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Effect of Macro-Nutrient Combinations on Yield and Economic Returns of Potato

Etiang J*, Uzatunga I, Barekye A, Turyamureeba G, Mwesige R, Mateka B, Kwikiriza G, Kutesa RA and Muherezi R

Abstract

Low macronutrient levels in the soil greatly affect the yield of Potato (*Solanum tuberosum L.*) in Uganda. The study was undertaken to determine the effect of macronutrient combinations on yield of potato. This was done in 6 sites across south western Uganda. The 5 levels of N:P:K combinations were laid in split plot arrangement with Mode of Application (MoA) allocated to main plots and nutrient combinations allocated to the sub plots. The results indicated that basal application significantly increased potato yield. Macronutrient combinations led to increase in potato yield with application of 100:75:200 performing better on ware and in season 2. Application of 75:50:150 was good for seed production and in season one when rains are not sufficient. Season 2 was the best season in the performance of macronutrient combinations. Karengyere was the best site for the potato yield response to nutrient combinations. The results showed 100:75:200 and 75:50:150 macro nutrient combination options as the most profitable in ware and seed potato respectively. This was attributed to the changes in the rainfall patterns in the two seasons. There is need to upscale blending of fertilizers for specific crops and with consideration of the seasons and agro-ecological conditions.

Keywords

Potato; Yield; Nitrogen; Phosphorus; Potassium; Mode of application; Macronutrients; Nutrient combinations; Economic returns

Introduction

Potato (*Solanum tuberosum L.*) is a crop of major economic importance worldwide; ranking the third most important food crop for human consumption after rice; wheat and maize. The crop is currently grown in over 130 countries around the world [1]. In Sub Saharan Africa it is a major food and income enterprise in areas where it is grown [2]. In Uganda; potato is identified as key among crops that can improve the livelihoods of smallholder farmers in areas where it is grown. This is possible through value addition in form of various processed potato products among them are chips and crisps. Besides the lucrative seed potato business has developed in the zone and has led to more farmers benefiting from incomes that accrue from seed potato. Despite the importance of potato in Uganda; its production still faces challenges related to low soil fertility; pests and diseases. The yields remain as low as 4.8 t/h as opposed to 40-60 t/h that is reported achievable in other countries. Low potato yields continue to reduce the potential incomes of farmers engaged in its production. The low potato yields have been attributed to decline in soil fertility; poor seed and poor management practices [3]. In fertile soils; ability of the crop to absorb; translocate and accumulate assimilates to the tubers is enhanced resulting in high potato yields. For efficient absorption; translocation and accumulation of assimilates to tubers; various plant nutrients are required; among them are nitrogen; phosphorus and potassium [4]. These nutrients are termed macronutrient and each has a specific role in the life of a potato plant. The nitrogen is an important nutrient for protein synthesis; respiration and growth of tubers. Its deficiency causes reduction in dry matter content and leaf area. The reduced leaf area provides less light interception and lowers the rate of photosynthesis and quantity of assimilates that are stored in the tubers [5]. Phosphorus on the other hand a key plant nutrient which promotes root growth; rapid formation of tubers and starch synthesis [6]. In soils with low pH of <5.5; P is fixed and forms precipitates with iron and aluminum hence decreasing its availability to the plants. The deficiency of P causes retardation in root growth; delayed tuber formation and reduction in starch synthesis. The poorly developed plant root system leads to reduction in its capacity to absorb soil nutrients and affect its growth and development. It will delay tuber formation and this will decrease the size of tubers produced within the lifespan of the potato crop. The reduction of starch synthesis leads to smaller amounts of sugars stored in the tubers; which translates to small sized tubers and low yields [7]. In addition; potassium is one of the most essential plant nutrients for translocation of sugars to the tubers and starch synthesis; which is a fundamental process for tuber growth and filling [5]. Its low supply will reduce the plant's capacity to produce sugars and their translocation to the tubers. This leads to reduction of the size of tubers and yield of potato [8]. Low soil supply of K is usually observed in sandy soils; and has been attributed to excess of Ca. It is a common problem in areas with salinity problems and clay minerals of 2:1 type. The areas with such problems limit availability of K for growth and development of the potato crop. Aware that these plant nutrients are key in increasing potato yields; there is need to replenish these key soil nutrients for sustainable potato production in the zone. The current levels of these nutrients are below the potato crop requirements. The current levels are mined through continuous cultivation year after year and failure to replenish them will lead to reduction in their availability for crop production. Earlier studies have shown that potato requires varying amounts of these nutrients for maximum production. In this case; use of straight fertilizers in isolation makes it difficult to meet the macro nutrient requirements for optimum potato growth and development [9]. However; application of complex mixtures of N:P:K leads to increased productivity in location where these nutrients are limiting [10]. In this approach; potato growers achieve the required quantities of macronutrients for crop growth and development. The relationship between N:P:K nutrient combinations and yield of potato is less documented particularly in the potato growing areas of Kigezi. This relationship is important as it will lead to determination of N:P:K nutrient combination for optimization of fertilizer application and returns to investment in potato. This led to a study to determine levels of N:P:K nutrient combinations that leads to increase in potato yields with consideration on Mode of Application (MoA) and returns to investment [11]. The study would address limitation that arise from deficiencies caused by inadequacy of these nutrients and lead to increase in the yield of potato. In this study it was hypothesized that application of N:P:K nutrient blends leads to higher potato productivity and returns on investment.

***Corresponding author:** Joseph Etiang, Kachwekano Zonal Agricultural Research and Development Institute, Kabale, Uganda, E-mail: joerets@gmail.com

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Materials and Methods

Characteristics of the study area

The study was conducted in South Western Highland Agro-ecological Zone (SWHAEZ) of Uganda. The area lies between 1˚13′20″S and 29˚53′20″E with an altitude range of 1200 m to 2350 m above sea level. The agro-climatic conditions of the area favor a wide range of crops and livestock; as a major source of livelihood for the inhabitants. Potato is the main crop grown for food and incomes and is grown in two seasons; from March–June and September to January. The zone receives bimodal rainfall pattern; with an average annual range of 1000-1500 mm and temperature range of 10°C-30°C. The average population density is 300 persons per sq.km and with population growth rate of 2.2%. The soils are acidic to slightly acidic loams; reddish brown clay loams; humus loams and yellowish red clay loams with good drainage (Table 1).

Experimental design

The experiment was laid in a split plot design with two Modes of Application (MoA) and 5 levels of N:P:K nutrient combinations. The 2 modes of applications were (i) Basal application at planting+Top-dress at 45 days after planting (MoA1) (ii) Basal application of all doses of nutrient combinations (MoA2). Mode of Application was allocated to the main plots; while the 5 N:P:K nutrient combinations; control (0:0:0); (75:50:150); (100:75:200); (150:100:250); and (200:125:300) were randomly allocated to the sub plots. The 5 NPK nutrient combinations were designated as N_0:P_0K_0; N_{75}:$P_{50}K_{150}$; N_{100}:$P_{75}K_{200}$; N_{150}:$P_{100}K_{250}$ and N_{200}:$P_{125}K_{300}$. This indicating the amounts of nutrient applied per hectare of a nutrient in a combination. The nutrient combinations involved use of DAP (0:46:18); TSP (0:0:46); NPK (17:17:17) and MOP (0:0:60) fertilizers. Under MoA-1; DAP and TSP amounts were applied at planting and NPK and MOP amounts were applied 45 days after planting. In MoA-2; all the fertilizer amounts were combined and applied under basal application. The fertilizer amounts in nutrient combinations were determined as follows;

$$\text{Amount to apply kgs / ha} = \frac{\text{Rate in kgs / ha}}{\text{\% Active Ingredient}} * 100$$

Rwangume potato variety of (seed size 45 mm-60 mm); was used in the experiment and in each of the 6 location treatments were replicated 3 times. The Seed potato tubers were planted at spacing of 70 cm × 30 cm and in plot sizes of 0.28 m × 0.3 m.

Data collection and analysis

Experimental data collected included total weight of tubers; number and weights of tubers categorized as big (45-60 mm); medium (30-45 mm) and small (<30 mm). It was subjected to ANOVA in the Genstat statistical computer package and means were compared using the least significant difference (l.s.d) at 5%. In addition; data on prevailing prices and cost of production was collected during the period for determining profitability and returns to investment. Calculation on total costs and revenues using the market prices was done using an acre as a unit of measure. The total yield per acre was determined in each of the seasons and under each macronutrient combination. Fixed costs and variable costs were estimated across nutrient combinations. The gross margins and returns to investment were determined for all macronutrient combinations. The profitability was determined across N:P:K nutrient combinations for each season in consideration of possible variability in seasons. The information obtained was translated into the returns to investments for seed and ware potato.

Results and Discussions

Effect of nutrient combinations on potato tuber numbers

The results in Table 2 show that the total number of tubers was significantly higher than the control on application of nutrient combinations [12]. The $N_{200}P_{125}K_{300}$ nutrient combination produced the highest total number of tubers; however this was not significantly different from $N_{100}P_{75}K_{200}$ and $N_{150}P_{100}K_{250}$ nutrient combinations. All the nutrient combinations were significantly different from the control (P<.001). The two nutrient combinations $N_{100}P_{75}K_{200}$ and $N_{75}P_{50}K_{150}$ were not significantly different from each other. Upon categorization; large tubers were <7%; medium sized were 50% and small sized tubers were 40% across nutrient combinations. Nutrient combination of $N_{200}P_{125}K_{300}$ and $N_{150}P_{100}K_{250}$ gave the highest percentage of large tuber numbers; which was significantly different from the control. On medium sized (30-45 mm); results showed that application of $N_{200}P_{125}K_{300}$; $N_{150}P_{100}K_{250}$ and $N_{75}P_{50}K_{150}$ led to significantly higher number of tubers. Since the medium sized tubers contributed to the increase in the total number of tubers it could have effect on the yield of tubers harvested. Medium sized tubers contributed to the overall number of the potato tubers produced under different nutrient combinations. Application of nutrient combination is key in initiation and development of tubers in potato [9]. This is probably attributed to additional nutrients that the potato crop needs for growth and development. With different roles played by different N:P:K nutrients; their availability leads to crop growth; establishment and translocation of assimilates from the leaves to the tubers. The medium sized tubers equally responded to the application of nutrient combination in the same trend as the large tubers. On the other hand; small sized tubers were few in the control as compared to plots with nutrient combinations. This could be attributed to the effect of nutrient combinations in tuber initiation. It means more tubers were produced and not fully developed to maturity. This could be attributed to other factors such as drought and management practices (Table 3).

The total number of tubers was obtained from Karengyere site while the lowest number was obtained from Kamuganguzi site. This was attributed to the high response in tuber formation to nutrient combinations in Karengyere. In Bukimbiri 1 and 2; the percentage of large sized tuber numbers was significantly higher than all other sites

Table 1: Characteristics of soil in the study area.

SITE	pH	OM	N	P	Ca	Mg	K
		--------%--------		--------------------(ppm)---------------------			
Hamurwa	4.1	13.07	0.52	4.79	305.1	97.7	21.3
Kamuganguzi	4.7	9.60	0.43	5.64	1877.2	314.0	19.9
Bukimbiri1	4.0	9.56	0.41	1.05	403.0	106.8	30.7
Bukimbiri2	4.0	10.06	0.41	0.03	837.3	135.6	23.2
Karengere	5.3	7.60	0.31	1.22	1736.5	859.4	24.7
Kachwekano	4.6	9.23	0.38	6.49	1412.3	382.5	101.7

Table 2: Effect of N:P:K Nutrient combinations on number of potato tuber/plot.

Nutrient combination	Number of tubers			
	% Large tubers	% Medium tubers	% Small tubers	Total Tuber Number
$N_0P_0K_0$	3.19a	52.45a	44.36a	228.2a
$N_{75}P_{50}K_{150}$	4.28b	56.98b	38.74bc	313.2b
$N_{100}P_{75}K_{200}$	5.37c	53.09c	41.53ac	328.7bc
$N_{150}P_{100}K_{250}$	6.7cd	53.98b	39.32bc	330.6c
$N_{200}P_{125}K_{300}$	6.84d	56.37b	36.79b	345.6c
s.e.d	0.519	1.569	1.583	13.61
l.s.d	1.072	3.238	3.267	26.78

Table 3: Effect of nutrient combinations on tuber numbers across sites.

Sites	Tuber numbers			
	% Large tubers	% Medium tubers	% Small tubers	Total Number
Bukimbiri-1	13.59a	55.97a	30.44a	307.6ab
Bukimbiri-2	11.21a	58.4a	30.39a	283a
Hamurwa	0.43b	25.56b	74b	334.1b
Kachwekano	4.68bc	71.48c	23.83a	272.8a
Kamuganguzi	0.32b	62.2d	37.48c	260.2a
Karengyere	6.32c	64.53d	29.15a	410.1c
s.e.d	1.086	3.036	2.953	15
l.s.d	2.659	7.429	7.225	29

followed by Karengyere and Kachwekano. The highest percentage of medium sized tubers was obtained from Kachwekano Karengyere and Kamuganguzi. Hamurwa site recorded the significantly high percentage of small tuber numbers. There were few large sized tubers in Hamurwa and Kamuganguzi which has implication on the total yield of tubers in those locations. Each site had specific response to nutrient combinations with some sites favoring large; medium and small tubers respectively. However; the contribution of medium sized tubers to the total number of tubers was significant and there number influences the overall tuber numbers. The nutrient combination that leads to higher percentage of medium sized tubers should be preferred.

The results in Table 4 show that % of medium sized tubers was significantly higher than the large and small sized tubers under all Modes of Application. There was no significant different between the percent of large sized tubers under different MoA. However; the % of the number of small sized tubers was significantly different (p=0.048) with MoA under application of $N_{75}P_{50}K_{150}$ and $N_{100}P_{75}K_{200}$. This could be attributed to the effect of nutrient combinations applied to the crop. The earlier application means that all the required nutrients are utilized by the crop within a few month of growth. With top dress the amount required by the plant is delayed and this causes the crop to delay to utilize it. The crop vigor brought about by the earlier application leads to the increased uptake and utilization of applied nutrients. In this case tuber production is enhanced by the availability of soil nutrients that are required by the potato crop. It is clear that the control plots had fewer tuber numbers as compared to all the nutrient combinations applied. This supports the role of plant nutrients in growth and development of the plant [13]. In that fertilizer application is required to increase tuber numbers and development of such tubers. The $N_{150}P_{100}K_{250}$ and $N_{200}P_{125}K_{300}$ nutrient combinations led to production of large tuber numbers in all Modes of applications. Irrespective of the basal and top dress application the nutrient combinations had significant effect on the number of tubers produced [14]. It means the application of the nutrient combinations encourages tuber formation. This is in agreement with findings of Baciu et al. [15]; where rates of application of NPK at 150-200 N active substance was found to be optimum for potato production.

The results in Table 5 show the % of large tubers in season 2 was significantly different from season 1; however; the % of large tubers in season 1 was not significantly different from season 2. The % of medium sized tubers was significantly different than that from large tubers and small tubers. The % of medium tubers in season 2 was significantly different from season 1. This implies that the conditions in season 1 favored production of small tubers as compared to season 2 and this could have led to reduction in overall yield. However; % of small tubers in season 1 was significantly different from season 2. Implying there was high number of small tubers in season one where the rains were unfavorable. There was no significant different on % of medium sized tubers across nutrient combinations within the season. The total number of tubers in season 2 was significantly different from season 1; with total tuber numbers coming from medium sized tubers. Application of nutrient combinations significantly increased the number of tubers as compared to no application.

Effect of nutrient combinations on potato yield

The results show significant increase in the weight of tubers on application of nutrient combinations Table 3. The nutrient combinations of $N_{150}P_{100}K_{250}$ and $N_{200}P_{125}K_{300}$ contributed to the highest weight of large tubers (45-60 mm) and medium tubers (30-45 mm) per plot. The average weight of small tuber under application of nutrient combinations was significantly different from the control. However there was no significant difference on weight of small tubers in all nutrient combinations. The highest yield of potato was obtained on application of $N_{200}P_{125}K_{300}$ nutrient combination. Each nutrient combination led to a yield significantly different from the control and each other. This probably explains the effect that each amount of nutrient combination has on potato yield [15]. The higher levels on N:P:K nutrient combinations tended to produce higher tuber yield; which is in agreement with the findings of where applied nutrients increase yield of potato (Tables 6 and 7) [16].

Application of nutrient combinations was significantly different across sites (p<0.001); with Karengyere and Kachwekano showing high yield of large and medium sized tubers. In all sites the weight of medium

Table 4: Effect of nutrient combinations on tuber numbers under different MoA.

	% Large tuber		**% Medium tuber**		**% Small tubers**		**Total number of tubers**	
	MoA1	MoA2	MoA1	MoA2	MoA1	MoA2	MoA1	MoA2
$N_0P_0K_0$	3.23a	3.15a	53a	51.9a	43.77a	44.96	221a	235.4a
$N_{75}P_{50}K_{150}$	3.88ab	4.68b	58.55b	55.4b	37.56b	39.92a	290.8bc	335.5b
$N_{100}P_{75}K_{200}$	5.02b	5.73b	53.19a	52.99b	41.79a	41.28a	294c	363.4bc
$N_{150}P_{100}K_{250}$	6.09b	7.31c	52.41a	55.55b	41.49a	37.14b	328.9c	332.4b
$N_{200}P_{125}K_{300}$	5.9b	7.78c	57.32b	55.42b	36.78b	36.8b	316.3c	374.9c
s.e.d	0.716		2.228		2.272		19.25	
l.sd	2.175		4.385		4.471		37.88	

Table 5: Effect of nutrient combinations on tuber numbers per plot across seasons.

Nutrient combination	**% Large tubers**		**% Medium tubers**		**% Small tubers**		**Total tubers**	
	Season 1	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
$N_0P_0K_0$	2.56ab	4.02	50.04	55.66	47.4a	40.31a	174.5	299.8
$N_{75}P_{50}K_{150}$	2.36a	6.84	54.67	60.05	42.97b	33.11b	233.8	419
$N_{100}P_{75}K_{200}$	3.49ab	7.89	50.36	56.74	46.15b	35.38b	241.9	444.4
$N_{150}P_{100}K_{250}$	4.69b	9.39	50.00	59.29	45.31b	31.32bc	258.7	426.6
$N_{200}P_{125}K_{300}$	3.71ab	11.02	54.16	59.32	42.13b	29.67c	263.2	455.5
s.e.d	1.125		2.268		2.312		19.59	
l.s.d	2.214		4.463		4.55		38.55	

Table 6: Effect of N:P:K Nutrient combinations on potato tuber yield.

	Weight of tubers/plot				
	Large tubers	**Medium tubers**	**Small tubers**	**Total weight**	**Yield t/ha**
$N_0P_0K_0$	0.992a	7.26a	1.433a	9.68	11.53
$N_{75}P_{50}K_{150}$	1.552b	10.09b	1.847b	13.48a	16.05a
$N_{100}P_{75}K_{200}$	2.041b	10.4b	2.099b	14.54b	17.31b
$N_{150}P_{100}K_{250}$	2.796c	11.26c	1.977b	16.04c	19.09c
$N_{200}P_{125}K_{300}$	3.076c	12.41d	1.924b	17.41d	20.72d
s.e.d	0.2801	0.354	0.1452	0.444	0.529
l.sd	0.5512	0.696	0.2857	0.874	1.04

Table 7: Effect of Nutrient combinations on potato yield across sites.

Sites	**Weight of tubers in kgs/plot**				
	Large tubers	**Medium tubers**	**Small tubers**	**Total weight**	**Yield t/ha**
Bukimbiri-1	4.982a	10.64	1.581a	17.2d	20.48a
Bukimbiri-2	3.994b	10.28	1.7b	15.97c	19.02b
Hamurwa	0.202c	3.19a	2.523c	5.92a	7.05c
Kachwekano	2.53d	15.12b	1.409a	19.06e	22.69d
Kamuganguzi	0.189c	8.32c	1.364a	9.88b	11.76e
Karengyere	2.549d	18.67d	2.472c	23.69f	28.2f
s.e.d	0.3025	0.382	0.1568	0.48	0.571
l.s.d	0.5953	0.752	0.3085	0.944	1.124
cv %	-	22.3	-	20.2	20.2

sized tubers was greater than large and small sized tubers. Hamurwa and Kamuganguzi had large tubers with weights not significantly different from each other. This could be attributed to the nature of the soils in those sites. On the medium sized tubers the sites performed differently with Bukimbiri site 1 and 2 producing tubers not significantly different from each other. These two sites had more less similar soil and climatic conditions. In Table 4, results show that medium sized tubers contributed greatly to the yield across sites. The higher tuber weights were recorded in Karengyere followed by Kachwekano sites and this could be due to the management practices in the two experimental sites and the soil characteristics. These sites are on-station sites where the attention is provided by the researcher as compared to other sites which are on-farm. However; there was a significant difference ($p<.001$) between application of nutrient combinations and the control plots (Table 8).

In Table 6, all nutrient combinations significantly yielded better than the control ($N_0P_0K_0$); with high tuber yields recorded with increasing amounts of N:P:K in a nutrient combination. The higher tuber weight was contributed by medium sized tubers across all modes of application. Therefore medium sized tubers contributed greatly to the total yield. Mode of application 2 significantly yielded more than mode of application 1; with the highest average yield of 22.2 t ha^{-1} obtained with application of nutrient combination of $N_{200}P_{125}K_{300}$. Implying that basal application of nutrient combinations is sufficient to increase potato tuber yield more that split application. It was noted that

$N_{150}P_{100}K_{250}$ and $N_{200}P_{125}K_{300}$ nutrient combination contributed to higher tuber weights across all modes of application.

There was significant interaction between locations and MoAs (p<0.001); which was attributed to site specific characteristics. However; the highest potato yields were observed on application of $N_{150}P_{100}K_{200}$ however this was not significantly different on application of the highest nutrient combination of $N_{200}P_{125}K_{300}$. Karengyere site presented the highest performance in tuber yield as compared to all the other sites. This was observed across all the modes of application and in this particular site mode of application one seemed better than mode of application 2 (basal application). This location was unique in terms of soil pH it was a site with at least a pH of 5.3 while all sites had pH range of 4.0-4.7. This probably could have had an implication on availability and uptake of nutrient combination by the plant. The performance of nutrient combination at Karengyere site was followed by Bukimbiri 1 and 2 locations; although MoA 2 was better than MoA 1 in these locations. Fourthly Kachwekano site followed Bulimbiri 1 and 2 sites. On the contrary; Hamurwa and Kamuganguzi location had the lowest yields and this was attributed to the nature of soils and the rainfall regime. In these two sites there is a lot of laterite with lot of marram spread on the surface. Any change in moisture availability affects crop performance. It is true that most of the area around these two locations has shallow soils and this has implications on the establishment of the potato crop. In addition the higher rates of nutrient combinations were observed better than the lower rates.

In Table 9, performance of season 2 yields was significantly higher (p<.001) than in season 1. This was observed irrespective of the size of tubers; while all nutrient combinations performed above the control (season 1=8.6 t/ha and season 2 with 15.5 t/ha). The highest average yield obtained in season 2 was 29.9 t/ha with application of the highest level of the nutrient combinations. The good performance of nutrient combinations in season 2 is attributed to the good rains observed in the season as compared to unstable rains season 1. The season 1 rains were not sufficient to allow for utilization of the top dressed nutrient combinations. However in season 2 the rains were sufficient throughout allowing for maximum utilization of nutrients applied to the soil. This translated to higher yields as nutrients were properly utilized by the crop; probably explaining the situation in Karengyere.

Profitability analysis

The results showed significant difference (p<.001) across seasons; with season 1 showing poor performance of the crop as compared to season 2. This was attributed to the inadequate rains in season 1 [8]; which affected fertilizer utilization in the season. Profitability analysis was conducted separately in the two seasons. It involved revenues per acre under each nutrient combination. In Table 10, nutrient combinations led to revenues higher than the control combination; where no additional nutrients were applied into the soil. Gross margins were higher with application of $N_{75}P_{50}K_{150}$; $N_{100}P_{75}K_{200}$ and $N_{150}P_{100}K_{250}$. This was higher than the application of higher levels of nutrient combination ($N_{200}P_{125}K_{300}$). On subjection to returns to investment calculations; it was found that application of $N_{75}P_{50}K_{150}$ had higher returns to investment followed by application of $N_{100}P_{75}K_{200}$. This could be attributed to the amount of moisture in the soil at the time of tuber initiation and bulking. The higher nutrient combination was found to increase the farmers' cost at the expense of profitability.

In season 2, all nutrient combinations showed higher returns to investment compared to season 1 (Tables 11 and 12). This is attributed

Table 8: Effect of nutrient combinations on tuber yield under different MoA.

	Weight of tuber per plot							
	Large tubers (kgs)		**Medium tubers (kgs)**		**Small tubers (kgs)**		**Av. Yield t ha^{-1}**	
	MoA1	**MoA2**	**MoA1**	**MoA2**	**MoA1**	**MoA2**	**MoA1**	**MoA2**
$N_0P_0K_0$	0.839a	1.145a	7.07a	7.45a	1.335a	1.531a	11a	12.05a
$N_{75}P_{50}K_{150}$	1.287ab	1.816ab	10.18b	10b	1.709a	1.985b	15.68b	16.43b
$N_{100}P_{75}K_{200}$	1.779bc	2.304b	9.69b	11.12c	1.827bc	2.371c	15.82b	18.8c
$N_{150}P_{100}K_{250}$	2.649cd	2.943bc	11.44c	11.08c	2.15c	1.804b	19.33c	18.85c
$N_{200}P_{125}K_{300}$	2.432c	3.721c	11.93c	12.88d	1.809bc	2.039bc	19.26c	22.19d
s.e.d	0.3961		0.5		0.2053		0.748	
l.s.d	0.7795		0.984		0.404		1.471	

[Note: l.s.d when comparing means of same levels of MoA large tubers 0.638]

Table 9: Effect of mode of application of nutrient combinations across sites.

		$N_0P_0K_0$	**$N_{75}P_{50}K_{150}$**	**$N_{100}P_{75}K_{200}$**	**$N_{150}P_{100}K_{250}$**	**$N_{200}P_{125}K_{300}$**
Bukimbiri-1	MoA1	11.9	16.2b	17.7b	22.5c	22.9c
	MoA2	16.1	22.3b	23.5b	23.8b	28c
Bukimbiri-2	MoA1	10.9	18.2b	18b	23.2c	22.3c
	MoA2	9.6	18b	21.9c	21.6c	26.4d
Hamurwa	MoA1	2.9	7.1b	5.9a	8.3b	9.6b
	MoA2	3.1	7b	9.4bc	6.6ab	10.7c
Kachwekano	MoA1	18.2	21.3b	21.3b	25.2c	24.4bc
	MoA2	19.5	21.5b	24c	22.7c	28.8d
Kamuganguzi	MoA1	6.2	10.4bc	9.4b	12.1bc	13.8c
	MoA2	6.4	12.1b	13.9bc	16.4c	16.9c
Karengyere	MoA1	22.3	27.9b	30.8bc	33.8c	30.1b
	MoA2	24.9	24.6a	27.4ac	29.5bc	30.8c

[Note: Comparison of means of different Nutrient Combinations s.e.d = 1.806, l.s.d = 3.554 2. Comparison of means of the same nutrient combinations) s.e.d=0.766, l.s.d = 1.508] to the favorable rains observed in season 2. However the highest returns to investment was observed under higher nutrient combination levels of $N_{100}P_{75}K_{200}$ and $N_{150}P_{100}K_{250}$ as compared to season 1. Since a farmer is able to obtain higher returns to investment with application of lower levels of nutrient combinations; it is important that higher levels of nutrient combinations are avoided to reduce costs to investments. The lower returns to investments experienced in season 1 could as well be experienced by farmers who plant late in the season as they loss the rains that would otherwise increase the yield of potato. In Table 13, it was noted that the net benefits/cost of investments was higher in season

Table 10: Effect of nutrient combinations on tuber yield across seasons.

Nutrient combinations	Weight of tuber per plot across seasons							
	Large tubers		Medium tubers		Small tubers		Yield t/ha	
	Season1	Season2	Season1	Season2	Season1	Season2	Season1	Season2
$N_0P_0K_0$	0.8a	1.2a	5.1a	10.2a	1.3	1.6a	8.6a	15.5
$N_{75}P_{50}K_{150}$	0.9ab	2.4b	7.2b	14.0b	1.6	2.2b	11.5b	22.1a
$N_{100}P_{75}K_{200}$	1.4ab	2.9b	7.2b	14.7b	1.7	2.7c	12.2bc	24.1b
$N_{150}P_{100}K_{250}$	1.8b	4.1c	7.5bc	16.3c	1.6	2.4c	13.0cd	27.2c
$N_{200}P_{125}K_{300}$	1.6b	5.0d	8.4c	17.7d	1.6	2.3c	13.9d	29.9d
s.e.d	0.4031		0.509		0.2089		0.761	
l.s.d	0.7932		1.002		0.4111		1.497	

[Note; s.e.d=0.761, l.s.d=1.508 comparing means of same level of treatments]

Table 11: Season 1 profitability analysis.

	NPK Nutrient Combination				
Cost Item	$N_0P_0K_0$	$N_{75}P_{50}K_{150}$	$N_{100}P_{75}K_{200}$	$N_{150}P_{100}K_{250}$	$N_{200}P_{125}K_{300}$
(a) Revenue per acre	3,374,089	4,572,874	4,740,486	5,093,927	5,403,644
(b) Fixed Costs					
Hire of land	450,000	450,000	450,000	450,000	450,000
Cost of Seed (Bags)	1,120,000	1,120,000	1,120,000	1,120,000	1,120,000
Fertilizer cost	0	508,273	677,698	1,016,546	1,355,395
Cost of seed transportation	80,000	80,000	80,000	80,000	80,000
Fertilizer transportation	0	22,554	30,072	45,109	60,145
Cost of fungicide (Ridomil)	80,000	80,000	80,000	80,000	80,000
Poly bags	48,000	48,000	48,000	48,000	48,000
Total fixed costs	1,778,000	2,308,828	2,485,770	2,839,655	3,193,540
(c) Variable cost					
Labour costs	652,000	674,554	682,072	697,109	712,145
Total variable costs	652,000	674,554	682,072	697,109	712,145
(d) Total costs (b+c)	2,430,000	2,983,382	3,167,843	3,536,764	3,905,685
(e) Gross margins/acre (a-d)	944,089	1,589,493	1,572,643	1,557,163	1,497,959
(f) Returns on investment (e/d)	0.39	0.53	0.50	0.44	0.38

Table 12: Season 2 Profitability analysis.

Cost Item	NPK Nutrient Combination				
	$N_0P_0K_0$	$N_{75}P_{50}K_{150}$	$N_{100}P_{75}K_{200}$	$N_{150}P_{100}K_{250}$	$N_{200}P_{125}K_{300}$
(a) Revenue per acre	5,797,166	8,420,648	9,182,186	10,220,648	11,091,498
(b) Fixed Costs					
Hire of land	450,000	450,000	450,000	450,000	450,000
Cost of Seed potato (Bags)	1,120,000	1,120,000	1,120,000	1,120,000	1,120,000
Fertilizer cost	0	508,273	677,698	1,016,546	1,355,395
Cost of seed transportation	80,000	80,000	80,000	80,000	80,000
Fertilizer transportation	0	22,554	30,072	45,109	60,145
Cost of fungicide (Ridomil)	80,000	80,000	80,000	80,000	80,000
Poly bags	48,000	48,000	48,000	48,000	48,000
Total fixed costs	1,778,000	2,308,828	2,485,770	2,839,655	3,193,540
(c) Variable costs					
Labour costs	652,000	674,554	682,072	697,109	712,145
Total variable costs	652,000	674,554	682,072	697,109	712,145
(d) Total costs (b+c)	2,430,000	2,983,382	3,167,843	3,536,764	3,905,685
(e) Gross margins/acre (a-d)	3,367,166	5,437,266	6,014,344	6,683,884	7,185,813
(f) Returns on Investm't (e/d)	1.39	1.82	1.90	1.89	1.84

Table 13: Costs, net benefits and profitability index (PI) of nutrient combinations.

Options	Total costs		Net benefit ware		Net benefit seed		*PI (Ware)		*PI (Seed)	
	season		season		season		season		season	
	1	2	1	2	1	2	1	2	1	2
$N_0P_0K_0$	2,430,000	2,430,000	944,089	3,367,166	3,193,482	7,231,943	0.39	1.39	1.31	2.98
$N_{75}P_{50}K_{150}$	2,983,382	2,983,382	1,589,493	5,437,266	4,638,076	11,051,031	0.53	1.82	1.55	3.70
$N_{100}P_{75}K_{200}$	3,167,843	3,167,843	1,572,643	6,014,344	4,732,967	12,135,801	0.50	1.90	1.49	3.83
$N_{150}P_{100}K_{250}$	3,536,764	3,536,764	1,557,163	6,683,884	4,953,115	13,497,649	0.44	1.89	1.40	3.82
$N_{200}P_{125}K_{300}$	3,905,685	3,905,685	1,497,959	7,185,813	5,100,388	14,580,145	0.38	1.84	1.31	3.73

*PI = Net Benefit/Cost of Investment

2 with farmers who produced ware and seed potato; with application of $N_{100}P_{75}K_{200}$ leading to the highest benefit. This is attributed to the low yields obtained in season one of the experiment. Seasonal variation therefore affects the net benefit/cost of investment as in agreement with the findings of Shaaban and Kisetu [12].

Conclusion

On application of N:P:K nutrient combination to potato; there was a significant increase in yields across different locations. The yield increase was significantly different to the options where no application was done. Season 2 performed significantly better than season 1 a situation attributed to the shorter rain experienced in season one of experimentation. In terms of location; Karengyere was the best site with the highest potato yield of 38 t/ha. The potato yield response to N:P:K nutrient combination was quite good in the location. The two modes of applications used MoA2 (Basal Application) performed better than MoA1 (Split Application). Therefore in this zone when applying N:P:K nutrient combination; basal application is recommended. This equally has an advantage of saving the labor cost required to top dress the fertilizer. Upon subjecting these yields to profitability analysis; $N_{75}P_{50}K_{150}$ recorded economically viable returns to investment for seed potato for season 1 when moisture is not sufficient for the growth of the potato. The $N_{100}P_{75}K_{200}$ was the best economically viable option for ware potato as well as for season 2 when the rains are stable. Although the $N_{200}P_{125}K_{300}$ nutrient combination gave the highest yield; this was not economically viable under the current growing conditions in the zone.

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Author Affiliation

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Kachwekano Zonal Agricultural Research and Development Institute - NARO Uganda