.s.l. It matures early in about 3.5 months with the yield ranging between (30,000-40,000 kg ha^{-1}). It is moderately susceptible to late blight (NPCK, 2019). Kenya karibu (Fig. 3C and Fig. 3D) variety is one of the popular potato varieties after Shangi, it grows well at altitudes between 1800-2600 m.a.s.l. The variety is a high yielder (35,000 - 45,000 kg ha^{-1}) and tolerant to late blight (NPCK, 2019). The varieties were selected because they are suitable for experimental sites and are grown by most of the farmers in Nakuru.

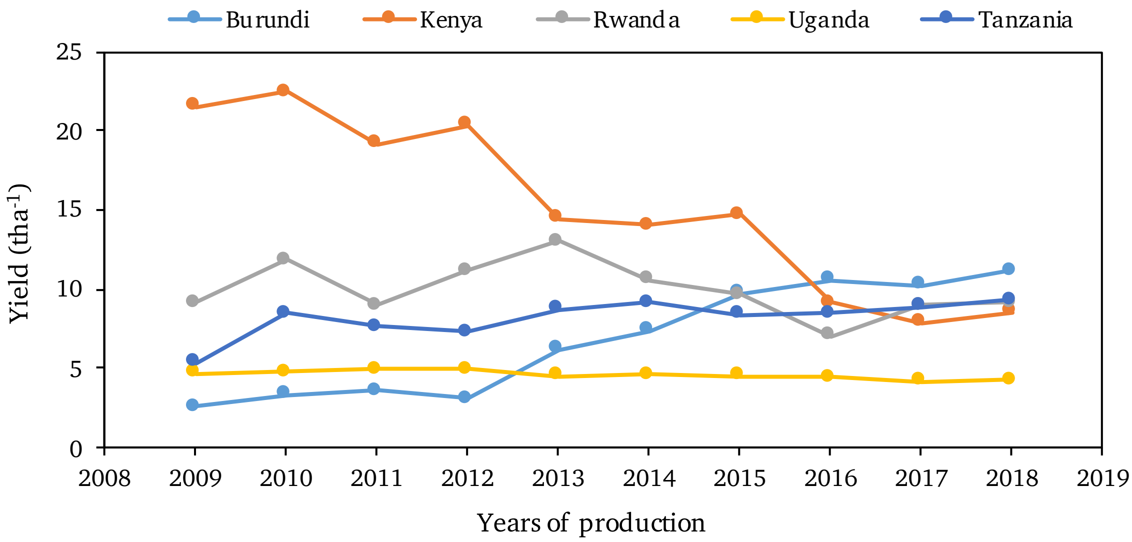

Figure 1. Potato production trends in selected East African countries over ten years. Source: FAOSTAT (2020)

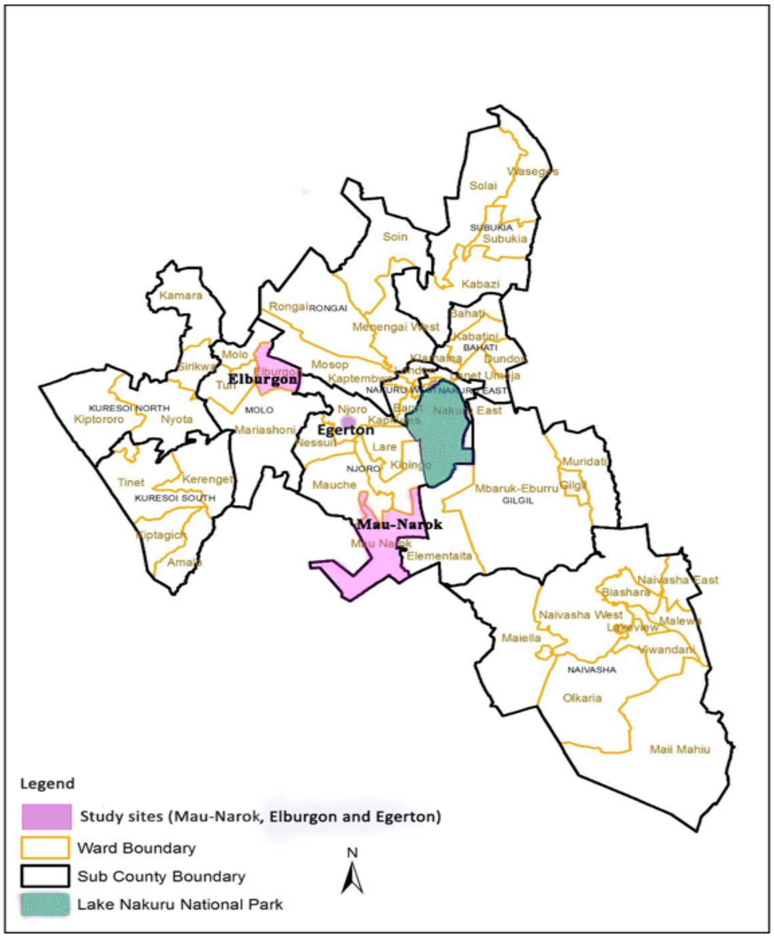

Figure 2. Map showing experimental sites Elburgon, Mau-Narok and Egerton. Source: County Government of Nakuru (2018)

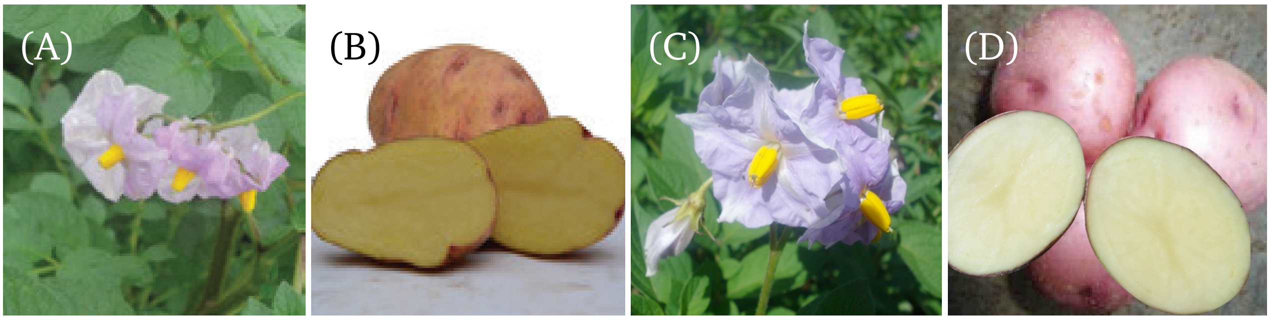

Figure 3. Flowers and tubers for Shangi (A and B) and for Kenya Karibu (C and D), respectively

2.3 Soil properties of the study sites

Before the experiments were set up, soils and canola green manure samples were sent to Kenya National Agricultural Research Laboratory (NARL) KALRO Kabete for physio-chemical analyses. Soil available nitrogen, available phosphorus, available potassium, calcium, magnesium, organic carbon, pH and soil texture were analyzed. Soil pH was determined using 1:2.5 ratio of soil: water by electrometric method, soil texture using Hydrometer method (Okalebo et al., 2002). Total nitrogen (TN) by wet-oxidation procedure of the Kjeldahl method (Sahlemedhin and Taye, 2020). Available (P, K, Ca and Mg) were analyzed using Mehlich double acid method (Mehlich et al., 1962) and total organic carbon using calorimetric method (acidified dichromate as an oxidizing agent) (Anderson and Ingram, 1996). In all sites the soils were found to be Sand clay loam texture. Based on potato nutrients requirement, phosphorus was low in all experimental site and calcium was low at Elburgon sites. Soil pH was ideal for potato growth at Mau-Narok and Egerton sites (Table 1). In addition, canola biomass (stem, leaves and flowers) sample was taken randomly from ten plants in the field. A sub sample of 500 g fresh biomass was sent to Kenya National Agricultural Research Laboratory (NARL) KALRO Kabete for total nitrogen, phosphorus, and potassium contents. The following principle was used during analysis; the samples were dried in oven at 70 °C and oxidized by hydrogen peroxide (30% H_2O_2) at relatively low temperature (100 °C). After decomposition of the excess H_2O_2 and evaporation of water, the digestion was completed by concentrated sulphuric acid at elevated (330 °C) temperature under the influence of Se (selenium) as a catalyst. Then the elements were determined using the following; potassium (K) was determined with a flame photometer, phosphorus (P) determined calorimetrically on spectrophotometer at 880 nm wavelength, N-total measured by distillation followed by titration with 0.3 N HCl (Walinga et al., 1995). The analysis indicated that canola biomass contained 3.03% nitrogen, 0.45% phosphorus and 3.92% potassium.

2.4 Experimental procedure

Field experiments were laid in randomized complete block design split-plot arrangement, canola green manure as main plot and combination of variety and fertilizer treatments as sub-plots replicated three times. After land preparation, canola seeds were sown on (3rd August 2019) at Mau-Narok site and (12th September 2019) at Elburgon at a rate of 6 kg ha^{-1} as recommended by Agriculture, Forestry and Fisheries (2016) and allowed to grow for a period of two months. Weed management was done in all plots (the one with green manure and the one without green manure). At early flowering stage (60 days after sowing), canola was uprooted, chopped (Approximately 1 cm) and incorporated into the soil in equal quantities (Mau-Narok 100 g m^{-2} and Elburgon 300 g m^{-2}) based on each site's productivity at depth of 15 cm (McGuire, 2016). Canola production at Mau-Narok was low because of heavy rainfall that washed away seeds before germination. The whole plot (with and without green manure) was covered with a polyethylene sheet for two weeks to avoid glucosinolate compounds from volatilization (Sintayehu et al., 2014). Two weeks after incorporation, certified potato seeds Shangi and Kenya karibu varieties sourced from Agricultural Development Cooperation (ADC) Molo were planted at a spacing of 75 cm × 30 cm (75 cm between the rows and 30 cm between the plants) with planting depth of 10 cm. The plot size was 3 × 1.5 m with 4 rows and 5 plants per row. NPK + Ca + Mg + micronutrients fertilizer treatments (Table 2) were applied in splits, two third at planting and one third at flowering stage (Adrien, 2013). Recommended DAP and CAN were used as positive control at rate of 500 kg ha^{-1} during planting and 300 kg ha^{-1} at flowering stage, respectively. The rates for fertilizer treatments were calculated according to farmers practice and recommended nitrogen rate (90 kg ha^{-1}) as indicated by NPCK (2013) and Nyongesa et al. (2008).

The pot experiment was laid out in completely randomized design in factorial arrangement with three replicates. Treatments combinations are shown in Table 3. Canola seeds were grown at Egerton Uni-

Table 1. Soil physical and chemical properties of the experimental sites

Soil fertility factors	Mau-Narok	Egerton	Elburgon
Soil pH	5.68	5.47	4.57
Total nitrogen (g kg^{-1})	3	2	3
Total organic carbon (g kg^{-1})	33.2	24.4	35.4
Available phosphorus (mg kg^{-1})	5	15	5
Available potassium (cmol kg^{-1})	1.48	1.34	0.94
Calcium (cmol kg^{-1})	6.2	4.6	0.6
Magnesium (cmol kg^{-1})	2.24	2.03	1.36

Table 2. Fertilizer rates treatments

Fertilizer	Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Compound fertilizer †	F1	0	0	0
	F2	25	65	25
	F3	57.5	149.5	57.5
	F4	90	234	90
DAP + CAN ‡	F5	90	230	–
		81	–	–

† NPK 10:26:10 + Ca, S, Mg, Cu, Zn, B, Mn, Mo ‡ Di-ammonium phosphate (DAP) 18% N and 46% P as Basal application and Mono-ammonium phosphate (CAN) 27% N as top dressing

Table 3. Treatment combinations for pot experiment

Treatment	Combination	Treatment	Combination
T1	V1F1G1	T21	V2F1G1
T2	V1F1G2	T22	V2F1G2
T3	V1F1G3	T23	V2F1G3
T4	V1F1G4	T24	V2F1G4
T5	V1F2G1	T25	V2F2G1
T6	V1F2G2	T26	V2F2G2
T7	V1F2G3	T27	V2F2G3
T8	V1F2G4	T28	V2F2G4
T9	V1F3G1	T29	V2F3G1
T10	V1F3G2	T30	V2F3G2
T11	V1F3G3	T31	V2F3G3
T12	V1F3G4	T32	V2F3G4
T13	V1F4G1	T33	V2F4G1
T14	V1F4G2	T34	V2F4G2
T15	V1F4G3	T35	V2F4G3
T16	V1F4G4	T36	V2F4G4
T17	V1F5G1	T37	V2F5G1
T18	V1F5G2	T38	V2F5G2
T19	V1F5G3	T39	V2F5G3
T20	V1F5G4	T40	V2F5G4

V1: Shangi, V2: Kenya Karibu, F5: DAP500 + CAN300 kg ha^{-1}, F4: NPK900 kg ha^{-1}, F3: NPK575 kg ha^{-1}, F2: NPK250 kg ha^{-1}, G1: no green manure, G2: green manure 50 g kg^{-1} of soil, G5: green manure 75 g kg^{-1} of soil, G5: green mnaure 100 g kg^{-1} of soil versity farm for two months following the same management as for field experiments. The treatments were four levels of canola and five fertilizer treatments. The pot size of 20 cm diameter and 30 cm length were each filled with 5 kg of top soil. A hundred and two pots were used in this experiment. At early flowering stage (60 days after sowing) canola was chopped and mixed into the soil in the pots at the rate of 0, 50, 75, 100 g kg^{-1} of soil and then covered with polyethylene sheet for two weeks before planting of potato seeds (Sintayehu et al., 2014). Certified seed potato (Shangi and Kenya Karibu variety) were planted one in each pot and fertilizer treatments applied at five rates as shown in the (Table 2). NPK + Ca + Mg + micronutrients fertilizer was applied in two splits, two third at planting stage and the remaining at flowering stage while DAP was applied at planting followed by CAN at flowering stage as for field experiment. The fertilizer treatments applied in the pots, were calculated based on the amount of soil per hectare (2,000,000 kg ha^{-1}) f.s (furrow slice) and converted to the amount of soil used in the pot (5 kg).

2.5 Crop management practices

Experiments were kept weed free and earthing up in the field experiments were done twice, first at two weeks and the second at sixth week after emergence. Late blight was controlled by alternating Equation pro (Famoxadone 225 g kg^{-1} + Cymoxanil 300 g kg^{-1}) sprayed at the rate of 10 g $20L^{-1}$ of water and Ridomil gold MZ 68 WG (Metalaxyl-M 40 gkg^{-1} + Mancozeb 640 g kg^{-1}) sprayed at a rate of 50 g $20L^{-1}$ of water. Spraying was done weekly during intensive rainy period and at two-week intervals in sunny period. Pests of canola such as aphids and flea beetles among others were monitored and controlled using; Cypertox 250EC (cyhalothrin 25 g L^{-1}). Canola pest attack were severe at early stage (2-4 weeks after planting), regular monitoring was done and sprayed twice depending on the attack.

2.6 Data collection

2.6.1 Growth and yield parameters

Number of stems per plant was counted at 28, 35 and 42 days after emergence (DAE) and plant height was measured at 28, 35, 42 and 56 (DAE) using a ruler. Ten plants from the middle rows were uprooted per plot, number of tubers counted and average number tubers per plant calculated. Tuber grading was done by ranking tubers in three classes; big size: >60 mm diameter, medium size: 30-60 mm diameter- small size: <30 mm diameter (IFDC, 2017). Different tuber grades were counted separately and converted into percentage of the total. Fresh tuber weight was taken after grading and a sub sample of 500 g of fresh tuber were taken in each plot. Fresh tubers were dried in the oven at 70 °C and weight obtained per plot converted into t ha^{-1}.

2.6.2 NPK uptake and use efficiency assessment

At maturity stage, three plants from selected treatments (F4: NPK 900 kg ha^{-1}, F5: DAP 500 + CAN 300 kg ha^{-1} and F1: control, with and without canola green manure) were uprooted for nitrogen (N), phosphorus (P), potassium (K) nutrients uptake analyses. Potato tuber samples of 50 g were dried in oven at 70 °C for 72 h. The samples were labeled and taken to NARL-KARLO Nairobi for N, P and K analyses using the methods described in the section 2.3. The nutrients uptake was calculated using the following formula:

$$U_i = n_i \times DW_{\text{tubers}} \tag{1}$$

where, U_i = uptake of nutrient i (kg ha^{-1}), n_i = concentration (%) of nutrient, i, in potato tubers, i = specific nutrient (N, P, K), DW_{tubers} = dry weight of potato tubers (kg ha^{-1}).

Agronomic efficiency (or fertilizer use efficiency) was calculated using potato production excluding control, over total input applied (Badr et al., 2012):

$$E_A = \frac{Y_t - Y_0}{F} \tag{2}$$

where, E_A = agronomic efficiency, Y_t = total tuber yield under treatment (kg ha^{-1}), Y_0 = total tuber yield under control (kg ha^{-1}), F = fertilizer applied (kg ha^{-1}).

Nutrient recovery was calculated using the following formula as suggested by Badr et al. (2012):

$$R_N = \frac{N_t - N_0}{N_a} \times 100 \tag{3}$$

where, R_N = nutrient recovery (%), N_t = total nutrient uptake by crop under treatment (kg ha^{-1}), N_0 = total nutrient uptake under control (kg ha^{-1}), N_a = Applied nutrient (kg ha^{-1}).

2.7 Data analysis

The data were subjected to normality test and the appropriate transformation (log or square root) was done to achieve normal distribution and meet the assumptions of ANOVA. Analysis of variance using (ANOVA) General Linear Model (GLM) procedures of SAS (9.3) at $P \leq 0.05$ was done. The significantly different treatment means were separated using Tukey's honest significant difference (HSD) test at 5% level of significance. Pearson correlation analysis at 5% level of significance was done to determine the relationship between tuber dry weight and other agronomic parameters (plant height, number of stems and number of tubers per plant) (Gomez and Gomez, 1984).

3 Results

3.1 Effect of treatments on potato growth

3.1.1 Number of stems

The number of stems were not significantly affected by fertilizer treatments and canola green manure for both field and pot experiments. However, significant difference was observed between varieties; Shangi had the higher number of stems (2-6) than Kenya Karibu (2-4) across field and pot experiment.

3.1.2 Plant height

Plant height was significantly affected by fertilizer treatments, where the trend was F4 (NPK: 900 kg ha^{-1}) >F5 (DAP: 500 kg ha^{-1})> F3 (NPK: 575 kg ha^{-1}) and the lowest was from F2 (NPK: 250 kg ha^{-1}) and control (F1). F4 treatment increased plant height by 4.0% and 46.0% compared to positive control (F5) and negative control (F1), respectively. Plant height differed by varieties; Shangi (22-81 cm) compared to Kenya Karibu (17-63 cm) under field conditions. Canola green manure treatments did not show a significant effect on plant height, though green manure increased plant height by 4.4% compared to none green manure under field condition. Plants treated with F4 fertilizer treatment had the highest plant height 63, 59 and 41 cm at Mau-Narok, Elburgon and pot experiment, respectively. The sites differences exhibited different plant height at 28, 42 and 56 day after emergence (DAE) under field condition. Plants at Mau- Narok exhibited higher plant height than Elburgon site. At Mau-Narok site, for Shangi variety, plant height was significantly affected by fertilizer levels for all days i.e. 28, 35, 42 and 56 days after emergence (DAE). The highest plant heights of 75, 72 and 71 cm were recorded for treatments treated with F4, F5 and F3, respectively and control had the lowest plant height (Fig. 4A). For Kenya Karibu, fertilizer treatment had significant effect on plant height at 35, 42, and 56 DAE, Kenya Karibu responded late to fertilizer due to its slow growth and root establishment. The highest plant heights 50, 47, and 45 cm were recorded for treatments with F4, F3, and F5, respectively for Shangi and control had the lowest value (Fig. 4B). Canola green manure had no significant difference on plant height for all varieties, though the highest values were recorded where green manure was applied.

At Elburgon site, all varieties, plant height was significantly affected by fertilizer for data collected at 35, 42 and 56 (DAE), while canola green manure did not have significant effect on plant height. The highest plant heights (66, 65 and 55cm for Shangi variety; 55, 52 and 49cm for Kenya Karibu variety) were recorded for treatments treated with F4, F5 and F3, respectively. The control had the lowest values (Fig. 4C and Fig. 4D). The same trend was observed in pot experiment; fertilizer treatments had a significant effect on potato plant height, means separations shows that, F4, F3 and F5 treatments had the tallest plants of 47, 44 and 41 cm, respectively at 56 DAE. Variety differences were observed as for field experiments, Shangi had the highest plant height over Kenya Karibu (Fig. 5). Canola green manure levels did not show any effect on plant height.

3.2 Effect of treatments on tuber yield

Number of tubers and tuber dry weight were significantly affected by fertilizer treatments under field and pot experiments. Canola green manure did not show significant effect on number of tuber and tuber dry weight as well, though an increase of 11% in tuber dry weight and 5% in number of tubers due to green manure application were observed. The highest number of tubers; 10, 9 and 9 per plant were from F5 followed by F4 and F3 treatments respectively, whereas the highest dry tuber weight; 8.19, 7.82, 6.41 t ha^{-1} were from F4 followed by F5 and F3 treatments, respectively. There was an increase of 5% and 83% of tuber dry weight from F4 treatment over positive control F5 and negative control F1, respectively. Varietal differences were observed on number of tubers but not significant on dry tuber weight, Shangi had higher number of tuber (9.19) than Kenya Karibu (7.53). At Elburgon site, the highest number of tubers and tuber dry weight were from the treatments treated with F5 followed by F4 and the lowest was from control for all varieties (Table 4) same for pot experiment (Table 6). Whereas at Mau- Narok site, the highest number of tubers and tuber dry weight were from F4 followed by F5 and the lowest from control for all varieties (Table 5).

3.3 Effect of treatments on tuber grades

Generally, the higher fertilizer treatment (F4) resulted in a higher percentage of big tubers (16.33%) while the negative control (F1) had significantly higher percentage of small size tubers. Canola green manure did not show a significant effect on tube size grades though, 18.68% increase of big size tuber grade was observed from canola green manure application over no green manure application under field conditions. Effect due to site differences were observed, Mau-Narok had high percentages of big tubers (16.03%) than Elburgon (9.00%) site. At Mau-Narok site, high percentages of big tubers 21.77, and 16.00% were observed from the treatment treated with F4 followed with F5 respectively, where Elburgon had the high percentages of big tuber 11.30 and 12.08%, and were from F5 followed with F4, respectively. Varietal differences were observed in tuber size distribution; Kenya karibu variety had the higher percentages of big tu-

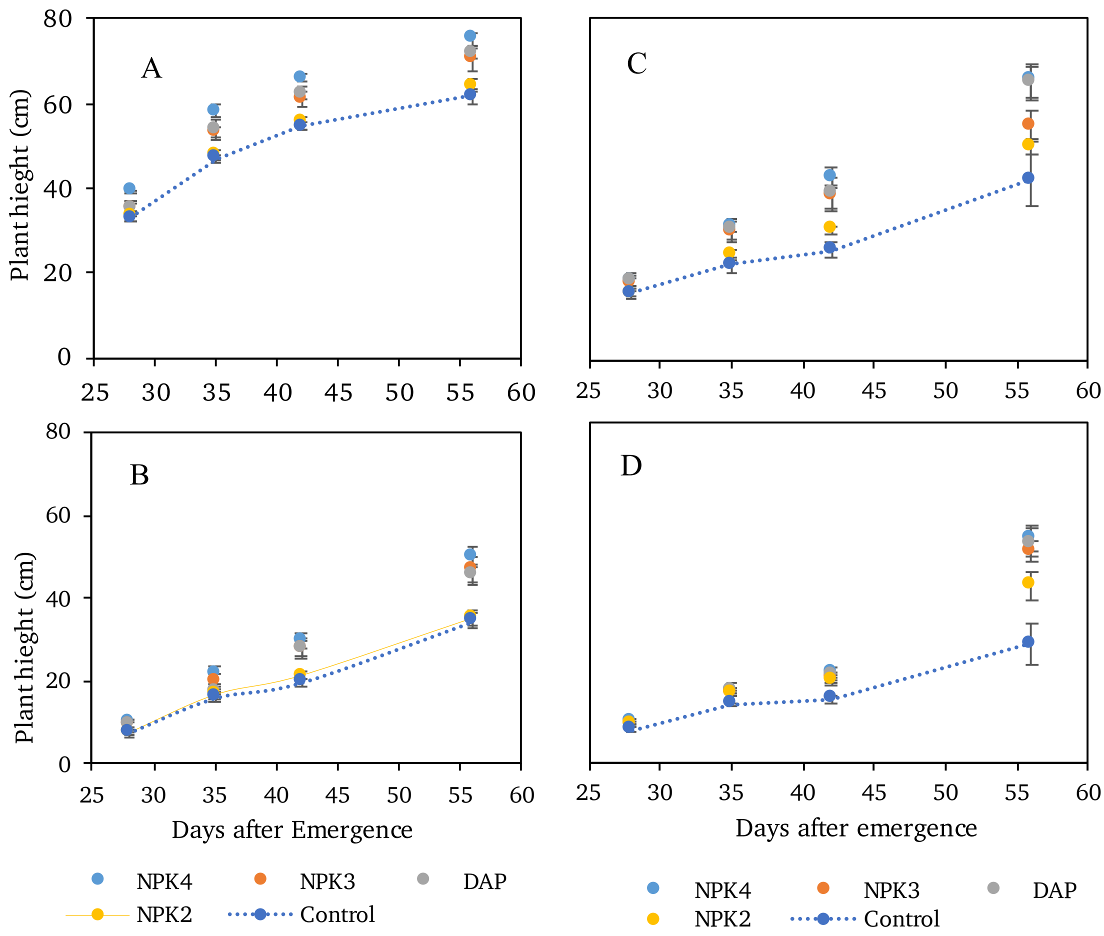

Figure 4. Fertilizer treatments effect on potato plant height (cm) for field experiment. A (Shangi) and B (Kenya Karibu) are for Mau-Narok site, C (Shangi) and D (Kenya Karibu) are for Elburgon site. NPK4: NPK900 kgha-1, NPK3: NPK575 kg ha^{-1}, NPK2: NPK250 kg ha^{-1}, DAP: DAP500 + CAN300 kg ha^{-1}. Error bars show standard error of the means

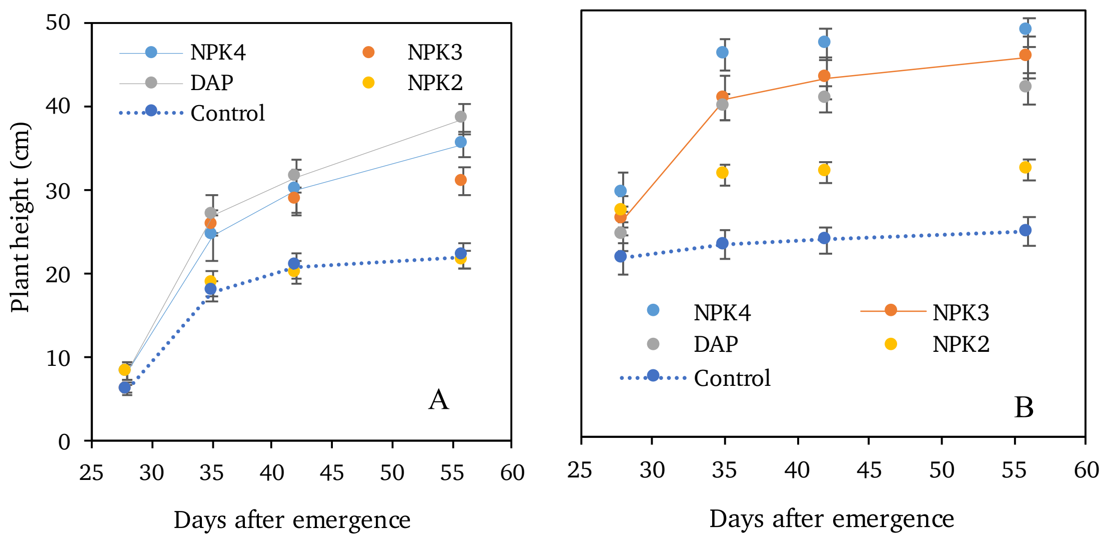

Figure 5. Fertilizer effect on potato plant height (cm) for pot experiment. (A: Kenya Karibu, B: Shangi). NPK4: NPK900 kg ha^{-1}, NPK3: NPK575 kg ha^{-1}, NPK2: NPK250 kg ha^{-1}, DAP: DAP500+CAN300 kg ha^{-1}. Error bars show standard error of the means

bers than Shangi. The two treatments (F4 and F5) performed better across sites and varieties (Table 7 and Table 8). For pot experiment, only Shangi variety was harvested and all the tubers were smaller in size.

3.4 Growth *vs* yield of potato

Growth parameters were positively correlated with yield parameters under field experiment. Plant height was observed to be positively correlated with yield parameters (number of tubers and tuber dry weight). Number of stems had a strong positive correlation with number tubers, but fairly correlated with tuber weight (Table 9).

3.5 Effects of treatments on nutrient balance

Nutrients nitrogen (N), phosphorus and potassium (P) uptake were significantly affected by selected fertilizer treatments. Nutrients (N, P and K) uptake were higher with F4 and F5 treatments than control. The highest nutrients 139.07, 10.58 and 119.26 kg ha^{-1} (N, P and K) uptake by potato tubers were observed where F4 fertilizer treatments were applied. Generally, F4 increased nutrients (N, P and K) uptake by 13, 25 and 3%, respectively over F5 under field experiment. Nutrients (N, P and K) uptake were not significantly different between potato varieties. Site differences exhibited differences on nutrients uptake, the plant at Mau-Narok showed higher 132.58, 10.72 and 121.95 kg ha^{-1} (N, P and K) than Elburgon 90.67, 5.12, 72.52 kg ha^{-1} (N, P and K). Canola green manure increased nutrients (N, P and K) uptake by 24, 21 and 11% over no green manure application under field experiment. The same trend was observed across the sites and pot experiment, where F4 and F5 treatments were not significantly different between them on nutrients uptake, but different from control (Table 10). Canola green manure had no significant effect across the sites and pot experiment.

Nitrogen recovery was significantly affected by selected fertilizer treatments (F4 and F5) but phosphorus was not significantly different on fertilizer treatments. Generally, F4 treatments increased nutrients recovery by 131% (N) and 55% (P) over F5. The same trends were observed across the sites and pot experiment that (N) was high with F4 treatment application (Table 11). There was no significant difference between F4 and F5 fertilizer treatments observed on pot experiment. Fertilizer use efficiency was not significantly different among fertilizer treatments, and the same trend was observed under pot and field experiments (Table 12).

4 Discussion

4.1 Potato growth response to treatments

Generally, fertilizer application corresponds to increased plant growth and yield, but care should be taken when choosing the type of fertilizer to apply depending on soil and crop requirement. Potato is a heavy feeder, shallow rooted and it requires a wide range of nutrients to realize full potential yield (Westermann, 2005). Assessment of fertilizer application success is based on crop growth and yield. In this study, fertilizer treatments did not affect the number of stems. Adhikari (2014) reported the same, on the study that was evaluating the effected of NPK fertilizer on growth and yield of potato, he found that fertilizer had no significant effect on number of stems. Number of stems may depend on variety character, number of eyes on seed tubers and pre-sprouting treatments instead of nutrients from the soil. WURR et al. (2001) found that the number of stems were associated with environmental conditions at the time of tuber initiation of potato plant and sprouting temperature. Nielson et al. (1989) reported that number of potato tuber eyes determine number of stems, tuber set and yield of potato cultivar, he also noticed a strong correlation coefficient between the number of eyes on potato seed tuber and number of stems produced. Bohl et al. (2000) reported that number of eyes per potato tuber seed influences stems number. He reported also that every eye has a potential to produce at least one stem under good physiological condition. Adrien (2013) observed that, number of shoots per plant depends mainly on genetic make-up of the variety, development phases of sprouts at planting time, grade (size) and the number of eyes of mother-tuber.

Although, fertilizer treatments enhanced potato plant height and (NPK + Ca + Mg + micronutrients) applied at rate of 900 kg ha^{-1} (F4) resulted in the highest plant height, generally the higher the rate of fertilizer application the higher the plant height. This may be attributed to the high amount of phosphorus that enhanced root development, and improved nutrients uptake, high nitrogen that enhanced vegetative growth, good canopy cover and photosynthesis. Nitrogen (N) is one of the most crucial macronutrients for plant growth and biomass development as reported by Koch et al. (2019). Adhikari (2014) in the study that was evaluating effect of different nutrient levels (0:0:0, 50:50:50, 100:50:50, 100:75:50, 100:75:100,100:100:100 and 150:100:100 N, P_2O_5 and K_2O kg ha^{-1}) on potato vegetative growth and yield, found that plant height was significantly affected by different levels of fertilizer application and increased by 15-42 percent as compared to the control. He concluded that was due to high dose of nitrogen (N) resulting in vigorous plant growth. The same trend

Table 4. Effect of canola green manure and fertilizer treatments on potato tuber yields at Elbugon, Kenya

Fertilizer levels (kg ha^{-1})	Shangi variety		Kenya Karibu variety	
	Tubers plant $^{-1}$	Tuber DW (t ha^{-1})	Tubers plant^{-1}	Tuber DW (t ha^{-1})
NPK900 (F1)	8.00 (±0.50) ab	7.85 (±0.81) ab	7.00 (±0.86) a	5.63 (±0.49) a
NPK575 (F3)	8.00 (±0.65) ab	5.73 (±1.13) bc	6.00 (±0.61)ab	4.77 (±0.46) ab
DAP500 + CAN300 (F5)	9.00 (±0.19) a	8.45 (±0.39) a	8.00 (±1.09) a	6.00 (±0.73) a
NPK250 (F2)	6.00 (±0.35) bc	4.82 (±0.63) c	7.00 (±0.54) ab	3.52 (±0.54) bc
Control (F1)	5.00 (±0.74) c	4.11 (±0.96) c	4.00 (±0.70) b	2.48 (±0.65) c
MSD	1.98	2.43	2.73	2.03
Green manure levels				
With green manure	7.00 (±0.46) a	6.50 (±0.61) a	7.00 (±0.60) a	4.85 (±0.48) a
Without green manure	7.00 (±0.52) a	5.88 (±0.71) a	6.00 (±0.54) a	4.11 (±0.49) a
MSD	NS	NS	NS	NS

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different; DW: dry weight

Table 5. Effect of canola green manure and fertilizer treatments on potato tuber yields at Mau-Narok, Kenya

Fertilizer levels (kg ha^{-1})	Shangi variety		Kenya Karibu variety	
	Tubers plant $^{-1}$	Tuber DW (t ha^{-1})	Tubers plant^{-1}	Tuber DW (t ha^{-1})
NPK900 (F1)	12.00 (±1.21) a	7.85 (±1.54) a	10.00 (±1.13) a	11.42 (±1.10) a
NPK575 (F3)	12.00 (±1.68) a	6.20 (±0.50) ab	9.00 (±0.49) ab	8.94 (±0.46) ab
DAP500 + CAN300 (F5)	11.00 (±0.75) a	6.29 (±0.42) ab	10.00 (±0.53) a	10.55 (±1.01) a
NPK250 (F2)	12.00 (±1.62) a	6.13 (±1.15) ab	8.00 (±0.59) ab	7.35 (±0.61) b
Control (F1)	9.00 (±0.71) a	4.57 (±0.71) b	7.00 (±0.93) b	6.71 (±1.17) b
MSD	NS	2.95	2.47	6.06
Green manure levels				
With green manure	11.00 (±0.87) a	6.84 (±0.76) a	9.00 (±0.73) a	9.04 (±0.90) a
Without green manure	11.00 (±0.77) a	5.58 (±0.42) a	9.00 (±037) a	8.94 (±0.49) a
MSD	NS	NS	NS	NS

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different; DW: dry weight

Table 6. Effect of canola green manure and fertilizer treatments on potato tuber yields for pot experiment

Fertilizer treatments (kg ha^{-1})	No. of tubers plant $^{-1}$	Tuber DW (t ha^{-1})
NPK900 (F1)	12.00 (±1.46) b	2.14 (±0.13) a
NPK575 (F3)	11.00 (±0.82) b	1.82 (±0.25) ab
DAP500+CAN300 (F5)	18.00 (±1.83) a	2.45 (±0.21) a
NPK250 (F2)	10.00 (±1.23) bc	1.64 (±0.17) ab
Control (F1)	6.00 (±0.81) c	1.19 (±0.15) b
MSD	5.43	0.81

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, DW: dry weight

Table 7. Effect of fertilizer and canola green manure on potato tuber grades at Mau-Narok, Kenya

Fertilizer levels (kg ha^{-1})	% Big size	% Medium size	% Small size
		Shangi variety	
NPK900 (F1)	15.00 (±3.97) a	19.66 (±3.72) a	65.34 (±7.05) a
NPK575 (F3)	7.30 (±2.78) a	16.78 (±2.62) a	75.79 (±2.89) a
DAP500 + CAN300 (F5)	9.38 (±2.60) a	18.15 (±3.76) a	72.46 (±4.45) a
NPK250 (F2)	8.30 (±2.28) a	20.83 (±5.02) a	70.84 (±5.10) a
Control (F1)	7.08 (±1.88) a	14.87 (±3.88) a	78.08 (±3.11) a
MSD	NS	NS	NS
With green manure	10.34 (±2.30) a	20.77 (±2.58) a	68.86 (±3.53) a
Without green manure	8.49 (±1.17) a	15.35 (±1.91) a	76.15 (±2.14) a
MSD	NS	NS	NS
		Kenya Karibu variety	
NPK900 (F1)	28.53 (±4.36) a	24.69 (±3.03) ab	46.79 (±5.17) b
NPK575 (F3)	20.10 (±2.07) a	27.69 (±2.59) a	52.21 (±2.29) ab
DAP500 + CAN300 (F5)	22.62 (±3.02) a	21.62 (±2.05) ab	54.14 (±3.58) ab
NPK250 (F2)	21.27 (±2.17) a	18.98 (±2.56) ab	59.79 (±2.08) ab
Control (F1)	20.72 (±3.11) a	17.08 (±1.16) b	62.22 (±2.23) a
MSD	NS	9.8	13.06
With green manure	23.01 (±1.88) a	22.00 (±1.74) a	54.34 (±2.70) a
Without green manure	22.28 (±2.11) a	22.02 (±1.91) a	55.72 (±2.16) a
MSD	NS	NS	NS

Big size = > 60 mm, Medium size = 30 – 60 mm, Small size = <30 mm; Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different

was observed by Nizamuddin et al. (2003), who found that, plant height increased with increased nitrogen application 54.37 cm when 150 kg N ha^{-1} was applied and 59.33 cm with 200 kg N ha^{-1} application.

4.2 Potato yield response to treatments

Fertilizer treatments also had effect on potato tuber dry weight and number of tubers, the results show that the two treatments (NPK + Ca + Mg + micronutrients) applied at rate of 900 kg ha^{-1} (F4) and DAP500 kg ha^{-1} (F5) were the best performer in all sites and pot experiment. These two treatments were not significantly different either for number of tuber or tuber dry weight as for growth parameters. Though there was an increase of 4.73% and 83.22% tuber dry weight from NPK 900 kg ha^{-1} fertilizer treatment over positive control DAP500 kg ha^{-1} and negative control, respectively under field condition and this may be due to additional nutrients in NPK over DAP. Normally potato requires adequate amount of primary macronutrients (N, P, and K) and secondary macronutrients (Ca and Mg) to grow well and gives high tuber yields (Haifa, 2020; Koch et al., 2019). The available potato recommendation in Kenya does not cater for potassium (K) due to believing that Kenyan soils have enough potassium (Muthoni and Nyamongo, 2009; Kanyanjua and Ayaga, 2006). Potassium is a key nutrient which is needed throughout potato growing period. Potassium in potato is critical for increased yield, it influences the transport of nutrients and the movement of sucrose from the leaf to the tuber. In five trials across three years on K-rich volcanic soils found that potassium (K_2O) applied at a rate of 120 kg ha^{-1} increased average yields by 10 kg ha^{-1} (Yara, 2020). Magnesium and calcium nutrients are not also considered in nutrients recommendation yet they have a great influence on potato yield and soil fertility maintenance. Magnesium fertilization enhances crop performance and yield through improved physiological process in plant (Wang et al., 2020). Magnesium plays an important role in photosynthesis and involves in translocation of sugars from leaves to the potato tubers and production of sugars and proteins. Magnesium is mostly need during potato bulking stage (Yara, 2020). Calcium is an important building block of cell wall and stability of membranes; it acts also as a bridge in transport of the phosphate and carboxylate groups of phospholipids and proteins at the membrane surfaces (Koch et al., 2019). The study conducted by Helal and AbdElhady (2015) showed that Ca and K fertilization applied at 178.57 (K) kg ha^{-1}

Table 8. Effect of fertilizer and canola green manure on potato tuber grades at Elburgon, Kenya

Fertilizer levels (kg ha^{-1})	% Big size	% Medium size	% Small size
		Shangi variety	
NPK900 (F1)	12.56 (±2.68) a	26.88 (±2.02) a	60.57 (±4.15) a
NPK575 (F3)	4.34 (±1.50) b	25.87 (±2.81) a	69.76 (±3.73) a
DAP500 + CAN300 (F5)	12.86 (±1.94) a	24.57 (±2.36) a	62.58 (±0.84) a
NPK250 (F2)	8.72 (±3.74) ab	25.87 (±4.15) a	65.42 (±6.25) a
Control (F1)	6.91 (±2.75) ab	27.50 (±5.57) a	65.58 (±7.59) a
MSD	8.12	NS	NS
With green manure	10.37 (±1.86) a	26.52 (±2.50) a	63.11 (±3.36) a
Without green manure	7.79 (±1.67) a	25.76 (±1.80) a	66.46 (±2.84) a
MSD	NS	NS	NS
		Kenya Karibu variety	
NPK900 (F1)	10.04 (±3.13) a	21.49 (±3.55) a	68.47 (±5.04) a
NPK575 (F3)	9.49 (±2.05) a	28.36 (±3.72) a	62.15 (±4.30) a
DAP500 + CAN300 (F5)	11.30 (±1.24) a	29.12 (±7.09) a	59.58 (±7.67) a
NPK250 (F2)	6.68 (±1.92) a	23.45 (±4.03) a	69.87 (±5.74) a
Control (F1)	7.11 (±2.81) a	18.56 (±5.34) a	74.32 (±6.63) a
MSD	NS	NS	NS
With green manure	10.62 (±1.60) a	25.16 (±1.79) a	64.23 (±2.37) a
Without green manure	7.23 (±1.15) a	23.23 (±4.04) b	69.53 (±4.81) a
MSD	NS	28.69	NS

Big size = > 60 mm, Medium size = 30 – 60 mm, Small size = <30 mm; Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different

Table 9. Pearson correlation coefficients (p-values) of growth and yield parameters for field experiment (combined for the two sites)

	Number of stems	Plant height	Number of tubers
Plant height	0.61 (<0.0001)		
Number of tubers	0.56 (<0.0001)	0.62 (<0.0001)	
Dry tuber weight	0.06 (0.54)	0.31 (0.0005)	0.63 (<0.0001)

and 47.62 (Ca) kg ha^{-1} enhanced potato growth and yield. A three years study conducted by Talukder et al. (1970) found that magnesium had significant effects on tuber yield of potato, treatment of 10 (Mg) kg ha^{-1} had higher tuber yield of 32.33, 31.63, and 28.03 t ha^{-1} in three successive years. Potato crop respond differently under different soil and agro-ecological zones. In this study, site differences were observed for growth and yield parameters where they were higher in Mau- Narok than Elburgon. Initially all sites had adequate N and K with low amount of phosphorus (P), and calcium (Ca) at Elburgon. Mau-Narok and Egerton sites had good soil pH ideal for potato production 5.68 and 5.47 respectively, whereas Elburgon site, had a strong acidic soil condition (pH 4.57) that was not ideal for potato production. Potato grows well in pH range of 5.5 to 7 with ideal of 5.5 (NPCK, 2019). Soil pH affect biochemical process in the soil and low pH is mostly as a result excessive leaching of basic cations (Ca, Mg, K, and Na), leaving H^+ and Al_3^+ ions (Neina, 2019). Too acidic soil affects availability of nutrients to plant roots, either by fixation and/or by toxification. In addition, calcium (Ca) deficiency interferes with root growth, causes deformation of foliage growth tips, and may result in reduced and poor quality yields as reported by (Haifa, 2020). There are many potato varieties grown in Kenya, all differ in genetic, morphology, growth habit, maturity, tuber dormancy period, yield potential, resistance to biotic and abiotic stresses and soil and climatic requirement (NPCK, 2019).

In this study, two potato varieties were used and

Table 10. Effect of selected fertilizer treatments on potato nutrients; nitrogen (N), phosphorus (P) and potassium (K) uptake for field and pot experiments

Fertilizer levels (kg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Shangi variety		Mau-Narok	
NPK900 (F4)	157.53(±36.04)a	13.99(±2.60)a	134.69(±19.34)a
DAP500 + CAN300 (F5)	119.43(±14.41)ab	8.06(±1.09)b	102.92(±13.38)a
Control (F1)	89.57(±18.87)b	6.89(±1.05)b	80.10(±17.78)a
MSD	44.72	4.34	70.69
		Elburgon	
NPK900 (F4)	140.65(±24.70)a	5.82(±0.84)ab	86.91(±6.45)ab
DAP500 + CAN300 (F5)	120.44(±7.63)a	9.13(±2.15)a	115.96(±17.90)a
Control (F1)	63.52(±16.09)b	3.60(±0.95)b	49.87(±14.32)b
MSD	46.45	5.48	49.62
		Pot experiment	
NPK900 (F4)	39.11(±2.89)a	3.41(±0.28)a	33.21(±3.36)ab
DAP500 + CAN300 (F5)	44.87(±4.58)a	4.12(±0.51)a	43.17(±7.72)a
Control (F1)	19.65(±2.89)b	1.84(±0.31)b	14.37(±2.05)b
MSD	13.17	1.52	19.18
Fertilizer levels (kg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Kenya Karibu variety		Mau-Narok	
NPK900 (F4)	165.34(±17.08)a	15.79(±1.86)a	182.61(±17.98)a
DAP500 + CAN300 (F5)	163.08(±11.18)a	12.53(±2.75)ab	158.09(±28.83)a
Control (F1)	100.54(±16.11)b	7.06(±1.13)b	73.31(±15.43)b
MSD	29.49	8	66.36
		Elburgon	
NPK900 (F4)	92.76(±10.93)a	6.72(±1.11)a	72.84(±10.77)ab
DAP500 + CAN300 (F5)	90.99(±12.00)a	4.00(±0.48)ab	87.24(±17.60)a
Control (F1)	35.69(±9.19)b	1.43(±0.42)b	22.32(±5.25)b
MSD	34.87	3	51.57
		Pot experiment	
NPK900 (F4)	–	–	–
DAP500 + CAN300 (F5)	–	–	–
Control (F1)	–	–	–
MSD	–	–	–

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different

Table 11. Effect of selected fertilizer treatments on potato nutrients; nitrogen (N) and phosphorus (P) recovery for field and pot experiments

Fertilizer levels (kg ha^{-1})	Shangi variety		Kenya Karibu variety	
	N (%)	P (%)	N (%)	P (%)
Mau-Narok				
NPK900 (F4)	75.51 (±53.42) a	3.04 (±1.11) a	72.00 (±25.45) a	3.73 (±0.92) a
DAP500 + CAN300 (F5)	18.55 (±18.19) b	0.51 (±0.77) b	38.85 (±13.87) b	2.38 (±1.59) a
MSD	42.05	1.98	30.4	NS
Elburgon				
NPK900 (F4)	83.75 (±23.26) a	0.95 (±0.58) a	63.42 (±15.74) a	2.26 (±0.48) a
DAP500 + CAN300 (F5)	35.35 (±10.54) b	2.40 (±0.76) a	34.34 (±7.92) b	1.12 (±0.32) a
MSD	41.99	NS	27.88	NS
Pot experiment				
NPK900 (F4)	21.63 (±4.44) a	0.67 (±0.12) a	–	–
DAP500 + CAN300 (F5)	14.31 (±3.50) a	0.91 (±0.28) a	–	–
MSD	NS	NS	–	–

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different

Table 12. Effect of fertilizer treatments on potato fertilizer use efficiency for field and pot experiments

Fertilizer levels (kg ha^{-1})	Field experiment (kg ha^{-1})	Pot experiment (kg ha^{-1})
NPK900 (F4)	4.19 (±0.77) a	1.06 (±0.21) a
DAP500 + CAN300 (F5)	4.19 (±0.74) a	1.10 (±0.36) a
NPK575 (F3)	3.38 (±0.82) a	1.57 (±0.53) a
NPK250 (F2)	3.95 (±2.03) a	1.82 (±1.07) a
MSD	NS	NS

Values are means ± standard errors; The means followed by the same letters are not significantly different using Tukeys' honest significant difference (HSD) test at 5% level of significance. MSD: minimum significant difference, NS: not significantly different

they showed a significant difference on growth and yield parameters. Shangi had high number of stems, plants height and high number of tubers per plant, though on tuber dry weight and percentage of big size tubers, Kenya karibu had higher values. Shangi was observed to be susceptible to potato bacterial wilt disease and heavy rains stress compared to Kenya Karibu. The differences in performance may also be attributed to genetic makeup difference and growth nature of the two varieties. Kenya Karibu observed to take long time to emerge, flower and mature compared to shangi variety. These findings are supported by Koch et al. (2019), who stated that genetic background determine the yield potential of the potato. Tsegaw (2011) on the study that was evaluating genotype by environment interaction for tuber yield, dry matter content and specific gravity for 11 potato genotypes, reported significant variations among potato genotypes with respect to tuber yields and dry matter content. Tapiwa (2016) reported that a significant difference in the yields was due to differences in genetic makeup of potato varieties.

4.3 Growth *vs* yield of potato

Mostly, vegetative growth determines the potato tubers to be produced, in this line pearson's correlation coefficient analysis showed that, plant height was positively correlated with number of tubers and tuber dry weight. This means that, the higher potato growth the more the number of tubers and tuber weight. Number of stems were strongly correlated to number of tubers, but fairly correlated with tuber weight, this means, the more the number of stems the more the number of tubers and tuber weight. These results are supported by Adhikari (2014) who revealed that, the yield increase of potato tuber was associated with increase in the plant height, fresh weight of leaves and stems as a result of applied NPK. The same results were observed by Arslan (2007) who found a strong positive correlation between tuber yield and plant height (r = 0.745) and was significant.

4.4 Potato nutrients use efficiency

Nutrient use efficiency (NUE) is one of the tools used to measure efficacy of soil supplied nutrients and is defined as a measure of how well plants use the available mineral nutrients. NUE depends on the ability of the plants to take up and utilize the nutrients available in the soil, and the ability of the soil to supply all necessary condition for the plants to take up the available nutrients (Hawkesford et al., 2014). One way of supplying nutrients to the plants is application of inorganic fertilizers. Fertilizer use efficiency may be affected by many factors such as; type of crop, soil properties, climatic condition, forms of fertilizer (NH_4^+-N or NO_3-N), soil microorganisms such as mycorrhiza, and others (Baligar et al., 2001). Nitrogen form (NH_4^+ or NO_3^-) has an important effect on potato nitrogen uptake and use efficiency (Petropoulos et al., 2020).

In this study (NPK + Ca + Mg + micronutrients) showed increased nutrients (N, P and K) uptake and nutrients recovery over diammonium phosphate (DAP) and this may be due to additional nutrients in (NPK + Ca + Mg + micronutrients) fertilizer over DAP that enhanced other nutrients uptake. Calcium (Ca) and magnesium (Mg) improves soil property and nutrients availability through improved soil pH and cation exchange capacity (CEC). Cation exchange capacity (CEC) reported by Hazelton and Murphy (2007) to be a very important soil property that influences physical and chemical properties such as; soil structure stability, nutrient availability, soil pH as well as the soil's ability to react with soil amendments (fertilizers). Nevertheless, (NPK + Ca + Mg + micronutrients) fertilizer seems to increase potato yield, and Rosen (2018) reported that yield is closely related to potato nutrients uptake, where double the yield will result in twice nutrients removal. Ammonium based fertilizers such as DAP are one of nitrogen (N) source that gradually acidify soil through release of H+ in the process of converting ammonium to nitrate by soil bacteria (Crop Nutrition, 2020). Low soil pH may lead to Mn and aluminum (Al) toxicity and P, K, Ca, and Mg deficiencies (Rosen, 2018) Fertilizer use efficiency can be improved by fertilizer best management practices, which includes application of right source of nutrients at the right rate, time, and place in consideration of soil conditions (Roberts, 2007).

5 Conclusions

Potato is a major crop in Kenya, and is of high economic importance to farmers and the population as a whole. The results from this study indicated that fertilizer (NPK + Ca + Mg + micronutrients) applied at the rate of 900 kg ha^{-1} increased potato yield and plant height by 5.0% (8.19 t ha^{-1}), 5.0%(61 cm), respectively over the normal recommended diammonium phosphate (DAP) fertilizer that is mostly used by potato producers in Kenya. NPK + Ca + Mg + micronutrients also increased nutrients (nitrogen, phosphorus and potassium) uptake by 13, 26 and 3%, respectively under field experiment over DAP. NPK + Ca + Mg + micronutrients have additional nutrients that are required by potato for better growth and production, and it doesn't have negative side effects on soil acidification as reported on continuous use of DAP. Generally, canola green manure did not show a significant effect on potato plant height and yield; although F4 (900 kg ha^{-1} of NPK + Ca+ Mg + micronutrients) with green manure application exhibited an increase of 7 and 38% on plant height and tuber dry weight, respectively over no green manure application. The study recommends the use of (NPK + Ca + Mg + micronutrients) applied at rate of 900 kg ha^{-1} for potato production in Kenya upon economic evaluation. The study further recommends additional research to assess compound fertilizers over more seasons with monitoring and evaluation of their effect on soil physical and chemical properties.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Adhikari RC. 2014. Effect of NPK on Vegetative Growth and Yield of Desiree and Kufri Sindhuri Potato. Nepal Agric. Res. J. 9:67–75. doi: 10.3126/narj.v9i0.11643.

Adrien T. 2013. Effect of timing and methods of mineral fertilizer application on Irish potato (*Solanum tuberosum* L.) performance in Musanze and Nyaruguru Districts, Rwanda. MS Thesis, University of Nairobi.

AGRA. 2019. Plant and harvest potato seeds in just three weeks. Online information available at https://agra.org/news/

plant-and-harvest-potato-seeds-in-just-three-weeks/, Accessed on 10 June 2019.

Agriculture, Forestry and Fisheries. 2016. Production guideline for canola. Online information available at https://www.daff.gov.za/CanolaProductionGuideline.pdf, Accessed on 28 July 2019.

Anderson JM, Ingram JSI. 1996. Tropical soil biology and fertility: A handbook of methods. CAB International, Oxon, UK.

Arslan B. 2007. Relationships among yield and some yield characters in potato (s. tuberosum l.). J. of Biological Sciences 7:973–976. doi: 10.3923/jbs.2007.973.976.

Badr M, El-Tohamy W, Zaghloul A. 2012. Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region. Agricultural Water Management 110:9–15. doi: 10.1016/j.agwat.2012.03.008.

Baligar VC, Fageria NK, He ZL. 2001. NUTRIENT USE EFFICIENCY IN PLANTS. Communications in Soil Science and Plant Analysis 32:921–950. doi: 10.1081/css-100104098.

Bohl PWH, Nolte GE, Kleinkopf, Thornton MK. 2000. Potato Seed Management: Seed Size and Age. Available at http:www.extension.uidaho.edupublishing.pdf, Accessed on 01 June 2020.

County Government of Nakuru. 2018. Annual development plan (ADP). Available at http://www.nakuru.go.ke/wp-content/uploads/NAKURU-ADP-FY-2019.2020.pdf.

Crop Nutrition. 2020. Diammonium phosphate. Available at https://www.cropnutrition.com/resource-library/Diammonium-phosphate, Accessed on 08 June 2020.

FAOSTAT. 2020. Foof and Agriculture Organization of the United Nations. Available at http://www.fao.org/faostat/data, Accessed on 13 May 2020.

Gomez KA, Gomez AA. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, New York, USA.

Haifa. 2020. Nutritional recommendations for potato. Available at http:www.haifa-group.comGuidesPotato.pdf, Accessed on 15 May 2020.

Hawkesford MJ, Kopriva S, Kok LJD. 2014. Nutrient Use Efficiency in Plants. Springer International Publishing. doi: 10.1007/978-3-319-10635-9.

Hazelton P, Murphy B. 2007. Interpreting Soil Test Results. CSIRO Publishing. doi: 10.1071/9780643094680.

Helal NAS, AbdElhady SA. 2015. Calcium and potassium fertilization may enhance potato tuber yield and quality. Middle East Journal of Agriculture Research 4:991–998.

IFDC. 2017. Final report on the promotion of Dutch potato varieties through farm level demonstrations in Uganda. International Fertilizer Development Center. Available at httpwww.dutch-potato-on-farm-demo-report.potato, Accessed on 07 May 2020.

Jaetzold R, Schimdt H, Hornetz B, Shisnaya C. 2007. Farm management handbook of Kenya. Natural conditions and farm management information. Volume II B. Nairobi Kenya.

Kanyanjua SM, Ayaga GO. 2006. A Guide to Choice of Mineral Fertilizers in Kenya. KARI Technical Note No 17. KARI, Nairobi, Kenya. Available at http:\www.kalro.orgfileadminpublicationstech_notesTecNote17_20060810.pdf.

Koch M, Naumann M, Pawelzik E, Gransee A, Thiel H. 2019. The importance of nutrient management for potato production part i: Plant nutrition and yield. Potato Res. doi: 10.1007/s11540-019-09431-2.

Maryanne N, Phumzile N, Simon R, Thando V. 2015. Non-confidential final report: market inquiry on fertilizer in Kenya. Available at https:www.cak.go.ke.KenyaFertiliserMarketInquiry.pdf Accessed on 04 May 2020.

McGuire AM. 2016. Green Manures. Washington State University Extension. Available at http://pubs.cahnrs.wsu.edu/publications/wpcontent/uploads.pdf, Accessed on 13 April 2020.

Mehlich A, Pinkerton A, Robertson W, Kepton R. 1962. Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agriculture. Laboratories, Nairobi.

MoALF. 2016. Climate Risk Profile for Nakuru. Kenya County Climate Risk Profile Serie. The Kenya Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

Muthoni J. 2016. Soil fertility situation in potato producing kenyan highlands case of KALRO-tigoni. ijh doi: 10.5376/ijh.2016.06.0025.

Muthoni J, Nyamongo DO. 2009. A review of constraints to ware Irish potatoes production in Kenya. Journal of Horticulture and Forestry 1:98–102.

Neina D. 2019. The role of soil pH in plant nutrition and soil remediation. Applied and Environmental Soil Science 2019:1–9. doi: 10.1155/2019/5794869.

Nielson M, Iritani WM, Weiler LD. 1989. Potato seed productivity: Factors influencing eye number per seed piece and subsequent performance. American Potato Journal 66:151–160. doi: 10.1007/bf02853676.

Nizamuddin, Mahmood MM, Farooq K, Riaz S. 2003. Response of potato crop to various levels of NPK. Asian J. of Plant Sciences 2:149–151. doi: 10.3923/ajps.2003.149.151.

NPCK. 2013. Guide to potato production and postharvest management in Kenya. National Potato Council of Kenya. Available at https://npck.orgbookspotatoproductionmanual.pdf. Accessed on 03 May 2020.

NPCK. 2019. Potato variety catalogue. National Potato Council of Kenya. Available at https://npck.org/catalogue/. Accessed on 15 April 2020.

Nyongesa M, Lung'aho C, Kinyae P, Wakahiu M, Karinga J, Kabira J. 2008. Production of food (ware) potato. KARI information brochure series / 35 /2008. Available at http://www.kalro.org/fileadmin/publications/brochuresII/Production_of_food_potatoes.pdf. Accessed on 07 March 2019.

Okalebo JR, Gathua KW, Woomer PL. 2002. Laboratory Methods of Soil and Plant Analysis: A Working Manual Second edition. TSBF-CIAT and SACRED Africa, Kenya.

Okello J, Zhou Y, Kwikiriza N, Ogutu S, Barker I, Schulte-Geldermann E, Atieno E, Ahmed J. 2016. Determinants of the use of certified seed potato among smallholder farmers: The case of potato growers in central and eastern kenya. Agriculture 6:55. doi: 10.3390/agriculture6040055.

Onwonga RN, Lelei JJ, Friedel JK, Freyer B. 2014. Soil Nutrient Status and Maize (*Zea mays* L.) Performance under Contrasting Legume-Maize Cropping Systems and Soils in Central Rift Valley, Kenya. Journal of Agriculture and Environmental Sciences 3:241–263.

Petropoulos SA, Fernandes Â, Polyzos N, Antoniadis V, Barros L, Ferreira IC. 2020. The impact of fertilization regime on the crop performance and chemical composition of potato (solanum tuberosum l.) cultivated in central greece. Agronomy 10:474. doi: 10.3390/agronomy10040474.

Roberts TL. 2007. Right product, right rate, right time and right place... the foundation of best management practices for fertilizer. Better Crops 91:14–15.

Rosen CJ. 2018. Potato fertilization on irrigated soils, University of Minnesota extension. Available at https://extension.umn.edu/crop-specific-needs/potato-fertilization-irrigated-soils Accessed on 08 June 2020.

Sahlemedhin S, Taye B. 2020. Procedures for Soil and Plant Analysis. Technical paper No.74, Addis Ababa, Ethiopia. Available at http://publication.eiar.gov. Accessed on 12 May 2020.

Sintayehu A, Ahmed S, Fininsa C, Sakhuja PK. 2014. Evaluation of green manure amendments for the management of fusarium basal rot (fusarium oxysporumf.sp.cepae) on shallot. International Journal of Agronomy 2014:1–6. doi: 10.1155/2014/150235.

Talukder M, Islam M, Kamal S, Mannaf M, Uddin M. 1970. Effects of magnesium on the performance of potato in the tista meander floodplain soil. Bangladesh J. Agric. Res 34:255–261. doi: 10.3329/bjar.v34i2.5797.

Tapiwa RM. 2016. Evaluation of new Irish Potato (*Solanum tuberosum* L.) varieties for yield potential in Zimbabwe. Thesis, Midlands State University, Faculty of Natural Resources Management and Agriculture. Available at http://hdl.handle.net/11408/2466. Accessed on 12 May 2020.

Tsegaw T. 2011. Genotype × environment interaction for tuber yield, dry matter content and specific gravity in elite tetraploid potato (*Solanum tuberosum* L.) genotypes. East African Journal of Sciences 5:1–5.

Walinga I, Lee JJVD, Houba VJG, Vark WV, Novozamsky I. 1995. Digestion in tubes with h2so4-salicylic acid- h2o2 and selenium and determination of ca, k, mg, n, na, p, zn. In: Plant Analysis Manual. Springer Netherlands. p. 7–45. doi: 10.1007/978-94-011-0203-2_2.

Wang Z, Hassan MU, Nadeem F, Wu L, Zhang F, Li X. 2020. Magnesium fertilization improves crop yield in most production systems: A meta-analysis. Front. Plant Sci. 10. doi: 10.3389/fpls.2019.01727.

Westermann DT. 2005. Nutritional requirements of potatoes. Am. J. Pot Res 82:301–307. doi: 10.1007/bf02871960.

World Weather Online. 2020. Mau-Narok monthly climate averages. Available at https://www.worldweatheronline.com/mau-narok-weather-averages/rift-valley/ke.aspx. Accessed on 21 August 2020.

WURR DCE, FELLOWS JR, AKEHURST JM, HAMBIDGE AJ, LYNN JR. 2001. The effect of cultural and environmental factors on potato seed tuber morphology and subsequent sprout and stem development. J. Agric. Sci. 136:55–63. doi:10.1017/s0021859600008431.

Yara. 2020. How to increase potato tuber size. Available at https://www.yara.co.uk/crop-nutrition/potato/increasing-potato-tuber-size/. Accessed on 03 June 2020.

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