AMERICAN JOURNAL OF AGRICULTURAL SCIENCE, ENGINEERING, AND TECHNOLOGY (AJASET)

ISSN: 2158-8104 (ONLINE), 2164-0920 (PRINT)

VOLUME 6 ISSUE 3 (2022)

PUBLISHED BY: E-PALLI, DELAWARE, USA

Volume 6 Issue 3, Year 2022
ISSN: 2158-8104 (Online), 2164-0920 (Print)
DOI: https://doi.org/10.54536/ajaset.v6i3.640
https://journals.e-palli.com/home/index.php/ajaset
American Journal of Agricultural Science, Engineering, and Technology (AJASET)

Evaluation of Potato Varieties for Yield and Dry Matter Response to Different Fertilizer Levels in Mid Altitude Region in Uganda

Nicholus Kagurusya[1*], D.S Osiru[1], Y.K Zaake[1], Edgar Muhumuza[2], Noel Kishaija[2]

Article Information

Received: September 23, 2022

Accepted: October 11, 2022

Published: October 15, 2022

Keywords

Yield, Dry matter content, Potato, Uganda

ABSTRACT

Potato is an important crop in Uganda that increasing its production and productivity must be emphasized. The yield and quality of potato tubers are partly influenced by the elevation, variety and fertilizers used. However, there is limited information on response of potato varieties to yield and dry matter under different NPK levels. This study therefore, was carried out to determine yield and dry matter response of potato in the mid altitude environment under different NPK (17:17:17) levels. Three potato varieties; Victoria, Rwangume and Kachpot1 were studied for two seasons at BSU Farm under a Randomized Complete Block design with three replications for each season at a fertilizer level of 0Kg/ha, 50Kg/ha and 100Kg/ha. Results showed dry matter was significantly different among the varieties and the overall mean ranged from 17.06% to 23.7%. Across the seasons, Kacpot1 had the highest dry matter content at 22.96% from fertilizer level one, whilst Rwangume had the lowest dry matter content at 18.08% from fertilizer level three. Fertilizer level three produced the highest overall mean of yield (12.19 t/ha) during 2019B and the lowest over all mean (5.3t/ha) from fertilizer level f1 during 2020A. Across the seasons, Katchpot1 yielded the best at 14.78 t/ha, whilst Victoria was the lowest yielder at 7.02 t/ha. The increase in fertilizer levels decreased the dry matter content of potatoes. Fertilizer level f2 is recommended for Katchpot 1, while f3 is recommended for Rwangume and Victoria for optimum yield.

INTRODUCTION

Potato is the third most consumed food commodity worldwide after rice and wheat and has hence been recommended as a food security crop by the Food and Agriculture Organization of the United Nations (FAO) (Devaux *et al*., 2014). It's the fourth most important food crop in the world in terms of production with 388 million tons produced in 2017, following rice, wheat and maize (FAOSTAT, 2019). Potato in Uganda occupies the 8th position as a food security and a cash crop (Mbowa and Mwesigye, 2016). Potato provides more food much faster than any other major crop and is high in nutrient content (FAO 2008; Lutaladio and Castaldi 2009). Moreover, potato is an important vegetable and a good source of antioxidants (Chen *et al*., 2007) and is also one of the sixteen (16) major food crops prioritized by the Government of Uganda (UBOS, 2018).

Uganda is the ninth largest producer of potato in Africa with an annual production of 188,000 tons harvested from about 39,000 ha per year (FAOSTAT, 2016) giving an average production of 4.8t/ha. In Uganda, the potatoes productivity at farm level is estimated at 7.1 t/ha (FAOSTAT, 2019) against a potential of about 25 t/ha (Harahagazwe *et al*., 2018) which can be achieved under good management and suitable varieties. The potato yields have remained low amidst an ever-increasing population that demands more food in the region (Otieno and Mageto, 2021). These low yields could be attributed to soil infertility, poor fertilizer use, pests and diseases, poor quality tuber seeds and low yielding varieties, untimed weed control, and within-season droughts (Schulte-Geldermann, 2013; Muthoni and Kabira, 2016; Otieno, 2019b; Okeyo *et al*., 2019; Mugo *et al*., 2020). Potato yield, quality and fertilizers application are significantly associated ((Innocent, 2021). The major production areas are the highlands of south-western Uganda, comprising of Kabale, Kanungu and Kisoro districts which account for 60% of total national production. The other potato producing areas are Kapchorwa, Sironko, Bulambuli and Bududa districts on the slopes of Mt Elgon in Eastern Uganda and Nebbi district in north-western Uganda. Potato cultivation has spread to non-traditional producing areas in Central Uganda, especially Mubende, Rakai and Masaka districts. According to Namugga *et al*. (2017) and Tatwangire and Nabukeera, (2017), the common varieties grown in Uganda are; Rutuku, Cruza, Sangema, Nakpot 1 to 5, Kachpot 1 and 2, Kabale red, Victoria, Wanale, Sankena, Megabond, Cruza and Kachpot, Rwangume (NAROPOT 4), Victoria, Kinigi, Rwashaki, Mumba, Sutama, Kimuli, Rutuku, Cruza and Mitare. This study used three varieties; Rwangume, Victoria and Kachpot 1 because they're relatively high yielding (Nuwamanya *et al*., 2011).

NPK 17:17:17 is the most commonly used fertilizer in Uganda (Kisakye *et al*., 2020). The nutrients in the soil influence the yield and dry matter content (DMC) of potatoes and a high level of dry matter content reflects consumer preferences, and is important to the processing and pharmaceutical industries. According to Naz *et al*. (2011), response of potato to NPK fertilizers varies depending upon the variety, soil characteristics and geographical location.

[1] Bishop Stuart University, Faculty of Agriculture, Environmental Sciences and Technology, P O Box 09, Mbarara, Uganda
[2] Makerere University, College of Agricultural and Environmental Sciences, PO Box 7062, Kampala, Uganda
[*] Corresponding author's e-mail: nkagurutsya@gmail.com

One of the contributing factors to low potato yields in most parts of the world is low soil fertility attributed to continuous cultivation without adequate replenishment of the mined nutrients (Kaguongo *et al.*, 2008; Muthoni and Kabira, 2011, Otieno, 2019b, Mugo *et al.*, 2020). Declining soil fertility is a major constraint to crop production in Uganda and is exacerbated by continuous cultivation of land, poverty, and lack of access to productive resources (Barungi *et al.*, 2013). Recognition of the use of fertilizers as the most viable mechanism for bolstering soil and general agricultural productivity cannot be over-emphasized, (MAAIF, 2016). In Uganda, mineral fertilizers and manure are applied on only 1.0% and 6.8% of the parcels of agricultural land, respectively, (UBOS 2018), and only 2% of smallholders use inorganic fertilizers, and only about 24% apply organic inputs – mostly on perennial crops (Ebanyat, *et al.*, 2010). The current fertilizer usage rate is estimated at just 0.23 - 1 kg/ha, the lowest among the countries in Sub-Sahara Africa, (Bekunda and Kaizzi, 2008). The nutrients are hardly replaced to the same degree that they are mined through crop harvests and other losses, resulting in high negative nutrient balances because most smallholder farmers hardly utilize organic or inorganic fertilizers.

However, there is little information on the response of fertilizers use on potatoes in the soils of mid-altitude areas on performance; yield and dry matter content. Such an understanding is necessary for farmers to decide confidently on use and application of NPK fertilizers. Therefore, this study aims at establishing and documenting the response of different potato varieties to yield and dry matter content to different doses of NPK (17: 17: 17) fertilizer levels in mid-altitude environment.

LITERATURE REVIEW

Fertilizer use in Uganda

The main contributing factors to low yields are poor inherent soil fertility, particularly N and P deficiencies (Bekunda *et al.*, 1997), exacerbated by soil fertility depletion (Vlek, 1993; Sanchez *et al.*, 1996; Lynam *et al.*, 1998) and other biophysical factors. N, P, and K are the key limiting nutrients to potato production in the major potato growing areas in East Africa, Mugo *et al.*, 2020. Declining soil fertility and land degradation have particularly affected the land on which the poor depend and threatened food security for the smallholder farmers (Sanchez, 2002). Uganda is among the countries with the most severe soil nutrient depletion in Africa, with mean N, P, and K depletion estimated to be 21, 8, and 43 kg ha–1yr–1, respectively (Stoorvogel and Smaling, 1990; Smaling *et al.*, 1997; Wortmann and Kaizzi, 1998; Nkonya *et al.*, 2005).

Potato is a heavy feeder of N, P, K nutrients and the amounts of these nutrients can only be supplied through fertilizer application, a strategy that may be beyond the means of the resource constrained smallholder farmers, (Gitari, H. I. *et al.*, 2018, Obare *et al.*,2010). To attain a tuber yield of 48 tons ha−1, potato tubers remove 47.6 kg N, 24 kg P, 103.4 kg K and 5 kg S, while the haulm requires 31.8 kg N, 8.2 kg P, 47.6 kg K and 3.2 kg S, (Burton 2018)

There has been considerable research and policy analysis on fertilizer promotion and use around the world (Crawford *et al.*, 2005), although in Uganda this has not been the case; only eight in one hundred farm households use inorganic fertilizers and about 26 out of 100 households use organic fertilizers in crop production (Uganda Census of Agriculture 2008/09, UBOS 2013).

Unfortunately, only 2% of smallholder farmers in Uganda use inorganic fertilizer (UBOS, 2013) and according to Gildrmacher, 2012, only 4.7% of the potato farmers use chemical fertilizers and 17.7% use farmyard manure.

Social and economic factors often do not favor the use of inorganic fertilizers by smallholder farmers. Inorganic fertilizer use in sub-Saharan Africa costs two to six times as much as in Europe (Sanchez, 2002), mainly due to transport costs, marketing inefficiencies, and other charges. The profitability of fertilizer use is highly variable and dependent on agro-climatic and economic conditions at the local and regional levels (Vlek, 1990), made worse by a lack of credit and agricultural subsidies. These factors contribute to a high cost of production and an unfavorable net return or benefit/cost ratio.

Although Uganda is among countries in SSA that signed the Abuja declaration of increasing fertilizer use from the continent average of 8 kg per hectare to at least 50 kg per hectare per annum by 2015 (African Union, 2006), there is little indication that the country is about to attain fertilizer use intensity of at least 5 kg of NPK per hectare per annum. Unless radical interventions occur, projected inorganic fertilizer consumption growth in SSA will remain at 1.9% per annum (Smaling *et al.*, 2006) for a long time.

Effects of fertilizers on yield and dry matter

Fertilizer application has important effects on the quality and yield of potato (Westermann 2005). Fertilizer supply plays an important role in the balance between vegetative and reproductive growth for potato (Alva L., 2004). Nitrogen influences tuber bulking rate and the time of tuber growth (Honeycutt *et al.*, 1996), K increases tuber yield, size and quality (Trehan 2009), while P enhances root development, tuber set and promotes tuber maturity (Burton 2018).

The stage of highest macronutrients demand by potatoes is during initial tuber bulking and varies from 42 – 70 days after planting (Fernandes *et al.*, 2011). High dry matter content (≥20%) as a quality component is a physicochemical characteristic that translates into desirable potatoes for processors and consumers (Mbowa and Mwesigye, 2016). The nutrient makes up the highest proportion of dry matter in plants compared to other nutrients; 3 – 4% of dry matter (FAO, 1978; Crop Nutrition, 2019) and the colour of the final fried potato product is influenced by potassium.

The average nutrient depletion in east Africa is estimated to be around 47-88kgs/ha/year in general and 100kgs/Ha/year in particular on highlands (Henao and Baanante, 1999) majorly because of; soil erosion, fixation of phosphorus and leaching in respect of nitrogen and potassium, further accelerated by deleterious land use practices resulting from high population pressure. According to Tisdale *et al*., (1995), factors limiting crop both quantity and quality can be categorised into four; soil, genetic make-up of the crop, climatic conditions and management practices mainly soil fertility. The use of adequate levels of fertilizers is recognized as one of the management practices that improve crop growth, development, quality and yield.

Though, potato is grown commonly and is adaptable to a wide range of climatic conditions, it has strict requirement for a balanced fertilization, without which yield and quality of tubers are directly affected. Fertilizers application depends upon soil type, soil fertility, crop rotation and irrigation facilities. Similarly, nutrient uptake by the potato crops also depends on the climatic condition, soil type and fertility status, variety cultivated and crop management practice (Sedera, and Shetata, 1994). According to Westennann, D., 2005, 30 tha^{-1} removes 150 Kg N, 60 Kg P and 250 Kg K, 90 Kg CaO and 30 Kg MgO.

MATERIALS AND METHODS

Study site

The study was carried out at Bishop Stuart University (BSU) Farm located at 0^{0}36'20.16'S 30^{0}37'14.91, 1,430 meters above sea level (m.a.s.l), Kakoba Division–Mbarara City. Mbarara city receives an average annual rainfall of 1,200mm with two rainy seasons, during the months of March-June and September-December. Temperature ranges between 17^{0}C to 30^{0}C, with a humidity range of 80-90%. The topography is a mixture of fairly rolling and sharp hills and mountains, shallow valleys and flat land. The soils are generally sandy, clay and slightly laterite loams, suitable for cultivation. The experiment was carried out over two rain seasons of 2019B and 2020A; 2019B (September–December 2019) and 2020A (March – June 2020).

Germplasm material

Three potato varieties recently released by the National Agricultural Research Organization (NARO) were used in this study. These varieties have relatively higher dry matter content (Nuwamanya *et al.* 2011). The varieties were sourced from seed multipliers attached to the potato breeding program in Kachwekano research institute as summarized in Table 1 below;

Table 1: Characteristics of the varieties used

Variety	Tuber shape	Skin colour	Flesh colour	Eye depth	Yield	Blight reaction
Rwangume	globe	red	cream	medium	MY	MR
Victoria	globe	red	white	shallow	MY	S
Kachpot 1	globe	red	cream	medium	MY	S

MY = moderate yielding (yields ranged between 15 to 30 t ha-1), MR= moderate resistance, S = suseptible (Namugga et al., 2017b, 2018).

Experimental design and trial establishment

The field experiments were laid out as Randomized Complete Block design with three replications for each season in a 4 x 4 factorial experiment arrangement. Three fertilizer (NPK 17:17:17) levels were used i.e. Level 1-control; f1 (0Kg/ha), level 2–half the recommended application rate, f2 (50Kg/ha), and level 3–the recommended rate, (100Kg/ha), (Namugga *et al*., 2018). The entire rates of fertilizers were applied at the time of planting. Medium size and well-sprouted potato tubers were planted at a spacing of 75 cm between rows and 30 cm between plants. The plot size was five rows of each 3 m long. Spacing between plots and replications were 1 and 1.5 m, respectively. Cultural practices such as weeding, cultivation and ridging were practiced as per the agronomic recommendations. To prevent blight disease, Indofil (3 g/l) was used monthly.

Data collection

Data were collected on soil nutrient content, yield parameters and dry matter content. For soil analysis, two air-dried soil samples were pounded, sieved through 2 mm to remove any debris then subjected to physical and chemical analysis following standard methods described by Okalebo *et al.* (2002)'. Soil pH was measured in a soil water solution ratio of 1:2.5; Organic matter by potassium dichromate wet acid oxidation method; total N determined by Kjeldhal digestion; Extractable P by Bray P1 method; exchangeable bases from an ammonium acetate extract by flame photometry (K+, Na+) and atomic absorption spectrophotometer (AAS) (Ca2+, Mg2+); and particle size distribution (texture) using the Bouyoucos (hydrometer) method.

Yield parameters collected included number of tubers per plant and weight of tuber per plant. Consequently, total tuber yield in tones per hectare (t/ha) per variety was calculated as a function of number of total tubers per plot and total weight of tubers per plot. The average weight per tuber was also computed per variety. The biomass (potato plant parts above ground) was measured per plot at 10 days before harvesting at dehaulming. At harvesting, data on the number of marketable (Tubers weighing between 80-200g or tubers between 30-60 mm) and non-marketable tubers (Tubers weighing less of 80 g or less of 30 mm) was collected according to CIP [2014]. Random samples of tubers from each variety per plot were weighed up to 1.0kg to make a primary laboratory sample. Each variety sample was taken for laboratory analysis at the Presidential Initiative on Banana Industrial Development Bio-analytical Laboratory in Bushenyi, for dry matter content. Following the method reported by Muhumuza *et al.* (2020b), 400 g of potato sample of each genotype per plot was weighed, washed under running water and dried with a cloth towel. The dried potato tubers were cut and chopped into smaller pieces and mixed manually to get a homogeneous sample. Approximately 200g of each homogenous sample were taken in duplicates for measurement of dry matter content by drying the sample in an oven to constant weight at a temperature of 1050C. The dried samples were reweighed and the dry matter content was calculated by the formula;

$$DMC = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times 100$$

The average calculation from the duplicate samples was taken as dry matter content per variety per plot.

Weather and soil data

There was regular rainfall in both seasons with season 2019 B having a higher rainfall peaks at 135.6mm in November 2019. Temperature varied from 28.50 c to 15.00 c through out the two seasons of the study (Table 2). From the soil analysis (Table 3), pH was favourable but with insufficient nitrogen, potassium, organic matter and micro nutrients.

Table 2: Rainfall and temperature from July 2019 to May 2020

	Months										
	Jul-19	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**	**Jan-20**	**Feb-20**	**Mar-20**	**Apr-20**	**May-20**
Min. T (0C)	15.5	16.2	16.3	16.4	16.4	16.6	17.0	16.7	17.3	17.2	17.0
Max. T (0C)	27.8	28.0	27.7	25.7	26.0	26.4	26.9	28.5	27.9	27.4	27.6
R.F (mm)	12.7	66.8	81.4	130.2	135.6	39.6	78.1	111.5	112.4	133.1	57.3

Source: Uganda National Meteorological Authority Mbarara, 2020

Table 3: Soil analysis of the two sites for the two seasons at BSU farm.

	P.H	E.C	O.M	N	AV.P	K	Na	Ca	Mg	sand	clay	silk	Cu	Zn	Fe	Mn
sample		Us/cm	%		ppm		cmoles/kg			% texture			mg/kg(ppm)			
2019B	6.5	61.2	1.61	0.11	25.4	0.52	0.12	4.3	2.12	44	15	41	1.02	21.2	152.3	12.3
2020A	5.8	73.1	2.01	0.01	65.8	0.64	0.11	4.1	1.96	38	14	48	0.98	26.3	112.3	14.2

pH = potential of hydrogen, OM = organic matter, N = nitrogen, P = phosphorus, Na = sodium, K = potassium, Ca = calcium, Mg = magnesium, % = percentage, PPM = parts per million and Cmolskg-1 = centimole per kilogram

Data for number of tubers per plant, weight of tubers per plant, average weight per tuber, marketable tubers, non-marketable tubers, total tuber yield and dry matter content were subjected to analysis by analysis of variance (ANOVA) approaches in Genstat 18th edition software. Genotypes were considered as fixed, and replication were random factors.

The predicted genotype mean performance for each traits found significant from the analysis were separated with Least Significant Difference (LSD's) at an alpha level of 0.05.

The linear model for analysis single season was as follows:

$$Y_{ijk} = \mu + R_k + V_j + F_i + V*F_{ij} + E_{ijk}$$

Where, μ is the grand mean performance, R_k is the replication effect, V_j is the variety treatment effect, F_i is the fertilizer treatment effect $V*F_{ij}$ is the interaction between fertilizer and variety, E_{ijk} is the error.

The linear model for analysis of across seasons is as follows;

$$Y_{hijk} = \mu + S_h + V_j + F_i + V*F_{ij} + S*V_{hj} + S*F_{hi} + S*V*F_{hji} + E_{hijk}$$

Where, μ is the grand mean performance, Sh is the season effect, V_j is the variety treatment effect, F_i is the fertilizer treatment effect $V*F_{ij}$ is the interaction between fertilizer and variety, $S*V_{hj}$ is the season and variety interaction effect, $S*F_{hi}$ is the season and fertilizer interaction effect, $S*V*F_{hji}$ is the season, variety and fertilizer interaction effect, Eijk is the error.

RESULTS

Analysis of variance

The analysis of variance for yield (yld), average weight per tuber (AWT), dry matter content (DM), number of tubers per plant (NTP), weight of tubers per plant (WTP), none marketable tubers (NMT), marketable tubers (MT), and bio mass (BM), among tested varieties are presented in table 4. Varieties did reveal significant differences across the seasons for average weight of tubers ($P<0.05$), dry matter content ($P<0.05$), number of tubers per plant ($P<0.001$), none marketable tubers ($P<0.001$), and bio mass ($P<0.01$). The interaction of season by variety by fertilizer had significant differences for yield ($P<0.01$), weight of tubers per plant ($P<0.01$), and bio mass ($P<0.001$) (Table 4).

The coefficient on variable fertilizer is 35.46 at 10% level of significance on yield, 27.1 on the number of tubers per plant, 22192 on the weight of tubers per plant, 2943.6 on the non-marketable tubers and 12.01 on the biomass at 1% level of significance (Table 4).

The coefficient on variable fertilizer with variety is 13.65 on yield, 115.02 on average weight per tuber, 8500 on weight of tubers per plant and 1.09 on biomass all at 5% level of significance (Table 4).

The coefficient on variable fertilizer with variety and season is 14.66 on yield and 9109 on weight of tubers per plant both at 5% level of significance and 4.35 on biomass at 1% level of significance (Table 4).

Table 4: Mean squares for yield components, bio mass and dry matter content for 2019b, 2020a and seasons for varieties and fertilizer levels evaluated at BSU, July 2019 – May 2020

Sov	df	yld (tha)	AWT (g)	DM (%)	NTP	WTP (g)	NMT	MT	BM
2019B									
REP	2	20.9	179.2	2.7	1.1	13032	328.3	0.9	0.2
VAR	2	6.7	2214.9***	53.1**	97.9***	4209	64343.3	35	22.8***
FERT	2	12.5	9.4	7.9	7.5	7819	2850.5	89.2	7.2***
VAR.FERT	4	5.8	42.2	1.8	1.9	3633	530.4	33	3.3***
ERROR	16	5.98	53.77	9.06	2.23	3737	977	71.24	0.3
cv%		21.5	15.7	16.7	21.8	21.5	22.1	36.3	34.1
2020A									
REP	2	52.0*	275.6	3.2	4.7	32499*	950.3	314.6	1.0
VAR	2	6.7	568*	1.4	69.3*	4163	16910.7***	195.6	23.7***
FERT	2	122.4***	32.9	10.3	103.2**	76501***	6556.3**	567.4	33.9***
VAR.FERT	4	79.1***	470.5*	7.1	24.1	49455***	1664.6	486.3	12.9***
ERROR	16	9.7	117.2	6.1	13.4	6037	996.6	355.1	1.3
cv%		32.4	32.6	10.8	45.3	32.4	37.6	58.36	44.4
Across seasons									
SEASON	1	14.4*	826.89***	107.2***	6.9	8933*	15039.6***	648.3**	4.76***
VAR	2	4.42	722.55*	11.8*	37.7***	2772	24259.7***	127.3	1.23**
FERT	2	35.46*	2.23	5.9	27.1***	22192***	2943.6***	197.9	12.01***
VAR.FERT	4	13.65**	115.02**	1.8	3.3	8500**	373.4	155.4	1.09**
SEASON.VAR	2	0.05	204.94**	6.4	18.0**	30	2816.8***	328.8*	14.27***
SEASON.FERT	2	9.52*	11.97	0.1	9.8**	5942*	190.5	7.5	1.70**
sea.var.fert	4	14.66**	55.29	1.156	5.4	9109**	358.1	160.2	4.35***
Pooled error	32	2.61	28.50	2.53	2.61	1629	328.93	71.06	0.25

, **, * Significant at P≤0.05, 0.01, and 0.001, respectively; Sov = source of variation; df = degrees of freedom; REP = replication; VAR = variety; FERT = fertilizer; CV = coefficient of variation*

These three sources of variations show a positive significant relationship between yield parameters and NPK 17:17:17 fertilizer application rates across the seasons thus failing to reject the null hypothesis. These findings agree with Abdissa *et al.* (2012) and Shaaban, H., and Kisetu, E. (2014) who reported the highest tuber yield parameters with the application of NPK fertilizers.

Performance of the genotypes for the tested tuber attributes.

The performance of different varieties under different fertilizer levels for yield, average weight per tuber, dry matter content, number of tubers per plant, weight of tubers per plant, none marketable tubers, marketable tubers, and bio mass presented in Table 5 and 6. The highest overall mean was achieved from fertilizer level f3 at 12.19 t/ha during 2019B and the lowest over all mean at 5.3t/ha from fertilizer level f1 during 2020A (Table 5). Kachpot1 yielded most at 18.3 t/ha during 2020A at fertilizer level f2, and still the lowest yielder at 4.8 t/ha at fertilizer level 1 during 2020A. Across the seasons, Katchpot1 was the highest yielder at 14.78 t/ha whilst Victoria was the lowest yielder at 7.02t/ha. The average weight per tuber had the highest overall mean from fertilizer level f1 at 47.93g during 2019B and the lowest over all mean at 31.4g from fertilizer level f1 during 2020A (Table 5). Kachpot1 had the highest weight of tuber at 61.3 g during 2019B at fertilizer level f1, while Rwangume had the lightest tuber 20.9g from at fertilizer level 1 during 2020A. Across the seasons, Victoria had the highest AWT at 54.55g at fertilizer level 3, f3 whilst Rwangume had the lowest AWT at 24.10g at f1. As far as dry matter content is concerned, the overall mean was the highest at 23.7% from fertilizer level f1 during 2020A and the lowest over all mean was 17.06% from fertilizer level f3 during 2019B (Table 5). Rwangume had the highest dry matter content of 25.17% at fertilizer level f1 during 2020A, and still Rwangume had the lowest dry matter content at 15.57% at fertilizer level f2 during 2019B. Across the seasons Kacpot1 had the highest dry matter content at 22.96% from fertilizer level f1 whilst Rwangume was the lowest yielder at 18.08% from fertilizer level f3. The highest overall mean for number of tubers per plant was from fertilizer level f3 at 11.1 during 2020A and still fertilizer level f3 during 2019B had the lowest over all mean at 4.4 (Table 5).

Rwangume had the number of tubers per plant at 11.92 at fertilizer level f2 during 2019B, while Victoria at 3.5, had the least number of tubers per plant from fertilizer level f1 during 2020A. Across the seasons Rwangume had the most number of tubers per plant at 10.98 from fertilizer level f3 whilst Victoria had the lowest number of tubers at 3.70 from fertilizer level f1.Total weight of tubers per plant had the heaviest overall mean from fertilizer level f3 at 304.67g during 2019B and the lowest over all mean at 133.7g from fertilizer level f1 during 2020A (Table 6). Kachpot1 had the highest weight tubers per plant at 458g from fertilizer level f2 during 2020A, but it also had the lowest weight of tubers per plant of 121g at fertilizer level f1 during 2020A. Across the seasons Kachpot1 had the heaviest weight of tubers per plant at 369.5 g from fertilizer level f2 whilst Victoria had the lowest weight of tubers per plant at 175.5 from fertilizer level f1. The overall mean of none marketable tubers was the highest from fertilizer level f2 at 156.57 per plot during 2019B and the lowest over all mean was 57.9 per plot from fertilizer level f1 during 2020A (Table 6). Rwangume had the most none marketable tubers at 267.3 per plot from fertilizer level f2 during 2019B, but Kachpot at 25.7 per plot, had the lowest none marketable tubers from fertilizer level f3 during 2020A. Across the seasons Rwangume had the most none marketable tubers at 215.8 per plot from fertilizer level f2 whilst Victoria had the least number of marketable tubers at 58.9 per plot from fertilizer level f1. Marketable number of tubers/plot had the highest overall mean from fertilizer level f2 at 35.2 per plot during 2020A and the lowest over all mean at 12.81 from fertilizer level f1 during 2019B (Table 6). Victoria had the most marketable Number of tubers/plot at 47.8 from fertilizer level f3 during 2020A, while Rwangume had no marketable Number of tubers/plot from fertilizer level f1 and f3 during 2019B. Across the seasons Victoria had the most marketable Number of tubers/plot at 39.4 from fertilizer level f3 whilst Rwangume had the least marketable Number of tubers/plot at 11.2 from fertilizer level f1. Bio mass had the highest overall mean from fertilizer level f3 at 4.4kgs/plot during 2020A and the lowest over all mean at 0.5kgs/plot from fertilizer level f1 during 2019B (Table 6). Rwangume had the highest bio mass at 8.03kgs/plot from fertilizer level f3 during 2020A.Victoria had lowest bio mass at 0.18kgs/plot from fertilizer level f1 during 2019B.

Across the seasons Rwangume had the highest bio mass at 4.535kgs/plot from fertilizer level f3 whilst Victoria had the least biomass at 0.375kgs/plot from fertilizer level f1.

Table 5: Performance of varieties and fertilizers for yield, average weight per tuber, dry matter content and number of tubers per plant evaluated at BSU, July 2019 – May 2020

	yld (tha)			**AWT (g)**			**DM**			**NTP**		
Variety	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**
Season 1												
Kachpot	11.21	11.23	11.39	61.3	54.1	51.1	22.23	20.97	19.07	4.89	5.2	5.61
Rwangume	9.53	13.38	13.64	27.3	28.2	30.4	16.87	15.57	15.7	8.6	11.92	11.42
Victoria	8.61	11.26	11.53	55.2	56	57.1	17.63	18.07	16.4	3.9	5.06	5.07
MEAN	9.78	11.96	12.19	47.93	46.10	46.20	18.91	18.20	17.06	5.80	7.39	7.37
SEM	2.50			7.50			3.08			1.53		
LSD	4.23			12.69			5.21			2.58		
Season 2												
Kachpot	4.8	18.3	6.7	34.6	42.6	14.2	23.7	24.07	22.13	3.06	11.85	16
Rwangume	5.8	10.6	14.4	20.9	27.5	32.5	25.17	21.9	20.47	6.74	9.67	10.55
Victoria	5.4	6.5	13.9	38.8	35.6	52	22.17	24.3	22.53	3.5	4.62	6.81
MEAN	5.3	11.8	11.7	31.4	35.2	32.9	23.7	23.4	21.7	4.4	8.7	11.1
SEM	1.794			6.25			1.428			2.115		
LSD	5.379			18.74			4.281			6.339		
Across												
Kachpot	8.41	14.78	9.03	47.95	48.35	32.65	22.96	22.52	20.60	3.97	8.53	10.80
Rwangume	7.64	11.99	14.00	24.10	27.85	31.45	21.02	18.73	18.08	7.67	10.79	10.98
Victoria	7.02	8.88	12.73	47.00	45.80	54.55	19.90	21.18	19.46	3.70	4.84	5.94
MEAN	7.69	11.89	11.92	39.68	40.67	39.55	21.29	20.81	19.38	5.11	8.05	9.24
SEM	0.93			3.08			0.92			0.93		
LSD	2.69			8.88			2.65			2.69		

yld is yield, AWT is average weight of tubers, DM is dry matter content, NTP is number of tubers per plant, SEM is standard error of mean, LSD is least significant difference

Table 6: Marketable and none marketable tuber yield and biomass of potato at different fertilizer levels, July 2019 – May 2020.

	WTP			**NMT**			**MT**			**BM**		
Variety	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**
Season 1												
Kachpot	299	281	285	87	108.7	112	19.7	21.5	22.7	1.06	3.697	5.233
Rwangume	238	334	341	204	267.3	245	0.00	22.0	0.00	0.347	0.933	1.04
Victoria	215	281	288	75	93.7	83	18.71	26.04	31.04	0.18	0.447	0.6
MEAN	250.7	298.7	304.7	122.0	156.6	146.7	12.8	23.2	17.9	0.5	1.7	2.3
SEM	62.56			31.99			8.64			0.296		
LSD	105.8			54.1			15.35			0.89		
Season 2												
Kachpot	121	458	167	35.3	101.7	25.7	20.4	40.4	10.0	0.22	2.2	0.13

Rwangume	144	265	359	95.7	164.3	141	22.3	39.1	45.8	0.9	3.33	8.03
Victoria	136	163	348	42.7	69.3	79.7	26.1	26.1	47.8	0.57	2.24	5.17
Mean	133.7	295.3	291.3	57.9	111.8	82.1	22.9	35.2	34.5	0.6	2.6	4.4
SEM	44.9			18.23			10.88			0.65		
LSD	134.5			54.64			37.15			1.95		
Across												
Kachpot	210.0	369.5	226.0	61.2	105.2	68.9	19.7	30.6	13.0	0.64	2.949	2.682
Rwangume	191.0	299.5	350.0	149.9	215.8	193.0	11.2	30.5	22.9	0.624	2.132	4.535
Victoria	175.5	222.0	318.0	58.9	81.5	81.4	22.4	26.1	39.4	0.375	1.3435	2.885
MEAN	192.2	297.0	298.0	90.00	134.2	114.4	17.77	29.07	25.10	0.546	2.141167	3.367167
SEM	23.3			10.47			4.87			0.291		
LSD	67.13			30.16			14.02			0.839327		

WTP is weight of tubers per plant, NMT is none marketable tubers, MT is marketable tubers, BM is bio mass, SEM is standard error of mean, LSD is least significant difference

Table 7: variation in means of yield parameters under different NPK 17:17:17 fertilizer rates for each variety across the seasons

Parameters	Fertilizer levels	Kachpot 1 and Rwangume	Kachpot 1 and Victoria	Rwangume and Victoria	LSD
Yield (t/ ha)	f1	**0.77**	**1.39**	0.62	2.69
	f2	**2.79**	**5.9**	3.11	
	f3	**4.97**	**3.7**	1.27	
AWT	f1	**23.85**	**0.95**	22.9	8.8
	f2	**20.5**	**2.55**	18	
	f3	**1.2**	**21.9**	23.1	
DM	f1	**1.94**	**3.96**	1.12	2.65
	f2	**3.79**	**1.34**	2.45	
	f3	**2.52**	**1.14**	1.38	
NTP	f1	**3.7**	**0.27**	3.97	2.69
	f2	**2.26**	**3.69**	5.95	
	f3	**0.18**	**4.86**	5.04	
WTP	f1	**19**	**34.5**	15.5	67.13
	f2	**70**	**147.5**	77.5	
	f3	**124**	**92**	32	
NMT	f1	**88.7**	**2.3**	91	30.16
	f2	**110.6**	**23.7**	134.3	
	f3	**124.1**	**12.5**	111.6	
MT	f1	**8.5**	**2.7**	11.2	14.02
	f2	**0.1**	**4.5**	4.4	
	f3	**9.9**	**26.4**	16.5	
BM	f1	**0.02**	**0.27**	0.25	0.84
	f2	**0.82**	**1.61**	0.79	
	f3	**1.85**	**0.2**	1.65	

yld is yield, AWT is average weight of tubers, DM is dry matter content, NTP is number of tubers per plant, WTP is weight of tubers per plant, NMT is none marketable tubers, MT is marketable tubers, BM is Bio mass, LSD is least significant difference.

Under yield, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at fertilizer levels 2 and 3 respectively, Kachpot 1 and Victoria varieties at fertilizer levels 2 and 3 respectively and Victoria and Rwangume varieties at fertilizer level 2.

Under the average weight of tubers, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at fertilizer levels 1 and 2 respectively, Kachpot 1 and Victoria varieties at fertilizer level 3 and Victoria and Rwangume varieties at all the fertilizer levels.

Under the Dry matter, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at fertilizer level 2, Kachpot 1 and Victoria varieties at fertilizer level 1

Under the number of tubers per plant, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at fertilizer level 1, Kachpot 1 and Victoria varieties at fertilizer levels 2 and 3 respectively and Victoria and Rwangume varieties at all the fertilizer levels.

Under the weight of tubers per plant, there is a significant difference between the means of Kachpot 1 and

Rwangume varieties at fertilizer levels 2 and 3 respectively, Kachpot 1 and Victoria varieties at fertilizer levels 2 and 3 respectively and Victoria and Rwangume varieties at fertilizer level 2.

Under the number of Non - marketable tubers, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at all the fertilizer levels and Victoria and Rwangume varieties at all the fertilizer levels.

Under the number of Marketable tubers, there is a significant difference between the means of; Kachpot 1 and Victoria varieties at fertilizer level 3 and Victoria and Rwangume varieties at fertilizer level 3.

Under the Biomass, there is a significant difference between the means of; Kachpot 1 and Rwangume varieties at fertilizer levels 3, Kachpot 1 and Victoria varieties at fertilizer level 2 and Victoria and Rwangume varieties at fertilizer level 3.There is a significant difference between the means of the three different varieties at different NPK 17:17:17 fertilizer levels across the seasons thus failing to reject the null hypothesis. These findings agree with Shaaban, H., and Kisetu, E. (2014) who reported the significant differences among potato varieties with the application of NPK fertilizers.

DISCUSSION

The study evaluated three potato varieties, Kachpot1, Rwangume and Victoria. These varieties were subjected to three levels of NPK; 17:17:17 fertilizer in a mid-altitude environment of Kakoba Mbarara city in the South Western Uganda. The study was conducted in two seasons 2019B and 2020A. According to Namugga *et al.* (2017a), south western uganda is a location that has potential for expansion of potato growing.

In this study, the total tuber yield increased with increase in fertilizer levels for varieties Rwangume and Victoria. This could be as result of differences in genetic characteristics among the varieties and also because of the low fertility of the soils as seen from the analysis (Table 5). Application of fertilizers therefore improved the availability of macro nutrients (Nitrogen, Phosphorous and Potassium) that affect the vegetative and reproductive / bulking phases. This is in agreement with Otieno, H. M. O., and Mageto, E. K. (2021) who reports the effects of NPK fertilizer application on potato yield and quality of tubers. Improved availability of the nutrients ensured the maintenance of photosynthetically active leaves for longer period and formation of new leaves with more nitrogen than when there is none (Getie *et al.*, 2015). The formation and retention of increased number of active leaves resulted into more photo assimilates which are thus stored in the tubers leading to increased yield (Crop *et al.*, 2000).

The results for variety Katchpot1 were not consistent; total tuber yield increased from fertilizer level f1 to level f2 but thereafter, there was a significant decline at f3 (Table 7). From this observation Katchpot1 reaches a peak performance at fertilizer level f2 and beyond that there is a detrimental decrease in yield (Table 7). This could be due to internal genetic response of Katchpot1 to fertilization, as excess fertilization could lead to increased vegetative growth which increased competition for assimilates to the tubers. In studies involving the same varieties, Namugga *et al.*, 2017b, 2018 obtained higher yield than what was produced in the experiment. This can be attributed to the differences in altitudes. This explains the lower yields of potato obtained in Mbarara as compared to when same varieties are grown at higher altitude of Kabale and Karengere (Iragaba, 2014).

Fertilizer levels had a significant effect on average weight per tuber across the varieties. The differences in average weight per tuber could be attributed to the inherent genetic differences in the varieties used in this study (Muhumuza *et al.*, 2020a, 2020b). Weight of tubers per plant had significant positive correlation to total tuber yield.

This observation is in agreement with Muhumuza *et al.* (2020b) who reports a significant positive correction between weight of tubers per plant and total tuber yield suggesting that tuber weight per plant is an important determinant of total tuber yield. In addition, the weight of tubers per plant significantly increased as fertilizer levels increased. The implication of this is that the level of nutrients in the soil must have been below the optimum potato nutrient requirements. Thus the higher the amount applied, the greater the response of the parameter. The availability of nutrients contributed to production of more photo assimilates by an active leaf area leading to an increase in number of tubers and more total yield per hectare. This is in agreement with Otieno, H. M. O., and Mageto, E. K. (2021) who found out that potatoes are very sensitive to changes in nutrient (NPK) levels that affect the vegetative phases, severely reduce tuber yields at the bulking stage negatively impacting the quality of tubers.

The number of tubers per plant increased significantly across the seasons with increases in fertilizer levels. This finding is similar to that of Zelalem *et al.* (2009) in which the number of tubers increased with an increase in fertilizer concentration. The increase in number of tubers per plant has been attributed to an increase in stolon numbers through the fertilizer effects on gibberellins bio-synthesis in potato. Furthermore, non-marketable tubers were more than marketable tubers at all fertilizer levels. This finding is in disagreement with Getie *et al.* (2015) who reports marketable tubers being more than none marketable tubers with increase in fertilization. The higher non-marketable tubers could be as a result of differences in altitudes; higher temperatures that lead to the lack of a sink strength caused by the malfunctioning of starch synthesizing enzymes which would enhance formation of many tuber initials, without allowing them to grow to substantial size (Otieno *et al.*, 2019; P.C. Struik *et al.*, 1996).

Fresh biomass significantly increased with increase in fertilization levels. Also, the higher the fresh biomass yield, the higher the total tuber yield per variety (Table

7). This is an indication that the nutrients in the fertilizers had exerted significant effects on the shoot biomass production and partitioning of assimilates in form of vegetative parts. This led to increased leaf formation and extended activity of the older leaves. This is in agreement with the study by Getie *et al.* (2015) on effects of fertilization on biomass production.

The dry matter content of potato varieties with values ≥ 20% produce high quality processed products (Abong *et al.*, 2010; Asmamaw and Tekalign, 2010; Pedreschi, 2012). Dry matter content is a main factor in determining the potato processing quality. Potatoes having higher dry matter content ≥ 20% have better texture and are preferred for frying because of the lower frying oil absorption in the finished product (Pedreschi, 2012). In this study, during season 1, only Katchpot 1 had dry matter content above the threshold of ≥ 20% but decreased with increased fertilization (Table 6). In season 2, all the varieties had above the threshold for the required dry matter content.

However, Rwangume had a steady decline of the dry matter content with increase in fertilization. Dry matter content has been reported to be influenced by genotypic and environment interactions (Kumar *et al.*, 2004). Kavvadias *et al.* (2012) reports a significant reduction of dry matter content with higher fertilization and the lower dry matter content was more pronounced at greater fertilizer rates. This observation could be part of the reasons why there was a gradual decrease in dry matter content with higher fertilizer rate applications in the study. In this study, DMC decreases with increase in fertilizer rates. This could be attributed to increase in excess uptake of water by the plants which tampers with the starch content of the tubers. DMC in season 2019B is lower than DMC in season 2020A at all the fertilizer levels. This could be attributed to longer periods of rain in season 2019B than season 2020A.

The findings from the study show a positive significant relationship between yield parameters and different NPK 17:17:17 fertilizer levels across seasons. This is in agreement with Shaaban, H., and Kisetu, E. (2014) and Otieno, H. M. O., and Mageto, E. K. (2021) whose findings reported the highest tuber yield parameters and significant differences among potatoes varieties with the application of NPK fertilizers.

CONCLUSION

The study indicated that yield and yield components of the potato varieties - Rwangume, Victoria and Katchpot1 can be improved through the application of different doses of NPK (17:17:17) fertilizer. Results of this study revealed that fertilizer requirements are also variety specific as Rwangume and Victoria increased yield steadily even to the maximum rate of 100Kg/ha, while Katchpot1 reached a peak yield output at 50kg/ha and any excess use beyond this rate leads to a decline in yield out. In addition, the varieties used in this study were released mainly for the highland areas of Uganda and therefore, the output in the mid altitude area of Mbarara revealed lower yield and more none marketable tubers. Season 2019B produces more yield compared to season 2020A at all fertilizer levels for all the varieties. As far as dry matter content is concerned, the study revealed a magnitude of genotype by environment interaction as indicated by the varied dry matter out puts per variety across the seasons. Fertilizer level f3 results into the least DMC across seasons and varieties. Season 2019B produces less dry matter Content compared to season 2020A. As a recommendation to potato farmers in the mid-altitude environment should utilize the season from September to December for higher yield as this season has consistently had longer periods of rainfall. Furthermore, fertilizer level f2 (50Kg/ha) of NPK (17: 17: 17) is recommended for Katchpot 1, while f3 is recommended for Rwangume and Victoria as the optimum yield output and dry matter obtained across in the Mbarara south western Uganda mid altitude environment.

Acknowledgements

Special thanks go to; The Bishop Stuart University (BSU) Farm for offering land for the experiment, Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) for provision of good quality seed, BIRDC and Makerere University science Labs for the opportunity for laboratory analysis and UNMA for provision of meteorological data for all the support rendered to the corresponding author.

REFERENCES

Abdissa, T., Dechassa, N., & Alemayehu, Y. (2012). Sweet potato growth parameters as affected by farmyard manure and phosphorus application at Adami Tulu, Central Rift Valley of Ethiopia. *Agricultural Science Research Journal, 2*(1), 1-12.

Abong, G.O., Okoth, M.W., Imungi, J.K., Kabira, J.N., Science, F., Box, P.O., Potato, N., Box, P.O., Nairobi, L. (2010). Evaluation of selected Kenyan potato cultivars for processing into potato crisps. *Agric. Biol. J. NORTH Am*. 886–893.

Al-Moshileh, A. M., & Errebi, M. A. (2004, November). Effect of various potassium sulfate rates on growth, yield and quality of potato grown under sandy soil and arid conditions. In *Proceedings of the IPI Regional Workshop on Potassium and Fertigation Development in West Asia and North Africa, Rabat, Nov.* 24-28.

Alva, L. (2004). Potato nitrogen management. *Journal of vegetable crop production, 10*(1), 97-132.

Ano, O., & Orkwor, G. C. (2006). Effect of fertilizer and intercropping with pigeon pea (Cajunus cajun) on the productivity of yam minisett (Dioscosrea rotundata) based system. *Nigeria Agricultural Journal, 37*, 65-73.

Asmamaw, Y., Tekalign, T. (2010). Specific Gravity, Dry Matter Concentration , pH , and Crisp-making Potential of Ethiopian Potato (*Solanum tuberosum L* .) Cultivars as Influenced by Growing Environment and Length of Storage Under Ambient Conditions. *Potato*

Res. 53, 95–109. doi:10.1007/s11540-010-9154-1

Babaji, B. A., Amans, E. B., Chiezey, U. F., Falaki, A. M., Tanimu, B., & Mukhtar, A. A. (2009). Unmarketable tuber yield and other agronomic parameters of four Varieties of Irish potato (Solanum tuberosum L.) as influenced by NPK fertilizer rate and type of seed tuber at Samaru, Nigeria. *Asian Journal of Crop Science, 1*(1), 26-33.

Barungi, M., Ng'ong'ola, D., Edriss, A., Mugisha, J., Waithaka, M., and Tukahirwa, J. (2013). Factors Influencing the Adoption of Soil Erosion Control Technologies by Farmers along the Slopes of Mt. Elgon in Eastern Uganda. *Journal of Sustainable Development*, 9-25.

Bekunda, and Kaizzi. (2008). Soil Health Program Country Report, Uganda.

Bekunda, M. A., Bationo, A., & Ssali, H. (1997). Soil fertility management in Africa: A review of selected research trials. *Replenishing soil fertility in Africa, 51*, 63-79.

Bennett, B. C. (2010). Plants as food. In B. Bennett (Ed.), *Economic botany: Encyclopedia of life support systems (EOLSS)*. Eolss publishers. Oxford, UK: Developed under the Auspices of the UNESCO.

Bezawit T., Agiro. (2011). *Analysis of socio-economic factors influencing potato production at household level.* The case of Shashemene, Shalla and Siraro Counties in West Arsi Zone; Ethiopia. International Development Studies (MID).

Bonabana-Wabbi, J., Ayo, S., Mugonola, B., Tayler, D. B., Kirinya, J., and Tenywa, M. (2013). *The performance of potato markets in South Western Uganda. J. Dev. Agric. Econ. 5*, 225–235.

Burton, A. (2018). *Influence of solution management techniques on nutrient use efficiency in hydroponically grown salad-type plants* (Doctoral dissertation, North Carolina Agricultural and Technical State University).

Byarugaba, A.A., Barekye, A., Mukasa, S.B., and Rubaihayo, P.R. (2021). Distribution of potato viruses in Uganda. *African Crop Science Journal, 29*(1), 77-99.

Camire, M.E. (2009). Potatoes and Human Health. *Crit. Rev. Food Sci. Nutr. 49*, 685–704.

Chen Q., Su J., Nandy S., and Kereliuk G. (2007). *Screening potato genotypes for antioxidant capacity and total phenolics*. Plant Canada Congress.

CIP, (Centro Internacional de la Papa)., (2014). Procedures for Standard Evaluation and Data Management of Advanced Potato Clones. *LIMA*.

Crop, A., Society, S., Gathungu, G.K.., Shibairo, S.I., Githiri, S.M., Kidanemariam, H.M.. (2000). effect of source , time and method of nitrogen application on growth and yield components of potato in kenya. *african crop sci. j. 8*.

Crop Nutrition. (2019). Nitrogen in Plants. Available at https://www.cropnutrition.com/efu-nitrogen

Dawson, N., Martin, A. and Sikor, T. (2016). Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. *World Development, 78*, 204-218. https://doi.org/10.1016/j.worlddev.2015.10.008

Devaux, A., Kromann, P., and Ortiz, O. (2014). Potatoes for sustainable global food security. *Potato Research, 57*(3–4), 185–199.

Ebanyat, P., de Ridder, N., De Jager, A., Delve, R. J., Bekunda, M. A., & Giller, K. E. (2010). Drivers of land use change and household determinants of sustainability in smallholder farming systems of Eastern Uganda. *Population and environment, 31*(6), 474-506.

FAO (2008). International year of the potato. Potatoes, nutrition and diets. In FAO factsheets. Rome, Italy: *Food and Agriculture Organization of the United States*. http://www.fao.org/potato-2008/en/potato/factsheets.html.

FAO (2017). *Plant health and food security*. http://www.fao.org/3/ai7829e.pdf.

FAOSTAT (2014). *Production statistics*. Available at http://faostat.fao.org.,

FAOSTAT. (2016). Food and Agricultural Organization Statistic data. Retrieved from http://www.fao.org/faostat/en/#data/QC;accessed on 18/09/2021

Food and Agriculture Organization Corporate Statistical Database- FAOSTAT (2019). *Crop: Potato Production*. Retrieved from http://www.fao.org/faostat/en/#data/Q

FAO (Food and Agriculture Organization). (2020). Strengthening linkages between small actors and buyers in the Roots and Tubers sector in Africa. Available at http://www.fao.org/in-action/african-roots-and-tubers/ countries

Fernandes, A. M.., Soratto, R. P., and Silva, B. L. (2011). Extração e exportação de nutrientes em cultivares de batata: I-macronutrientes. *Revista Brasileira de Ciência do Solo, 35*(6), 2039-2056.

Hijmans, R. J., and Spooner, D. M. (2001). Geographic distribution of wild potato species. *American journal of Botany, 88*(11), 2101-2112.

Garrett, K. A., Nelson, R. J., Mundt, C. C., Chacon, G., Jaramillo, R. E., and Forbes, G. A. (2001). The effects of host diversity and other management components on epidemics of potato late blight in the humid highland tropics. *Phytopathology, 91*(10), 993-1000.

Getie, A.T., Dechassa, N., Tana, T. (2015). Response of Potato (Solanum tuberosum L .) Yield and Yield Components to Nitrogen Fertilizer and Planting Density at Haramaya , Eastern Ethiopia. *J. Plant Sci. 3*, 320–328.

Gildemacher, P., Demo, P., Kinyae, P., Wakahiu, M.., Nyongesa, M., and Zschocke, T. (2007). Select the Best: Positive Selection to Improve Farm Saved Seed Potatoes. Trainers Manual. *Lima: International Potato Center*.

Gildemacher, P. (2012). *Innovation in Seed Potato Systems in Eastern Africa* (PhD Thesis). Wageningen University, Wageningen

Gitari, H. I. *et al.* (20018). Optimizing yield and economic returns of rain-fed potato (Solanum tuberosum L.)

through water conservation under potato-legume intercropping systems. *Agric. Water Manag 208*, 59–66

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. J. Biol. Sci. 9*, 463–493.

Harahagazwe, D., Condori, B., Barreda, C., Bararyenya, A., Byarugaba, A.A., Kude, D.A., and Ochieng, B. (2018). How big is the potato (Solanum tuberosum L.) yield gap in Sub-Saharan Africa and why? A participatory approach. *Open Agriculture, 3*(1),180-189.

Hakiza, J. J., Turyamureeba, G., Kakuhenzire, R. M., Odongo, B., Mwanga, R. M., Kanzikwera, R., & Adipala, E. (2000, May). Potato and sweetpotato improvement in Uganda: a historical perspective. In *African Potato Association Conference Proceedings,* 5, 47-58.

Hakiza, J. J., Turyamureeba, G., Kakuhenzire, R. M., Odongo, B., Mwanga, R. M., Kanzikwera, R., & Adipala, E. (2000, May). Potato and sweetpotato improvement in Uganda: a historical perspective. In *African Potato Association Conference Proceedings, 5,* 47-58.

Hassanpanah D, Gurbanov E, Gadimov A, Shahriari R (2008) Determination of yield stability in advanced potato cultivars as affected by water deficit and potassium humate in Ardabil region, Iran. *Pak J Biol Sci. 11*, 1354-1359.

Hawkes, J.., 1994. Origin of cultivated potato and species relationships.

Henao J, Baanante C (1999). Estimating rates of nutrient depletion in soils of agricultural lands of Africa. *International Fertilizer Development Center (IFDC).* Musck Shoals, Alabama, USA, 76.

Henao, J., and Baanante, C. (2006). *Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development.* Muscle Shoals, AL. International Fertilizer Development Center.

Hourton, D. E. (1987). Potatoes: Production, Marketing, and Programs for Developing Countries, Colorado, Westview press, Inc.

Honeycutt, C. W., Clapham, W. M. and Leach, S. S. Crop rotation and N fertilization effects on growth, yield, and disease incidence in potato. *Am. Potato J., 73*, 45–61. https://www.yara.co.uk/crop-nutrition/potato/influencing-potato-tuber-dry-matter-content/

Innocent, U. (2021). Effects of fertilizer application on yield and yield related parameters of low yielding potato varieties in Uganda. *African Journal of Agricultural Research, 17*(12), 1540-1546.

International Potato Center (2011). Roadmap for Investment in the Seed Potato Value Chain in Eastern Africa. Lima.

Iragaba, P., (2014). inheritance and stability of earliness in potato (Solanum tuberosum L.). Makerere University.

J. W. LOW, (1997). Potato in Southwest Uganda: Threats to sustainable production. *African Crop Science Journal, 5*(4), 395-412.

Jasim AH, Hussein MJ, Nayef MN (2013). Effect of foliar fertilizer (high in potash) on growth and yield of seven potato cultivars (Solanum tuberosom L.). *Euphrates J. Agric. Sci.5*(1), 1-7.

Kaguongo, W.P., Gildemacher, P., Demo, P., Wagoire, W., Kinyae, P., Andrade, J., Forbes, G., Fuglie, K., and Thiele, G. (2008). Farmer practices and adoption of improved potato varieties in Kenya and Uganda. *CIP, Lima, Peru, 5*, 42.

Kaguongo, W., Gildemacher, P., Demo, P., Wagoire, W., Kinyae, P., Andrade, J., ... & Thiele, G. (2008). *Farmer practices and adoption of improved potato varieties in Kenya and Uganda.* International Potato Center.

Kavvadias, V., Paschalidis, C., Akrivos, G., Petropoulos, D. (2012). Nitrogen and Potassium Fertilization Responses of Potato (Solanum tuberosum) cv . Spunta. *Commun. Soil Sci. Plant Anal. 43*, 176–189.

Kisakye, S., Tinyiro, E., Mayanja, S., and Naziri, D. (2020). Current status of knowledge about end-user preferences for boiled potato in Uganda – A food science, gender and demand perspective.

Khan, M. Z., Akhtar, M. E., Mahmood-ul-Hassan, M., Mahmood, M. M., and Safdar, M. N. (2012). Potato tuber yield and quality as affected by rates and sources of potassium fertilizer. *Journal of Plant Nutrition., 35*(5), 664-677.

Kumar, D., Ezekiel, R., Khurana, S.M.P. (2004). effect of location, season and cultivar on the processing quality of potatoes. J. Indian Potato Assoc. 30, 247–251.

Loebenstein, G. (2009). Origin, Distribution and Economic importance. In G. Loebenstein and G. Thottappilly (eds.) The Sweetpotato. *Springer Dordrecht, The Netherlands*, 9-12.

Low, JW. (1997). Potato in southwest Uganda: threats to sustainable production. Afr Crop Sci J 5:395–412

Lutaladio, N., and Castaldi, L. (2009). Potato: The hidden treasure. *Journal of Food Composition and Analysis, 22*(6), 491–493.

Lynam, J.K.S., S.M. Nandwa., and E.M.A., Smaling. (1998). *Editorial. Agric. Ecosyst. Environ. 71*, 1–4.

Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). (2016). National Fertiliser Policy. 1-33.

Mbowa, S., and Mwesigye., F. (2016). Investment Opportunities and Challenges in the Irish Potato Value Chain in.

Mugo, J. N., Karanja, N. N., Gachene, C. K., Dittert, K., Nyawade, S. O., and Schulte-Geldermann, E. (2020). Assessment of soil fertility and potato crop nutrient status in central and eastern highlands of Kenya. *Scientific Reports, 10*(1), 1-11. https://doi.org/10.1038/s41598-020-64036-x

Muhinyuza, JB., Shimelis, H., Melis, R., Sibiya, J., Nzaramba, MN. (2012). Participatory assessment of potato production constraints and trait preferences in potato cultivar development in Rwanda. *Int J Develop Sust. 1*, 358-380.

Muhumuza, E., Edema, R., Namugga, P., Barekye, A. (2020a). Combining ability analysis of dry matter content , reducing sugars and yield of potato (Solanum tuberosum L .) genotypes in Uganda. *J. Sci. Agric. 4*, 1–8.

Muhumuza, E., Edema, R., Namugga, P., Barekye, A., (2020b). Evaluation of Potato Genotypes for Desirable Processing Tuber Attributes in Uganda. *Am. J. Agric. Sci. 7*, 17–24.

Muthoni J., Kabira JN. (2011). Effects of different sources of nitrogen on potato at Tigoni, Kenya. *J. Soil Sci. Environ. Manage. 2*(6), 167-174.

Muthoni J., and Kabira J. N. (2016). Potato production under drought conditions: Identification of adaptive traits. *International Journal of Horticulture, 6*(12), 1-10. https://doi.org/doi: 10.5376/ijh.2016.06.0012

Muthoni, J., Shimelis, H., Melis R. (2013). Potato production in Kenya: Farming systems and production constraints. *Can J Agr Sci. 5*, 182-197.

Muthoni, J., and Nyamongo, D. O. (2009). A review of constraints to ware Irish potatoes production in Kenya. *Forestry 1*, 98–102.

Muthoni, J. (2016). Soil fertility situation in potato producing Kenyan highlands -case of KALRO-Tigoni. *Int. J. Hortic. 6*.

Namugga, P., Melis, R., Sibiya, J., and Barekye, A. (2017). Participatory assessment of potato farming systems , production constraints and cultivar preferences in Uganda. *Aust. J. Crop Sci., 11*, 932–940.

Namugga, P., Sibiya, J., Melis, R., and Barekye, A. (2018). Yield Response of Potato (Solanum tuberosum L.) Genotypes to late blight caused by Phytophthora infestans in Uganda. *American Journal of Potato Research, 95*(4), 423-434.

Namugga, P., Sibiya, J., Melis, R.., Barekye, A.., Namugga, P., Sibiya, J., Melis, R.,. Phenotypic, A.B. (2017). Phenotypic characterisation of potato (Solanum tuberosum) genotypes in Uganda. *South African J. Plant Soil, 1862*, 1–8.

Namugga, P., Sibiya, J., Melis, R.., Barekye, A.., Namugga, P., Sibiya, J., Melis, R., and Phenotypic, A. B. (2017b). Phenotypic characterization of potato (Solanum tuberosum) genotypes in Uganda. *South African Journal of Plant and Soil, 1862*, 1–8.

Naz F., Ali, A., Iqbal, Z., Akhtar, N., Asghar, S., and Ahmad, B. (2011). Effect of different levels of NPK fertilizers on the proximate composition of potato crop at Abbottabad. *Sarhad J. Agric., 27*(3), 353-356.

Nuwamanya, E., Baguma, Y., Wembabazi, E., and Rubaihayo, P. (2011). A comparative study of the physicochemical properties of starches from root, tuber and cereal crops. *African Journal of Biotechnology, 10*(56), 12018-12030.

Obare, G., Nyagaka, D., Nguyo, W. and Mwakubo, S. M. (2010). Are Kenyan smallholders allocatively efficient? Evidence from Irish potato producers in Nyandarua North district. *J. Dev. Agric. Econ. 2*, 78–85.

Okeyo, G. O., Narla, R. D., Otieno, H. M. O., and Schulte-Geldermann, E. (2019). Response of Selected Potato Genotypes to Natural Virus Infection in the Field. *Asian Journal of Research in Crop Science*, 1-13, https://doi.org/10.9734/ajrcs/2019/v3i230044

Otieno, C., Paul, S., William, R.. (2019). Importance of whole plant dry matter dynamics for potato (Solanum tuberosum L.) tuber yield response to an episode of high temperature. *Environ. Exp. Bot. 162*, 560–571.

Otieno, H. M. O., and Mageto, E. K.. (2021). A review on yield response to nitrogen, potassium and manure applications in potato (Solanum tuberosum L.) production. *Archives of Agriculture and Environmental Science, 6*(1), 80-86. https://dx.doi.org/10.26832/24566632.2021.0601011

Otieno, H. M. O. (2019b). Impacts and Management Strategies of Common Potato (Solanum tuberosum L.) *Pests and Diseases in East Africa, Frontiers in Science, 9*(2), 33-40.

Okoboi, G., Kashaija, I., Kakuhenzire, R.., Lemaga, B., and Tibanyendera, D. (2014). Rapid assessment of potato productivity in Kigezi and Elgon highlands in Uganda, in Challenges and Opportunities for Agricultural Intensification of the Humid Highland Systems of Sub-Saharan Africa, Eds B. Vanlauwe, P. Van Asten, and G Blomme (*Switzerland: Springer International Publishing*), 29–37.

Okwadi J. (2013). Overview of the Potato Sector in Uganda, Stepping Stones Consulting Associates Ltd, October 2013.

P.C.Struik, Dam, J. Van, Kooman, P.L. (1996). Effects of temperature and photoperiod on early growth and final number of tubers in potato (Solanum tuberosum L.). *Potato J. 39,* 51–62.

Pender, J., Nkonya, E., Jagger, P., Sserunkuuma, D., and Ssali, H. (2004). Strategies to Increase Agricultural Productivity and Reduce Land Degradation: Evidence from Uganda. *Agricultural Economics, 31*, 181-195.

Worku, A. (2014). Potato yield gap analysis in SSA through participatory modeling : Optimizing the value of historical breeding trial data, CIP.

Pedreschi, F. (2012). Frying of Potatoes: Physical, Chemical, and Microstructural Changes. *Dry. Technol. 30,* 707–725.

Sanchez, P.A. (2002). *Soil fertility and hunger in Africa. Science 295*, 2019–2020.

Sedera, F. A., and Shetata, S. (1994). Effect of irrigation frequency and N, K level on growth, yield, chemical composition and storage ability of potato. Zagazig Journal of Agriculture Research, 21, 129-149.

Shaaban, H., and Kisetu, E. (2014). Response of Irish potato to NPK fertilizer application and its economic return when grown on an Ultisol of Morogoro, Tanzania. *Journal of Agricultural and Crop Research, 2*(9), 188-196.

Shrestha, J. (2019). P-Value: A true test of significance in agricultural research.

Schulte-Geldermann, E., Wachira, G., Ochieng, B., and Barker, I. (2013). Effect of field multiplication generation on seed potato quality in Kenya: in Seed Potato Tuber Production and Dissemination Experience, Challenges and Prospects (Bahir Dar: *Ethiopian Institute of Agriculture Research, Amhara Regional Agricultural Research Institute),* 81–90.

Scott GJ., Rosegrant MW., Ringler C. (2000). Global projections for root and tuber crops to the year 2020. *Food Policy, 25*, 561–597.

Scott, G.J., Labarta, R., Suarez, V. (2013). Booms, Busts, and Emerging Markets for Potatoes in East and Central Africa 1961-2010. *Potato Res. 56*, 205–236. doi:10.1007/s11540-013-9240-2

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A. M. N., ... & Woomer, P. L. (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. *Replenishing soil fertility in Africa, 51*, 1-46.

Smaling, E., Toure, M., de Ridder, N., Saginga, N., and Breman, H. (2006). Fertilizer use and the environment in Africa: friend or foes? Background Paper Prepared for the Africa fertilizer summit, Abuja.

Ssendiwanyo, E.V., Isabirye, M, and Semalulu.O. (2000). Sustainable use of land resources: Towards a new approach in Uganda. *Uganda Journal of Agricultural Sciences. (NARO). 5*, 44-55.

Stoorvogel, J.J., and E.M.A. Smaling. (1990). Assessment of soil nutrient depletion in sub-Saharan Africa, 1983–2000. Rep. 28. Winand Staring Ctr. for Integrated Land, Soil and Water Res., Wageningen, the Netherlands.

Tatwangire, A., & Nabukeera, C. (2017). Technical Report: Market and value chain analysis of ware potato from eastern Uganda with a focus on postharvest management practices and losses.

Tesfaye, A. (2010). Markets for fresh and frozen potato chips in the ASARECA region and the potential for regional trade: Ethiopia, Tanzania, Rwanda, Kenya, Burundi and Uganda. International Potato Center.

Trehan, S. P., Pandey, S. K. and Bansal, S. (2009). Potassium Nutrition of the Potato Crop - the Indian Scenario. e-ifc (2009).

UBOS. (2018). Statistical abstract. Uganda bureau of statistics, 2018.

UBOS. (2014). National Population And Housing Census 2014.

UBOS. (2017). Statistical Abstract 2017, Vol. 1. Kampala: Uganda Bureau of Statistics Statistics.

Vlek, P.L.G. (1990). The role of fertilizers in sustaining agriculture in sub-Saharan *Africa. Fert. Res. 26*, 327–339.

Vlek, P.L.G. (1993). *Strategies for sustaining agriculture in sub-Saharan Africa*. 265–277.

Wabbi, J.B., Ayo, S., Mugonola, B., Taylor, D.B., Kirinya, J., Tenywa, M. (2013). The performance of potato markets in South Western Uganda. *J. Dev. Agric. Econ. 5*, 225–235.

Westennann, D. (2005). Nutritional Requirements of Potatoes. *American Journal of Potato Research, 82,* 301-307.

Worku, A. (2014). Potato yield gap analysis in SSA through participatory modeling : Optimizing the value of historical breeding trial data, CIP.

Wortmann, C.S., and C.K. Kaizzi. (1998). Nutrient balances and expected effects of alternative practices in farming systems of Uganda. *Agric. Ecosyst. Environ. 71*, 115–129.

Zelalem, A., Tekalign, T., 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 J. Plant Sci. 3*, 16–24.