Potato (Solanum tuberosum L.) Tuber Yield and Yield Components as Influenced by Different Levels of Nitrogen, Phosphorus and Potassium in Rwanda

Article *in* Agricultural Science Digest - A Research Journal · October 2019

DOI: 10.18805/ag.D-155

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RESEARCH ARTICLE

Potato (*Solanum tuberosum L.*) Tuber Yield and Yield Components as Influenced by Different Levels of Nitrogen, Phosphorus and Potassium in Rwanda

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10.18805/ag.D-155

Abstract

Despite potato yield potential, its intensification level remains low in Rwanda, translating into low yield occasioned mainly by the decline in soil fertility. Field experiments were conducted in Birunga, Mudende [L_1]) and Buberuka, Rwerere [L_2] highlands Agro-ecological zones (AEZs), during September to December 2016 and March to June 2017 crop growing seasons to determine the effects of varying rates of N, P and K on potato tuber yield and yield components. The experiments were laid out using a randomized complete block design with a factorial arrangement, with four replicates. Factors were N rates (N_X) i.e N_1-0 kg ha^{-1}, N_2 _ 50 kg ha^{-1}, N_3 _ 100 kg ha^{-1} ; P_2O_5 rates (P_X) i.e P_1-0 kg ha^{-1}, P_2 _ 50 kg ha^{-1}, P_3 _ 100 kg ha^{-1}and K_2O rates (K_x) i.e K_1- 0 kg ha^{1}and K_2- 50 kg ha^{-1}. Number of tubers per plant, fresh tuber weight, small tuber yield, medium tuber yield, large tuber yield, and total tuber yield were measured. Analysis of variance, performed using SAS-version 9.2, revealed that interaction effects of N×P×K were very highly significant on all parameters. Generally, $N_3P_3K_2$ performed better than other treatments and recorded highest tuber yields in all situations: (32.73 ± 0.43) t ha^{-1}[L_1] and (29.36 ± 0.41) t ha^{-1} [L_2] and (31.05 ± 0.52) t ha^{-1}for pooled analysis of variance (ANOVA). Contrarily to what happened at L_2, $N_3P_3K_2$ and $N_2P_3K_2$ were not significantly different at L_1. N_2P_3 K_2 is recommended to L_1 whereas $N_3P_3K_2$ is recommended to L_2.

Key words: Potato, N-P-K nutrients, location-specific fertilizer recommendation, Rwanda.

Agricultural Science Digest (2019)

Introduction

Agriculture accounts for one-third of Rwanda's gross domestic product (GDP), and the sector is, however, characterized by low productivity resulting from soil fertility decline over the years, which primarily results from continuous cultivation without adequate addition of external nutrient inputs (MINECOFIN, 2012). In permanent agricultural systems, soil fertility is maintained through the application of organic and mineral fertilizers (IFDC, 2009), their application varies across locations and seasons due to difference in soil types, nutrient availability of the soil, moisture supply and variety (Zelalem *et al.,* 2009).

Potato is an important crop for food and income generation in Rwanda; its cultivation is intensively carried out year-round in Birunga and Buberuka highlands AEZs where weather and soil conditions are potentially favorable for the crop performance (MINAGRI, 2011). Potatoes are heavy feeders, and therefore require adequate and balanced quantities of nutrients throughout their growth period (Zelalem *et al.,* 2009). In Rwanda, the crop is mainly grown by smallholder farmers who realize only about 10.2 t ha^{-1} compared to the potential yield of 40 t ha^{-1} (MINAGRI,2011). Low soil fertility occasioned by continuous cultivation coupled with Inefficient addition of external nutrient inputs is a major constraint, affecting growth and tubers yield (MINAGRI, 2004). Nitrogen, phosphorus, and potassium are the major macronutrients in agro-ecosystems, therefore are the first to limit potato crop production (Jenkins and Mahmood, 2003). The fertilizer recommendation prevailing in Rwanda is general (blanket); 300 kg of compound fertilizer 17-17-17 ha^{-1} and does not consider heterogeneity in the soil at a landscape level. The general application of fertilizers leads to soil fertility decline, thus impeding potato

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How to cite this article: Turamyenyirijuru, A., Nyagatare, G., Gesimba, R.M. and Birech, R.J. (2019). Potato (*Solanum tuberosum L.*) tuber yield and yield components as influenced by different levels of nitrogen, phosphorus and potassium in Rwanda. Agricultural Science Digest, 39(3): 195-199.

Source of support: NUFFIC for providing research funds, Q-Point and NICHE/RWA/185 project for effective implementation of the project, University of Rwanda and Egerton University for offering diverse facilities, support and assistance.

Conflict of interest: None

Submitted: 07-05-2019 **Accepted:** 26-08-2019 **Published:** 02-10-2019

growth and reduced tuber yields (IFDC, 2009). This research is aimed at assessing potato tuber yield and yield components response to different levels of nitrogen, phosphorus, and potassium in Birunga and Buberuka highlands AEZs. The research data provided useful information to refine potato farm management practices, boost productivity, maintain soil fertility, and achieve sustainable and reasonable utilization of soils and lands while enhancing potato tuber yield and yield components.

Materials and methods

Study sites

The study was conducted in two locations; Mudende (Rubavu district) (L1) and Rwerere (Burera district) (L2) located in Birunga and Buberuka highlands AEZs, respectively; during September- December 2016 and March-June 2017 crop growing seasons. A bimodal rainfall pattern characterizes both locations. Their soils are dominated by volcanic soils being in association with lesser areas of other soils such as alisols identified in part of Burera (MINIRENA, 2004). The volcanic soils of Rwandan are volcanic ash or andosols (andisols) (Birasa *et al.*, 1990). Rubavu district is located at 1°40´52.54´S of latitude and 29°19´45.55´E of longitude, and at 1600 m above sea level. It is part of Birunga highlands AEZ, receives about 1200 mm to 1350 mm of rainfall and has a mean temperature of 21° C (Rubavu district, 2013). Burera district is located at 1°28´26.18´´S of latitude and 29°50´4.85´´E of longitude, at an altitude of 2100 m above the sea level. It is part of Buberuka and Birunga AEZs, receives about 1400 mm of rainfall and has a temperature ranging from 9° C to 29° C (Burera district, 2013). The study was conducted in part of Buberuka highlands AEZ. Compared with Buberuka AEZ, Birunga AEZ is more fertile, with lighter soil, cooler weather and higher potato yield; it is considered to be the best agricultural land in Rwanda (Rukundo *et al.*, 2019). Soil properties of the study sites are depicted in Table 1.

Soil sample preparation and characterization

Soil samples were collected from the research locations just before the onset of September- December 2016 rainy season. Soil particle-size distribution was determined using the hydrometer method, and bulk density was measured using the core method as outlined by Okalebo *et al.* (2002). Soil pH (1:2.5 soil-water ratio), was determined using glass electrode pH meter, organic carbon (OC) was determined using the Walkley–Black method, total N (TN) was obtained using the Macro Kjeldahl digestion–distillation method, cation exchange capacity (CEC) was obtained using 1M ammonium acetate (NH_4OAC) saturation method and available K in the extract was determined using flame photometer as specified by Okalebo *et al.* (2002). Available P was determined using the Mehlich 3 method (Mehlich, 1984).

Table 1: Soil properties of the experimental sites

Property	*Value* Mudende location (L1)	Rwerere location (L2)
Textural class	Sandy loam	Sand clay loam
Bulk density	1.42	1.57
pH-H_2O	6.42	5.93
Organic C (%)	5.33	3.89
Total N (%)	0.28	0.20
Available P (ppm)	9.20	8.67
Available K (meq/100g)	0.47	0.32
CEC (meq/100g)	18.53	17.40

Experimental layout and design

The factors under study were N, P_2O_5, and K_2O rates of application. The experiment was laid out in randomized complete block design with 3 × 3 × 2 factorial arrangement of treatments, with four replicates and using Kinigi variety as the test crop. An experimental unit of (2.8 × 1.8) m^2 was used, and guard-rows of 0.6 m separated adjacent plots. Treatments were allocated randomly on each replicate. Fertilizers were applied in the form of urea, triple superphosphate and muriate of potash to supply N, P and K nutrients, respectively. N and P_2O_5 were supplied at 0, 50 and 100 kg ha^{-1} rates while K_2O was supplied at 0 and 50 kg ha^{-1} rates only.

Agronomic practices

Soil tillage, seedbed preparation, and ridging were done in such a way that quick emergence, deep root penetration and good drainage were insured. One tuber-seed was planted per hole. The spacing of 70 cm between the rows and 30 cm within the rows was used and well-sprouted tubers of medium and homogenous seed size were planted at a depth of 10 cm. Full P_2O_5, K_2O, and half N were applied at the time of planting and rest of N was top-dressed at 14 days after emergence (14DAE). Fertilizers were uniformly spread within 10 cm diameter of the planting hole before depositing tuber seed or around the plant 14DAE. Weeds removal was executed by hand hoeing 14DAE while ridging was carried out 28DAE by hand hoeing and digging soil adjacent to the crop and covering the tubers. Late (*Phytophthora infestans)* and early blight (*Alternaria solani*) were controlled using mancozeb (dose of 30g per 15 L, sprayed once per week).

Agronomic parameters measurement

Data were obtained from eight plants in the middle two rows of each plot. Average fresh tuber weight was measured using an electronic balance and expressed in grams. Tuber yield grading was done after harvesting. Tubers were grouped in three tuber diameter classes, using potato size grading machine. Large (big) size: > 60 mm, medium size: 30-60 mm and small size: < 30 mm. Different grades were weighed separately, and values recorded were converted into t ha^{-1}. Total tuber yield was wet weighed per plot, and values recorded were also converted into t ha^{-1}.

Table 2: Interaction effect of nitrogen, phosphorus and potassium on potato tuber yield and yield components

Trt	Mudende location [L1]						Rwerere location [L2]					
	NTP	FTW	STY	MTY	LTY	TTY	NTP	FTW	STY	MTY	LTY	TTY
332	10.33 ± 0.11^{a}	83.48 ± 1.12^{a}	1.59 ± 0.10^{j}	20.27 ± 0.43^{a}	10.87 ± 0.27^{a}	32.73 ± 0.43^{a}	9.78 ± 0.11^{a}	72.80 ± 1.03^{a}	1.71 ± 0.08^{j}	17.57 ± 0.18^{a}	10.08 ± 0.24^{a}	29.36 ± 0.41^{a}
322	9.19 ± 0.11^{c}	74.26 ± 1.04^{c}	1.71 ± 0.10^{hi}	17.79 ± 0.40^{c}	9.55 ± 0.23^{b}	29.05 ± 0.44^{b}	8.58 ± 0.12^{b}	67.11 ± 0.97^{b}	1.83 ± 0.08^{hi}	15.20 ± 0.18^{b}	8.72 ± 0.22^{b}	25.74 ± 0.42^{b}
331	8.66 ± 0.13^{d}	70.01 ± 1.15^{d}	1.81 ± 0.10^{g}	16.68 ± 0.43^{e}	8.96 ± 0.27^{c}	27.46 ± 0.48^{d}	8.02 ± 0.13^{c}	62.77 ± 1.12^{c}	1.93 ± 0.10^{g}	14.05 ± 0.20^{c}	8.06 ± 0.22^{c}	24.04 ± 0.46^{c}
321	6.68 ± 0.13^{g}	53.99 ± 1.05^{g}	2.10 ± 0.10^{e}	12.41 ± 0.35^{g}	6.67 ± 0.15^{d}	21.18 ± 0.47^{f}	5.9 3± 0.14^{f}	46.38 ± 1.13^{f}	2.17 ± 0.08^{e}	9.90 ± 0.21^{f}	5.68 ± 0.19^{f}	17.76 ± 0.45^{f}
222	9.06 ± 0.06^{c}	73.25 ± 0.69c	1.76 ± 0.11^{gh}	17.53 ± 0.29^{cd}	9.44 ± 0.24 $^{b c}$	28.72 ± 0.32^{bc}	7.84 ± 0.06^{c}	61.38 ± 0.54^{c}	1.90 ± 0.09^{gh}	13.73 ± 0.11^{c}	7.87 ± 0.20^{c}	23.51 ± 0.29^{c}
232	9.99 ± 0.19^{b}	80.74 ± 1.59^{b}	1.64 ± 0.11^{ij}	19.47 ± 0.41^{b}	10.54 ± 0.43^{a}	32.16 ± 0.64^{a}	8.73 ± 0.19^{b}	68.32 ± 1.50^{b}	1.79 ± 0.10^{ij}	15.49 ± 0.39^{b}	8.88 ± 0.30^{b}	26.16 ± 0.61^{b}
231	8.84 ± 0.11^{d}	71.45 ± 1.00^{d}	1.80 ± 0.10^{gh}	17.05 ± 0.35^{de}	9.17b ± 0.24^{c}	28.02 ± 0.43^{cd}	7.54 ± 0.12^{d}	59.01 ± 0.96^{d}	1.94 ± 0.08^{g}	13.13 ± 0.18^{d}	7.53 ± 0.21^{d}	22.6 ± 0.41^{d}
221	6.80 ± 0.07^{fg}	54.98 ± 0.53^{fg}	2.04 ± 0.13^{ef}	12.68 ± 0.24^{fg}	6.85± 0.17^{d}	21.57 ± 0.32^{f}	5.39 ± 0.07^{g}	42.17 ± 0.65^{g}	2.18 ± 0.12^{e}	8.87 ± 0.07^{g}	5.09 ± 0.15^{g}	16.15 ± 0.30^{g}
312	7.06 ± 0.13^{e}	57.06 ± 1.09^{e}	1.96 ± 0.08^{f}	13.28 ± 0.38^{f}	7.14 ± 0.16^{d}	22.38 ± 0.48^{e}	6.33 ± 0.14^{e}	49.51 ± 1.15^{e}	2.06 ± 0.06^{f}	10.74 ± 0.23^{e}	6.16 ± 0.21^{e}	18.96 ± 0.46^{e}
311	4.06 ± 0.08^{i}	32.77 ± 0.52^{i}	2.45 ± 0.13^{cd}	6.77 ± 0.18^{h}	3.64 ± 0.10^{ef}	12.87 ± 0.32^{g}	3.15 ± 0.08^{i}	24.67 ± 0.71^{i}	2.53 ± 0.11^{d}	4.39 ± 0.10^{i}	2.53 ± 0.11^{i}	9.45 ± 0.30^{i}
212	6.89 ± 0.12^{ef}	55.65 ± 0.99^{ef}	1.98 ± 0.10^{f}	12.91 ± 0.36^{fg}	6.94 ± 0.17^{d}	21.83 ± 0.45^{ef}	5.47 ± 0.13^{g}	42.85 ± 1.06^{g}	2.13 ± 0.09^{ef}	9.08 ± 0.21^{g}	5.21 ± 0.19^{g}	16.41 ± 0.43^{g}
211	4.18 ± 0.09^{hi}	33.76 ± 0.59^{hi}	2.41 ± 0.13^{d}	7.04 ± 0.23^{h}	3.81 ± 0.15^{e}	13.26 ± 0.35^{g}	3.03 ± 0.07^{i}	23.72 ± 0.60^{i}	2.55 ± 0.12^{d}	4.15 ± 0.15^{i}	2.39 ± 0.13^{i}	9.09 ± 0.26^{i}
132	4.29 ± 0.09^{h}	34.63 ± 0.57^{h}	2.36 ± 0.12^{d}	7.33 ± 0.19^{h}	3.9 ± 0.11^{e}	13.59 ± 0.34^{g}	3.39 ± 0.09^{h}	26.56 ± 0.76^{h}	2.51 ± 0.11^{d}	4.87 ± 0.11^{h}	2.80 ± 0.12^{h}	10.17 ± 0.31^{h}
122	3.73 ± 0.09^{j}	30.09 ± 0.60^{j}	2.54 ± 0.12^{c}	6.03 ± 0.18^{i}	3.25 ± 0.09^{f}	11.82 ± 0.34^{h}	2.80 ± 0.09^{j}	21.92 ± 0.78^{j}	2.68 ± 0.11^{c}	3.63 ± 0.12^{j}	2.09 ± 0.11^{j}	8.40 ±0.31^{j}
131	3.30 ± 0.09^{k}	26.68 ± 0.57^{k}	2.65 ± 0.12^{b}	5.08 ± 0.17^{j}	2.75 ± 0.09^{g}	10.48 ± 0.33^{j}	2.38 ± 0.07^{k}	18.43 ± 0.76^{k}	2.79 ± 0.11^{b}	2.71 ± 0.13^{k}	1.56 ± 0.11^{k}	7.06 ± 0.30^{k}
121	3.26 ± 0.09^{k}	26.30 ± 0.61^{k}	2.70 ± 0.09^{b}	5.26 ± 0.34^{j}	2.69 ± 0.08^{g}	10.65 ± 0.39^{j}	2.33 ± 0.07^{k}	18.04 ± 0.78^{k}	2.84 ± 0.08^{b}	2.58 ± 0.14^{k}	1.49 ± 0.11^{k}	6.91 ± 0.31^{k}
112	3.18 ± 0.09^{k}	25.69 ± 0.62^{k}	2.8 ± 0.10^{a}	4.72 ± 0.19^{j}	2.57 ± 0.08^{g}	10.09 ± 0.34^{i}	2.26 ± 0.07^{k}	17.42 ± 0.79^{k}	2.94 ± 0.08^{a}	2.36 ± 0.14^{k}	1.37 ± 0.11^{k}	6.67 ± 0.31^{k}
111	2.88 ± 0.11^{l}	22.18 ± 0.72^{l}	2.87 ± 0.10^{a}	3.78 ± 0.19^{k}	2.07 ± 0.08^{h}	8.72 ± 0.36^{j}	1.94 ± 0.10^{l}	14.76 ± 0.88^{l}	3.01 ± 0.09^{a}	1.45 ± 0.15^{l}	0.84 ± 0.10^{l}	5.30 ± 0.33^{l}
$\bar{x}$	6.24	50.39	2.18	11.45	6.16	19.78	5.27	40.99	2.31	8.55	4.91	15.76
lsd	0.20	1.57	0.09	0.63	0.48	0.65	0.21	1.67	0.10	0.42	0.24	0.62
CV	3.16	3.13	4.38	5.59	7.93	3.32	4.07	4.10	4.19	4.98	4.97	3.95

Mean followed by the same letter(s) within each column do not differ statistically (p= 0.05).

Treat (XYX): treatment combination ($N_XP_YK_Z$), $\bar{x}$: mean, lsd: Least Significant Difference, CV: Coefficient of Variation.

Table 3: Interaction effect of nitrogen, phosphorus and potassium on potato tuber yield and yield components [Pooled analysis-Locations 1and 2]

Trt.	NTP	FTW	STY	MTY	LTY	TTY
332	10.05 ± 0.10^{a}	78.14 ± 1.56^{a}	1.65 ± 0.06^{l}	18.92 ± 0.41^{a}	10.47 ± 0.20^{a}	31.05 ± 0.52^{a}
322	8.88 ± 0.11^{c}	70.69 ± 1.15^{c}	1.77 ± 0.06^{jk}	16.50 ± 0.40^{c}	9.13 ± 0.19^{c}	27.40 ± 0.52^{c}
331	8.34 ± 0.12^{d}	66.39 ± 1.21^{d}	1.87 ± 0.07^{i}	15.37 ± 0.40^{de}	8.51 ± 0.19d^{e}	25.75 ± 0.55^{de}
321	6.30 ± 0.13^{g}	50.19 ± 1.23^{g}	2.14 ± 0.06^{f}	11.16 ± 0.38^{g}	6.18 ± 0.17^{g}	19.47 ± 0.54^{g}
222	8.45 ± 0.16^{d}	67.31 ± 1.59^{d}	1.83 ± 0.07^{ij}	15.63 ± 0.51^{d}	8.66 ± 0.25^{d}	26.12 ± 0.71^{d}
232	9.36 ± 0.21^{b}	74.53 ± 1.92^{b}	1.72 ± 0.08^{k}	17.48 ± 0.58^{b}	9.71 ± 0.33^{b}	28.91 ± 0.83^{b}
231	8.19 ± 0.18^{e}	65.23 ± 1.74^{e}	1.87 ± 0.06^{i}	15.09 ± 0.54^{e}	8.35 ± 0.26e	25.31 ± 0.76^{e}
221	6.10 ± 0.19^{h}	48.58 ± 1.70^{h}	2.11 ± 0.09^{fg}	10.78 ± 0.51^{g}	5.97 ± 0.25^{g}	18.86 ± 0.73^{h}
312	6.69 ± 0.13^{f}	53.29 ± 1.24^{f}	2.01 ± 0.05^{h}	12.01 ± 0.39^{f}	6.65 ± 0.18^{f}	20.67 ± 0.55^{f}
311	3.61 ± 0.13^{j}	28.72 ± 1.13^{j}	2.49 ± 0.08^{e}	5.58 ± 0.32^{i}	3.09 ± 0.16^{h}	11.16 ± 0.49^{j}
212	6.18 ± 0.20^{gh}	49.25 ± 1.80^{gh}	2.06 ± 0.07^{gh}	10.99 ± 0.53^{g}	6.07 ± 0.25^{g}	19.12 ± 0.76^{gh}
211	3.61 ± 0.16^{j}	28.74 ± 1.36^{j}	2.48 ± 0.09^{e}	5.59 ± 0.40^{i}	3.10 ± 0.21^{h}	11.17 ± 0.58^{j}
132	3.84 ± 0.13^{i}	30.59 ± 1.14^{i}	2.44 ± 0.08^{e}	6.10 ± 0.34^{h}	3.35 ± 0.16^{h}	11.89 ± 0.49^{i}
122	3.26 ± 0.14^{k}	26.01 ± 1.16^{k}	2.61 ± 0.08^{d}	4.83 ± 0.33^{j}	2.67 ± 0.16^{i}	10.11 ± 0.50^{k}
131	2.84 ± 0.13^{l}	22.55 ± 1.16^{l}	2.72 ± 0.08^{c}	3.90 ± 0.32^{k}	2.16 ± 0.17^{j}	8.77 ± 0.49^{l}
121	2.79 ± 0.13^{l}	22.17 ± 1.17^{l}	2.77 ± 0.06^{c}	3.92 ± 0.39^{k}	2.09 ± 0.17^{j}	8.78 ± 0.54^{l}
112	2.72 ± 0.13^{l}	21.55 ± 1.17^{l}	2.87 ± 0.07^{b}	3.54 ± 0.33^{k}	1.97 ± 0.17^{j}	8.39 ± 0.49^{l}
111	2.41 ± 0.14^{m}	18.47 ± 1.10^{m}	2.94 ± 0.07^{a}	2.61 ± 0.32^{l}	1.45 ± 0.17k	7.01 ± 0.50^{m}
$\bar{x}$	5.76	45.69	4.27	10.00	5.53	17.77
lsd	0.14	1.13	0.07	0.40	0.29	0.44
CV	3.56	3.55	2.24	5.68	7.52	3.58

Mean followed by the same letter(s) within each column do not differ statistically (P= 0.05).

Trt (XYX): treatment combination ($N_XP_YK_Z$), $\bar{x}$: mean, lsd: Least Significant Difference, CV: Coefficient of Variation.

Data analysis

Data collected were subjected to analysis of variance (*P = 0.05*) using Statistical Analysis System (SAS) Version 9.2 statistical software (SAS Institute Inc., 2008). Homogeneity of residual variances was tested prior to a combined analysis over seasons and locations using Bartlett's test. An F-protected least significant difference (*p = 0.05*) was used for mean separation.

Results and discussion

Variances of homogeneity from results of the Bartlett test revealed that the mean squares of individual seasons (within the location and across locations) and locations were homogenous and so a combined ANOVA was found appropriate, that was done after the homogeneity confirmation. ANOVA for each single location (Mudenge location [L_1] and Rwerere location [L_2] and on pooled basis for both locations (locations 1 & 2) revealed that effects of Location × Season × N× P× K, Location × N× P× K and season × N× P× K were not significant ($p > 0.05$) for total tuber yield and all yield components while the interaction N× P× K effects were very highly significant ($p < 0.001$) on total tuber yield and all yield components. $N_3P_3K_2$ treatment combination, reflected by a combination of the highest levels of the research factors, was the best performer. $N_3P_3K_2$ treatment combination produced higher number of tubers per plant [(10.33 ± 0.11) [L_1] ; (9.78 ± 0.11) [L_2]) and (10.05 ± 0.10) [$L_{1\&2}$]], fresh tuber weight [(83.48 ± 1.12) g [L_1]; (72.80 ± 1.03) g [L_2] and (78.14 ± 1.56) g [$L_{1\&2}$]], medium tuber yield [(20.27± 0.43) t.ha^{-1} [L_1]; (17.30 ± 0.18) t.ha^{-1} [L_2]) and (18.92 ± 0.41)t.ha^{-1}[$L_{1\&2}$]], large tuber yield [(10.87± 0.27) t.ha^{-1} [L_1] ; (10.08 ± 0.24) t.ha^{-1} [L_2] and (10.47 ± 0.20) t.ha^{-1}[$L_{1\&2}$]] and total tuber yield [(32.73 ± 0.43) t.ha^{-1}[L_1]; (29.36 ± 0.41) t.ha^{-1}[L_2] and (31.05 ± 0.52) t.ha^{-1}[$L_{1\&2}$]] while $N_1P_1K_1$ treatment combination produced higher small tuber yield [(2.87 ± 0.10) t.ha^{-1} [L_1]; (3.01 ± 0.09) t.ha^{-1} [L_2] and (2.94 ± 0.07) t.ha^{-1}[$L_{1\&2}$]]. The effects of $N_3P_3K_2$ and $N_2P_3K_2$ on total tuber yield [(32.73 ± 0.43) t.ha^{-1} and (32.16 ± 0.64) t.ha^{-1}, respectively] were not significantly different from each other at location 1 (Tables 2 and 3). When roots grow in an environment, copiously supplied with water and nutrients, they produce additional root hairs, and root surface area of absorption is increased; which results in more nutrient uptake and high growth of potato (Kumari, 2012). This physiological process culminates in taller crops (Zelalem *et al.*, 2009; Daniel *et al.*, 2016), with significantly larger leaf area index, and higher photosynthesis rate resulting in good translocation and storage capacity, high stolon initiation rate, worthy tubers swelling, high number of tubers of medium and big size, and then leading to high mean tuber weight and aggregate tuber yield (Geremew *et al.*, 2007; Kumari, 2012). Increase in growth and yield depends on an increase in the dry mass of plants which depends on the amount of nutrients supplied and photoassimilates fixed through photosynthesis (Geremew *et al.*, 2007). This could have been the case in the present study since single location ANOVA and ANOVA on pooled basis revealed that the effects of N×P×K were significant on total tuber yield and all tuber yield components, and $N_3P_3K_2$ performed better than other treatment combinations. The treatment combination $N_1P_1K_1$ was the last in performance, indicating that less assimilates were available for crop growth, stolon initiation, consequently lower tuber bulking and yields. This suggests that not enough assimilates were supplied by the source to meet the demands of growing sink tubers; the yield was limited mainly by the source capacity. The present results are in line with findings of Nava *et al.* (2007), Ram (2009) and Muhammad *et al.* (2015) who reported that interaction effects of N×P×K were significant on tuber yield and yield components.

Conclusion

The study was undertaken to determine the effects on N, P and K on potato growth and tuber yield in Birunga and Buberuka highlands AEZs. It was found that in general, the two locational results showed similar response patterns with regard to effects of N×P×K on potato tuber yield and yield component traits. The effects of N×P×K were found to be very highly significant on all tuber yield and yield component traits in both locations. The analysis showed that $N_3P_3K_2$performed better than other treatment combinations for all potato tuber yield and yield component traits, except small tuber yield for which it recorded the lowest value. However, the effects of $N_3P_3K_2$ and $N_2P_3K_2$ were not significantly different from each other at location 1. Therefore, adoption of $N_2P_3K_2$and $N_3P_3K_2$ rate combinations are recommended to locations 1 and 2, respectively.

Acknowledgments

The authors thank NUFFIC for providing research funds, Q-Point and NICHE/RWA/185 project for effective implementation of the project, University of Rwanda and Egerton University for offering diverse facilities, support and assistance.

References

Birasa, E., Bizimana, I., Bouckaert, W., Deflandre, A., Chapelle, J., Gallez, A., Vercruysse, J. (1990). Carte Pédologique du Rwanda. Kigali, Rwanda: MINAGRI.

Burera District. (2013). District development plan (2013-2018). Kigali, Rwanda: MINALOC.

Daniel, Z. Z, Sewa, L., Tesfai, T. K. and Biniam, M. G. (2016). Effect of Potassium Levels on Growth and Productivity of Potato Varieties. American Journal of Plant Sciences, 7(1): 1629–1638.

Geremew, E. B., Steyn, J. M., & Annandale, J. G. (2007). Evaluation of growth performance and dry matter partitioning of four processing potato (Solanum tuberosum) cultivars. New Zealand Journal of Crops and Horticultural Science, 35(3): 385–393. https://doi.org/10.1080/01140670709510204

IFDC. (2009). An action for developing agricultural inputs markets in Rwanda. Kigali, Rwanda: MINAGRI.

Jenkins, P.D. and Mahmood, S. (2003). Dry matter productionand partitioning in potato plants subjected to combined deficiencies of nitrogen, phosphorus and potassium. Annals of Applied Biology, 143(2): 215–229.

Kumari, S. (2012). Influence of drip irrigation and mulch on leaf area maximization, water use efficiency and yield of potato (Solanum tuberosum L.). Journal of Agricultural Science, 4(1): 71–80.

Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Soil Sci. Plant Anal., 15, 1409–1416.

MINAGRI. (2004). Strategic Plan for Agriculture Transformation in Rwanda. Kigali, Rwanda: Republic of Rwanda.

MINAGRI. (2011). Strategies for sustainable crop intensification in Rwanda-Shifting focus from producing enough to producing surplus. Kigali, Rwanda: Republic of Rwanda.

MINECOFIN. (2012). Rwanda vision 2020 revised. Kigali, Rwanda: Republic of Rwanda.

MINIRENA. (2004). National Land Policy. Kigali, Rwanda: Republic of Rwanda.

Muhammad, N., Zahid, H., Rahmdil and Niaz, A. (2015). Effect of different doses of NPK fertilizers on the growth and tuber yield of potato. Life Sciences International Journal: 9, 3098–3105.

Nava, G., Roque, D., and Lucia, I. . (2007). Effect of the nitrogen, phosphorus and potassium fertilization on the potato tuber yield. Horticultura Brasileira, 25(3): 365–370.

Okalebo, J.R., Gathua, K.W. and Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual (2nd ed.). Nairobi, Kenya: Moi University.

Ram, C. A. (2009). Effect of NPK on Vegetative Growth and Yield of Desiree and Kufri Sindhuri Potato . Nepal Agriculture Research Journal, 9: 67–75.

Rubavu district. (2013). District Development Plan (2013-2018). Kigali, Rwanda: MINALOC.

Rukundo, P., Ndacyayisenga, T., Ntizo, S., Kirimi, S. and Nshimiyima, J. C. (2019). Yield and yield components of CIP advanced potato clones under Rwandan agro-ecologies. Journal of Applied Biosciences, 136: 13909-13920.

SAS Institute Inc. (2008). SAS/STAT® 9.2 User's Guide. Cary, NC: SAS Institute Inc.

Zelalem, A., Tekalign, T. and Nigussie, D. (2009). Response of potato (Solanum tuberosum L .) to different rates of nitrogen and phosphorus fertilization on vertisols at Debre Berhan , in the central highlands of Ethiopia. African Journal of Plant Science, 3: 16–24.