BISHOP STUART UNIVERSITY

YIELD AND DRY MATTER RESPONSE OF POTATO (SOLANUM TUBEROSUM) TO DIFFERENT NPK 17:17:17 FERTILIZER LEVELS IN MID ALTITUDE REGION IN UGANDA

By

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Declaration

I declare that this work has not been submitted for a degree in any other university.

I also declare that this work is the result of my own investigations.

Signed .... Date 06/12/2022.

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Approval

This report has been submitted with our approval as academic supervisors,

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Glory and Honour go to the Almighty God for bringing me this far. Amen

Dedication

I dedicate this thesis work to my Family.

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Abbreviations and acronyms

ANOVA	Analysis of Variance
BSU	Bishop Stuart University
CIP	Centro Internacional de la Papa
DMC	Dry Matter Content
FAO	Food Agriculture Organization
IPC	International Potato Center
NARO	National Agricultural Research Organization
NFP	National Fertilizer Policy
PIBID	Presidential Initiative on Banana Industrial Development
S.W	South Western
UBOS	Uganda Bureau of Statistics
UNMA	Uganda National Meteorological Authority

ABSTRACT

Potato is an important food and cash 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 and fertilizers used / nutrient level. There is an increased land degradation and low use of fertilizers by famers in Uganda leading to low potato yields and poor quality – dry matter. Most of the potato varieties in Uganda are bred for high altitude environments. In order to address these, this study was designed with the aim of establishing the yield and dry matter response of the potato in the mid altitude environment. The objectives of the study were to determine the yield output and dry matter content of potato varieties under different NPK 17:17:17 fertilizer levels; 0Kgs/ha, 50Kgs/ha and 100Kgs/ha. Three potato varieties; Victoria, Rwangume and Kachpot1 were studied for two seasons at BSU Farm Mbarara under a 4 x 4 factorial experiment arranged in a Randomized Complete Block design with three replications for each season. Soil analysis was carried out for the two sites.

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, f3. The varieties were significantly different for; total tuber yield, average weight per tuber, tuber weight per plant, marketable/non-marketable tubers, biomass and number of tubers per plant. Fertilizer level three produced the highest overall mean of yield at 12.19 t/ha during Season I and the lowest over all mean at 5.3t/ha from fertilizer level f1 during Season II. Across the seasons, Katchpot1 yielded the best at 14.78 t/ha whilst Victoria was the lowest yielder at 7.02 t/ha. Fertilizer level three had the highest overall mean for number of tubers per plant at 11.1 during Season II. 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. From this study, fertilizer requirements are also genotype specific. The output in the mid altitude area of Mbarara revealed lower yield and more none marketable tubers because the varieties studied were bred targeting highland areas of Uganda. There was a magnitude of genotype by environment interaction as indicated by the varied dry matter out puts per variety across the seasons and varying soil types. The fertilizer levels manipulated dry matter content with a steady reduction as more fertilizer of NPK 17:17:17 was applied. Fertilizer level f2 is recommended as optimum levels for optimum yield output. Further studies could focus on the interaction of different fertilizer levels and potato spacing, effect of potassium levels on dry matter content.

CHAPTER ONE

1.0 BACKGROUND AND INTRODUCTION

1.1 Origin and distribution of potato

The Potato **(***Solanum tuberosum)* has its origin in South America, around Lake Titicaca near the present border of Peru and Bolivia (Hourton, 1987). Potato is a major food and cash crop, mainly grown by small-scale farmers in the highland regions of many African countries. 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. 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 studied three varieties; Rwangume, Victoria and Kachpot 1 because they're relatively high yielding (Nuwamanya *et al.* (2011).

In Uganda, the potatoes productivity at farm level is estimated at 7.1 tha^{-1} (FAOSTAT, 2019) against a potential of about 25 t/ha (Harahagazwe *et al*. (2018) which can be achieved under good management and when suitable varieties are used. This yield is low in comparison to the production statistics of many other countries and considering that a yield of 25 tha^{-1} is attainable (IPC, 2011). The potato yields have remained low amidst an ever-increasing population that demands more food in the region (Otieno *et al.* (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, Season I; Okeyo *et al.*, 2019; Mugo *et al*., 2020).. Potato yield and fertilizers application are significantly associated and fertilizers improve the yield and quality significantly (Srek *et al.,* 2010) Diseases are the major limiting factors and these include; - late blight caused by *Phytophthora infestans* (Mont.) de Bary, bacterial wilt (BW) (*Ralstonia solanacearum*) (Muthoni *et al.* (2013) and viruses (Byarugaba *et al.* (2021). Late blight is the most devastating disease of potato leading to yield losses of up to 70% (Namugga *et al.*, 2017b, 2018). The situation is worsened by the continued soils degradation and nutrient mining.

Most of the available potato varieties in Uganda are late maturing with physiological maturity attainable after 100 days from planting if they are to reach their full yield potential (Namugga *et al.*, 2017b, 2018). These varieties were selected for the highlands (>2000 meters above seas level (masl)), and thus are well adapted and produce good yields with excellent culinary qualities in the highlands.

Fertilizer NPK 17:17:17 is a composite field grade fertilizer comprising of Nitrogen, Phosphorous and potassium in balanced proportions. NPK 17:1717 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. NPK fertilizers improve yield and quality of potato tubers (Innocent, 2021). Potato requires high amounts of NPK but more K fertilizer for optimum growth, production and tuber quality (Al-Moshileh and Errebi, 2004), but the ability of this crop to recover P and K is very low. According to Naz *et al.* (2011), response of potato to NPK fertilizers varies depending upon the variety, soil characteristics and geographical location. There is scanty documentation available for deliberate use of NPK 17:17:17 fertilizer in soils of Mid-altitude region aiming at increasing performance and hence yield and dry matter of Irish potato.

1.2 Importance and uses of potato.

Potato plants are essential for food security, or access to sufficient, affordable, safe and nutritious food for mankind (FAO 2017). Potato is a hunger breaking crop during food shortages, especially in Eastern Africa (Gildemachar, 2012; Haverkort and Struik, 2015). Potatoes contribute directly to over 80% of the human diet (Bennett 2010). On dry matter basis, it ranks fourth in total world food crop production after wheat, maize, rice (Loebenstein, 2009 and FAO, 2020).). Potato is generally regarded as a food and cash crop, as well as an industrial material, with its usefulness for diverse purposes being derived mainly from its root dry matter content.

Potato is vital to small-scale farmers who are limited in land, labour and capital. One of the greatest values of this crop is its ability to be harvested piecemeal for either home consumption or income generation. It is an important food security crop, and also important as an income generating commodity in rural communities. The availability of improved varieties should keep the crop in a position to meet these two uses.

Potato is one of the most nutritious vegetables. The leaves and shoots are also edible but the storage tubers are the most important products and are rich in dietary fiber, vitamin C, and vitamin B6 (Loebenstein, 2009). Potato storage roots used for food are most frequently boiled, fried, or baked, while industrial uses include the production of starch and alcohol. All parts of the plant are used as animal feed. High in phenolic content and anti-oxidant activity, potato can be processed into powders for use in food products, such as ice cream, juices, tea drinks and bread (Yasmin *et al.,* 2006). Potato is among the major food crops grown in more than 100 countries in the world (Nyunza and Mwakaje, 2012), Tanzania inclusive. In Uganda, potato is an important strategic commodity recognized by the government as a potential driver of improved rural livelihoods (Mbowa and Mwesigye, 2016).

1.3 Problem statement

According to UBOS 2006, only 1.0% and 6.8% of Uganda's agricultural land parcels are fertilized with mineral fertilizers and manure, respectively. Only 2% of smallholder farmers use inorganic fertilizers, and only approximately 24% utilize organic inputs, largely on perennial crops (Pender et al., 2001). Only 0.23 to 1 kg/ha of fertilizer are now being used, the lowest rate among Sub-Saharan African nations (Bekunda and Kaizzi, 2008). Because most smallholder farmers virtually ever employ organic or artificial fertilizers, the nutrients are rarely restored to the same extent as they are mined through crop harvests and other losses, leading to substantial negative nutrient balances.

Potatoes are majorly grown in high altitude areas in Uganda (Kisakye *et al.,* 2020) and a lot of research has been conducted in these areas for example 100kgs/ha of NPK 17:17:17 is recommended for potatoes basing on research from high altitude areas leaving the low and mid altitude areas with scanty information on potato production and fertilizer use.

Low soil fertility related to prolonged cultivation without proper replenishment of the mined nutrients is one of the causes of low potato yields in much of the world (Kaguongo et al., 2008; Muthoni and Kabira, 2011, Otieno, Season I, Mugo et al., 2020). Crop production in Uganda is severely hampered by declining soil fertility, which is made worse by ongoing land cultivation, poverty, and a lack of access to useful resources (Barungi et al., 2013). It cannot be overstated that the application of fertilizers is the most practical method for increasing soil and overall agricultural output (National Fertilizer Policy (NFP) 2016).

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 17:17:17 fertilizer. Therefore, this study aims at establishing and documenting the response of different potato varieties to yield and dry matter content to different NPK 17:17:17 fertilizer levels in mid-altitude environment.

1.4 Justification of the study

In Uganda, where it is grown as a staple meal and, for many, a cash crop that supplements the family income, potatoes are a significant crop. Therefore, any increase in its productivity and quality characteristics, such as DMC, will help people who depend on this crop directly or indirectly have better access to food and better quality of life (Hall et al., 2009). Its productivity should be improved by addressing the production-limiting issues.

Fresh potato serves as a food reserve when the major grain crops fail due to drought or pests. However, its poor storability and low value in fresh form limit its profitability and make it less competitive with cereal grains. Such disadvantages might be reduced by improving its dry matter Content in the mid-altitude environment. High DMC is associated with consumer preferences and desirable as an important material for industry.

1.5 Objectives.

1.6 Main objective

The overall objective of this study is to examine the response of different potato varieties to different NPK 17:17:17 fertilizer levels in mid-altitude environment in Uganda (Mbarara City).

1.7 Specific objectives

i. To determine yield response of potato varieties at different NPK 17:17:17 fertilizer levels for two seasons.

ii. To determine dry matter content response of potato varieties at different NPK 17:17:17 fertilizer levels for two seasons.

1.8 Hypothesis

1. Potato varieties have the same yield levels under different NPK 17:17:17 fertilization levels
2. Dry matter content of potato varieties is not affected by different NPK 17:17:17 fertilization levels

1.9 Scope of the Research

The research work herein involved studying yield and dry matter content in response to different NPK 17:17:17 fertilizer levels in Solanum tuberosum varieties in the tropics. This was achieved through experiments conducted in South Western Uganda at mid altitudes in Mbarara city. The same experiment replicated in two seasons (I & II) focused on agronomic and yield parameters;, Average Weight of tubers, Yield / ha, Number of Tubers /plant, Weight of tubers /plant,, Number of

Tubers /plant, No. and Weight of Marketable tubers, dry matter content and fresh biomass. In this experiment, three varieties majorly grown by farmers in the region were evaluated at different three NPK 17:17:17 fertilizer levels.

The determination of the dry matter content of the three varieties under different three NPK 17:17:17 fertilizer applications was done by analysis of the potato samples in the laboratory at PIBID Bushenyi. Both yield and dry matter content response were studied over two seasons (I and II) in a mid - altitude region of Mbarara Uganda at BSU Farm.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and spread of potato in Uganda

Potatoes were introduced by colonial administrators early in the 1900s. Potato rapidly spread in the highland areas of Uganda as a garden crop, but was practically wiped out by late blight (Phytophthora infestans De Bary) in 1946 (Akimanzi, 1982). Imports of potato seed from Kenya re-established the crop, but yields slowly declined due to lack of suitable varieties and disease problems. In 1968/69, the Potato Improvement Programme for Uganda was initiated and by 1973, a number of varieties were released, of which locally named as; Uganda Rutuku, Bufumbira, Malirahinda, Rosita, and Makerere are among those still being grown today. Potato production in Uganda may have reached 90,000 Ha in the 1970's, but the outbreak of a long period of political turmoil resulted in a dramatic drop in production, to approximately 19,000 Ha in 1986 (Van der Zagg, 1994).

Breeding activities were re-initiated in 1989 through a collaborative project between the International Potato Centre (IPC) and the National Potato Research and Development Programme. Three new varieties were released in 1991 (Victoria, Kisoro, and Kabale) and clean seed of existing popular varieties (e.g. Rutuku) were bulked and distributed in the early 1990s (Sikka, 1994). By the mid-1990s, the potato emerged as a major cash crop for the majority of households in the districts. Commercialized production occurred in large valleys during the dry Season Is well as at higher elevations (>1900 m) on the hillsides. The most important production areas of potato in Uganda are in the districts of Kabale and Kisoro in the Kigezi highlands (1,500–3,000 m a.s.l.) (Kaguongo *et al.*, 2008; Bonabana-Wabbi *et al.*, 2013).

2.2 Major production constraints.

According to IPC, 2011; Schulte-Geldermann *et al.,* 2013; Wang'ombe and Van Dijk, 2013; Thomas –Sharma *et al.,* 2016; Okwadi, 2013, there' several constraints leading to low potato yields in Uganda among small scale farmers; soil infertility, limited clean and improved seed tubers and lack of sole potato cropping. These low yields have been attributed to a number of confounding factors which are biotic, abiotic, and socio-economic constraints as well as poorly adapted and adopted varieties.

Potato yields in Uganda have remained low at about 7.5t/ha (FAOSTAT, 2018, Okoboi *et al.,* 2014) against a potential of about 25t/ha which can be achieved under good management and when suitable varieties are deployed. In Kenya, potato productivity averages 8–15t/ha which is far much below the potential yield of 40t/ha (Muthoni *et al.,* 2009, 2016) and this is attributed to; poor nutrient management strategies, poor cropping systems, accelerated soil erosion rates and high cost of inorganic fertilizers (Muthoni, 2016, Burke, 2016, Bationo, 2004).

Diseases are the major limiting factor and these include; - late blight caused by *Phytophthora infestans* (Mont.) de Bary, bacterial wilt (BW) (*Ralstonia solanacearum*) (Muthoni *et al.*, 2013) and viruses (Muhinyuza *et al.,* 2012). Late blight is the most devastating disease of potato leading to yield losses of up to 70% (Sedláková *et al.,* 2011). This disease is present in all main potato growing areas (Hijmans *et al*., 2001) and is favoured by moderately low temperatures and extended times of leaf dampness. It is particularly detrimental in the highland tropics where potatoes are grown throughout the year, coupled with poor ability of farmers to understand and manage the disease (Garrett *et al.,* 2001). Late blight regularly reduces potato productivity leading to large differences between actual and realized yields. Attempts to develop late blight resistant cultivars therefore call for superior attention to disease management.

Most of the available potato varieties in Uganda are late maturing with physiological maturity attainable after 100 days from planting if they are to reach the full yield potential of more than 15t /ha. These varieties were selected for the highlands (>2000 meters above seas level (masl)), and thus are well adapted and produce good yields with excellent culinary qualities in the highlands. Attempts to grow these varieties at low and mid-altitudes (<1700 masl) have resulted into loss of tuber quality and low yields (Hassanpanah *et al.,* 2008). Early maturing varieties would allow all year round cultivation of potato with favourable rotation periods and improved yields in the face of climate change. This is especially advantageous for smallholder farmers who depend entirely on potato for both food and income security in areas with land shortage. Additionally, these varieties would be grown in low altitude areas of Uganda with short lived rainfall seasons where potato production is currently expanding. Since short rainy seasons are often erratic; early maturing cultivars stand a higher chance of carrying the crop to full maturity.

In general, diseases are the main constraints limiting potato production across all the regions (Namugga *et al*., 2017). Other challenges are; limited soil nutrients, pests, high cost of agro inputs, limited land for potato production, reducing yields and unfavourable weather conditions. Major diseases are bacterial wilt in the low lands and late blight in the highland areas. Cutworms and aphids are the most predominant pests across all the regions.

2.3 Fertilizer use in Uganda.

Poor intrinsic soil fertility, specifically N and P shortages, which are aggravated by soil fertility loss (Vlek, 1993; Sanchez et al., 1996; Lynam et al., 1998) and other biophysical variables are the main causes of low yields (Bekunda et al., 1997). According to Mugo et al. (2020), the main limiting elements for potato production in the main potato-growing regions of East Africa are N, P, and K.

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 $ha^{-1}yr^{-1}$, 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.

2.4 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, & 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.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental 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 17^0C to 30^0C, 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 – Season I (September –December 2019) and Season II (March – June 2020).

The rainfall and temperature data for the two seasons are attached in the appendices.

3.2 Experimental design

The experiments were carried out to evaluate for yield and dry matter content of the three potato varieties. The experiments were laid out as a 4 x 4 factorial experiment arranged in a Randomized Complete Block design with three replications for each season. 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). Fertilizer NPK 17:17:17 was used because it is among the most used fertilizers in Uganda (Kisakye *et al.*, 2020). 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. The Cultural practices such as weeding, cultivation and ridging were practiced as per the recommendations. To prevent blight disease, Indofil (3 g/l) was used monthly.

Table 1; The field lay out at BSU Farm for season I and Season II (3 plots and 9 replicates)

Block No.	Replicates								
	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Rep 5**	**Rep 6**	**Rep 7**	**Rep 8**	**Rep 9**
Block 1									
Treatment	100kgs/Ha	50kgs/Ha	0kgs/Ha	50kgs/Ha	0kgs/Ha	0kgs/Ha	100kgs/Ha	100kgs/Ha	50kgs/Ha
Block 2									
Treatment	50kgs/Ha	100kgs/Ha	100kgs/Ha	0kgs/Ha	50kgs/Ha	50kgs/Ha	0kgs/Ha	100kgs/Ha	0kgs/Ha
Block 3									
Treatment	50kgs/Ha	0kgs/Ha	50kgs/Ha	50kgs/Ha	100kgs/Ha	0kgs/Ha	0kgs/Ha	100kgs/Ha	100kgs/Ha

Plate 1: Experimental layout; Season I

Plate 2: Experimental inspection by the Researcher at the BSU Farm

3.3 Site (Garden) preparation and planting

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 2: 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).

At planting, respective NPK 17:17:17 fertilizer levels were applied in the respective plots/blocks in the planting furrows at rates of 0kgs/ha, 50kgs/ha and 100kgs/ha. All the agronomic practices, pest and disease management measures were done as recommended.

3.4 Data collection

3.4.1. Soil content analysis

Using soil augers, two soil samples were taken from each of the two test sites. The samples were subjected to physical and chemical examination using the indicated standard procedures after being air-dried, pounded, and sieved through a 2 mm sieve to eliminate any debris 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. Trace Elements by AAS from an EDTA extract.

3.4.2 Measuring Yield parameters

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 too 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. Different agronomic traits were measured at 15 and 45 days after planting (CIP, 2014). Random samples of tubers from each variety per plot were weighed up to 1.0kg to make a 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.

3.4.3. Dry matter content, DMC

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 105^0C. 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.

3.5 Data analysis

Data were analyzed using analysis of variance (ANOVA) approach in Genstat software for each trait. The predicted genotype mean performance for agronomic traits and yield parameters from the analysis were separated with Least Significant Difference (LSD's) at an alpha level of 0.05. When the difference between the means of the varieties is above the LSD value, then there is a significant difference between the means (Shrestha, J. 2019).

The linear model for analysis in a 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.

CHAPTER FOUR

4.0 RESULTS

4.1 Weather and soil data

There was regular rainfall in both seasons with season I having a higher rainfall peaks at 135.6 mm in November 2019. Temperature varied from 28.5^0 c to 15.0^0 c through out the two seasons of the study (Table 3).

Table 3; 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 (^{0}C)	15.5	16.2	16.3	16.4	16.4	16.6	17.0	16.7	17.3	17.2	17.0
Max. T (^{0}C)	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: UNMA Mbarara 2020

The rainy months where the experiment was carried out were September – December (Season I and February – May (Season II)

Table 4; 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**	**F**
sample		Us/cm	%		ppm		cmoles/kg			% texture			mg/kg(pp		
Season I	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	15
Season II	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	11

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

At the two sites where the experiments were carried out, PH was favourable but the major and micro nutrients were generally insufficient.

4.1 Analysis of variance for yield parameters, bio mass and dry matter content evaluated.

The analysis of variance (Table 5) revealed highly significant effects (P≤0.01), for the varieties, fertilizer levels and interactions per individual Season Ind across seasons.

Table 5: Mean squares for yield components, bio mass and dry matter content for varieties and fertilizer levels evaluated.

Sov	df	yld (tha)	AWT (g)	DM (%)	NTP	WTP (g)	NMT	MT	BM
Season I									
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
Season II									
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≤0.1, 0.05, and 0.01, respectively. Sov is source of variation, D.f is degrees of freedom REP is replication, VAR is variety, FERT is fertilizer, CV is coefficient of variation.

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 5).

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 5).

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 5).

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 concur also with those of Abdissa *et al.* (2012) and Shaaban, H., & Kisetu, E. (2014) who reported the highest tuber yield parameters with the application of NPK fertilizers.

4.2 Response of potato varieties to fertilizer levels

Yield (t/ha)

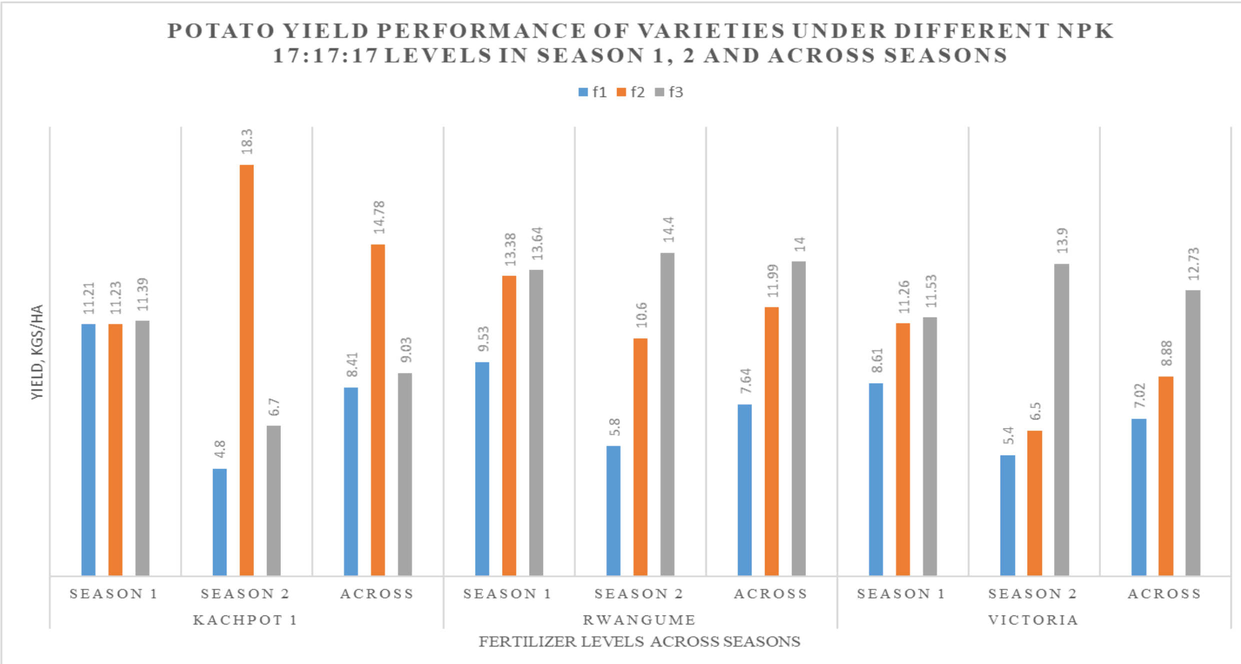
The highest overall mean was achieved from fertilizer level f3 at 12.19 t/ha during Season I and the lowest over all mean at 5.3t/ha from fertilizer level f1 during Season II (Table 6). Kachpot1 yielded most at 18.3 t/ha during Season II at fertilizer level f2, and still the lowest yielder at 4.8 t/ha at fertilizer level 1 during Season II. Across the seasons, Katchpot1 was the highest yielder at 14.78 t/ha whilst Victoria was the lowest yielder at 7.02t/ha.

Table 6: Yield performance of varieties at different fertilizer levels

	yld (t/ha)		
Variety	**f1**	**f2**	**f3**
Season I			
Kachpot1	11.21	11.23	11.39
Rwangume	9.53	13.38	13.64
Victoria	8.61	11.26	11.53
MEAN	**9.78**	**11.96**	**12.19**
SEM	**2.50**		
LSD	**4.23**		
Season II			
Kachpot1	4.8	18.3	6.7
Rwangume	5.8	10.6	14.4
Victoria	5.4	6.5	13.9
MEAN	**5.3**	**11.8**	**11.7**
SEM	**1.794**		
LSD	**5.379**		
Across			
Kachpot1	8.41	14.78	9.03
Rwangume	7.64	11.99	14.00
Victoria	7.02	8.88	12.73
MEAN	**7.69**	**11.89**	**11.92**
SEM	**0.93**		
LSD	**2.69**		

yld is yield, SEM is standard error of mean, LSD is least significant difference.

Chart 1; Potato yield performance of varieties under different NPK 17:17:17 levels across seasons



Average weight per tuber, AWT

The average weight per tuber had the highest overall mean from fertilizer level f1 at 47.93g during Season I and the lowest over all mean at 31.4g from fertilizer level f1 during Season II (Table 7). Kachpot1 had the highest weight of tuber at 61.3 g during Season I at fertilizer level f1, while Rwangume had the lightest tuber 20.9g from at fertilizer level 1 during Season II. 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.

Table 7: Average Weight per tuber of varieties at different fertilizer levels

	AWT (g)		
Variety	**f1**	**f2**	**f3**
Season I			
Kachpot1	61.3	54.1	51.1
Rwangume	27.3	28.2	30.4
Victoria	55.2	56	57.1
MEAN	**47.93**	**46.10**	**46.20**
SEM	**7.50**		
LSD	**12.69**		
Season II			
Kachpot1	34.6	42.6	14.2
Rwangume	20.9	27.5	32.5
Victoria	38.8	35.6	52
MEAN	**31.4**	**35.2**	**32.9**
SEM	**6.25**		
LSD	**18.74**		
Across			
Kachpot1	47.95	48.35	32.65
Rwangume	24.10	27.85	31.45
Victoria	47.00	45.80	54.55
MEAN	**39.68**	**40.67**	**39.55**
SEM	**3.08**		
LSD	**8.88**		

AWT is average weight of tubers, SEM is standard error of mean, LSD is least significant difference.

Dry matter content

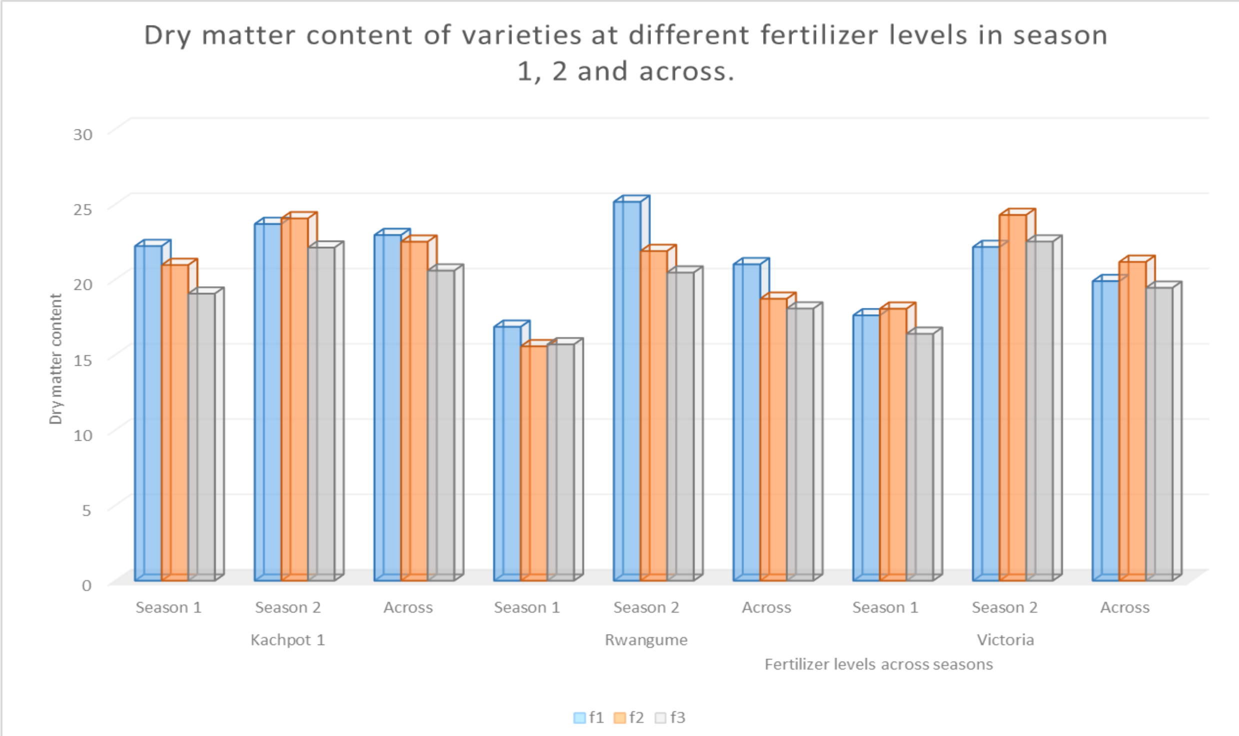
As far as dry matter content is concerned, the overall mean was the highest at 23.7% from fertilizer level f1 during Season II and the lowest over all mean was 17.06% from fertilizer level f3 during Season I (Table 8). Rwangume had the highest dry matter content of 25.17% at fertilizer level f1 during Season II, and still Rwangume had the lowest dry matter content at 15.57% at fertilizer level f2 during Season I. 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.

Table 8: Dry matter content of varieties at different fertilizer levels

		DM	
Variety	**f1**	**f2**	**f3**
Season I			
Kachpot1	22.23	20.97	19.07
Rwangume	16.87	15.57	15.7
Victoria	17.63	18.07	16.4
MEAN	**18.91**	**18.20**	**17.06**
SEM	**3.08**		
LSD	**5.21**		
Season II			
Kachpot1	23.7	24.07	22.13
Rwangume	25.17	21.9	20.47
Victoria	22.17	24.3	22.53
MEAN	**23.7**	**23.4**	**21.7**
SEM	**1.428**		
LSD	**4.281**		
Across			
Kachpot1	22.96	22.52	20.60
Rwangume	21.02	18.73	18.08
Victoria	19.90	21.18	19.46
MEAN	**21.29**	**20.81**	**19.38**
SEM	**0.92**		
LSD	**2.65**		

DM is dry matter content, SEM is standard error of mean, LSD is least significant difference.

Chart 2; Dry matter content of varieties under different NPK 17:17:17 levels across seasons



Number of tubers per plant

The highest overall mean for number of tubers per plant was from fertilizer level f3 at 11.1 during Season II and still fertilizer level f3 during Season Ihad the lowest over all mean at 4.4 (Table 9). Rwangume had the number of tubers per plant at 11.92 at fertilizer level f2 during Season I, while Victoria at 3.5, had the least number of tubers per plant from fertilizer level f1 during Season II. 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.

Weight of tubers per plant

Total weight of tubers per plant had the heaviest overall mean from fertilizer level f3 at 304.67g during Season Iand the lowest over all mean at 133.7g from fertilizer level f1 during Season II (Table 9). Kachpot1 had the highest weight tubers per plant at 458g from fertilizer level f2 during Season II, but it also had the lowest weight of tubers per plant of 121g at fertilizer level f1 during

Season II. 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.

Table 9: Number of Tubers per plant and weight of tubers per plant of potato at different fertilizer levels.

	NTP				WTP		
Variety	**f1**	**f2**	**f3**	**var**	**f1**	**f2**	**f3**
Season 1				**Season I**			
Kachpot1	4.89	5.2	5.61	Kachpot1	299	281	285
Rwangume	8.6	11.92	11.42	Rwangume	238	334	341
Victoria	3.9	5.06	5.07	Victoria	215	281	288
MEAN	**5.8**	**7.39**	**7.37**	**MEAN**	**250.67**	**298.67**	**304.67**
SEM	**1.53**			**SEM**	**62.56**		
LSD	**2.58**			**LSD**	**105.8**		
Season 2				**season 2**			
Kachpot1	3.06	11.85	16	Kachpot1	121	458	167
Rwangume	6.74	9.67	10.55	Rwangume	144	265	359
Victoria	3.5	4.62	6.81	Victoria	136	163	348
MEAN	**4.4**	**8.7**	**11.1**	**Mean**	**133.7**	**295.3**	**291.3**
SEM	**2.115**			**SEM**	**44.9**		
LSD	**6.339**			**LSD**	**134.5**		
Across				**Across**			
Kachpot1	3.97	8.53	10.8	Kachpot1	210	369.5	226
Rwangume	7.67	10.79	10.98	Rwangume	191	299.5	350
Victoria	3.7	4.84	5.94	Victoria	175.5	222	318
MEAN	**5.11**	**8.05**	**9.24**	**MEAN**	**192.17**	**297**	**298**
SEM	**0.93**			**SEM**	**23.3**		
LSD	**2.69**			**LSD**	**67.13**		

NTP is number of tubers per plant, SEM is standard error of mean, LSD is least significant difference.

None marketable tubers

The overall mean of none marketable tubers was the highest from fertilizer level f2 at 156.57 per plot during Season I and the lowest over all mean was 57.9 per plot from fertilizer level f1 during Season II (Table 10). Rwangume had the most none marketable tubers at 267.3 per plot from fertilizer level f2 during Season I, but Kachpot at 25.7 per plot, had the lowest none marketable tubers from fertilizer level f3 during Season II. 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.

Table 10; Non Marketable tubers and Marketable tuber yield at different fertilizer levels

	NMT		
var	**f1**	**f2**	**f3**
season 1			
Kachpot1	87	108.7	112
Rwangume	204	267.3	245
Victoria	75	93.7	83
MEAN	**122**	**156.57**	**146.67**
SEM	**31.99**		
LSD	**54.1**		
season 2			
Kachpot1	35.3	101.7	25.7
Rwangume	95.7	164.3	141
Victoria	42.7	69.3	79.7
Mean	**57.9**	**111.8**	**82.1**
SEM	**18.23**		
LSD	**54.64**		
Across			
Kachpot1	61.2	105.2	68.9
Rwangume	149.9	215.8	193
Victoria	58.9	81.5	81.4
MEAN	**90**	**134.17**	**114.43**
SEM	**10.47**		
LSD	**30.16**		

	MT		
var	**f1**	**f2**	**f3**
season 1			
Kachpot1	19.71	21.54	22.71
Rwangume	0	22	0
Victoria	18.71	26.04	31.04
MEAN	**12.81**	**23.19**	**17.92**
SEM	**8.64**		
LSD	**15.35**		
season 2			
Kachpot1	20.4	40.4	10
Rwangume	22.3	39.1	45.8
Victoria	26.1	26.1	47.8
Mean	**22.9**	**35.2**	**34.5**
SEM	**10.88**		
LSD	37.15		
Across			
Kachpot1	19.7	30.6	13
Rwangume	11.2	30.5	22.9
Victoria	22.4	26.1	39.4
MEAN	**17.77**	**29.07**	**25.1**
SEM	**4.87**		
LSD	**14.02**		

NMT is none marketable tubers, SEM is standard error of mean, LSD is least significant difference. MT is marketable tubers, BM is bio mass, SEM is standard error of mean, LSD is least significant difference.

Marketable tubers

Marketable Number of tubers/plot had the highest overall mean from fertilizer level f2 at 35.2 per plot during Season II and the lowest over all mean at 12.81 from fertilizer level f1 during Season I(Table 10). Victoria had the most marketable Number of tubers/plot at 47.8 from fertilizer level f3 during Season II, while Rwangume had no marketable Number of tubers/plot from fertilizer level f1 and f3 during Season I. 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

Bio mass had the highest overall mean from fertilizer level f3 at 4.4kgs/plot during Season II and the lowest over all mean at 0.5kgs/plot from fertilizer level f1 during Season I(Table 10). Rwangume had the highest bio mass at 8.03kgs/plot from fertilizer level f3 during Season II.Victoria had lowest bio mass at 0.18kgs/plot from fertilizer level f1 during Season I. 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 11: Biomass of potato at different fertilizer levels

		BM	
var	f1	f2	f3
Season I			
Kachpot1	1.06	3.697	5.233
Rwangume	0.347	0.933	1.04
Victoria	0.18	0.447	0.6
MEAN	**0.5**	**1.7**	**2.3**
SEM	0.2961		
LSD	0.89		
Season II			
Kachpot1	0.22	2.2	0.13
Rwangume	0.9	3.33	8.03
Victoria	0.57	2.24	5.17
Mean	**0.6**	**2.6**	**4.4**
SEM	**0.65**		
LSD	**1.95**		
Across			
Kachpot1	0.64	2.9485	2.6815
Rwangume	0.6235	2.1315	4.535
Victoria	0.375	1.3435	2.885
MEAN	**0.546167**	**2.141167**	**3.367167**
SEM	**0.291367**		
LSD	**0.839327**		

BM is bio mass, SEM is standard error of mean, LSD is least significant difference

Table 12; Variation in means of yield parameters under different NPK 17:17:17 fertilizer rates for each variety across the seasons;

Parameters	**Yield (t/ha)**			**AWT**			**DM**			**NTP**			**WTP**			**NMT**			**MT**			**BM**
Fertilizer levels	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**
Kachpot 1 and Rwangume	0.77	2.79	4.97	23.85	20.5	1.2	1.94	3.79	2.52	3.7	2.26	0.18	19	70	124	88.7	110.6	124.1	8.5	0.1	9.9	0.0
Kachpot 1 and Victoria	1.39	5.9	3.7	0.95	2.55	21.9	3.96	1.34	1.14	0.27	3.69	4.86	34.5	147.5	92	2.3	23.7	12.5	2.7	4.5	26.4	0.2
Rwangume and Victoria	0.62	3.11	1.27	22.9	18	23.1	1.12	2.45	1.38	3.97	5.95	5.04	15.5	77.5	32	91	134.3	111.6	11.2	4.4	16.5	0.2
LSD	**2.69**			**8.8**			**2.65**			**2.69**			**67.13**			**30.16**			**14.02**			**0.8**

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

From the above Table 12, 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, 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 fertilizer levels across the seasons thus failing to reject the null hypothesis. These findings concur also with those Shaaban, H., & Kisetu, E. (2014) who reported the significant differences among potato varieties with the application of NPK fertilizers.

4.3. Correlation between average weight per tuber, number of tubers per plant, tuber weight per plant, total tuber yield, and dry matter content.

There was a significant positive correlation between bio mass and number of tubers per plant ($P \leq 0.05$), (Table 13). A positive correlation ($P \leq 0.01$) was observed between tuber yield and weight of tubers per plant.

Table 13; Correlation between bio mass, dry matter content, marketable tubers, none marketable tubers, number of tubers per plant, weight of tubers per plant, average weight per tuber and yield.

TRAITS	BM	DM	MT	NMT	NTP	WTP	AWT	YLD
BM								
DM	-0.19							
MT	-0.91	-0.24						
NMT	0.81	-0.73	-0.49					
NTP	1.00*	-0.22	-0.89	0.83				
WTP	0.99	-0.08	-0.95	0.74	0.99			
AWT	-0.93	0.54	0.69	-0.97	-0.94	-0.88		
YLD	0.99	-0.08	-0.95	0.74	0.99	1.00**	-0.88	

*, **represent significance level at $P \leq 0.05$, $P \leq 0.01$, BM is bio mass, DM is dry matter content, MT is marketable tubers, NMT is none marketable tubers, NTP is number of tubers per plant, WTP is weight of tubers per plant, AWT is average weight per tuber, YLD is yield

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion

The study evaluated three potato varieties at three levels of NPK; 17:17:17 fertilizer in a mid-altitude environment of Kakoba Mbarara city in the South Western Uganda under two seasons; Season I and Season II. According to Namugga *et al.* (2017a), this location has a potential area 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 4). 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., & 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 6). From this observation Katchpot1 reaches a peak performance at fertilizer level f2 and beyond that there is a detrimental decrease in yield (Table 6). 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., & 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 6). 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 has been reported to be the main factor in potato processing quality, with values of ≥ 20% being considered to be high quality processed products (Abong *et al.*, 2010; Asmamaw and Tekalign, 2010; Pedreschi, 2012). 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 8). 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 I is lower than DMC in season II at all the fertilizer levels. This could be attributed to longer periods of rain in season I than season II.

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., & Mageto, E. K. (2021) whose findings reported the highest tuber yield parameters and significant differences among potatoes varieties with the application of NPK fertilizers.

5.2 Conclusion and recommendations

5.2.1 Conclusion

The study indicated that yield and yield components of the potato varieties - Rwangume, Victoria and Katchpot1 can be improved through the application 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 I produces more yield compared to Season II 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 I produces less dry matter Content compared to Season II.

5.2.2 Recommendations

- **i.** Potato farmers in the mid-altitude environment should utilize the season from September to December for higher yields. This season has longer periods of rainfall.
- **ii.** Fertilizer level f2 (50Kg/ha) is recommended as the optimum level for optimum yield output and dry matter across the seasons.

Additional studies on these varieties could focus on the interaction of different fertilizer levels and potato spacing, effect of potassium levels on dry matter content.

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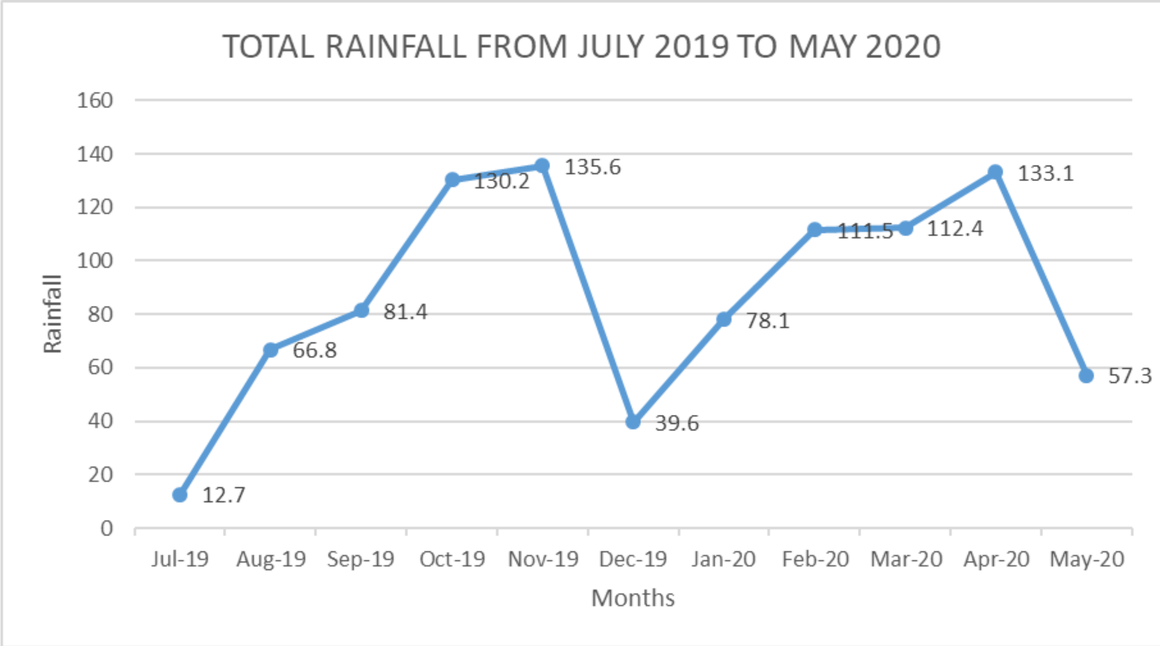
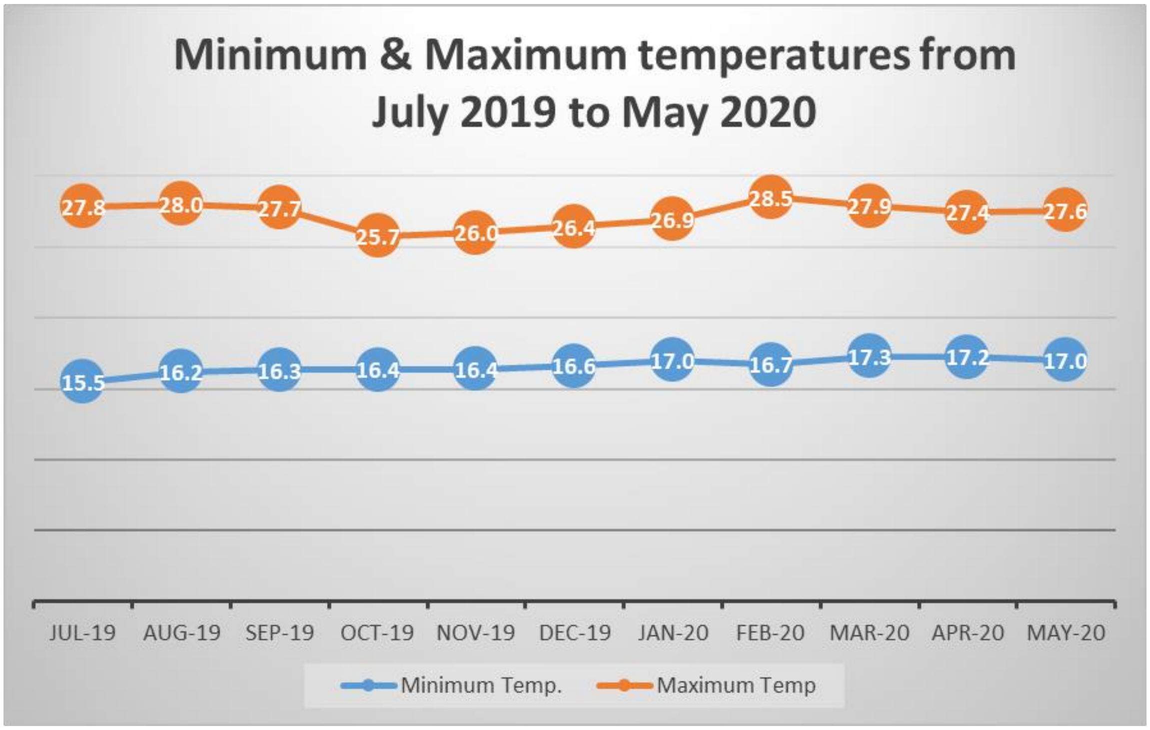
Appendices

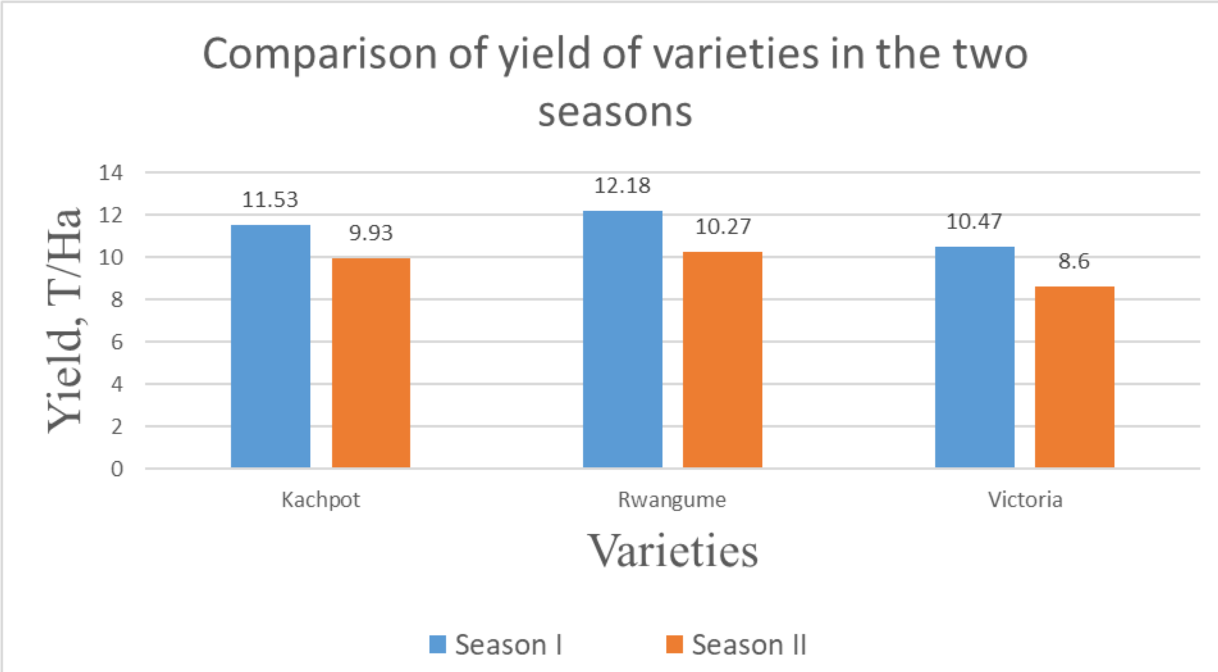
Appendix 1; Total rainfall from UNMA Mbarara for the months, July 2019 to May 2020.



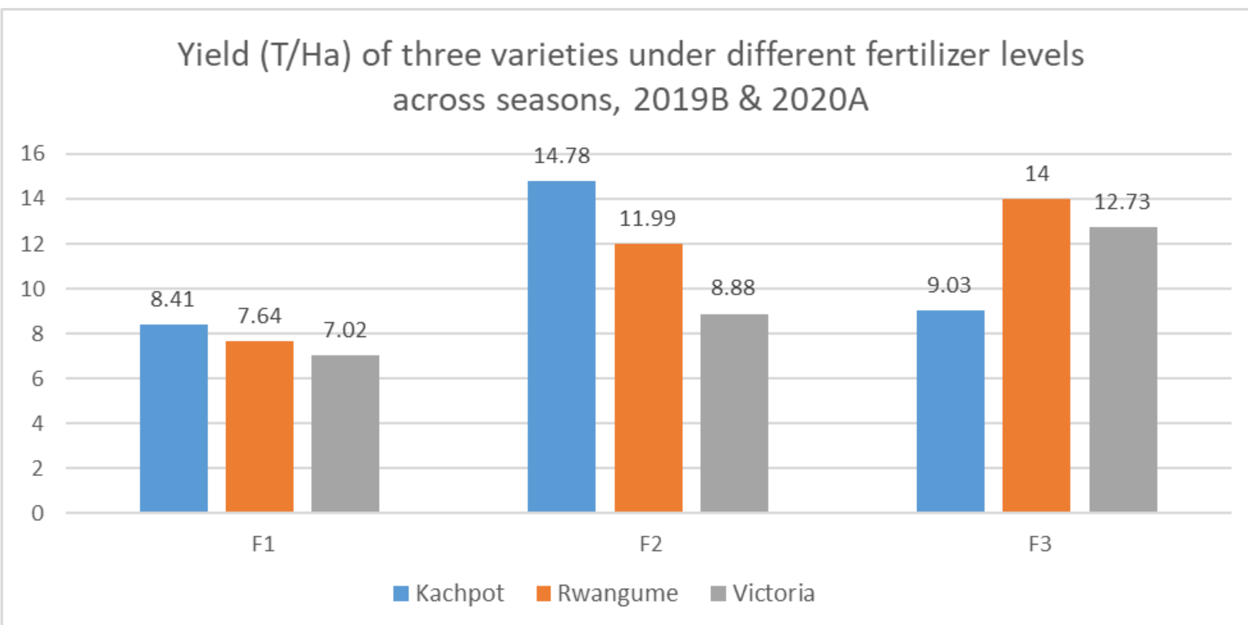
Appendix 2; Maximum and minimum temperatures for the study area from July 2019 to May 2020.



Appendix 3; Comparison of yield of varieties in the two seasons of the study area.



Appendix 4; Yield of the three varieties under different fertilizer levels across seasons, I & II



Appendix 5: Skeleton ANOVA, yield parameters and dry matter content for single Season analysis.

SOV	D.F	MS	F-CAL
R	2	MS-R	MS-R/MS-E
V	2	MS-V	MS-V/MS-E
F	2	MS-F	MS-F/MS-E
V.F	4	MS-V.F	MS-V.F/MS-E
E	16	MS-E	

SOV is source of variation, D.F is degrees of freedom, M.S is mean square, R is replication, V is variety, F is fertilizer, E is 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, S_h 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 Ind variety interaction effect, $S*F_{hi}$ is the Season Ind fertilizer interaction effect, $S*V*F_{hji}$ is the season, variety and fertilizer interaction effect, E_{ijk} is the error.

Appendix 6: Skeleton ANOVA, yield parameters and dry matter content for across analysis.

SOV	D.F	MS	F-CAL
R	1	MS-S	MS-S/MS-P.E
V	2	MS-V	MS-V/MS-P.E
F	2	MS-F	MS-F/MS-P.E
V.F	4	MS-V.F	MS-V.F/MS-P.E
S.V	2	MS-S.V	MS-S.V/MS-P.E
S.F	2	MS-S.F	MS-S.F/MS-P.E
S.V.F	4	MS-S.V.F	MS-S.V.F/MS-P.E
P. E	32	MS-P.E	

SOV is source of variation, D.F is degrees of freedom, M.S is mean square, R is replication, Vis variety, F is fertilizer, P.E is pooled error.

Appendix 7: Performance of varieties and fertilizers for yield, average weight per tuber, dry matter content and number of tubers per plant evaluated at BSU.

	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.

Appendix 8: Marketable and none marketable tuber yield and biomass of potato at different fertilizer levels, July 2019 – May 2020.

	WTP			NMT			MT			BM		
var	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	**f1**	**f2**	**f3**	f1	f2	f3
season 1												
Kachpot	299	281	285	87	108.7	112	19.71	21.54	22.71	1.06	3.697	5.233
Rwangume	238	334	341	204	267.3	245	0.00	22.00	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	**250.67**	**298.67**	**304.67**	**122.00**	**156.57**	**146.67**	**12.81**	**23.19**	**17.92**	**0.5**	**1.7**	**2.3**
SEM	**62.56**			**31.99**			**8.64**			0.2961		
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	210.00	369.50	226.00	61.20	105.20	68.90	19.70	30.60	13.00	0.64	2.9485	2.6815
Rwangume	191.00	299.50	350.00	149.90	215.80	193.00	11.20	30.50	22.90	0.6235	2.1315	4.535
Victoria	175.50	222.00	318.00	58.90	81.50	81.40	22.40	26.10	39.40	0.375	1.3435	2.885
MEAN	**192.17**	**297.00**	**298.00**	**90.00**	**134.17**	**114.43**	**17.77**	**29.07**	**25.10**	**0.546167**	**2.141167**	**3.367167**
SEM	**23.30**			**10.47**			**4.87**			**0.291367**		
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.